Note to Exhibits

There are no Exhibits numbered 26, 29, and 30. For the convenience of the reader these exhibits, which are all scientific opinions specific to the North Tualatin Mountains, and primarily for the BCF and MCF, have been placed in Appendix F.

The first exhibit is Exhibit A. Thereafter the exhibits are numbered consecutively with the exception noted above

Exhibit D.5.c

Exhibit A

My Name is Rob Lee. I've been secretary of the Linnton Neighborhood Association, and a board member, for more than five years, and live on the edge of Forest Park. For the past eight years I've led a number of ecological restoration projects in Linnton, have won three volunteer awards for this work -- two from WMSWCD and one from the NW Examiner -- and founded, and remain active in, the Harborton Frog Group. (My comments are my own.) I am very supportive of bicycle riding, it being my main means of transportation.

The thing that bothers me most about the aggressive push to expand single-track mountain biking in our local forests is the dishonest assertions it depends on. We're led to believe these single-track enthusiasts are families out for a bucolic Sunday afternoon ride, when the mountain bike riders that pass my house every day going to and from Forest Park are easily more than 90% young white guys. We're assured well designed trails will obviate any worries about erosion and landscape degradation, when I've seen a trail I once loved, after being open to bikes for <u>one</u> month, had all the vegetation on both sides of the trail obliterated, the earth rutted into channels and exposed to the beating rain. I hear about how well the bikers will be managed, but listened to friends, excited after a ride, exclaim about riding up and down stream beds. Metro's Master Access Plan of 2016 mentions that frogs will be free of the bikes at night, but I see bikers flash by in the dark all the time, coming out of Forest Park, enforcement of the night riding ban a joke. The city can't even keep "No Bike" signs on the Wildwood Trail because the bikers take them down.

The Harborton Frog Group has, for the past five years, attempted to help a population of red-legged frogs avoid rush hour traffic and breed successfully. Our yearly totals of frogs delivered to the wetland has varied between 580 and 834; modest improvement for a difficult problem. This bike plan is not a help. The Plan makes the claim that, "increased access" will "raise awareness" about the frog migration, as if speeding bicyclists will ever notice a creature as stealthy as red-legged frogs! Worse, Hail Mary passes like this expose the document for what it is; political happy talk, not science, and certainly not giving a damn about the frogs, whose habitat is to be invaded by speeding machines and flying mud. The Plan also states that the Harborton Frog Group partnered with Metro, the context implying we endorse this bike plan, and did so in 2016. I've asked our group if anyone knows about such an arrangement, and it seems no one does. Last month the Group agreed to work with three researchers from PSU and Pacific University on a frog study. They are partnered with Metro, but Metro hasn't broached partnering with the Frog Group, and our group has never discussed such a partnership. To me, agreeing to such an arrangement would be a betrayal of the frogs.

Rob Lee

Exhibit 1

Note to Exhibit. 1: Photo of Forest Park and wildlife corridor area between the Park and the Coast Range.

The large foreground area outlined in green is Forest Park. The four red oval areas above the Park show the locations of Metro's four North Tualatin Mountain Forests. The red ovals represent the location of these forests and are not scaled for their size.

The upper right oval closest to Multnomah Channel is Burlington Creek Forest. The upper more circular oval to the left of the BCF is McCarthy Creek Forest. The largest of the oval figures, below McCarthy Creek and Burlington Creek Forests, is Ennis Creek Forest. The Oval farthest to the left is Abbey Creek Forest.

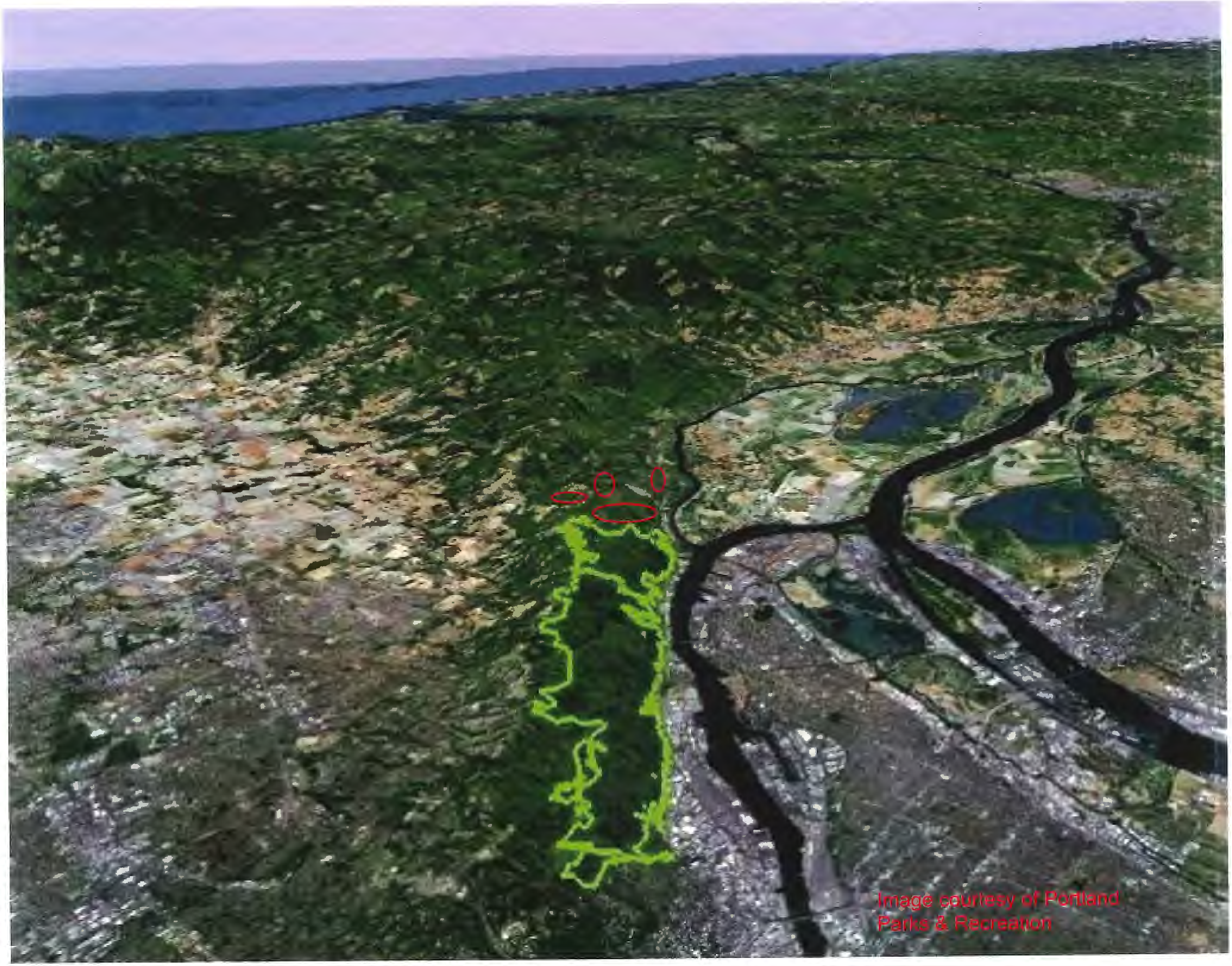


Image courtesy of Portland
Parks & Recreation

Exhibit 2

1

Gmail

RE: Input Received: OPRD Public Records Request

HAVEL Chris * OPRD <Chris.Havel@oregon.gov> Thu, Nov 9, 2017 at 10:48 AM
To: Hank McCurdy <hankmccurdy@gmail.com>

The application and all associated documents are submitted through a website (https://oprdgrants.org/). I can get you everything they submitted, but the submission process only involves clicks through that web application; so far as I know, neither email nor actual printed correspondence are ever involved.

Hold on a sec and I'll see what else they submitted.

From: Hank McCurdy [mailto:hankmccurdy@gmail.com]
Sent: Thursday, November 09, 2017 10:44 AM
To: HAVEL Chris * OPRD
Subject: Re: Input Received: OPRD Public Records Request

Chris,

Thanks for following up on this so promptly. I see the printed name of the person that submitted this on behalf of Metro, Karen R. Vitkay, but no signature in cursive. just to be clear, there is no form that metro submitted with an actual signature. Did Metro submit it by email or with a cover letter. If so I need to get a copy of either the email submission message or the cover letter.

Hank

On Thu, Nov 9, 2017 at 9:40 AM, HAVEL Chris * OPRD <Chris.Havel@oregon.gov> wrote:

Your form is similar to the one in our file (attached), but our file copy doesn't have a written signature, either. These forms are submitted online and there's a digital equivalent to the written signature applied by the applicant when it's submitted; that doesn't show up in the attached file. The copy I'm attaching was digitally signed, so you may treat it as authoritative.

This project has not been approved or funded, of course. The application is under review.

2

The applicant has not submitted any amendments to the form, so this is the only document we have that natches your record request. Let me know if you need anything else.

From: Hank McCurdy [mailto:hankmccurdy@gmail.com]
Sent: Thursday, November 09, 2017 9:08 AM
To: HAVEL Chris * OPRD
Subject: Re: Input Received: OPRD Public Records Request

Chris,

Thanks for your attention to this. I am attaching the copy of the document that I have, It does not have any signatures on it. I need the funding application with the signature(s) on it, along with any amendments/changes to the application that may have been made. If you can send them by email that would be great.

Thank you,

Hank McCurdy

On Thu, Nov 9, 2017 at 8:46 AM, HAVEL Chris * OPRD <Chris.Havel@oregon.gov> wrote:

My apologies for the delay ... totally my fault. I didn't see any matching records in our database and intended to follow up with other staff, but didn't follow through. Taking care of this today. Thanks for your patience.

From: ORPrdSupport@egov.com [mailto:ORPrdSupport@egov.com] **On Behalf Of** hankmccurdy@gmail.com
Sent: Tuesday, October 10, 2017 1:36 PM
To: HAVEL Chris * OPRD
Subject: Input Received: OPRD Public Records Request

OPRD Public Records Request

Submitted: 10/10/2017 1:36:24 PM

3

Burlington Creek Forest Natural Surface Trails (RTP)

Application #3910 - Grant Application Summary Manage Edit

Project Information

Project Name

Burlington Creek Forest Natural Surface Trails

Brief Project Description

Construct five miles of trails, stream crossings, an information kiosk & wayfinding signs; to connect hikers, mountain bikers and equestrians with nature, regional trails and an ancient forest.

Project Start Date

01/01/2018

Project End Date

10/31/2019

Site Name

Burlington Creek Forest

Site City/Town/Area

Portland

Site County

Multnomah

Site Description

The Burlington Creek Forest is a densely forested upland ridge located just outside Portland's urban growth boundary. Formerly owned by a timber company, Metro is actively working to restore the site to a healthy natural area. Burlington Creek bisects the site and is paralleled by several drainages. The site's valleys and ridges undulate between 100 to 600 feet in elevation offering views of Sauvie's Island, the Multnomah Channel and several Cascade Peaks.

Site Acreage

354

Latitude

45.64475321658682

Longitude

-122.84543707966805

Contact Information

Applicant

Metro

Applicant Federal Tax Id

93-0636311

Applicant DUNS Number

Project Contact

Karen Vitkay

Address

Karen Vitkay
Metro - Parks and Nature
600 NE Grand Avenue
Portland, OR 97232
karen.vitkay@oregonmetro.gov
503.797.1874

Reimbursement Contact

Karen Vitkay

Financial Information

Requested Amount

$242,318.00

Match Amount

$74,375.00

Total Project Cost

$316,693.00

Grant %

76.5151108486768 %

Match %

23.484889151323205 %

Project Budget Worksheet

Description	Qty	Unit	$/Unit	Cost	Match	Request	Source of Funding
Shared trail A	5653	LF	$8.50	$48,050.50	$0.00	$48,050.50	
Shared trail B	3027	LF	$8.50	$25,729.50	$0.00	$25,729.50	

5

Description	Qty	Unit	$/Unit	Cost	Match	Request	Source of Funding
Hiking trail C	721	LF	$8.50	$6,128.50	$0.00	$6,128.50	
Shared trail D	1474	LF	$8.50	$12,529.00	$0.00	$12,529.00	
Shared trail E	4090	LF	$8.50	$34,765.00	$0.00	$34,765.00	
Shared trail F	4025	LF	$8.50	$34,212.50	$0.00	$34,212.50	
Shared trail G	6385	LF	$8.50	$54,272.50	$0.00	$54,272.50	
Shared trail H	3133	LF	$8.50	$26,630.50	$0.00	$26,630.50	
Crossing 1	75	SF	$185.00	$13,875.00	$13,875.00	$0.00	Metro Levy
Crossing 2	90	SF	$185.00	$16,650.00	$16,650.00	$0.00	Metro Levy
Crossing 3	100	SF	$185.00	$18,500.00	$18,500.00	$0.00	Metro Levy
Crossing 4	60	SF	$125.00	$7,500.00	$7,500.00	$0.00	Metro Levy
Information Kiosk	1	EA	$5,200.00	$5,200.00	$5,200.00	$0.00	Metro Levy
Wayfinding Markers	22	EA	$575.00	$12,650.00	$12,650.00	$0.00	Metro Levy
Totals				$316,693.00	$74,375.00	$242,318.00	

Total Project Cost

$316,693.00

Total Match from Sponsor

$74,375.00

Grant Funds Requested

$242,318.00

Supplemental Information

SUPPLEMENTAL PROJECT INFORMATION

Project Eligibility Category

Construction of new recreational trails

Trail Users – Non-motorized

Hiker,Mountain Bike,Equestrian,Hiker,Mountain Bike,Equestrian,Hiker,Mountain Bike,Equestrian|Hiker|Mountain Bike|Equestrian

Trail Users – Motorized

None

SUPPLEMENTAL FINANCIAL INFORMATION

Is a minimum of 5% of your project funding from non-federal funding?

Yes

Are your design, engineering and/or permitting costs more than 15% of your budget?

No

Do you have the financial capacity to pay for expenses prior to submitting reimbursement requests to OPRD?

Yes

ENVIRONMENTAL – FEDERAL LANDS

Is this project located on Federal Land? If yes, provide responses to questions in this section.

No

Forest Management Plan or BLM Resource Area Management Plan (Title and Date)

Has a decision been issued as part of the NEPA review process?

No

If yes, list the date and type of document (Decision Memo, Finding of no significant impact, determined exempt) and ensure documentation is attached.

If no, when do you expect the decision?

ENVIRONMENTAL – NON-FEDERAL LANDS

Is this project located on non-Federal Land? If yes, provide responses to questions in this section.

Yes

Have you completed and attached the RTP Environmental Screening Form?

Yes

Which agencies have you received consultation forms from?

DLCD (Department of Land Conservation and Development),DEQ (Department of Environmental Quality)|DLCD (Department of Land Conservation and Development)|DSL (Department of State Lands)|DEQ (Department of Environmental Quality)

If you have not received an agency consultation form from an agency(s), please list the date of your submitting to them.

ODFW Communication

Initial Submittal: April 12 and 18, 2017
Email follow up: April 27, 2017

7

Email follow up: May 15, 2017
Phone consultation: May 18, 2017
Email follow up: May 24, 2017
Left phone message: May 30, 2017

RECENT AWARDS (Criterion #2 - 5 points)

Have you received an RTP grant in the past 10 years?

Yes

If yes, please provide the RTP grant number(s) or other identifying information.

RTP 10-12
Bi-State Regional Trails Website and Map

ECONOMIC DEVELOPMENT OPPORTUNITIES (Criterion #3 - 5 points)

How will the project facilitate economic development?

Outdoor recreation is a significant contributor to Oregon's economy. Numerous studies indicate park and trail developments lead to higher property values, increased spending on outdoor apparel and related secondary spending.

Outdoor recreation including hiking, mountain biking, equestrian activity, and wildlife viewing at Burlington Creek Forest will generate jobs and revenue supporting the local economy. It is estimated that trail construction will create three temporary jobs (for three and a half months) and ongoing employment related to trail maintenance, naturalist tour guides and other work.

Trail users will buy gear and equipment, gas and oil, groceries, food and beverage services and lodging from Portland area businesses. Since the trails are located near an urban area, Northwest Portland and St. John's neighborhood businesses such as cafes, bicycle shops and the Linnton Feed and Seed are expected to benefit from day use and tourist recreation. Benefits most commonly associated with trail-related spending are increased local incomes and employment. Home values near the new nature park and tax revenues may also increase. Any increase in the demand for public services (e.g., extra police or improved public rest rooms) and the cost of trail promotion will also add to the economy.

Outdoor recreation and active lifestyles not only create jobs and build businesses, they cut health care costs, bring families closer together, help kids learn in school and lead to long term protection of the environment.

PROJECT SCOPE AND PLAN (Criterion #4 - 10 points)

Scope Overview

What are you proposing to do?

The Burlington Creek Forest (BCF) Natural Surface Trails project will expand opportunities to walk, hike, mountain bike, ride horses and enjoy nature in the Portland metropolitan area. BCF creates five miles of new shared-use, natural surface trails. This experience will be enhanced by the building of three bridges and one boardwalk, as well as an information kiosk and wayfinding signs. Informed by the April 2016-adopted North Tualatin Mountains Access Master Plan, a sustainably designed shared-use trail system will connect visitors to nature, wildlife, healthy lifestyles, an ancient forest and future regional trails. Located a short twenty minute drive from downtown Portland, BCF presents a spectacular opportunity for trail and nature access close to home.

What trail standards or guidelines is the project utilizing?

- IMBA, Trail Solutions: IMBA's Guide to Building Sweet Singletrack, 2004.
- IMBA, Managing Mountain Biking: IMBA's Guide to Providing Great Riding, 2007.
- Metro, Green Trails: Guidelines for Environmentally Friendly Trails, 2004.

8

- US Forest Service, Forest Service Trail Accessibility Guidelines, 2013.
- US Access Board. Architectural Barriers Act Accessibility Guidelines; Outdoor Developed Areas, 2013.

How are you proposing to complete the work?

Metro will oversee final design and trail construction via Metro staff, professional contracted trail builders and volunteer support. Metro hires Certified Office for Business Inclusion and Diversity (COBID) firms whenever possible to support inclusive and diverse businesses. Youth Ecology Corps (YEC) members have already been utilized for site restoration work in the North Tualatin Mountains and they have gained valuable skills and experience building trails with Metro staff at our natural areas. Trail building at Burlington Creek Forest is an ideal candidate for a YEC project.

While Metro intends to use a professional contractor to build the proposed trails at Burlington, finding opportunities for disadvantaged youth to work with professionals is a priority. Working alongside professional contractors helps YEC youth develop skills and build relationships that could lead to future employment opportunities. YEC anticipates working alongside professional trail builders to complete the trail work at Burlington Creek Forest.

Now at 30% design, Metro plans to submit its land use application in August, 2017 to receive approval needed to proceed with construction. The land use decision is expected in January, 2018, followed by finalizing the design of the trails, crossing structures, information kiosk and wayfinding as well as the design engineering for the (separately funded) trailhead and roadway improvements.

The current trailhead design provides parking for about twenty-five vehicles. This number may increase given the BCF's anticipated popularity. The parking area and trailhead will have an entry sign to welcome visitors, automatic gates to close the site at night, a prefabricated restroom, two picnic tables and an information kiosk with park rules, information and orientation map. Grading work and vegetation removal along McNamee Road will be completed to meet sight distance requirements in order to facilitate safe public access to the site.

The trail system takes advantage of two existing crossings of Burlington Creek, while four new structures will be necessary to cross smaller drainages on the site. Small hand-built drainage improvements are also anticipated to ensure trails hold intended alignments without unreasonable detours during wetter months.

Trail design will accommodate multiple uses and be informed by shared-use standards promoted by the International Mountain Biking Association (IMBA). The former IMBA design director is a project consultant. As topography allows, trail grades will be gentle, though some sections may exceed guidelines for accessibility. Best practices, such as adequate sight distances and passing areas will be employed to minimize potential for conflicts between different user groups. Metro will also inform and educate visitors, via signs and direct person-to-person outreach, about other users to expect and proper trail courtesy.

Several trail loop opportunities will offer opportunities for riders with both beginner and intermediate skill levels. Trails will have short uphill sections, turns and speed checks to slow cyclists, and gateways or qualifiers to filter less experienced riders from challenging segments and provide a safe and pleasant experience for all trail users. Beginner trails will be designed with wider trail beds and gentler grades. Intermediate-level trails will be designed to present narrow trails and steeper grades for more confident riders.

Metro will require pre-qualification for the design-build bid process to ensure bidders have sufficient knowledge and experience, are licensed contractors and qualified members of the Professional Trail Builders Association. The contractor selected will be a qualified trail builder with a minimum of two years of experience in purpose-built mountain bike trail building, and will have successfully completed a minimum of three purpose-built mountain bike natural surface trail projects following IMBA Guidelines on projects of similar size and scope to the BCF project.

Once trails are completed and open for use, BCF volunteer groups will provide site stewardship via "eyes and ears" above and beyond what Metro staff provide. Through routine walking and monitoring of the trails, volunteer site stewards will alert staff early to issues requiring attention. They will also serve as "ambassadors" for the North Tualatin Mountains, answer questions and ensure visitors are abiding by rules and trail etiquette.

9

Site stewardship agreements with organizations representing individual user groups are an opportunity to foster an ethic of taking care of the land and trails, and helping to improve habitat. Stewardship agreements will include responsibility to encourage appropriate use of trails and the site.

Have you attached a project timeline?

Yes

Why is the project being completed?

Residents within the Portland metropolitan region approved two bond measures and two operating levies between 1995 and 2016 to protect habitat and water quality within the region while providing opportunities to access nature close to home. Properties comprising the Burlington Creek Forest site of the North Tualatin Mountains were acquired between the years 2000 to 2014 utilizing voter approved bond funds.

Since Metro's purchase, the properties have been informally used for hiking, mountain biking, horseback riding and enjoying nature. Between 2014 and 2016 a public planning process was conducted to create an access plan for the site. Community members identified the desire within the region for additional hiking trails and opportunities to access nature. A significant lack of mountain biking and equestrian trails was also identified.

In April 2016, the North Tualatin Mountains Access Master Plan was adopted by the Metro Council. This Burlington Creek Forest Natural Surface Trails project will complete a first phase of trail development in accordance with the Master Plan vision.

The need for additional unpaved dirt trails for walking and hiking is the highest non-motorized trail priority both statewide and in the Portland region. Nearly half (47%) of residents in the Portland region place a moderate or high priority on creating additional trails for single track bicycling, the highest level of support statewide. Most off-road cyclists expressed a preference for rides between 30 minutes and 2 hours in length, or about 3 – 11+ miles. BCF is being designed to offer up to a 90-minute visit to offer a worthwhile experience for those traveling to the site from up to 45 minutes away. 1.5 million Oregonians, and 1.9 million residents live within a 45 minute drive of BCF.

See Criterion 9 response for sense of Project Urgency to achieve shared-use trails and increased off-road cycling opportunities.

Project Planning & Readiness to proceed

What is the current level of design for the project?

30% Design

Construction and Restoration Project

What permits or land use actions will need to be completed for the project?

Land Use - Compatability Form,Land Use - Type I Review,Land Use - Type II Review,Building Permits,Grading Permits,DEQ 1200c|Land Use - Compatability Form|Land Use - Type II Review|Grading Permits|DEQ 1200c|Other|Building Permits

Have any permits been applied for or received?

We're planning to submit our land use application this summer with approval anticipated in January 2018. We'll then proceed with final design and permitting.

Acquisition Project

Is your right-of-way file in compliance with the Uniform Act?

No

10

Was the seller provided with documentation outlining their rights that are consistent with the Uniform Act?

No

Do you have proof of a willing seller or donor?

No

Do you have a completed Yellow Book compliant appraisal?

No

Do you have a completed preliminary title report?

No

Has a Level 1 or higher environmental assessment been completed?

No

Has an offer been made yet?

No

Design, Safety or Education Project

Has a scope of work and deliverables been completed?

No

Have you developed a request for proposal or similar bid document for this project?

No

Has a firm been hired or is on retainer?

No

Have you completed any artwork, copy or curriculum?

No

Do you have a proof of the product?

No

Do you have production ready design, artwork, etc.?

No

American With Disabilities (ADA)

Does the project meet ADA accessible guidelines?

No

Have you completed the Trail Accessibility Assessment Memorandum?

Yes

ISSUES AND NEEDS (Criterion #5 - 30 points)

Statewide Trail Management Issues

The Project is responsive to the State Trails Master Plan's priority to provide more trails connecting people and places, improved trail maintenance and increased trail signage. Dating back to the 1992 Greenspaces Master Plan, Metro has affirmed intentions for regional trail connections north from Forest Park in Northwest Portland.

This project provides initial public access at one of Metro's four natural areas in the North Tualatin Mountains, northwest of Portland. With careful planning, it's possible to create opportunities for people to enjoy nature while also protecting it. Well-designed and constructed trails will limit habitat impacts by aligning and designing trails to minimize erosion, avoiding stream crossings when possible, retaining habitat areas for the exclusive use of wildlife, and monitoring trails on a regular basis.

As the 2015 – 2024 Oregon Trails Plan acknowledges, "With respect to race and ethnicity, minorities are under represented among trail users...Oregon's recreation providers should consider developing marketing strategies to encourage regular use of existing trail systems by elderly and minority populations in their jurisdictions..." Metro's commitment to the principles of diversity, equity and inclusion inform the selection of this project site and future plans for community education. The project Stakeholder Advisory Committee affirmed the importance of BCF's proximity and accessibility from the diverse neighborhoods of inner North and Northeast Portland, located just across the St. Johns Bridge and Oregon Highway 30, which leads to the trailhead.

Since 2014, Metro has partnered with the non-profit Self Enhancement Inc. (SEI) to connect hundreds of at-risk youth of color with nature programming at North Tualatin Mountains' North Abbey Creek and McCarthy Creek sites. During the park planning process, SEI youth were exposed to nature education and conducted a joint planting party with the Northwest Trail Alliance. Metro and SEI staff are currently exploring opportunities for SEI participants to further experience nature education at BCF during the summer of 2017.

Unfortunately BCF, in its current state, is not feasible for programming with youth as young as middle school age due to the lack of infrastructure such as formal parking, restrooms, shelter and wayfinding. Until such features are in place, SEI program opportunities will be limited to short-duration visits focused on high school students. Outreach to and partnerships with marginalized communities for nature education and engagement will expand once trail construction is completed.

(1) Need for more trails connecting towns and public places. Trails at BCF will provide access to a new nature park just outside the Urban Growth Boundary. This project launches five miles of new shared-use, natural surface trails within a natural setting, while offering education opportunities and beginner to intermediate challenge levels. Informed by the April 2016-adopted North Tualatin Mountains Access Master Plan, a sustainably designed multi-use trail system will connect urban visitors to nature and wildlife at one of Metro's newest nature parks, Burlington Creek Forest. Park features will further include parking, a restroom, picnic tables and an information kisok to ensure a welcoming experience.

BCF is located at the crossroads of the future Pacific Greenway and Helvetia regional trails. The project completes a gap within the Pacific Greenway Trail, a regional trail planned to ultimately extend from Portland's famed 5,157-acre Forest Park through BCF to public lands in the Coast Range to the west. Trails at BCF will provide a crucial link connecting Portland's urban parks and neighborhoods to the broader regional system of trails, including the Banks-Vernonia Trail, the CZ Trail, the planned Salmonberry Trail and conceptual Helvetia Regional Trail.

The Burlington Creek site offers opportunities for kids from nearby Skyline Elementary School to access and learn about nature. During the planning process, Metro's nature education staff engaged with children and teachers from Skyline School to share opportunities for learning about nature in their neighborhood within the North Tualatin Mountains. Due to the proximity of BCF to Skyline School, youth will have easy access to nature at one of Metro's newest nature parks.

These shared-use trails designed for hiking and off-road cycling will also facilitate access to the adjacent Forest Park Conservancy's Ancient Forest Preserve. Access to the Ancient Forest Preserve is only available through BCF. At the Ancient Forest Preserve, visitors will experience stands of 500-year-old trees and envision what BFC will become with continued forest management. While only hiking and walking are allowed within the Ancient Forest Preserve, all park visitors will be guided to Preserve access points by a new information kiosks, wayfinding signs

12

and maps.

Metro's BCF project trails are optimized for off-road cycling and responsive to the growing demand for this type of nature-based recreation. Not everybody connects with nature through binoculars or hikes, and it's important to provide a variety of opportunities for people to experience the outdoors in different ways. The trails will be managed for both off-road cyclists and those travelling by foot.

BCF trail development achieves three of the top five SCORP-identified community needs selected by the public as preferred activities within Multnomah County: dirt walking trails and paths, nature and wildlife viewing, and off-street bicycle trails and pathways. SCORP is Oregon's Statewide Comprehensive Outdoor Recreation Plan.

(2) Need for improved trail maintenance. This project directly addresses the need for trail maintenance by committing consistent professional resources combined with volunteer support. Annually funded ongoing routine trail maintenance improves trail safety and prolongs the longevity of BCF's trails. Regularly scheduled monitoring will achieve early identification of trail problems in order to catch and address "social trails". Trail volunteer groups such as - Northwest Trail Alliance, Trailkeepers of Oregon and Oregon Equestrian Trails - will act as site stewards and enhance the capacity of Metro as trail overseers. Both Norwest Trail Alliance and Trailkeepers of Oregon have pledged to organize volunteer work parties to engage community members and be called upon for ongoing support for maintenance after the trails have been developed.

Ongoing trail maintenance activities involve vegetation clearing and pruning to keep passages and selected views open, erosion control measures, bridge and culvert clearing and upkeep, litter and illegal dumping removal, sign replacement, and closing any social trails through the use of natural barriers and vegetation.

(3) Need for more trail signs. Public input into the planning and design process documented the need for effective signage. A variety of signs will be utilized to convey park rules and responsibilities, directional information, allowed activities and courtesy etiquette:

- Locator signs lead people to trailheads and parking areas. Metro's standard monument sign will be placed in clear view from McNamee Road to direct visitors to the parking area and trailhead. "You are here" orientation maps and messages on an information kiosk at the trailhead will enhance visitor navigation and minimize negative impacts on trail resources.

- Directional signs let people know where they are in the park. Twenty-two posts with wayfinding information will be placed at decision points throughout the trail system for the benefit of hikers, mountain bikers and equestrians. Following Metro's sign standards, each post will include a map indicating current location, trails and major orienting features. Destinations such as viewpoints, Burlington Creek, the Ancient Forest Preserve and trailhead will be highlighted. Posts will further identify user information to clearly indicate which trails are open to hikers, mountain bikers and/or equestrians. Directional signs may further include miles markings and/or geographical coordinates to aid responders in locating individuals in the event of an emergency.

- Interpretive signs describe the natural or cultural history of the area. Interpretive signs - to be installed when future funding is secured - will tell stories through nature education and interpretive features including: (1) Red-legged frogs' use of the site: migration patterns, life cycle, habitat loss and efforts underway to improve their outcomes, (2) History and the unique role of Tualatin Mountains Geology and Geography; (3) Forestry Practices - the proximity of Burlington Creek to the Ancient Forest Preserve will give visitors an opportunity to experience the difference between a twenty-five year-old forest compared to an older forest of 500+ year old trees, (4) Streams, Hydrology and Habitat - The proximity of Burlington Creek Forest to Burlington Bottoms provides a unique opportunity to share the historic hydrologic connection between the wetlands in the floodplain, and the upland and riparian forests of the Tualatin Mountains. Metro's staff naturalists will lead hikes along BCF's natural surface paths to provide nature education before interpretive signs can be installed.

- Regulatory signs explain the do's and don'ts of the nature park. A welcoming trailhead kiosk will describe visitor responsibilities including "leave no trace" principles as well as trail user etiquette. The kiosk will also provide an overall site map and detailed information allowing visitors - including the elderly, disabled, traditionally underserved and marginalized communities - to choose a route compatible with their capability and skill level. Trails will be described by difficulty level including information on: length, surface, width, running slope and cross slope as per accessibility guidelines. Trail markers found at decision points will include information about allowed users, trail options and difficulty level.

Regional Trail Management Issues

Three regional trail management issues commonly occur in the Metro Portland region (Multnomah, Clackamas and Washington Counties): the need for more trails connecting towns/public places, improved trail maintenance and better access for experiencing the nearby natural environment. Metro shares the vision of the Intertwine Alliance, a metropolitan Portland coalition of 150+ public, private and nonprofit organizations, of "an exceptional multi-jurisdictional, interconnected system of neighborhood, community and regional parks, natural areas, trails, open spaces, waterways and working lands, educational programming and recreation opportunities distributed equitably throughout the region." An interconnected system of land and water trails has been envisioned since the 1992 adoption of the Metro Greenspaces Plan.

The BCF project will serve residents from across Metro's three counties and be a destination park for those living beyond.

(1) More trails connecting towns/public places. New natural surface trails at BCF will enhance trail connectivity within the region while providing public access to a new nature park. This asset is key to appreciating the outdoors and will promote conservation efforts to sustain this natural area for future generations. Trails will lead users to the adjacent Forest Park Conservancy's Ancient Forest Preserve, only accessible from Burlington Creek Forest.

BCF is located at the crossroads of the future Pacific Greenway and Helvetia regional trails. The BCF trails will complete a gap within the Pacific Greenway Trail, which is envisioned to one day extend from public lands in the Coast Range through BCF to Portland's famed 5,157-acre Forest Park to the southeast. Trails at BCF will provide a crucial link from Portland's urban parks and neighborhoods to the broader system of regional trails, including the Banks-Vernonia Trail, the CZ Trail, the planned Salmonberry Trail and the conceptual Helvetia Regional Trail within existing rail right-of-way.

The Burlington Creek site offers opportunities for kids from the nearby Skyline Elementary School to access and learn about nature. During the planning process, Metro's nature education staff engaged with children and teachers from Skyline School to share opportunities for learning about nature in their neighborhood within the North Tualatin Mountains. Due to the close proximity of BCF to Skyline School, youth will have easy access to nature at one of Metro's newest nature parks.

Within close proximity to Portland, off-road cyclists will be able to ride to or take a Tri Met bus to within a short distance to Burlington Creek Forest. Given the deficit of off-road cycling opportunities close to home, the addition of five miles of trails offers significant allure for mountain bikers.

(2) Improved Trail Maintenance. As stated above under Statewide Trail Management Issues, this project directly addresses the need for trail maintenance by committing consistent professional resources combined with volunteer support. Annually funded ongoing routine trail maintenance improves trail safety and prolongs the longevity of Burlington Creek Forest's trails. Regularly scheduled monitoring will achieve early identification of trail problems in order to catch and address social trails. Trail volunteer groups - Northwest Trail Alliance, Trailkeepers of Oregon and Oregon Equestrian Trails - will enhance the capacity of what Metro staff can do alone.

3) Ability to experience the natural environment. Oregonians' sense of place is rooted in the forests, rivers and meadows Metro protects. Nature makes this place feel like home. Providing access to nature is fundamental to what we do every day at Metro. In 2016, Metro Council adopted a System Plan to guide the work of our Parks and Nature department. The Parks and Nature System Plan lays out our department mission: Metro Parks and Nature protects water quality, fish and wildlife habitat, and creates opportunities to enjoy nature close to home through a connected system of parks, trails and natural areas. Valuable forests, streams, views and wildlife at BCF, make it a great place for people to experience the natural environment close to home.

14

At BCF Metro is creating trails to maximize visitors' connection with nature. Interpretive signs will focus on how the North Tualatin Mountains fit within the region, different types of habitat and views, and the role of watershed restoration. Scenic viewpoints will emphasize the critical importance of water quality in our streams and the connections between Burlington Creek, McCarthy Creek, Burlington Bottoms wetlands, and the Multnomah Channel. From each viewpoint location visitors will enjoy views of Sauvie Island, the Multnomah Channel and the Cascade Peaks.

Nature programs that have already occurred and are expected to continue at the North Tualatin Mountains include: the guided "Elk of North Tualatin Mountains" public tour, education programs with Skyline Elementary School, volunteer restoration and nature education with Self Enhancement Inc. and the Northwest Trail Alliance, and nature education for Metro's Youth Ecology Corps.

Metro's Parks and Nature Department fills a crucial role as the hub of a wheel of urban providers including cities and parks districts, and federal and state parks. The greater Portland region has a strong network of local park providers and an excellent system of protected state and federal land. Metro is one of the few agencies focusing on large-scale conservation of natural areas close to home in an urban setting.

Over the last quarter-century, voters supported investments to build a regional park system spanning 17,000 acres and, touching every community in the greater Portland area. Metro is proud to serve as steward of the forests, savannas, wetlands and riverbanks that make this region unique.

Statewide Trail Need

The State Trails Plan affirms the primary non-motorized trail needs as connecting trails into larger trail systems, providing more signs and trail wayfinding, and repair of major trail damage. According to the 2013-2017 Oregon SCORP, the highest priority for additional trails was for walking/ hiking access both inside and outside one's community. The 2016-2025 Oregon Statewide Trails Plan acknowledges that close-to-home trail investments will maximize everyday use by local residents.

Significant direct responses to these priorities are detailed above, including:

(1) Connecting trails into larger trail systems. BCF is located at the crossroads of the future Pacific Greenway and Helvetia regional trails. BCF trails will complete a gap within the Pacific Greenway Trail, envisioned to one day extend from public lands in the Coast Range through BCF to Portland's famed 5,157-acre Forest Park to the southeast. Trails at BCF will fill a crucial link connecting Portland's urban parks and neighborhoods to the broader system of regional trails, including the Banks-Vernonia Trail, the CZ Trail, the planned Salmonberry Trail and the conceptual Helvetia Trail to the town of Banks within existing rail right-of-way.

This project will add five miles of new shared-use, natural surface trails to 2.5 miles of existing gravel roads leading to an Ancient Forest Preserve. Scenic vistas will enhance visitor's connection with the broader landscape around them. Shared-use trails will accommodate hikers as well as beginning and intermediate mountain bike riders, and provide several trail options.

(2) More signs and trail wayfinding. This project will provide locator, directional, interpretive and regulatory signs, including a welcoming trailhead kiosk. Signs will inform trail users of issues related to trail length, grade, surface, obstacles and degree of difficulty, view points and more. This information will allow users - including the elderly, disabled, traditionally underserved, and marginalized communities - to choose trails within their skill and capability level.

Wayfinding signs let people know where they are in the park. A new information kiosk located at the trailhead will include a map of the park with trails indicated in relation to major geographic forms and destinations. Twenty-two posts with directional information will be placed at decision points throughout the trail system for the benefit of hikers, mountain bikers and equestrians. Following Metro's sign standards, waywarker posts will include a location map indicating current location, trails and major orienting features. Destinations such as viewpoints, Burlington Creek, the Ancient Forest Preserve and trailhead will be highlighted. Posts will further identify user information to clearly indicate which routes are open to hikers, mountain bikers and/or equestrians. Directional signs may further include miles markings and/or geographical coordinates to aid responders in locating individuals in the event of an emergency.

Future interpretive signs, requiring new funds still to be secured, will use site features to tell stories such as: (1) Red-legged frogs' use of BCF habitat, (2) History and unique role of Tualatin Mountains Geology and Geography; (3) Forestry Practices - new and ancient forest; (4) Streams, Hydrology and Habitat. Metro's staff naturalists will lead educational hikes along BCF's natural surface paths. Targeted outreach will engage underserved communities (SEI and other partners) and the local elementary school students.

(3) Repair of major trail damage. Trails will be assessed following major weather events in order to identify and address trail damage caused by events such as strong wind, heavy rain, lightning, etc. Damage will be repaired at the earliest possible opportunity. This project directly addresses the need for trail maintenance by committing consistent professional resources combined with volunteer support. Annually funded ongoing routine trail maintenance improves trail safety and prolongs the longevity of BCF trails. Regularly scheduled monitoring will achieve early identification of trail problems, allowing Metro to catch and address "social trails" and issues caused by erosion. Trail volunteer groups - Northwest Trail Alliance, Trailkeepers of Oregon and Oregon Equestrian Trails - will provide vital assistance in monitoring the site above and beyond what Metro staff can provide. Metro has three full-time staff dedicated to managing volunteer efforts.

Local Funding Need

(A) More Trails, Repair of major trail damage, Connecting trails into larger trail systems. This project creates five miles of new shared-use, natural surface trails offering diverse and engaging trail experiences with respect to setting, education opportunities, and challenge levels. Informed by the April 2016-adopted North Tualatin Mountains Access Master Plan, a sustainably designed multi-use trail system will connect visitors to nature and wildlife at Metro's Burlington Creek Forest.

Shared-use trails at BCF will provide public access to one of Metro's newest nature parks. Trails are being designed to provide beginner and intermediate challenge levels, and the trail network offers opportunities to enjoy a variety of loops. Trails will also facilitate non-motorized trail access to the adjacent Forest Park Conservancy's Ancient Forest Preserve. Trails at BCF will fill a gap in the future Pacific Greenway Trail, an essential link connecting Portland's urban parks and neighborhoods to the broader regional system of trails, such as the Banks-Vernonia Trail, the CZ Trail, the planned Salmonberry Trail and future Helvetia Regional Trail.

An urgent and compelling local need is for more trails designed for mountain biking. An inventory completed by Metro in 2016 found a deficiency in opportunities to ride off-road bicycles in the Portland region, particularly on single-track and multi-use trails. There are only 42 miles of single track and natural surface multi-use trails open to mountain biking in the metropolitan region for our population of nearly 2.4 million. Less than 20 of those miles are located within the urban area and fewer than 10 of those miles are available in nearby Forest Park. The addition of five miles of trails for off-road cycling in the Portland region is significant. The growth in mountain biking as a desired activity is supported by SCORP data which showed a 2008 participation rate of 13% increased to 23% as of 2016. Mountain biking is growing in popularity and is often cited by community members as their preferred way to exercise, enjoy a mental escape, socialize, and enjoy nature.

(B) Satisfy priority needs as shown in recent planning document. This project is directly informed by the recommendations in the North Tualatin Mountains Access Master Plan, adopted by the Metro Council on 4/21/16. Development of a Master Plan for Metro's North Tualatin Mountains properties, including Burlington Creek Forest, has been a long-term process.

The North Tualatin Mountains Access Master Plan now guides the next 20 years and states: Proposed improvements at Burlington Creek Forest include a parking lot, a trailhead and shared-use trails designed specifically for hiking and off-road cycling. Visitors to Burlington Creek Forest will be able to continue walking, and riding bikes and horses on 2.5 miles of existing logging roads. The plan recommends 5 miles of new multi-use trails. Multi-use trails will accommodate hikers, beginner and intermediate cyclists, and provide several trail options.

16

During the Master Plan process, community members were asked about the types of activities they wanted to pursue at the North Tualatin Mountains. Priority needs included hiking, off-road cycling, and being in nature. Members of the public were also asked about the types of trails they want to experience. Participants expressed a preference for a variety of uses, including hiking, off-road cycling and equestrian trails. A clear preference for loop trails as opposed to out-and-back trails was identified, and a preference to use existing road networks for access where possible to minimize new trail construction in order to retain areas for conservation was expressed. Metro also heard off-road cycling on a single track trail is preferred to cycling on logging roads.

The 2006 voter approved Natural Areas bond measure and subsequent 2007 Refinement Plan for the Forest Park Connections Target Area, which encompasses the North Tualatin Mountains sites, established goals and objectives for the area. The Refinement Plan states the following: The Forest Park Connections target area is a regionally significant natural area due to its fish, wildlife, regional recreation and water quality values. It further established the following goals:

- Acquire key properties to connect Forest Park to other public lands and
- Connect Forest Park to Rock Creek and the Westside Trail to keep important wildlife corridors intact and provide trail connections between the region's largest urban park and Washington County.

In 2013, Metro regional voters approved a 5-year levy to help care for regional parks and natural areas. In 2016, this support was renewed by 72% of voters in Multnomah, Washington and Clackamas Counties. Roughly half of all levy funds go toward land restoration and management, including controlling invasive plants, planting native species, and improving habitat for fish and wildlife. The remainder of the levy pays for park maintenance and improvements, support of volunteer programs, conservation education, community grants and natural area improvements for visitors. The 2013 levy identified sites in the North Tualatin Mountains as opportunities to provide public access to nature.

DEMONSTRATION OF PUBLIC SUPPORT (Criterion #6 - 5 points)

Have you attached any letters of support for your project?

Yes

Other than letters of support, how else can you demonstrate public support for the project? Describe any processes that have taken place to receive public input and gain support.

Letters of Support from 12 stakeholders representing a diverse array of public and private partners are attached. Examples include the Northwest Trail Alliance, Forest Park Conservancy, Trackers Earth, Skyline Ridge Neighbor, Skyline School, Portland Design Works, Metro Council, Urban Greenspaces Institute, Self Enhancement Inc, Trailkeepers of Oregon and the Intertwine Alliance.

This application is the culmination of two years of community conversations crafting a vision for the future of these four special places. Metro received hundreds of comments, ranging from wishes to keep all four sites completely closed to public access - to wanting extensive trails and other improvements across all four sites. Visitors will soon be able to enjoy hikes through lush forests, rides on trails optimized for off-road cycling, panoramic views of Sauvie Island and more, all while restoration and forest management continues.

A project Stakeholder Advisory Committee (SAC) met five times to work closely with Metro to shape this project and ensure community viewpoints are reflected. Members included representatives of surrounding neighborhoods, trails groups, and partner park providers and advocates, including Forest Park Conservancy, Forest Park Neighborhood Association, Northwest Trail Alliance, Oregon Department of Forestry, Oregon Recreation Trails Advisory Committee, Portland Community College, Portland Parks & Recreation, Skyline Ridge Neighbors, Skyline School, Trackers Earth, and West Multnomah Soil and Water Conservation District. The SAC actively engaged in neighborhood outreach and assisted at four community events resulting in hundreds of interested residents learning about the project and encouraged to weigh in.

The plan was completed in Winter 2015-16 and the North Tualatin Mountains Access Master Plan was adopted by Metro Council on April 21, 2016.

17

SUSTAINABLE TRAIL DESIGN (Criterion #7 - 5 points)

Please describe how the trail project results in a well-designed, managed and sustainable trail system.

The proposed trail network creates diverse trail experiences with respect to setting, education opportunities, and challenge levels. A sustainably designed shared-use trail system will connect visitors to nature and wildlife while minimizing impacts to natural resources. Development at Burlington Creek Forest will adhere to the following as outlined in the State's 2012, "Developing Sustainable Park Systems in Oregon" report:

- Minimizing environmental impacts from the onset through sensitive siting of a park within the landscape and careful consideration of the various uses within the park boundaries
  - o Metro's four North Tualatin properties were considered as a whole to determine where site development and public access would be most appropriate. In terms of conservation value, the Burlington Creek Forest is the most impacted of the four sites due to existing recreation activities, the presence of power and water utility infrastructure and past commercial timber use.
  - o Careful consideration has been given to activities to be supported at the site. New shared-use trails will be built for hikers and mountain bikers, while equestrians will be allowed to utilize the existing gravel roadways. This approach is responsive to both the steep slopes of the site and the input of community members.

- Protecting and enhancing habitat areas
  - o To date, Metro has completed over $1,000,000 of restoration at the North Tualatin Mountains including: 1.3 miles of stream restoration, 700 acres of forest thinning, and the planting of 85,000 native shrubs and trees. Additional planned restoration includes: three miles of road decommissioning, culvert removal and replacement, and continued forest management for wildlife habitat and water quality.
  - o Proposed trails at Burlington Creek Forest have been aligned and designed to minimize impacts to natural resources. The trail planning and design addresses: avoiding trails adjacent to streams, minimizing the number of stream crossings, utilizing boardwalks and bridges to reduce impacts to riparian areas and minimizing erosion potential by aligning trails to follow contours, utilize grade reversals and offer outslopes to shed stormwater locally.
  - o Existing roads and road beds will be re-purposed for trail use to reduce the need for new trails.
  - o Trails will be aligned to avoid impacts to existing trees.
- Educating the public about the value of natural resource stewardship
  - o Metro has an active nature education program that provides a variety of public programs ranging from studies of bird language and mushroom identification to wildlife tracking. Metro also operates custom trips for school groups, a year-long immersion series, and youth ecology work study.
- Incorporating rain water re-use, grey water for irrigation, efficient irrigation systems, etc.
  - o Plantings at Burlington Creek Forest will utilize a native palette to minimize the need for water resources. Typically, Metro plants during the onset of the rain season with native plants, most of which only require water only for initial establishment.
- Minimizing pollution impacts resulting from park features and user activities
  - o As the proposed trail system is focused on non-motorized users, no pollution from user activities on site is anticipated.
  - o Materials to build trails will be sourced locally to minimize fuel expenses.
  - o Materials will be sourced from the site; rocks unearthed during excavation will be incorporated into trail features.
- Promoting alternative forms of transportation (e.g., greenways, bike trails, safe routes to schools)
  - o As a site near the urban area, many visitors will be able to ride their bikes or take a Tri Met bus to within biking distance of the park.
- Reducing maintenance and operations costs
  - o Proposed trails at Burlington Creek Forest have been aligned and designed to require a minimum amount of maintenance. Trail alignments discourage shortcuts and erosion potential is reduced by constructing trails to follow contours, utilize grade reversals and provide outslopes to shed stormwater locally. Bridge and boardwalk structures are expected to use a durable pultruded fiberglass decking material to ensure a long life.
  - o Trails will be aligned to provide desirable experiences such as solitude, exercise, and fun in order to

18

discourage the creation of social trails. Trails reach "positive control points" (e.g., views) and avoid "negative control points" (e.g., nesting and other habitat areas).

- Involving the public as partners, customers, volunteers, participants, stakeholders, etc.
  - o Metro has a staff of full-time volunteer coordinators who will work with trail stewardship groups such as Trailkeepers of Oregon and Northwest Trail Alliance to monitor and maintain trails at BCF while encouraging site stewardship.
  - o Metro's staff provide nature education programs to schools, groups and the general public.
- Encouraging partnerships with various organizations
  - o Metro's Partners in Nature grant program provides opportunities for diverse communities to connect with nature. At the North Tualatin Mountains, Metro partners with Self Enhancement Inc. to introduce hundreds of at-risk urban youth to nature curriculum.
  - o During the planning process, a Stakeholder Advisory Committee was formed. Members include: representatives of surrounding neighborhoods, trails groups, and partner park providers and advocates, including Forest Park Conservancy, Forest Park Neighborhood Association, Northwest Trail Alliance, Oregon Department of Forestry, Oregon Recreation Trails Advisory Committee, Portland Community College, Portland Parks & Recreation, Skyline Ridge Neighbors, Skyline School, Trackers Earth, and West Multnomah Soil and Water Conservation District.

TRAIL MAINTENANCE AND MANAGEMENT (Criterion #8 - 10 points)

Do you have dedicated funding for ongoing trail operation and maintenance?

Yes

If yes, what is the approval cycle?

Annual

Do you have permanent staff for ongoing trail operation and maintenance?

Yes

If yes, please identify the number of permanent and seasonal staff

Permanent Staff

10

Seasonal Staff

4

Do you have a resolution of support for long-term maintenance (or similar guarantee of financial support)?

Yes

Do you have organizations that adopts / assists with trail maintenance?

Yes

If Yes, please identify those organizations.

Organizations that have committed to assisting with trail maintenance are the Youth Ecology Corp, Trailkeepers of Oregon, and Northwest Trail Alliance.

Do you have an adopted trail management plan?

Yes

If yes, please identify the title of the document and when it was adopted by a governing body.

North Tualatin Mountains Access Master Plan, adopted 4/21/2016 by Metro Council. Also a letter of commitment to trail management dated 4/25/2017. Metro recently completed a final draft of an Operations and Maintenance Plan to guide future work. The document is expected to be finalized in June of 2017.

Metro has committed to long-term funding for ongoing maintenance of the public access facilities at the Burlington Creek Forest Nature Park. Ongoing funding is provided by Metro's overall operating budget, supported by general fund monies, and supplemented with funds from the 2013 and 2016 parks and natural areas levies approved by voters.

Routine trail maintenance on a year-round basis improves trail safety and prolongs the longevity of North Tualatin Mountains' trails. The keys to trail maintenance are regularly scheduled monitoring to achieve early identification of trail problems catching and mitigating social trails. Major trail damage caused by weather (wind, lightning, etc.) will be immediately identified and repaired at the earliest possible opportunity.

During the first year after construction, and after the first heavy rains, close attention will be paid to drainage and erosion patterns on soft surface trails. It is common for trails to need additional maintenance and adjustment during the first season. Ongoing trail maintenance activities will typically include vegetation clearing and pruning to keep passages and selected views open, erosion control measures, trail surface stabilization, bridge and culvert clearing and upkeep, litter and illegal dumping clean-up, replacing signs, and closing social trails through the use of natural barriers and vegetation. Staff or volunteers will hike the trail a minimum of twice a month and keep a log of trouble areas, with corrective action taken within the same week.

Once trails are open for use, the BCF volunteer groups - Northwest Trail Alliance and Trailkeepers of Oregon - will provide site stewardship via "eyes and ears" above and beyond what Metro staff can provide. Through routine walking and monitoring of the trails, volunteer site stewards can alert staff early to issues requiring action. They can also serve as "ambassadors" for North Tualatin Mountains, answering questions and ensuring visitors abide by rules and proper trail etiquette.

PROJECT URGENCY (Criterion #9 - 5 points)

Please describe how your project has an urgent need.

The public involvement in this project's planning generated hundreds of individual comments urging immediate public access to one or more of the four Metro natural areas in the North Tualatin Mountains. People are enthusiastic about opportunities to hike, mountain bike, ride their horses and experience nature at Burlington Creek Forest. A strong voice came from the mountain biking community seeking off-road cycling opportunities close to home, and Metro seeks to pilot a shared-use approach at the site most suitable for an expanded trail network.

This message was furthered by an inventory of off-road cycling opportunities, completed by Metro in 2016, that found a lack of opportunities to ride off-road bicycles in the Portland Metropolitan area. Mountain biking is growing in popularity and is often cited by community members as their preferred way to exercise, enjoy a mental escape, socialize, and enjoy nature.

Given the proximity to the City of Portland, community members could potentially ride or take transit to within a short distance of Burlington Creek Forest. With a deficit of off-road cycling opportunities close to home, the addition of five miles of trails is a significant and welcome increase for the Portland region.

Without additional funding, only the trailhead and roadway improvements will be completed during the initial phase of development due to project costs. No trails will be built and visitors will only be able to experience the site by walking, cycling or riding a horse on 2.5 miles of existing gravel roads.

Inaction is to be avoided for three reasons: (1) Existing gravel roads do not offer the same quality visitor experience as well aligned trails, (2) Several areas of the road have steep grades creating a serious challenge for many trail users, and (3) Unsafe conditions and resource degradation could occur without formal trails.

10

An open site with parking for visitors (currently budgeted) could entice enthusiastic trail users to develop their own trail system. If this happened, without the benefit of professional design, adverse results including unsafe trails, habitat fragmentation, vegetation trampling, and erosion will be the likely result. It is imperative to both public safety and natural resource protection that trail opportunities be coupled with the opening of the trailhead.

YOUTH CONSERVATION (Criterion #10 - 5 points)

Does your project utilize Youth Conservation Corps, Youth Community Conservation Corps, Certified Youth Conservation Corps or other youth service organization to complete your project?

Yes

MISCELLANEOUS

Does the entity or organization applying own the land that work will be performed on?

Yes

If no, describe the land manager's involvement in project planning, project approval, and the level of involvement that the land manager will have throughout implementation.

Are any pre-agreement project planning or environmental costs included in the match?

No

If yes, describe the budget elements and indicate when the pre-agreement work will take place.

Applicant Certification

As an authorized representative of **Metro** , I certify that the applicant agrees that as a condition of receiving **Recreational Trails Grant Program** assistance, it will comply with all applicable local, state and federal laws and regulations.

This application has been prepared with full knowledge of, and in compliance with, the Oregon Parks and Recreation Department's (OPRD) Grants Manual for the Recreational Trails Grant program.

I also certify that to my best knowledge, information contained in this Application is true and correct. I will cooperate with Oregon Parks and Recreation Department by furnishing any additional information that may be requested in order to execute a State/Local Agreement, should the project receive funding assistance.

Karen Vitkay, 07/24/2017

▲ 29 Files

Description	File type	Size
State Agency Review Form - Completed	pdf	23 kb
Land Use Compatibility Statement (LUCS) - Completed	pdf	833 kb

Description	File type	Size
Vicinity Map	pdf	1,105 kb
Letters of Support	pdf	309 kb
Letters of Support	pdf	53 kb
Land Manager Approval Form - Completed	pdf	395 kb
State Agency Review Form - Completed	pdf	20 kb
Site Plan	pdf	18,521 kb
Letters of Support	pdf	67 kb
Property Deed or Easement or Lease Agreement	pdf	3,385 kb
Letters of Support	pdf	341 kb
Other	pdf	342 kb
Project Timeline - Completed	pdf	86 kb
RTP Environmental Screening Form - Completed	pdf	103 kb
Park Boundary Map	pdf	1,160 kb
Letters of Support	pdf	111 kb
Letters of Support	pdf	96 kb
Letters of Support	pdf	171 kb
State Agency Review Form - Completed	pdf	941 kb
Letters of Support	pdf	88 kb
Other	pdf	2,939 kb
Trail Accessibility Assessment Memorandum - Completed	pdf	43 kb
Letters of Support	pdf	72 kb
Letters of Support	pdf	147 kb
Other	pdf	91 kb
Letters of Support	pdf	42 kb
Letters of Support	pdf	72 kb
Site Plan	kmz	78 kb
Other	pdf	2,687 kb

No Comments

▲ 8 Logged Events

Event	By	Date
Application Status changed to Closed.	Jodi Bellefeuille	11/08/2017
Application recommended by committee	Jodi Bellefeuille	11/08/2017
Application Status changed to Reviewed.	Jodi Bellefeuille	07/26/2017
Application 3910 - Burlington Creek Forest Natural Surface Trails has been submitted.	Karen Vitkay	07/24/2017
Application Status changed to Editable.	Jodi Bellefeuille	07/19/2017
Application 3910 - Burlington Creek Forest Natural Surface Trails has been submitted.	Karen Vitkay	05/31/2017
LOI for application 3910 submitted	Karen Vitkay	03/30/2017
Application created.	Karen Vitkay	03/29/2017

This application requires a Letter of Intent

Show Letter of Intent

27

APPROVAL BY LAND MANAGER

As the official responsible for management of the land on which the project is located, I agree to the following:

1. The proposed trail project or facility will remain accessible for public use.

2. The project as described in this application has my approval.

3. The project as described is in compliance with Section 1302 (e)(2)© of the Recreational Trails Program that prohibits the use of grant funds to accommodate motorized use on trails that have been predominately used by non-motorized trail users prior to May 1, 1991.

4. If this project is located on federal lands:

   (a) The project is in compliance with all applicable laws, including the National Environmental Policy Act, the Forest and Rangeland Renewable Resources Planning Act, the Federal Land Policy and Management Act, and the Wilderness Act.

   (b) The project is in conformance with the appropriate Forest Management Plan or BLM Resource Area Management Plan titled:

Title:	Date:

   (c) A decision has been issued as part of the NEPA environmental review process. Attach copy of decision notice/finding of no significant impact.

   (d) If a decision has not been issued, please state when a decision is expected.

Signature:	Date: 4/20/17
Print or Type Name: Don Robertson	
Title: Interim Director	
Phone Number: 503-797-1948	
Email: don.robertson@oregonmetro.gov	

24

Oregon Parks and Recreation Department 02/28/2017 12:55PM 000001 36270
2007 SARAH
BLD P/LUCS $75.00

Local Government Grant Program – Project Application

Land Use Compatibility Statement (LUCS)

What is a LUCS? A Land Use Compatibility Statement (LUCS) is the form OPRD uses to ensure that proposed projects are consistent with local land use requirements.

How to Complete the LUCS: The applicant completes Section 1. Section 2 must be completed by the local Planning Official. The applicant then submits the completed LUCS to OPRD as part of the Grant Project Application.

LUCS Fee: $75 / BP-2017-7383

SECTION 1: Applicant & Site Information			
Print Applicant Name: *Karen R. Vitkay*		Applicant Signature: [signature]	
Property Owner Name: *Metro*			
Subject Property Address (Or adjacent to): *Adjacent to: 16448 NW MCNAMEE RD PORTLAND, OR 97231-2151*			
Site Description: *The Burlington Creek Forest property of the Tualatin Mountains is composed of 339 acres of forested ridges and valleys within the unincorporated area of Multnomah County.*			
Describe the planned use for the property: *Planned development includes a formal parking area for 15-20 vehicles along with public access to three miles of existing gravel roadway for hiking, off-road cycling and equestrian use. Also 5-7 miles of new trails for use by hikers and off-road cyclists.*			
Township(s) *2N*	Range(s) *N1*	Section(s) *W19, W20*	Tax Lot(s) *100, 200, 300, 400, 500, 600, 800, 3700*

SECTION 2 must be filled out by a Local Planning Official

SECTION 2: Determination of Compliance with Local Land Use Requirements

The subject property is: ☐ Inside ☑ Outside City Limits ☐ Inside ☑ Outside UGB

Current Comprehensive Plan Designation: CFU Current Zoning: CFU (Commercial Forest use)

Is a Comprehensive Plan or Zoning Amendment Proposed? YES ☑ NO ☐

If YES, list the proposed plan designation: CFU + parks use Proposed zoning: No Change

Does the activity, use, or development require land use review to determine compliance with land use regulations? YES ☑ NO ☐

If NO, it means that no local land use review is needed. **Skip to Local Planning Official Information below.**

If YES, what is the status of the land use application: ☐ **Approved** ☐ **Denied** ☐ **Under Review** ☑ **Not Yet Received**

List file number(s): Is the decision final: YES ☐ No ☐

Comments: Applicants are in for pre-application. Application will entail a Comp. Plan Amendment & Conditional use, as well as other environmental & technical permits.

Local Planning Official Information:

Jurisdiction: Multnomah County	
Print Planning Official's Name & Title: Kevin Cook, Senior Planner	
Mailing Address: 1600 SE 190th Ave.	
City: Portland, OR	Zip Code: 97233
Phone: 503·988·0188	Fax: 503·988·3389

2-A

Metro

600 NE Grand Ave.
Portland, OR 97232-2736
oregonmetro.gov

April 21, 2017

Jodi Bellefeuille, RTP Grant Coordinator
Oregon Parks and Recreation Department
725 Summer Street, Suite C
Salem, OR 97301

RE: Burlington Creek Forest Property Ownership

Dear Ms. Bellefeuille,

This letter and attached information is submitted in support of Metro's application for an RTP grant. The project is located within the North Tualatin Mountains in Multnomah County. The Burlington Creek Forest site is located at:

- Latitude 45.641725, Longitude 122.844272
- See attached for tax lot numbers

The Agency has authority to develop this property by:

X Fee Simple Title

☐ Easement

☐ Use/Lease Agreement

☐ Other: ____________________

The following restrictions or other rights are located on this project and could impact this project or its future operation for public recreation:

☐ None

X Easement (Types: Utility lines and facilities, conservation easement for hiking trail and vehicle access)

☐ Access/Lease/Use Agreement

X Other: (Types: United Railway Company right-of-way, Multnomah County road right-of-way)

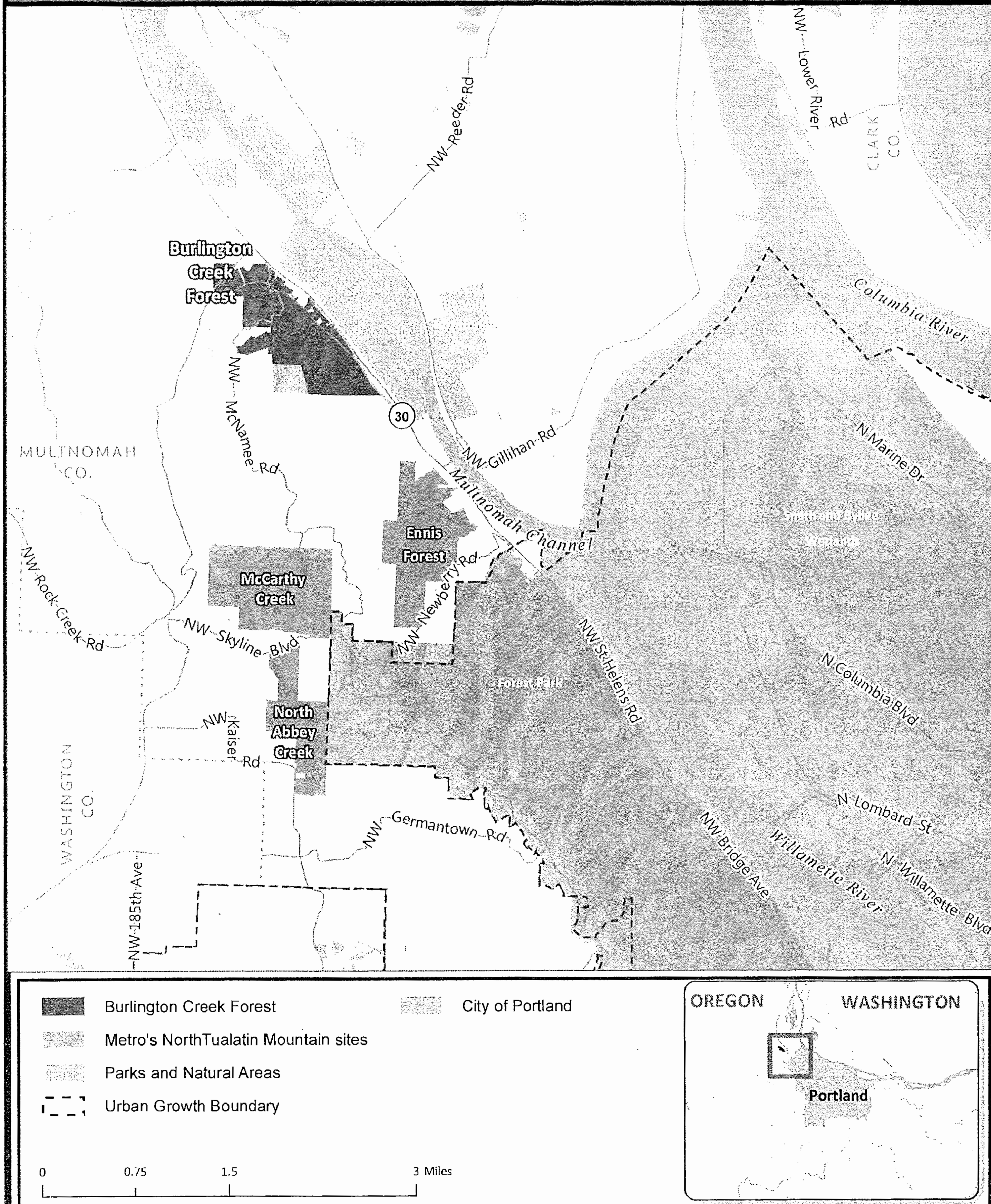
I certify that the above information is correct.

Sincerely,

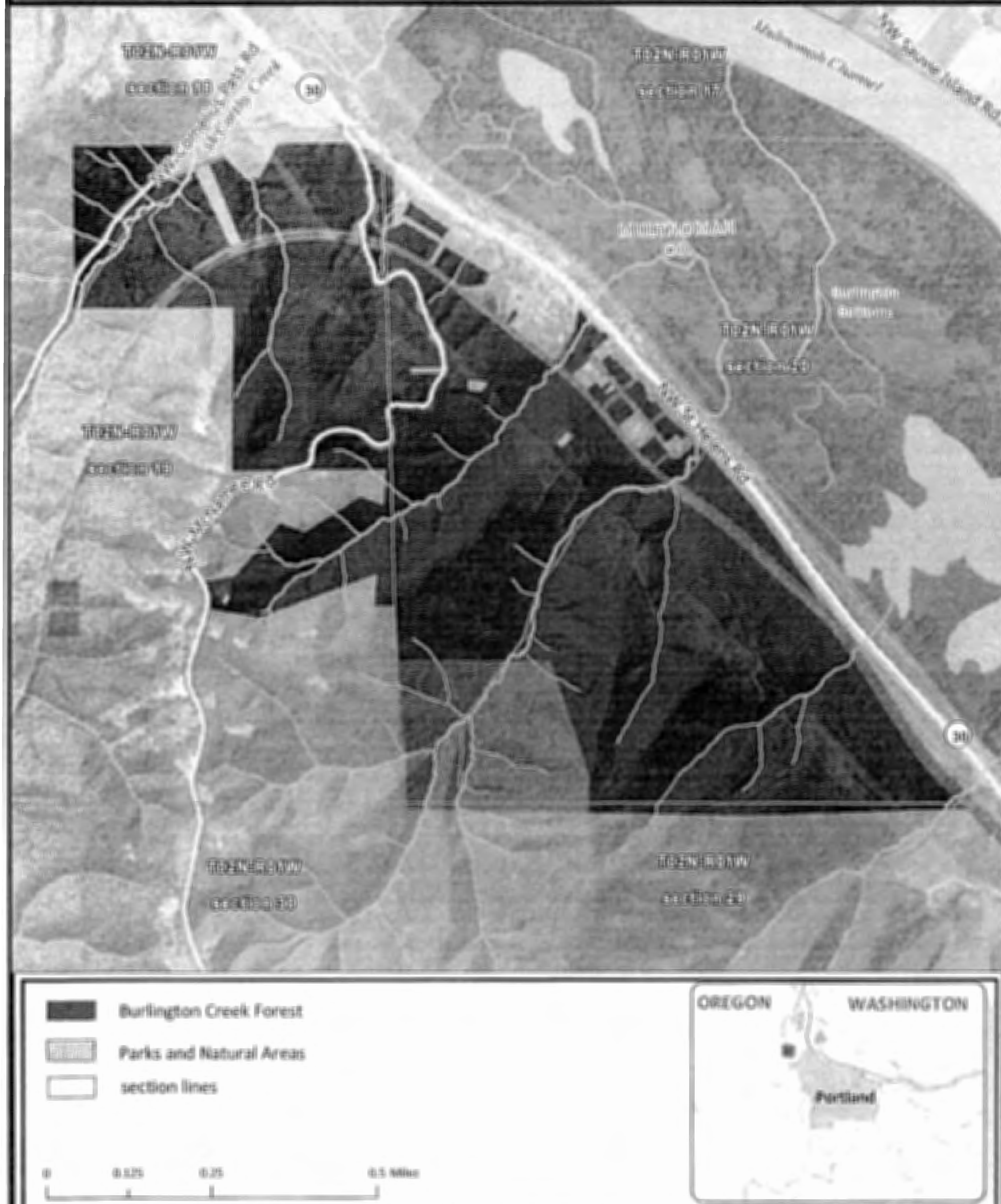
Don Robertson
Interim Director
don.robertson@oregonmetro.gov

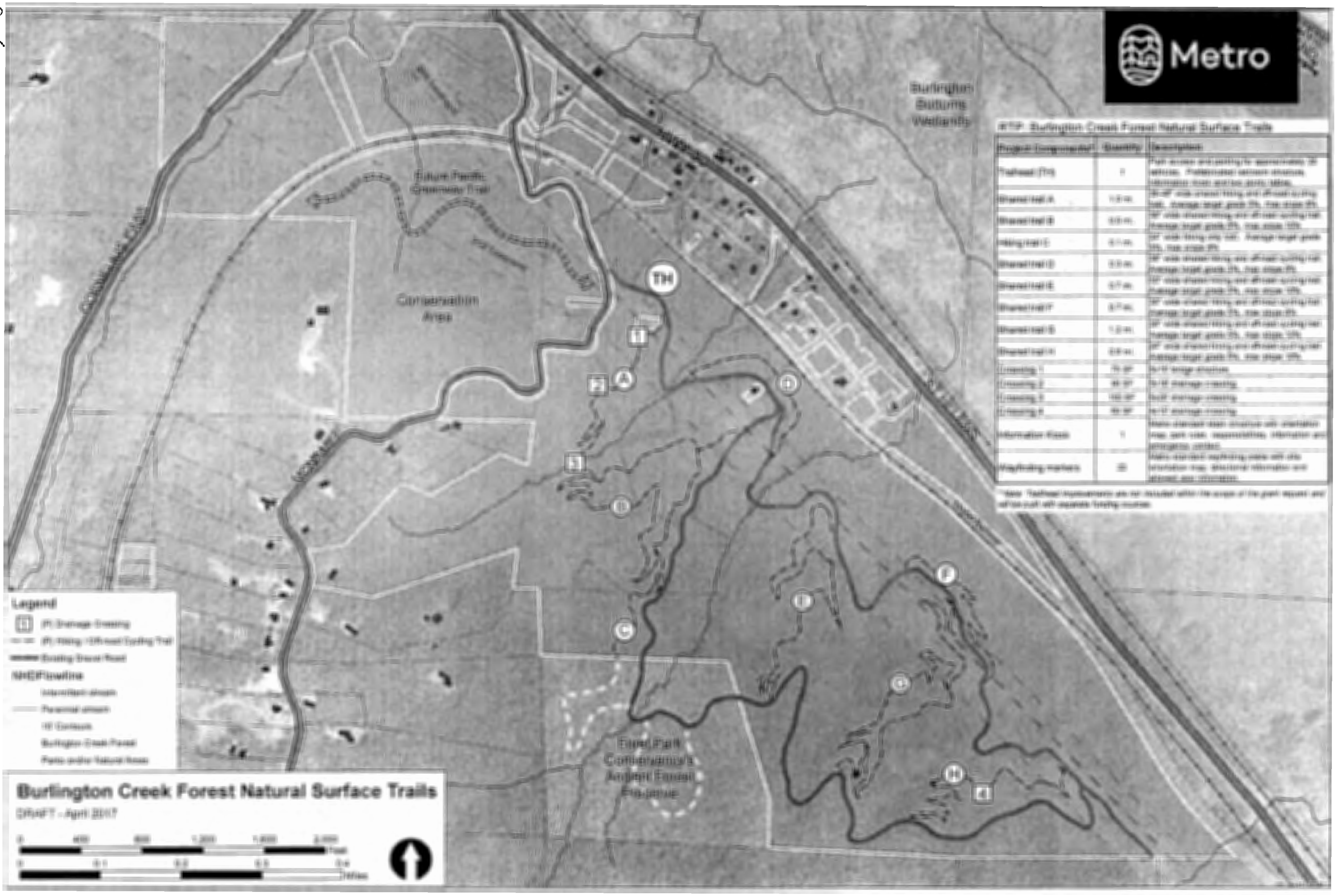
26

Vicinity Map

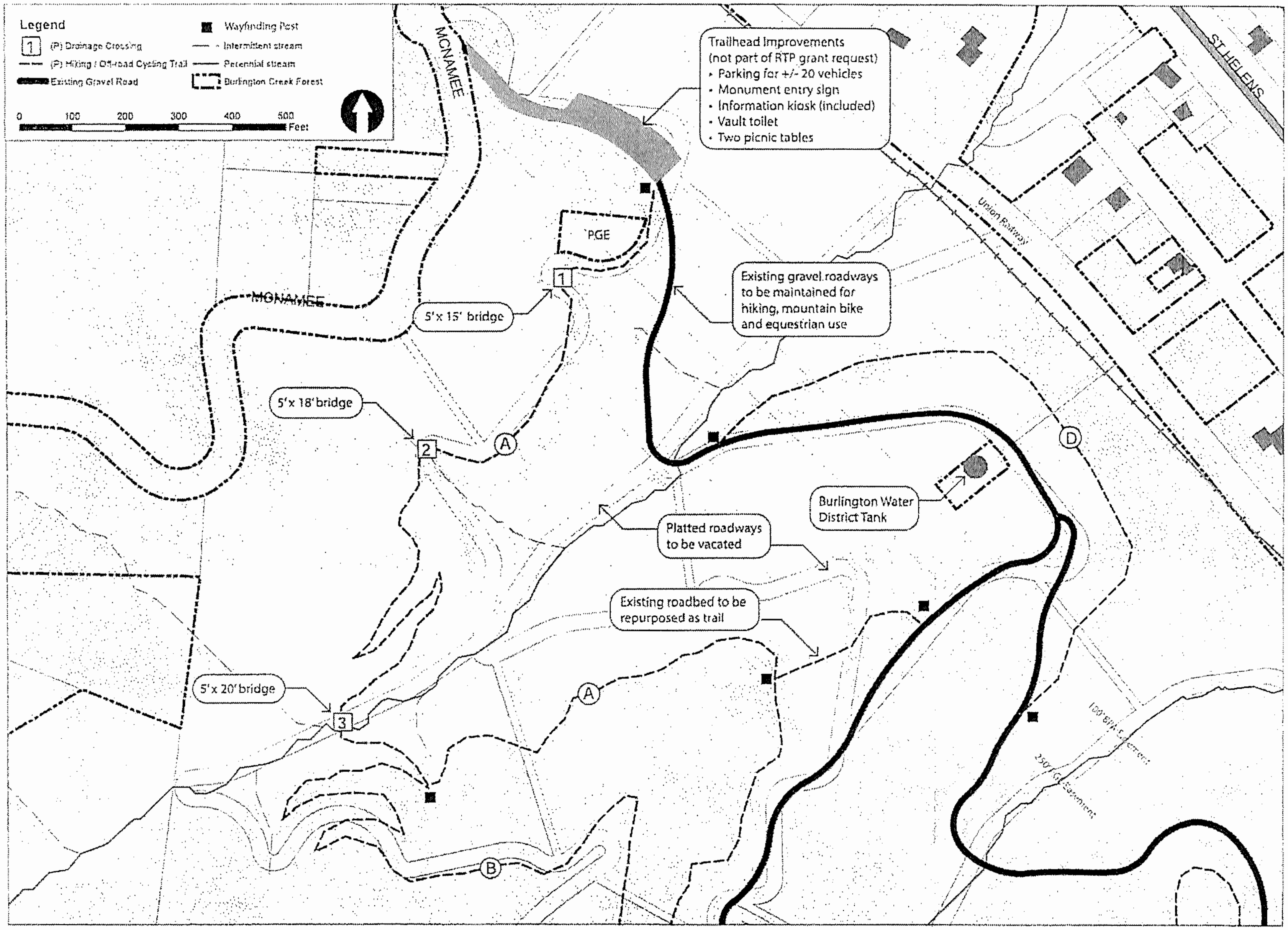


Project Boundary Map





Metro
Burlington Bottoms Wetlands
RTP: Burlington Creek Forest Natural Surface Trails
Future Pacific Greenway Trail
Conservation Area
TH
A
B
C
D
E
F
G
H
Legend
Burlington Creek Forest Natural Surface Trails
DRAFT - April 2017



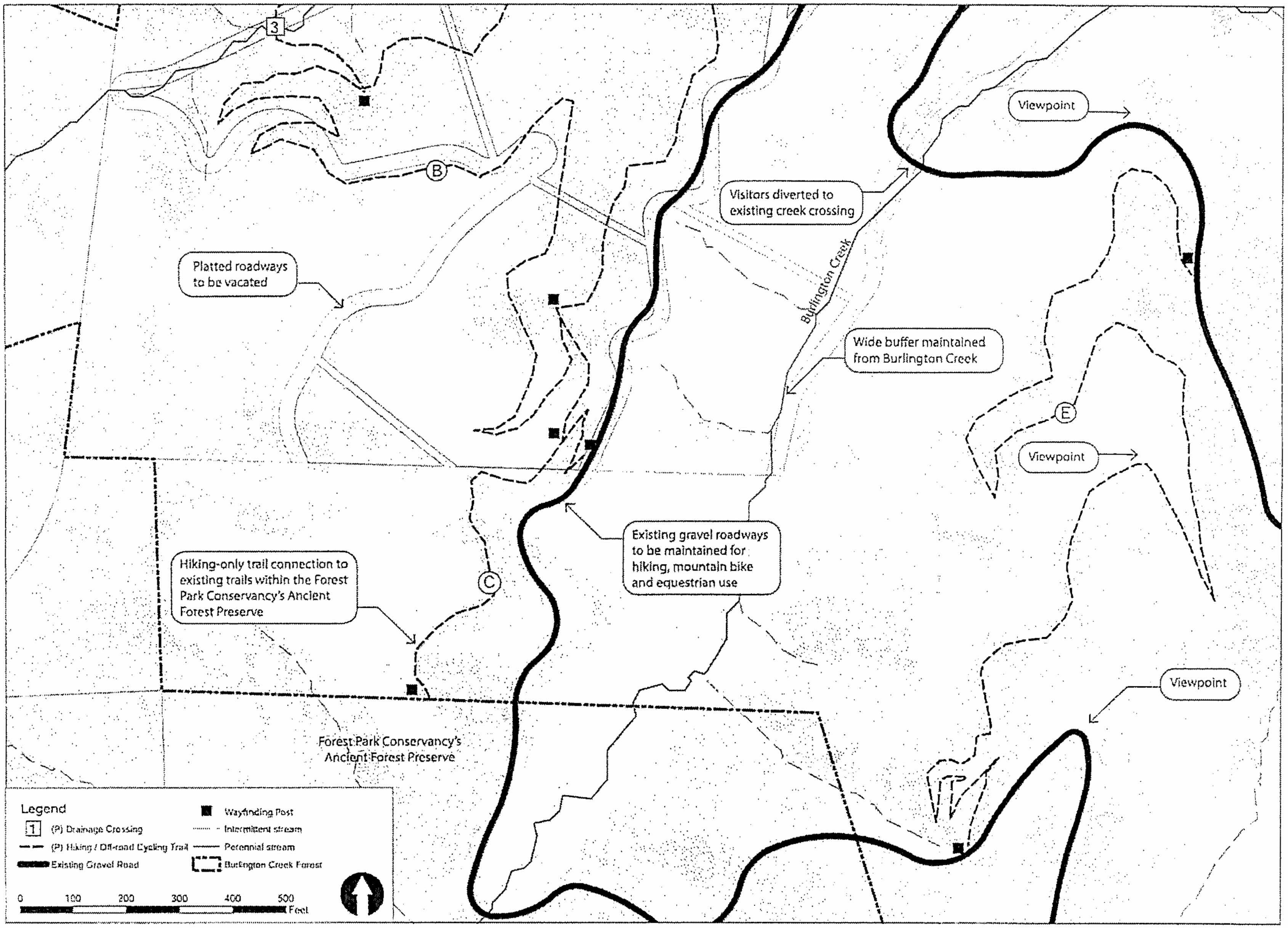
Metro

Burlington Creek Forest
Trail Improvements
NORTHWEST

SUBMITTAL:
30% REVIEW SET

North Tualatin Mountains
Multnomah County

DATE:
26 APRIL 2017



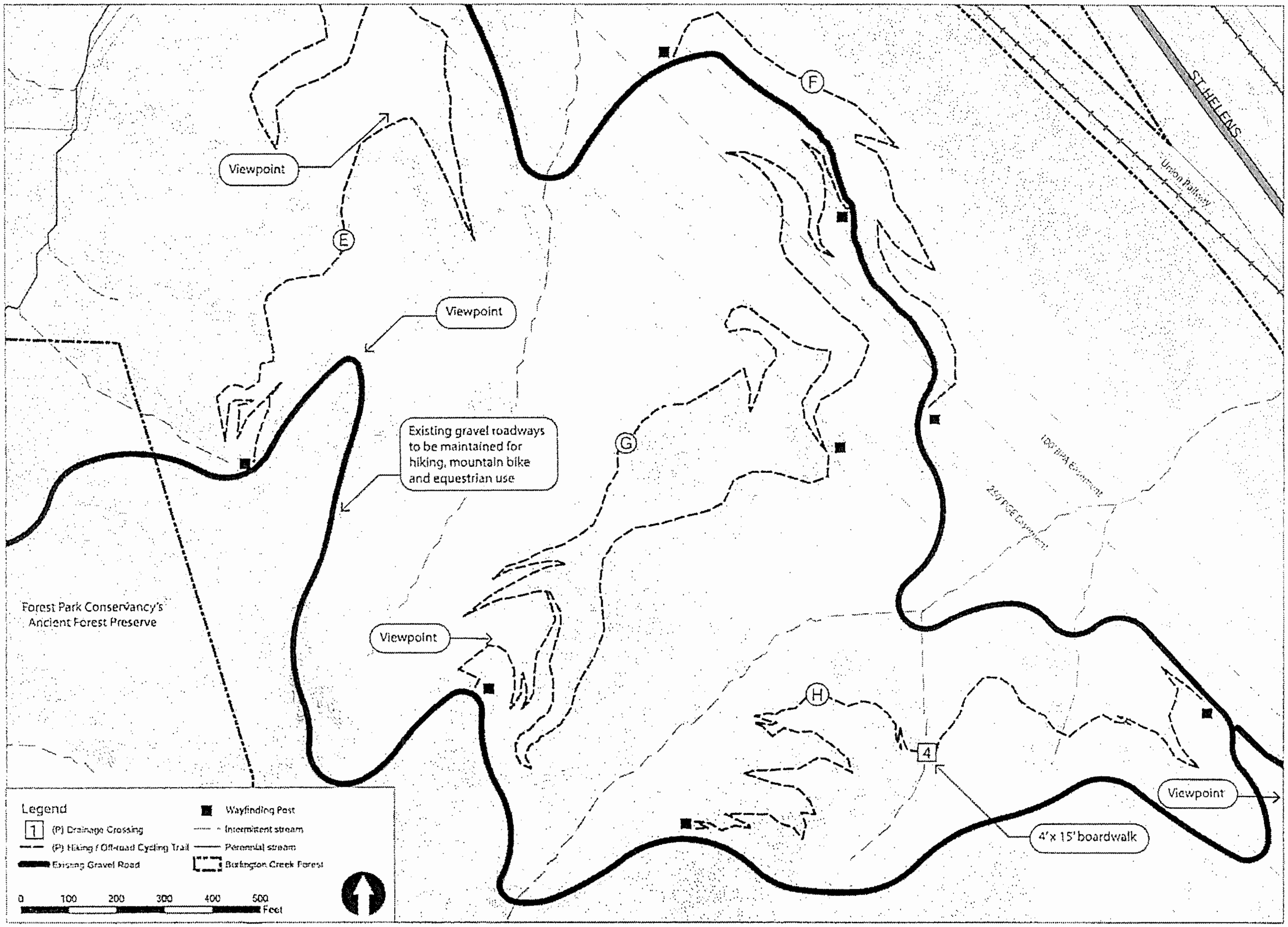
Metro

Burlington Creek Forest
Trail Improvements
SOUTHWEST

SUBMITTAL:
30% REVIEW SET

North Tualatin Mountains
Multnomah County

DATE:
26 APRIL 2017



Metro

Burlington Creek Forest
Trail Improvements
EAST

SUBMITTAL:
30% REVIEW SET

North Tualatin Mountains
Multnomah County

DATE:
26 APRIL 2017

1k

37

RTP Environmental Screening Form

Sponsor Name:
Metro Parks and Nature

Project Name:
Burlington Creek Forest Natural Surface Trails

OREGON STATE PARKS
Nature HISTORY Discovery

Part I: Project Description: What will this grant fund?

On behalf of the public, Metro owns 1,300 acres of the North Tualatin Mountains which extend from the fringes of Oregon's Coast Range into the greater Portland metropolitan area. A public planning process was held over a two year period to identify desired activities and the most suitable location for public access to nature at four different sites within the North Tualatin Mountains properties. This grant request, if awarded, would fund the building of natural surface trails at one of those sites, Burlington Creek Forest. Approximately five miles of shared use, natural surface, hiking and mountain biking trails, along with needed drainage crossing structures, information kiosk and wayfinding signs would be constructed.

In keeping with its mission, Metro has completed extensive work to improve habitat and water quality at its four North Tualatin Mountains properties. Work has included 1.3 miles of stream restoration, 700 acres of forest thinning and the planting of 85,000 native trees and shrubs. Further planned restoration includes the decommissioning of three miles of existing gravel roads, culvert removal and replacement and continued forest management to improve water quality and wildlife habitat.

Proposed trails at Burlington Creek Forest are being designed sustainably and have been aligned to minimize impacts to natural resources. Sustainable trail design and construction techniques to be employed include: maintaining wide buffers from riparian corridors, minimizing the number of stream crossings, utilizing boardwalks and bridges to reduce impacts to riparian areas and minimizing erosion potential by aligning trails to follow contours, utilize grade reversals and to have outslopes that shed stormwater locally. Natural surface trails will vary in width, ranging between 24 and 48".

Part II: Alternatives to Proposed Action(s): Are there project Alternatives? If so, please describe.

A public master plan process was held over a two year period to determine the most feasible site for public access among the four separate sites that compose the 1,300 acre North Tualatin Mountains. A landscape scale assessment considered the habitat conservation value of each property based on key ecological attributes and a desired future condition scenario (see the attached 2016 Site Conservation Plan).

During the access planning process, two of the four sites, McCarthy Creek and Burlington Creek Forest, were selected for formal public access based on current conditions, conservation targets, habitat restoration goals, existing visitor use, feasibility and ease of public access. At North Abby Creek and Ennis Creek Forest, habitat and water quality will remain the priority along with a provision for a possible future Pacific Greenway Trail segment. A landscape scale assessment considered the habitat conservation value of each property based on key ecological attributes and a desired future condition scenario (see the attached 2016 Site Conservation Plan).

Site alternatives explored different options for where formal public access and trails would be located as well as the most suitable places to protect land for conservation purposes. The alternative scenarios are attached and the 2016 adopted North Tualatin Mountain Access Master Plan is available at: www.oregonmetro.gov/north-tualatin-mountains-access-master-plan.

Utilizing public input, Burlington Creek Forest was selected for the first phase of development. Alternative concept plans explored opportunities to provide public access as well as places to protect core habitat areas.

Part III: Environmental Consequences: Complete the following. For each "yes," describe the magnitude of the impact and the potential for significant impact (based on context and intensity). Attach appropriate supporting

937

277

documentation.		
A. Property Acquisitions: (Note: Acquisitions under Eminent Domain is not a permissible activity under the RTP program.)	**Yes**	**No**
1. Is the project seeking permanent acquisitions from private landowners or local authorities?		X
2. If yes, is the project seeking full or partial acquisition(s)?		
3. Is the project on, or is it seeking transfer of Federal or State Land?		X
4 If yes to any of the above, describe the proposed acquisition below and attach figures depicting affects to the property(ies):		

B. Local Land Use:	**Yes**	**No**
1. Is the project consistent with Federal, State and or Local land use plans?		X

2. If yes, identify land use plans and briefly describe how the project meets consistency.
If no, please explain:

Metro is in the process of obtaining land use approval through Multnomah County. Our land use pre-application meeting was held during March of 2017. The approval process will involve an amendment to the County's Comprehensive Plan and a conditional use permit. While recreational uses, including trails, are allowed uses in Commercial Forest Use zoned lands, our trailhead development (not part of the RTP application) is considered a conditional use.

C. Social and Economic:

1. Describe the positive and negative social and economic affects (if any) of the project to the local community(ies), individual residents, and/or businesses:
(For example, consider immediate and near future affects to local commuters, the elderly, the handicapped, other recreational users, churches, schools; and consider comments received from the public in Section IV below.)

Situated less than two miles northwest of the City of Portland, the Burlington Creek Forest site is less than an hour drive for the Portland region's nearly 2.4 million residents. In addition to the long term protection of nature, studies show that parks and trails have numerous benefits for community members. These include improved mental and physical health, increased property values for adjacent neighbors, and economic development for businesses supporting outdoor recreation as well as local businesses providing essential services.

New natural surface trails at Burlington Creek Forest, will enhance trail connectivity within the region. New trails will provide public access to nature, an essential component of establishing appreciation of nature and a conservation ethic in order to ensure nature protection for future generations. Trails at Burlington Creek Forest Nature Park will also facilitate access to the adjacent Forest Park Conservancy's Ancient Forest Preserve (access is only available through Burlington Creek Forest). The formal opening of the site will further complete a gap within the Pacific Greenway Trail, which is envisioned to one day extend from public lands in the coast range to Portland's famed 5,157 acre Forest Park to the southeast.

The 2013-2017 Statewide Comprehensive Outdoor Recreation Plan (SCORP) found that "although Oregon is a state with abundant natural resources, there is growing evidence that Oregon's youth are gravitating away from outdoor experiences and towards a virtual indoor reality By providing Oregon's youth with opportunities to learn outdoor recreation skills in outdoor settings, we have the opportunity to rebuild the foundation for future outdoor recreation participation, reestablish personal connections with nature and their public lands, and improve not only health and well-being of future youth and adults, but also instill a passion for nature that result in future nature stewardship." The SCORP also found that one of the most important management action that will lead to a large increase in recreation followed is "developing walking/hiking trails closer to home and providing more free-of-charge recreation opportunities."

Metro is committed to getting all people outdoors as a means to ensure a conservation ethic within our population. We enjoy a partnership with the non-profit Trackers Earth who actively accesses Metro properties within the North Tualatin Mountains for their camps and outdoor programming.

324

Furthermore, Metro focuses on providing opportunities for all our community members to experience nature close to home. It is only with ease of access and familiarity will people gain lifelong healthy habits and appreciation of nature. Metro does not intend to charge a fee to visit Burlington Creek Forest in order to avoid a potential barrier for community members of lower socio-economic status.

Participation in day hiking experienced a nearly 20% growth rate in Oregon between 1982 and 2009 (SCORP). Trail development at Burlington Forest would meet three of the top four identified community needs when asked about preferred activities: dirt walking trails and paths, nature and wildlife viewing and off-street bicycle trails and pathways.

An inventory of off-road cycling opportunities, completed by Metro in 2016, found a deficiency in opportunities to ride off-road bicycles in Portland Metropolitan area. Mountain biking is growing in popularity and is often cited by community members as their preferred way to exercise, enjoy a mental escape, socialize, and enjoy nature. Given the proximity to the City of Portland, off-road cyclists could potentially ride or take transit within riding distance of Burlington Creek Forest. Given the deficit of off-road cycling opportunities close to home, the addition of approximately five miles of trails is a significant increase for the region's community members.

While the majority of community members are enthusiastic to have another protected natural park in the region, some neighbors have expressed concerns. We have heard concerns about increased traffic on area roadways. The Burlington Creek Forest site, however, is an ideal option for development as park access is proposed just a quarter mile from a highway and Metro owns all the property on both sides of the road for that length. Others have concerns about the potential impacts to wildlife that may result from trails. Metro is a conservation organization with habitat and water quality protection at the core of its mission. The third essential piece of the mission is to provide public access to nature. We realize that some impacts to nature will occur and actively work to minimize these impacts. We view public access as critical to ensuring future conservation and protection of nature in our region.

An investment in Metro's nature parks ensures a public benefit to a wide array of diverse community members. Metro is proud to be recognized as a leader in advancing diversity, equity and inclusion in the region. This important work includes providing parks and natural areas that are welcoming to all people so that future park visitors reflect our region's growing diversity.

D. Archeological and Historical Resources:	**Yes**	**No**
1. Are there National Register-listed or eligible sites in the project area?		X
2. Would the project affect any listed or eligible sites?		X
3. Are the effects of the project adverse to listed or eligible sites?		X

4. If yes to any of the above, briefly summarize below and attach the following: survey report, accompanying determinations and concurrences from State Historic Preservation Office, and any agreement for resolution of adverse effects.

A cultural resource overview was completed by Archaeological Investigations Northwest in September of 2014. A review of archaeological records and a field review were conducted. The records search found no previously recorded cultural resource investigations and no cultural resources were found during fieldwork. Given the history of land use for agriculture, forestry, and (rarely) housing, few, if any, undisturbed portions of landforms were found. The landscape observed in all cases was highly undulating, likely due to the traverse of tracked vehicles. The undulations, along with the subsequent erosion, make the probability for cultural resources in the areas visited low.

E. Fish & Wildlife: Attach a completed and signed Intergovernmental Consultation Form from **Oregon Department of Fish & Wildlife.** (See Section 1.8 for instructions and Section 6.1 of the RTP manual for the form and contact information.)	**Yes**	**No**
1. Are there Threatened or Endangered species or their habitat present?		X
2. Are anadromous or resident fish populations present?		X
3. Are migratory bird habitat or raptor nest present?	X	
4. Does the project affect wildlife resources (game/subsistence species)?	X	

5. Will the project cross Essential Fish Habitat (EFH)?		X
6. For questions 2-5, are any permits required?		X

7. Describe impacts; attach supporting documentation and the Intergovernmental Consultation Form.

Upland forests like Burlington Creek Forest are known to provide suitable habitat to native birds, mammals, reptiles and amphibians. While there are benefits to providing access to nature, human presence and recreational trail development can have adverse effects on wildlife by increasing stress/reducing fitness, disrupting breeding and foraging behaviors, and increasing risk of direct mortality and illegal collection. No threatened or endangered species are known to be present in or near the project area, however it is assumed that red legged frogs, a state sensitive species, migrate onto the site from the Burlington Bottoms Wetland site on the East side of Highway 30.

Although anadromous fish are present in McCarthy Creek which does flow through a portion of the Burlington Creek Forest natural area, the project area is located out of the McCarthy Creek watershed. The site provides habitat for a wide variety of migratory passerine and raptor species.

Metro has conducted monitoring for game species (elk). Limited evidence of elk use was observed within Burlington Creek (Figure 6). No trails were identified that would indicate regular use by elk. Sign observed included a few tracks in the SE portion of the study area as well as in the roadbed on spurs just south of the Metro gate, and one rub that was in excess of 6' up tree bole in a clearing area adjacent to McNamee Rd. Several other rubs were present on alders along the roadside but they could not be positively definitely identified as elk or deer. Browse of planted native shrubs and trees was also apparent in this area, and probable elk browse was observed on western wahoo shrub in the Burlington Creek canyon. Expanses of western red cedar, a highly preferred food plant for elk, appeared un-browsed. A fair amount of black-tailed deer tracks and scat was observed throughout the study area.

F. Wetlands & Floodplains: Attach a completed and signed Intergovernmental Consultation Form from the **Department of State Lands.** (See Section 1.8 for instructions and Section 6.1 of the RTP manual for the form and contact information)			**Yes**	**No**
1. Will the project area impact Wetlands? (If yes, complete questions a-d)				X
a. Total wetland acres affected:	unknown			
b. Total wetland fill quantities:	< 50 Cubic Yards			
c. Dredge quantities of wetland:	< 50 Cubic Yards			
d. US Army Corps of Engineers authorization required:	☒ None	Type: ☐ NWP ☐ Individual ☐ Other		
2. Does the project encroach onto the 100-year floodplain?				X
a. If yes, would the project increase the backwater elevation of the 100-year floodplain one foot or greater?				
3. Is the project within a regulatory floodway?				X
a. If yes, does the project adversely affect the floodway?				

4. Describe impacts, attach supporting documentation and the Intergovernmental Consultation Form.

According to National Wetland Inventory data, no wetlands occur on site. Wetlands are unlikely in most areas due to significant slopes, however some may be present in association with riparian areas. Also, the project occurs outside of the 100-year floodplain.

This summer, the refined trail alignments will be flagged and then walked by a biologist or wetland scientist to inventory wetland areas. Trail alignments will be adjusted to avoid and/or minimize impacts to wetland areas. Two proposed small drainage crossings may have minor impacts on wetland areas. Crossing structures will be aligned and designed to minimize impacts.

G. Water Bodies: Attach a completed and signed Intergovernmental Consultation Form from the **Department of State Lands.** (See Section 1.8 for instructions and Section 6.1 of the RTP manual for the form and contact information)	**Yes**	**No**
1. Does the project affect a navigable water body (as defined by Section 9 of the Rivers and Harbor Act)?		X

2. Does the project affect waters and navigable waters of the U.S. (as defined by Section 404 of the Clean Water Act and/or Section 10 of the Rivers and Harbors Act)?		X

3. Proposed river or stream involvement:	☒ Bridge ☐ Relocation	☐ Culvert ☐ Diversion	☐ Embankment Fill
a. The proposed stream involvement is :	☒ Permanent	☐ Temporary	
4. Type of stream or river habitat impacted:	☐ Spawning ☐ Riffle	☐ Rearing ☐ Undercut Bank	☐ Pool

5. Describe the impacts; attach supporting documentation and the Intergovernmental Consultation Form.

Two drainage crossing structures are proposed. The USGS National Hydrography Dataset classifies one drainage as a perennial stream and the other as an intermittent steam. The proposed structures are associated with trails and are expected to be one bridge approximately 5 feet wide by 18 feet long and one boardwalk 4 feet wide by 15 feet long. While designs have not yet been completed, the decking is anticipated to be made of pultruded fiberglass grating.

H. Oregon Coastal Management Program: Attach a completed and signed Intergovernmental Consultation Form from the **Oregon Department of Land Conservation and Development.** (See Section 1.8 for instructions and Section 6.1 of the RTP manual for the form and contact information).	**Yes**	**No**
1. Is the project within the Oregon Coastal Management Program boundary?		X

2. Describe the impacts; attach supporting documentation and the Intergovernmental Consultation Form.

I. Water Quality: Attach a completed and signed Intergovernmental Consultation Form from the **Oregon Department of Environmental Quality.** (See Section 1.8 for instructions and Section 6.1 of the RTP manual for the form and contact information)	**Yes**	**No**
1. Does the project affect a public or private drinking source?		X
2. Does the project affect a designated impaired water body?		X
3. Indicate how many acres of ground-disturbing activities will result from the project:	2.0 acres	
4. Is there a municipal separate storm sewer system (MS4) National Pollution Discharge Elimination System permit (NPDES) or will runoff be mixed with discharges from an NPDES permitted industrial facility?		X
a. If yes, provide NPDES permit #		

5. Describe the impacts; attach supporting documentation and the Intergovernmental Consultation Form.

Burlington Water District owns a parcel of land within the Burlington site. They have a domestic water tank located on this property.

Ground disturbing activities will include excavation for nearly five miles of natural surface trails. Trails are proposed to be 24-48" wide.

J. Hazardous Waste:	**Yes**	**No**
1. Are hazardous wastes located within the project area?		X

2. Describe the impacts:

Part IV: Public Involvement: Describe how public involvement was solicited and attach copies of public notices, comments received and the responses to comments.

The central goal of the master plan development process was to identify the best locations for formalized recreation access and amenities. To help answer this question, Metro engaged community members and scientists in looking at the four individual sites that together comprise the North Tualatin Mountains. A Stakeholder Advisory Committee was established for the project, and met five times to share technical expertise and insights into community needs and desires. Committee meetings, four community events, conversations with community members, and numerous comments submitted online helped to identify places to provide access, and where to prioritize protection of undisturbed core habitat areas.

This process relied on available data, principles of landscape ecology, the expertise and experience of

37

local natural resource scientists and wildlife biologists, and landscape-scale design strategies to determine the most appropriate opportunities for public access and connecting with nature.

The planning process followed a cyclical, four-step strategy involving a series of internal and external stakeholder meetings followed by Metro Council member updates and public open house events. A Stakeholder Advisory Committee was composed of local agency representatives, public officials, recreation advocates, environmental activists and residents. Internal coordination involved collaboration with Metro natural resource scientists, land managers, communications staff, operations supervisors, planners and various senior leadership from departmental and program management.

Stakeholder Advisory Committee
The project Stakeholder Advisory Committee (SAC) met five times, at key project milestones. The committee included representatives of Forest Park Conservancy, Forest Park Neighborhood Association, Northwest Trails Alliance, Oregon Department of Forestry, Oregon Recreation Trails Advisory Committee, Portland Community College, Portland Parks & Recreation, Skyline Ridge Neighbors, Skyline School, Trackers Earth, and West Multnomah Soil and Water Conservation District. In addition to contributing their time and insight to the planning discussion, the SAC was actively involved in neighborhood outreach and assisted at four community events.

Community Outreach and Engagement
Metro held four community events to engage the broader public in the planning process. The first two events were held at the Skyline Grange. To accommodate larger community events as the project generated interest, the third and fourth events took place at Skyline School. Approximately 40 people attended the first event, and between 150 and 250 people attended the following three events. Staff collected comments via questionnaires and one-on-one discussions.

Metro staff met informally with neighbors, providing additional opportunities to weigh in. Nearby neighbors had an opportunity to preview open house materials and talk with staff prior to the fourth event. In addition to the information presented at community events, Metro posted information online and solicited the public to submit comments online.

Community Input and Responses
A summary of community input received and resulting plan adjustments, has been extracted from the master plan and attached for reference. Appendix A, summarizing the community meetings, is also attached.

Part V: Environmental Commitments and Mitigation Measures: List commitments and measures that will be taken to avoid, minimize or mitigate all resource impacts identified in Section III, IV and VI; and list all permit conditions. Environmental commitments are actions that the grantee will be held to during the project implementation.

Metro is committed to the protection of habitat and water quality in the development of its natural areas. Proposed trails were professionally aligned and field verified to avoid, minimize and mitigate impacts to natural resources. Recognized best practices utilized in the design and proposed for construction include:
1) Trails to have rolling contour alignments, with maximum grades between 5% - 10%, frequent grade reversals, cambering of the trail tread to oppose user forces and to drain water locally.
2) Avoidance of new construction in floodplains, wetlands, and other codified critical habitat areas.
3) Avoid or minimize stream crossings. When new stream crossings are needed, use bridges or boardwalk structures that do not constrain the stream channel or impede wildlife movement. Consider climate change in bridge design.
4) Finishing construction as it occurs to minimize exposed soil.
5) Where practical, using existing roadbeds for trails to minimize new construction.
6) Providing desirable experiences such as solitude, exercise, and fun.
7) Avoiding areas of open canopy (such as powerline corridors) that increase erosion due to exposure to rain, sun, and wind.

78

8) Deploy techniques such as side-hill trails to decrease the ability of users to leave the trail.
9) Bringing the trail to "positive control points" (e.g., views) and avoiding "negative control points" (e.g., habitat areas).
10) Minimization of trail placement within recognized geological hazard areas.
11) Conducting earth moving activities during the dry season.
12) Avoiding heavy construction activities during nesting seasons of native bird species.
13) Avoiding earth disturbing activities during sensitive fish spawning seasons.
14) Restricting construction activities to limited areas and flagging sensitive resource areas.
15) Maintain existing trees on site.
16) Maintain smooth trail surfaces to avoid ruts that can create challenges for amphibians.
17) Follow adaptive management of the site. If issues with erosion are discovered once the trail system is open, implement seasonal closures. If priority wildlife species are found on site, implement seasonal closures during peak activity times such as breeding season.
18) Survey wildlife presence and patterns to inform trail siting and management of public access.
19) Avoid and minimize direct mortality of fish and wildlife species present at the time of construction.

Per section III, all required conditions of the land use decision and site development permit shall be met.

Part VI: Motorized Project Questions: Answer this section **only if** you have motorized recreation as part of your project scope.

A. Air Quality:	**Yes**	**No**
1. Is the project area in a designated non-attainment or maintenance area for air quality? (Locations include: Portland, Salem-Keizer, Eugene-Springfield, Rogue Valley(Central Point to Ashland), Grants Pass, LaGrande, Oakridge, Klamath Falls or Lakeview)		
2. If yes, is the project listed on the exempt projects list (40 CFR 93.126)?		
B. Noise:	**Yes**	**No**
1. Is the project in an existing designated recreational land use area or park?		
2. Is the project located near any residential areas, campgrounds, wildlife refuges or wilderness areas?		

3. If yes to any of the above, describe the proximity to types of areas and describe noise impacts:

a. What types and numbers of mechanized vehicles do you anticipate on the trail daily and seasonally? (Example: 30 snowmobiles day/winter and 30 OHVs day/summer-fall)

Part VII: Applicant Certification:

I certify the information above was completed to the best of my knowledge to be accurate and correct:

Signature: ______________________ Date: May 1, 2017

Printed Name: __________Karen R. Vitkay ______________________

For Official Use Only

Land & Water Conservation Fund Act (LWCF), Section 6(f)(3):	**Yes**	**No**
1. Are Section 6(f)(3) properties affected by the project?		
2. If yes, will the use of the Section 6(f)(3) property constitute a conversion?		

☐ Further coordination not required ☐ Further coordination required

Approved: ______________________ Date: __________
LWCF State Liaison Officer

79

Trails Coordinator Certification:	**Yes**	**No**
Project qualifies as a Categorical Exclusion, per 23 CFR 771.117 and Stipulation 2 of the 2007 Programmatic Agreement between FHWA and OPRD. (If project does not qualify as a CE, consult with the FHWA RTP Manager)		
Certified: ______________________ Date: __________ Trails Coordinator		
Federal Highways Administration Approval:		
Accepted: ______________________ Date: __________ FHWA Recreational Trails Program Manager		

HO

OFFSITE WETLAND DETERMINATION REPORT
OREGON DEPARTMENT OF STATE LANDS
775 Summer Street NE, Suite 100, Salem OR 97301-1279, Phone: (503) 986-5200

BATCH
WD#: 2017-0176

At your request, an offsite wetland determination has been conducted on the property described below.

County: Multnomah City: NA

Other Address: Karen Vitkay, PLA, Senior Regional Planner, Parks and Nature, Metro, 600 NE Grand Ave., Portland, OR, 972332-2736

Township: 2N Range: 1W Section: 19 and 20 Q/Q: ______ Tax Lot: Multiple

Project Name: Burlington Creek Forest Trail Project

Site Address/Location: No situs

☒ The National Wetlands Inventory shows waterways on or adjacent to the sites.

☐ The county soil survey shows hydric (wet) soils at one of the sites. Hydric soils indicate that there may be wetlands.

☐ It is unlikely that there are jurisdictional wetlands or waterways on the property based upon a review of wetlands maps, the county soil survey and other information. An onsite investigation by a qualified professional is the only way to be certain that there are no wetlands.

☒ There are waterways on or adjacent to some of the properties subject to the state Removal-Fill Law.

- ☒ A state permit is required for ≥ 50 cubic yards of fill, removal, or ground alteration in the wetlands or waterways.
- ☒ A state permit may be required for any amount of fill, removal, or other ground alteration in the Essential Salmonid Habitat and hydrologically associated wetlands.

☐ A state permit will be/will not be required for the project if ________________________.

☐ The proposed parcel division may create a lot that is largely wetland and thus create future development problems.

☒ A wetland determination or delineation is needed prior to site development; the wetland delineation report should be submitted to the Department of State Lands for review and approval.

☒ A permit may be required by the Army Corps of Engineers: (503) 808-4373

Note: This report is for the state Removal-Fill Law only. City or County permits may be required for the proposed activity.

Comments: On April 11, 2017, DSL received a request from Karen Vitkay to perform an offsite jurisdictional determination for Burlington Creek Forest Trail Project. Based on the information provided, it is impossible to say definitively whether or not the project will impact wetlands or waterways. DSL recommends an onsite inspection by a qualified wetland consultant prior to site development to determine if the proposed project may impact wetlands or waters. If wetlands are present, a wetland delineation is needed to determine precise wetland boundaries. The wetland delineation report should be submitted to DSL for review and approval.

Determination by: Pete (Peter Ryan) Date: 04/25/2017

☐ This jurisdictional determination is ~~valid~~ for five years from the above date, unless new information necessitates a revision. Circumstances under which the Department may change a determination and procedures for renewal of an expired determination are found in OAR 141-090-0045 (available on our web site or upon request). The applicant, landowner, or agent may submit a request for reconsideration of this determination in writing within six months from the above date.

☒ **This is a preliminary jurisdictional determination and is advisory only.**

Copy To: ☐ Other ☒ Enclosures: karen.vitkay@oregonmetro.gov
☐ ___________, Planning Department
☐ , DSL

FOR OFFICE USE ONLY

Entire Lot(s) Checked? ☐ Yes ☒ No	**Waters Present** ☒ Yes ☐ No ☐ Maybe	**Request Received:** 04/ 11 /2017
LWI Area: NA **LWI Code:** NA	**Latitude:** 45.64251 **Longitude:** - -122.845163	**Related DSL File #:** NA
Has Wetlands? ☐Y ☐N ☒Unk **ESH?** ☒Y ☐N	**Wild & Scenic?** ☐Y ☒N **State Scenic?** ☐Y ☒N	**Coast Zone?** ☐Y ☒N ☐Unk
Adjacent Waterbody: Multiple. **NWI Quad:** Sauvie Island ☒ Scanned	☒ Mailings Completed	☒ Data Entry Completed

A1

INTERGOVERNMENTAL CONSULTATION FORM

STATE / FEDERAL AGENCY REVIEW

A REVIEW OF A PROPOSED OUTDOOR RECREATION PROJECT WHICH FEDERAL ASSISTANCE HAS BEEN REQUESTED

Project Name:	Burlington Creek Forest Natural Surface Trails
Project Sponsor:	Metro Parks and Nature
Return Date:	Wednesday, April 26, 2017

To Agency Addressed: **This is a Federal Aid Grant. A comment is required.**
If your agency cannot respond by the return date, please notify us immediately.

PROGRAM REVIEW AND COMMENT

We have reviewed the subject notice and have reached the following conclusions on its relationship to our plans and programs:

[**X**] It has no effect.
[ ] We have no comment.
[ ] Effects, although measurable, would be acceptable.
[ ] It has adverse effects. (Explain in Remarks Section.)
[ ] We are interested, but require more information to evaluate the proposal. (Explain in Remarks Section.)
[ ] Additional comments for project improvement. (Attach if necessary).

REMARKS

Consider employing Stormwater Construction Low Impact Development Practices - located at https://www.oregon.gov/deq/wq/tmdls/Pages/TMDLs-LID.aspx

Agency: Oregon Department of Environmental Quality

David Kunz

Reviewed By: David Kunz, Senior Natural Resource Specialist
Telephone No. 503-229-5336

Return to: Karen Vitkay
Metro Parks and Nature
600 NE Grand Avenue
Portland, Oregon 97232

cc: Rocky Houston, Recreational Trails Program Coordinator
Oregon Parks and Recreation Department
725 Summer St. NE, Suite C
Salem, OR 97301

47

INTERGOVERNMENTAL CONSULTATION FORM

STATE / FEDERAL AGENCY REVIEW

A REVIEW OF A PROPOSED OUTDOOR RECREATION PROJECT WHICH FEDERAL ASSISTANCE HAS BEEN REQUESTED

Project Name:	Burlington Creek Forest Natural Surface Trails
Project Sponsor:	Metro Parks and Nature
Return Date:	Wednesday, April 26, 2017

To Agency Addressed: **This is a Federal Aid Grant. A comment is required.**
If your agency cannot respond by the return date, please notify us immediately.

PROGRAM REVIEW AND COMMENT

We have reviewed the subject notice and have reached the following conclusions on its relationship to our plans and programs:

[ ] It has no effect.
[X] We have no comment.
[ ] Effects, although measurable, would be acceptable.
[ ] It has adverse effects. (Explain in Remarks Section.)
[ ] We are interested, but require more information to evaluate the proposal. (Explain in Remarks Section.)
[ ] Additional comments for project improvement. (Attach if necessary).

REMARKS

Please be sure to obtain any necessary land use approvals.

Agency: Department of Land Conservation & Development (DLCD)

Reviewed by: Jon Jinings — Community Services Specialist
Name — Title

Return to: Karen Vitkay
Metro Parks and Nature
600 NE Grand Avenue
Portland, Oregon 97232

cc: Rocky Houston, Recreational Trails Program Coordinator
Oregon Parks and Recreation Department
725 Summer St. NE, Suite C
Salem, OR 97301

Exhibit 3

Department of Community Services
Land Use Planning Division
www.multco.us/landuse

Multnomah County

1600 SE 190th Avenue, Portland OR 97233-5910 • PH. (503) 988-3043 • Fax (503) 988-3389

October 27, 2017

Gary Shepherd
Office of Metro Attorney
600 NE Grand Avenue
Portland, OR 97232

RE: Application for Comprehensive Plan Text Amendment (Case #T4-2017-9166) and for park related development (Case #T3-2017-9165), which includes the following permits/reviews: Conditional Use/Community Service, Design Review, Significant Environmental Concern, Hillside Development, Lot of Record Determination, and Forest Development Standards Review.

Dear Mr. Shepherd:

Thank you for submitting the above referenced applications for Metro owned properties located in the West Hills / Tualatin Mountains. As requested, the applications are being processed and reviewed concurrently. The applications have been reviewed by Land Use & Transportation Planning staff to determine if all required materials have been provided. It is obvious that a lot of time and careful consideration by many people went into preparing the applications. As is common with applications subject to multiple approval criteria, we have identified additional information needed in order to process the applications.

Information and Materials Requested:

1. We request that you provide a primary site plan of the Burlington site as well as for the individual trail segments. With applications of this size it is often useful to refer to the primary site plan. Additionally, when changes are proposed it is easier for staff (and interested community members) to track the iterations on a single primary site plan, which in turn, inform changes to all related plans. Conversely, changes to specific plans may necessitate changes to the primary site plans.

2. It is unclear whether some trail development is proposed in the near term or longer term. We request that Metro provide some indication of the contemplated timing and/or phasing of proposed and future trails and trail-head development.

3. The request for an exception to the secondary fire safety zone must be processed through an application for an Exception (a type II permit). Please submit the application fee ($227.00) for an Exception to the Secondary Fire Safety Zone.

4. The proposed information kiosk is also a structure that is subject to the fire safety and forest practices standards. Therefore, it appears that the firebreak and setback areas need to be revised to include the structure.

5. It appears that the restroom building and sign kiosk are proposed on lands that are greater than 10% slope, which would require the primary fire safety zone to be extended 50 feet further downslope. Please provide a revised plan showing the extended primary fire safety zone.

6. The request for an Exception to the Secondary Fire Safety Zone must be processed through an application for an Exception. Please submit the required $227.00 application fee along with the appropriate site plan and findings. An adjustment may also be required if you are also seeking to adjust the forest practices setbacks in the CFU zone. You may request to reduce the setbacks by up to 40%. If you are also requesting an adjustment to setbacks please submit the required $488.00 application fee along with the appropriate form, site plan and findings addressing the adjustment criteria in MCC 33.7601 through MCC 33.7611.

7. If any portion of the required fire safety zones would be located off the subject property and/or the forest practices setbacks cannot be accommodated on the subject property, you may pursue either (or a combination of) a Property Line Adjustment or Lot Consolidation. If you wish to pursue either of these options please submit the required forms, application fees, site plan and findings addressing the approval criteria.

8. If any new uses or development (including trails) will be located within either of the Protected Aggregate Mineral overlays, please either submit a PAM application or provide information why the uses and/or developments are exempt from the PAM overlay review.

9. Regarding your findings for MCC 33.2045(A)(2), please consider providing additional information with respect to minimizing the threat of wildfires that may result with increased visitation to forested sites owned by Metro. In light of the recent Eagle Creek fire in the Columbia River Gorge and the location of homes and infrastructure located upslope of Metro owned properties (McNamee Rd. and Skyline Blvd. for example), please consider providing additional information addressing how Metro intends to manage public access during fire season.

10. In several of your findings, you state that the development and/or trail development are exempt from the Significant Environmental Concern criteria pursuant to MCC 33.4515. Staff does not find any such exemptions in 33.4515. Staff believes that all proposed development, including trail development, is subject to the SEC criteria. We respectfully ask that all SEC approval criteria be addressed in the application (i.e. any proposed trails and stream crossings in SEC streams overlay). Please note, however, that the proposed information kiosk along with any other proposed signs does appear to be exempt from SEC review pursuant to MCC 33.4515(A)(4).

11. Please provide details regarding the colors and materials that are proposed for the both the retaining wall and the bathroom building in order to better address visual subordinance in the SEC view overlay.

12. Please provide details regarding the proposed lighting on the bathroom building (and any other light fixtures if proposed) in order to better address the SEC view overlay and Compliance with the Dark Skies code standards.

13. Please submit an onsite sanitation review form completed and signed by the City of Portland Sanitarian (who reviews on site sanitation on a behalf of Multnomah County and as an agent of DEQ). This information is needed in order to insure that the proposed restroom location and design are allowed under DEQ rules.

14. Please address MCC 29.003(B), which requires evidence that Metro has applied to have the property (with structures) served by an appropriate fire agency. This standard can be met by either applying to be included in a fire district or demonstrating that the property cannot be annexed or served by a particular district. We appreciate the information provided by Portland Fire and we ask that you also contact Tualatin Fire, Scappoose Fire, and Sauvie Island Fire in order to determine which, if any, of the Fire Departments are able to provide structural fire service to the site.

15. Stream crossings are subject to the Flood Hazard permit requirements in MCC chapter 29. Please indicate whether you intend to apply for and address those criteria as part of this application or prefer to defer the review to a separate Type I application at a later date.

16. A transportation review fee of $49.00 is required.

Transportation Comments (Provided by Kate McQuillan, AICP Transportation Planner):

"Thank you for providing Transportation Planning the opportunity to review the North Tualatin Mountains Nature Park Comprehensive Plan Amendment Application (T4-2017-9166) and the various permit applications for the Burlington Creek Forest Nature Park (T3-2017-9165).

Upon reviewing the application materials submitted, Transportation Planning has the following comments as they relate to application completeness:

<u>Burlington Creek Forest Nature Park (T3-2017-9165)</u>

Multnomah County Transportation has two comments regarding this application:

1. Unbuilt public rights of way
The application materials fail to acknowledge the unbuilt public rights of way noted in the pre-application memo to the Applicant from Multnomah County Transportation Planning and Development Program memo (EP-2017-6780, dated March 28, 2017). Unbuilt public right of way exists throughout the site planned for the Burlington Creek Forest Nature Park, including the proposed access to the parking lot. In the memo EP-2017-6780 from Multnomah County Transportation, staff outlined two options to move forward with their proposal to develop the Burlington Creek Forest Nature Park: (1) obtain encroachment permits and improve the unbuilt rights of way, or (2) initiate the right of way vacation process for the unbuilt rights of way.

Based on the application materials submitted, Multnomah County Transportation understands the Applicant is not proposing to improve the rights of way, and in fact plans to install an automatic gate to restrict access on a public right of way as it were a private road. Therefore, Multnomah County will require the Applicant to pursue a right of way vacation for the unbuilt rights of way throughout the park site.

For the purposes of this application, Multnomah County Transportation requests the application materials (including relevant exhibits) acknowledge the unbuilt rights of ways in the various site descriptions, and also refer to the "existing access road" connecting to the proposed parking lot as Bonito Drive, an unbuilt right of way under the jurisdiction of Multnomah County, where ever mentioned.

2. Trip generation information in Traffic Analysis Letter (Exhibit 3)
Multnomah County staff appreciate the effort to provide trip generation estimates above the rates provided within the ITE Trip Generation Manual based on visitor rates at two existing Metro nature parks. Multnomah County understands that the Burlington Creek Forest Nature Park will provide increased opportunities for off-road bicycling, which has garnered a lot of public attention. Given this potential popularity and close proximity to a densely populated city, Multnomah County Transportation staff request that Metro seek out and provide additional trip data for comparable nature parks, even if not operated by Metro. Powell Butte Nature Park, managed by the City of Portland, would make an excellent comparison with its shared-use trails, popularity for off-road cyclists and close proximity to the city.

North Tualatin Mountains Nature Park Comprehensive Plan Amendment Application (T4-2017-9166)

On pages 25 through 70 of the application, the Applicant provided findings for the Multnomah County Comprehensive Plan's goals and policies. However, for the findings related to Chapter 12 of the County's Comprehensive Plan, which is the County's Transportation System Plan, the Applicant did not include the County's Transportation goal and its subsequent 24 policies. In its place, the Applicant incorrectly references the Oregon Administrative Rules (OAR) that govern local jurisdiction's responsibility under the State's Transportation Planning Rule. Transportation Planning staff request that the applicant submit findings to show the Master Plan for the North Tualatin Mountains Natural Area is consistent with the County's Transportation System Plan's goal and 24 policies."

Notes:

1. Prior to the Planning Commission, you will need to pay a deposit on the required public notice signs to be placed along the property frontages. Please contact Kevin Cook in order to arrange for the signs to be picked up for posting.

2. A Grading and Erosion Control permit may be required for ground disturbing activities that will occur outside of those areas already addressed in the Hillside Development permit application. We understand that Metro has acknowledged this in the application and has suggested a condition of approval for any needed GEC permits, rather than apply for one as part of the current application.

3. Please note that one or more addresses will need to be assigned by our office to properties prior to development permits primarily so that emergency service providers will have an address in their databases in order to facilitate short response times to on site emergencies. Each address assignment will require a separate address application fee.

Once you have gathered all of the requested information and materials, you will need to submit all items in **one single submittal packet**. Once you have submitted a complete packet addressing the requested items, we will conduct a new completeness review of your application.

The County's code gives you two options at this point. You can either elect to provide this missing information by March 28, 2018, or deem your application complete as it exists. We have enclosed a written option statement to assist you.

If you are unable to make your application complete within the 180 days, your application will be closed and your materials returned (application fees are forfeited) [MCC 37.0600B].

Please indicate on the attached form which option you would like to proceed under. You must sign the form and return it to my attention no later than November 24, 2017. If you do not return this form by the date provided above, we will assume you believe your application is complete and no additional information is needed. Your application will then be processed based upon what has been submitted.

Please do not hesitate to contact me if you have any questions.

Sincerely,

Kevin C. Cook

Kevin C. Cook
Senior Planner

cc: File

Department of Community Services
Land Use Planning Division
www.multco.us/landuse

Multnomah County

1600 SE 190th Avenue, Portland OR 97233-5910 • PH. (503) 988-3043 • Fax (503) 988-3389

Application # T4-2017-9166 / T3-2017-9155
Case Planner: Kevin Cook

APPLICANT'S RESPONSE
(Return by November 24, 2017)

☐ **I intend** to provide the additional information identified in the attached letter from Multnomah County Planning within 180 days. I understand that if I do not make my application complete by March 28, 2018 my application will be closed and I will forfeit my application fees.

☐ **I refuse** to provide the additional information identified in the attached letter from Multnomah County Planning and I am deeming my application complete. I understand that my application will be processed with the supplied information. I am aware that failure to meet the applicable code requirements is grounds for denial of my application.

____
Signed and Acknowledged (Applicant)

____
Date

Exhibit 4

Green Trails

Guidelines for environmentally friendly trails

METRO

PEOPLE PLACES
OPEN SPACES

Green Trails

Guidelines for
environmentally
friendly trails

METRO

PEOPLE PLACES
OPEN SPACES

Acknowledgements

The efforts of numerous people during a span of many years inspired this project and brought it to the trailhead, so to speak. These people, from all walks of life and work, have supported the development of a regional trail network. They are community and business leaders, funding strategists, policy advisors, municipal staff to parks, members of Metro advisory committees, natural resource managers and technical specialists, municipal employees, teachers and citizens. They share a vision of a network of trails that wends like green ribbons through our communities and natural areas – trails that provide routes to a livable future for residents of the Portland metropolitan region.

Metro greenspaces trails advisory committee working group

Jennifer Budhabhatti, Ph.D., senior environmental planner; project manager
Don Baack, Southwest Trails Group, SW Neighborhoods Coalition, Portland, Ore.
Gregg Everhart, senior planner, Portland Parks and Recreation
Lisa Hamerlynck, natural resource coordinator, city of Lake Oswego
Mel Huie, senior planner, Metro Parks and Greenspaces Department
Sean Loughran, state trails planner, Oregon State Parks
Julie Reilly, natural resource specialist, Tualatin Hills Park and Recreation District
Jennifer Thompson, fish and wildlife biologist, U.S. Fish and Wildlife Service

Consultant
Marty Mitchell, CPESC, ClearWater West, Inc.

Publication team
Cathy Thomas, senior public affairs specialist, Metro
Teri S. Matias, associate graphic design specialist, Metro
Laura Pritchard, Laura Pritchard Graphic Design
Carey Cramer and Barbara Macomber, nature illustrations

Photos
Jennifer Budhabhatti, Ethan Cassidy, C. Bruce Forster, Mel Huie, Ron Klein, Marty Mitchell and Lia Waiwaiole

Green Trails: An Overview

What is the Purpose of the Green Trails Handbook?

Many of this region's most important fish and wildlife areas are in our publicly owned natural areas. As the region grows and the desire for trails increases, there is a need to develop guidelines to plan, design, construct and maintain trails so that impacts on natural resources are kept to a minimum. In some parts of the region, existing trails need rehabilitation and maintenance because of poor drainage capability. In other areas, trails near seasonal wetlands, streams and other sensitive habitat could be moved or improved to better protect aquatic and wildlife resources.

This publication is intended to provide guidelines for environmentally friendly (or green) trails that support the goals of Metro's Greenspaces Master Plan. Those goals seek to promote an interconnected system of parks, natural areas, trails and greenways for fish, wildlife and people throughout the Portland metropolitan region while maintaining biodiversity and protecting water quality. These guidelines are not standards; they are recommendations to complement existing standards and guidelines adopted by local cities, counties, park providers and watershed groups in the region.

There is no single source of information that comprehensively addresses planning, construction and maintenance of environmentally friendly or "green trails" – trails that avoid or minimize impacts to water resources and fish and wildlife habitat. This guidebook fills that gap. It is a resource for citizens, trail planners, designers, builders and maintenance staff. It focuses on trails in environmentally sensitive areas and recommends strategies for avoiding or limiting the impacts on wildlife, water quality and water quantity. It also provides an extensive bibliography of other sources that provide more specific guidelines for trail planning, design, construction and maintenance in a range of other settings. Readers of this book are encouraged to seek professional help in designing and implementing trail plans.

Table of Contents

Introduction

Chapter 1 Introduction

1.1 Trails and the quality of life 3
1.2 Where will the trails go? 3
1.3 Partnerships for regional trails and greenways 4
1.4 Planning trails with natural resource protection in mind 4

Planning

Chapter 2 Setting the stage for trail planning

We have an idea for a trail. What do we do first?

2.1 Introduction 9
2.2 Why have trails here? 10
2.3 What is the purpose of the trail? 10
2.4 Assess zoning and the review process 11
2.5 Plan a process to involve the interested and affected public 11
- Identify stakeholders 11
- Involve community stakeholders 11
- Involve users of the trail 11
- Distribute newsletters and surveys 11
- Develop a plan 12
- Integrate committees 12

2.6 Identify appropriate uses and intensity of use 12
2.7 Establish an interdisciplinary technical team 13
2.8 Identify natural resource opportunities and challenges 14
2.9 Identify access needs and constraints 14
2.10 Identify broad, tentative route possibilities 15
2.11 Identify the costs of building and maintaining trails 15
2.12 Long-term management 15

Chapter 3 Assessing natural resource conditions in urban and natural areas

What should we consider when planning the trail?

3.1 Site assessment in urban and natural areas 19
3.2 Site analysis 20
- Existing site uses 20
- Natural area management plans 20
- Regional and municipal trail maps 21
- Municipal zoning and comprehensive plans 21
- Vegetation and wildlife habitats 22
- Fish habitat 23
- Water resources and hydrology 23
- Soils and geology 24
- Topography 26

3.3 Natural resource restoration 26
3.4 Cultural resources 27
3.5 Viewpoints and interpretive opportunities 27

Chapter 4 General principles for planning trails

How can the trail preserve sensitive natural resources?

4.1 Avoiding natural resource impacts 31
4.2 Vegetation and wildlife habitat 31
- Keep trails to a minimum 31
- Use existing disturbance corridors 31
- Locate trails at habitat edges 32
- Keep trails out of core habitat areas 32
- Maintain habitat connectivity 32
- Avoid small patches of high-quality connector .... habitat 33
- Avoid habitat for threatened, endangered and sensitive species 33

4.3 Fish habitat 33
4.4 Water resources 33
- Avoid crossing streams, wetlands and floodplains 33

4.5 Runoff and erosion 34
- Avoid steep trail pitches 34
- Encourage infiltration 34

• Don't let watercourses run down the trail 34
• Avoid long sustained grades 34
• Avoid flat ground and steep cross-slopes 34
• Avoid discharging trail runoff onto fill slopes and unprotected soils 34
• Avoid discharging trail runoff into streams and wetlands.. 34
• Avoid removing trees and shrubs at stream crossings 35
• Avoid stacking switchbacks and climbing turns... 35

Chapter 5 Guidelines for minimizing the impact of trails on natural resources

What are some practices for minimizing the natural resource impacts of trails?

5.1 Minimizing natural resource impacts 39
5.2 Protecting vegetation (wildlife habitat)....................39
• Techniques for limited access areas 39
• Vegetative screening 39
• Setbacks for threatened, endangered and sensitive species 40
• Trail closure 40
5.3 Minimizing impacts to fish habitat.........................40
• Use appropriate setbacks for trails near fish bearing habitat 40
• Trail closure 40
• Work windows for threatened, endangered and sensitive species 40
• Stream crossings...41
5.4 Protecting water resources (streams, wetlands, floodplains and riparian corridors).........................42
• Minimize stream corridor crossings.....................42
• Fords, bog bridges, causeways and boardwalks....43
5.5 Preventing erosion..46
• Techniques for the planning process....................46
• Strategies for drainage design.............................47
• A note about drainage features and bicyclists.......51
5.6 Working with steep slopes......................................52
• Climbing turns 52
• Switchbacks 53
• Stairs...54
• A word about groundwater.................................56

Implementation

Chapter 6 Environmental regulations and permits

What environmental permits will we need?

6.1 Introduction...59
6.2 Municipal natural resource codes and standards.....59
• Alternatives analysis...59
6.3 State and federal environmental permitting............59
• Federal agencies and acts 60
• State agencies 61
6.4 Application fees and turnaround times...................62
6.5 Useful contacts..62

Chapter 7 Plotting trail routes at the site scale

How do you site a potential trail route?

7.1 Evaluate trail routes in natural areas and restricted urban corridors 67
7.2 Set control points and plot test alignments.............67
• Plot test grades for potential routes.....................67
7.3 Identify existing and planned infrastructure...........68
7.4 Field-locate alternative alignments 68
7.5 Identify areas where there are no alternatives..........69
7.6 Identify areas where users want to go 70
7.7 Identify current and future public uses at the site....70
7.8 Refine each test alignment.....................................71
7.9 Select the best route that avoids or minimizes impacts 71
7.10 Re-evaluate goals for the trail use, scale, materials, connections or location 71
7.11 Identify potential stewardship and maintenance partners for the alignment....................................71

Chapter 8 Trail types, dimensions and materials

What resource-friendly trail materials are available?

8.1 Fitting the trail and materials to the setting 75
8.2 The Anatomy of trails 75
- Constructed trails 75
- Earthen trails 77
- Drainage considerations 77
- Geotextile fabrics 77

8.3 Preparing the ground 78
8.4 Resource-friendly materials 78
- Natural and native trail surfaces 78
- Hardeners for natural and native trail surfaces 80
- Permeable surfaces 80
- Recycled materials 81
- Hard surfaces 82

8.5 A note about equestrian trails 84
8.6 Trail materials for wet areas and wetlands 84
- Native local wood 84
- Plastic lumber 85
- Selection of trail materials in water resource areas 85

8.7 Summary: Choosing trail materials, widths and surface types 86

Chapter 9 Managing trail construction to protect natural resources

What are some resource-friendly construction techniques?

9.1 Introduction 91
9.2 Procurement 91
- Identify natural resource protection measures as separate bid items 91
- Provide descriptions of bid items for natural resource protection 91
- Identify pre-qualified designers and contractors 91
- Consider alternatives to the traditional design-bid process 92
- Use a qualification-based selection process 93
- Require pre-qualified construction equipment 93
- Provide contingency rock and material quantities for the contractor to bill against 93

9.3 Communications 94
- Construction drawings and specifications 94
- Training for contract managers 94
- Worker education 94

9.4 Construction staging and site management 94
- Construction boundaries 95
- Erosion control and water resource protection 95
- Management of excavated and stockpiled soil and rock 96
- Management of fuels and toxic materials 96
- Management of treated-wood construction materials 96
- Management of concrete in streams and lakes 96

9.5 Quality assurance and quality control 97
- Construction observation and inspection 97
- Observation and inspection records 97
- Contractor's point person for natural resource protection 97

9.6 Schedule 97
- Seasonal work windows 97
- Duration, sequence and phasing 98

9.7 Post-construction monitoring and maintenance 98

Chapter 10 Trail maintenance

How should we take care of the trail?

10.1 The goals of resource-friendly trail maintenance 103
10.2 Administering a trail maintenance program 103
- Develop an overview of maintenance activities 103
- Develop a multi-year budget 104
- Develop tracking methods 104

- Provide training for staff 104
- Develop a program of environmental improvements 104
- Develop resource-friendly contracting practices 105

10.3 Inspecting trails
- A word about earthen and soft-surface trails ... 107

10.4 Maintaining trails 107
- Drainage features 107
- Trail-side vegetation 108
- Seasonally closed trails 110
- Unsurfaced gravel park roads 110

10.5 Evaluating existing trails 110
- Social trails 111
- Trails in wet meadow and wetlands 111
- Signs of erosion caused by runoff from trails ... 111
- Reshaping the trail template 112

10.6 Planning for trail upgrades 113

10.7 Using new trail alignments to accomplish natural area restoration 113

10.8 Integrated pest management 113
- Integrated pest management defined 114
- Strategies for avoiding risky pest controls 114

10.9 Strategies for minimizing risky pest controls 115
- Restore native plants 115
- Rethink turf and turf mixes 115
- Consider alternatives to agressive non-natives in stormwater swale and erosion control plantings 115
- Use a zoned approach to pest control 116

References and Appendices

Glossary
Definitions of selected technical terminologies 119

Selected references
Where to get more detailed information 125

Appendix A
Regional trails map 139

Appendix B
Sources of information for trail planning 145

Appendix C
Ranges of functional riparian area widths for wildlife habitat, fish habitat and water quality, sensitive species list 151

Appendix D
Environmental regulatory checklist 157

Appendix E
Trails surface materials matrix 159

Appendix F
Notes and best practices for the use of treated wood products 163

Chapter summary

Introduction

Chapter 1 Purpose of this guidebook and the benefits of having trails in a community. Importance of regional trails in the Portland metropolitan area.

Planning

Chapter 2 First steps in planning a trail, including identifying the purpose and intensity of use, involving the public, researching opportunities and challenges, costs and long-term management options.

Chapter 3 What information should be gathered to determine if there would be an impact on natural resources when planning a trail. Includes plans, contact information and web site addresses of agencies that deal with natural area management plans, zoning, vegetation and wildlife habitats, fish habitat, water resources and hydrology, geology, topography, cultural resources, viewpoints and interpretive opportunities. Offers a short checklist for assessing natural resource information.

Chapter 4 Principles of planning for "green trails" and rules of thumb for avoiding impacts to natural resources, including vegetation and wildlife habitat, fish habitat, water resources and hydrology.

Chapter 5 Ways to minimize impacts to natural resources. Identifies planning guidelines, setbacks and seasonal windows for working in fish and wildlife habitats, as well as strategies for planning and designing drainage ways to avoid concentrated flows and decrease erosion.

Implementation

Chapter 6 Environmental permits and permitting processes that may be needed if a trail has an impact on natural resources. Web addresses and phone numbers assist the reader in getting additional information from agencies.

Chapter 7 Ways to plan a route on site, including refining test alignments and identifying trail stewards.

Chapter 8 Construction techniques, surface material and width of trail that could be used in sensitive areas.

Chapter 9 Procurement of services to construct "green trails."

Chapter 10 Resource-friendly "green trail" maintenance program, including developing a schedule of activities, inspecting trails, maintaining drainage and vegetation and evaluating existing trails.

1.1 Trails and Quality of Life

Almost everyone enjoys the chance to explore a trail and get out into nature. In fact, area residents told the Oregon Parks and Recreation Department in a 2002 survey[1] that their favorite outdoor recreation activities – running and walking for pleasure – are trail-related. The same study found that people generally engage in these activities close to home and on a regular basis. These neighborhood trails encourage healthy lifestyles.

The Portland metropolitan region boasts a unique landscape of mountains, buttes and rivers that makes it a perfect setting for a variety of trails. People are fond of their trails – from the neighborhood pathways they take to their favorite natural areas to the multi-use trails shared with cyclists, walkers, skaters, equestrians, wheelchair users and joggers. Trails help residents of all ages and abilities get around in the community and explore the region, making it a highly desirable place to live.

By offering connections to and between places people want to go, trails reduce dependence on driving and promote healthy recreational opportunities close to where people live. They provide routes to work, to parks, to public transit, to the post office, to shopping and to schools. Trails offer people the chance to be immersed in the beauty of nature, alone or with family, friends or community. Trails contribute to the character of the natural settings they traverse by building bonds between people and the environment and by fostering environmental awareness and community pride. By connecting to other features, trails bring people and the landscape together in a way that encourages adventure, healthy lifestyles and a commitment to take care of our natural resources. When people of all cultures, ages, levels of income and ability enjoy the amenities trails provide, everyone benefits.

1.2 Where Will the Trails Go?

When conceived 100 years ago by landscape architect John Charles Olmsted, a 40-mile loop of parkways and boulevards was to encircle Portland. Since then, the metropolitan area has grown – and so has the vision of a regional trail system. In 1992, the Metro Council adopted the Greenspaces Master Plan, which included the Regional Trails and Greenways Plan, an updated vision for this network of regional trails connecting parks, natural areas and communities. The Greenspaces Master Plan assigned Metro the responsibility of building a regional trail system in coordination with local governments, the state, the 40-mile Loop Land Trust and other partners. Passage of a regional bond measure in the mid-1990s provided local governments and Metro with additional funds to bolster trail construction and right of way acquisition efforts. To date, 150 miles of the proposed 650 miles of regional trails have been completed.

Local governments and Metro have worked together to determine the general locations of proposed greenways and land and water trails. Refer to Appendix A for more information about the location of existing and proposed regional trails.

1.3 Partnerships for Regional Trails and Greenways

Residents of the region are so passionate about their trails, parks and natural areas that local park providers, the 24 cities and three counties in the Portland metropolitan region are working with Metro to implement the Regional Trails and Greenway Plan. This network extends to and includes cooperation and partnerships with Vancouver/Clark County, Wash. Trail connections also extend beyond the metro area to state and federal trail networks on the Pacific Coast, in the Cascade Range and in Central Oregon and Washington.

Cities and counties also are working to extend their local trail systems to connect with the Regional Trails and Greenways Plan. Ultimately, trails will connect large and small natural areas, neighborhoods and parks throughout the region.

Achieving this vision of a regional trail network will require planning and sustained effort by all levels of government, non profit groups, park providers and individuals. Many successes already have been realized. For example, several municipalities have developed integrated trail master plans and completed trail projects. On the east side of the region, the Springwater Corridor extends from downtown Portland to Clackamas County. On the west side, the Fanno Creek Greenway Trail is halfway complete and one day will provide a separate pathway connecting Portland to the Tualatin River. Other regional trail segments are in the planning and design phase or under construction. The Trolley Trail, a former rail line running from Milwaukie to Gladstone, has been acquired for conversion to a multi-use greenway trail. The first phase of construction has begun on the Gresham-to-Fairview Trail, another segment of the long-ago inspired 40-Mile Loop Trail.

The public will continue to play a key role in the success of these trail projects in many ways. Residents will help identify trail user groups and their needs and be involved in the details of route selection. Community members will contribute ideas to trail and trailhead design and to the development of interpretive programs. They will help identify local safety and landscaping needs and will assist in the development of funding strategies. Finally, communities and trail user groups will become important stewards who will assist in the long-term care of the trails they have helped foster.

1.4 Planning Trails With Natural Resource Protection in Mind

On a clear day, a person looking out over the region from Cooper Mountain, Skyline Ridge or Powell Butte sees a rolling urban landscape softened by green. Streams and lakes glint in the sunshine. About 1.3 million people live in the 24 cities located in this lush landscape between the forested mountains of the Coast and Cascade ranges. Still, bald eagles spiral over rivers where otter, mink and bobcat can be tracked on river margins. Salmon and steelhead spawn in local streams. Tundra swans and snow geese spend the winter with other migrating waterfowl in the vast wetlands of the Columbia River floodplain. In spring, the calls of thousands of small migrating birds echo in wooded hilltop parks throughout the region where they make short stopovers on their long journeys. Elk, brown bear and cougar occasionally wander in from the wild to the city's edge. The residents of the region are aware of and appreciate the unique wildlife resources that contribute to the character of the place they call home.

Many of the decisions trail planners will contemplate about trail location and design will be influenced by the desire to protect and manage greenspaces for fish and wildlife as well as for people. Environmental regulations concerning the protection of wetlands, endangered species and water quality plays an important role. With thoughtful planning during the early phases, trail planners can avoid many issues that could harm fish and wildlife, cause project delays or add expense due to natural resource regulatory processes.

Many of the trails will be constructed to the standards of the American with Disability Act (ADA). That means they will be wide, firm-surfaced trails that will be accessible to people of all ages and abilities. Many of these trails double as transportation corridors and may be eligible for federal, state or local transportation funding. Because many of these proposed trails may be built close to riparian corridors, there will be implications for water quality, quantity and fish and wildlife habitat. This guidebook discusses ways to plan and build trails that will avoid and minimize impacts to natural resources. The guidebook primarily considers two kinds of trails: those in urban corridors that will receive multiple uses at high levels, and those in natural areas that may receive a more limited variety and levels of use.

Reference materials. The following chapters touch on the key points of many complex topics, leaving readers to follow up by reviewing more technically detailed resource material. Sources that were particularly useful in preparing this guidebook are listed in Selected References at the end of the book. Readers can also refer to the glossary for definitions of technical terms used in the guidebook. Finally, as they embark on the exciting tasks of bringing new trails into existence, readers are encouraged to seek help from professionals with specialized trail knowledge.

---

[1] Johnson, Rebecca L., *Oregon Outdoor Recreation Survey. 2002. Oregon Parks and Recreation in cooperation with Oregon State University.*

We have an idea for a trail. What do we do first?

2.1 Introduction

Building a regional trail system requires a shared vision and long-term commitment of many people. Long before a trail segment can be constructed, funding strategies need to be identified. The public should be engaged in a dialogue about the trail's location and amenities. Land or rights of way need to be acquired and specific challenges regarding access, safety, utilities and myriad other details need to be solved. In fact, many years of lead-in planning at the local, regional, state and federal levels are required to bring a trail from concept to an on-the-ground reality.

Ideally, planning starts at the landscape or the watershed level, depending on the scale of the project. A watershed is the area of the land that drains into a particular river or stream. Watersheds can be as large as all of the land draining to the Columbia River or as small as 20 acres draining to a pond. A landscape and watershed overview can help trails be more compatible with wildlife, fish and people. For example, it is helpful to understand the connectivity of wildlife habitats, as well as connections between neighborhoods, natural areas, urban nodes and transportation systems, including trails. This overview can help planners gain an understanding of a watershed's natural hydrologic dynamics and the effects of human activities on watershed conditions. Potentially important opportunities and constraints become evident at this scale of analysis. These include the need to avoid geologically unstable slopes or the habitats of threatened and endangered species, or the opportunity to restore a previously disturbed site. Once planners understand the landscape and watershed conditions, planning can take place at the site level.

Sites are local areas being considered for trails. A site may be a

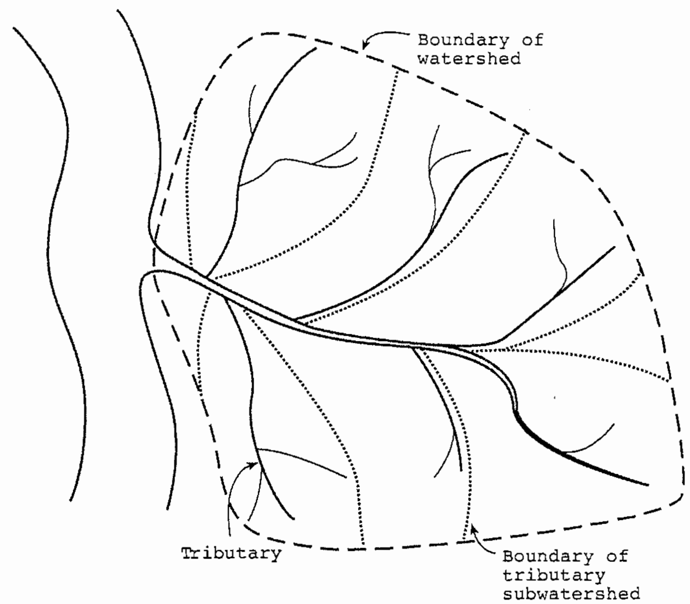


Figure 2-1 A watershed is an area of land that drains into a particular stream. It includes the stream's tributaries and associated subwatersheds.

large natural area that possesses many natural habitat features such as East Buttes and Forest Park. A site may be an urban greenway such as the Springwater Corridor, whose natural resources can lend relief to trail users, particularly in the context of the surrounding city.

2.2 Why Have Trails Here?

Proposed trail routes should provide users with an aesthetically pleasing outdoor experience. In natural areas, users also want to use trails to increase their fitness level or to commute from one place to another. If these needs are not met, "social trails" (also known as demand trails) tend to increase in natural areas and urban corridors. Social trails are unplanned trails users create to get to a scenic point or to a short cut through an area. Sometimes they also develop along long-established corridors such as fence lines, utility easements and existing right of ways.

The presence of social trails in an area can indicate the need to construct trails at that location. It is important that future trails enhance the area and augment users' experience of it. The trail should be easy to maintain and should support both existing and future uses. The planning process must consider how the trail could provide these amenities while preserving and protecting natural and scenic resources.

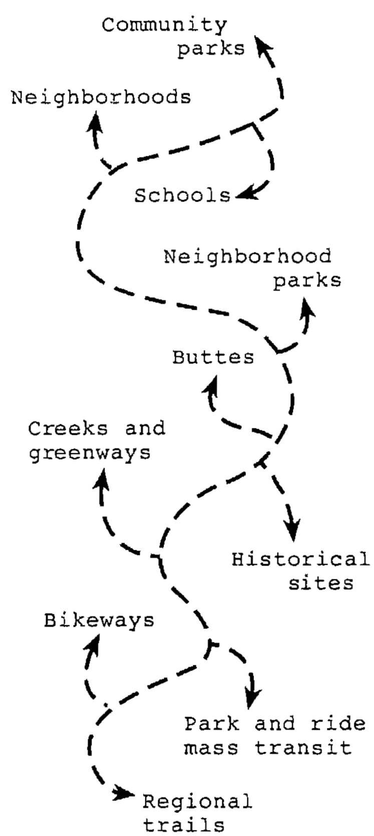


Figure 2-2 Trails connect people to places they want to go. (Gresham Trails Master Plan, 1997)

Trails and paths provide recreational opportunities as well as increased transportation choices.

2.3 What is the Purpose of the Trail?

Trails can be used for recreation, transportation or a combination of both. Some recreational trails double as commuter corridors. Others are barrier-free, multiple-use recreation routes. Still others function as narrow footpaths for hikers and walkers. While some trails are essential to link communities, arterial streets or regional greenspaces, others will serve very local uses. Trail planners need to identify users and levels of use in order to avoid or minimize user conflicts by means of trail location and design.

This guidebook considers two kinds of trails: those in urban corridors that will receive multiple uses at high levels, and those in natural areas that may receive a more limited variety and level of use. Within each broad group of trails it is possible to have a range of different dimensions and surface materials, depending on natural resource conditions, users and levels of use.

Trails in highly urbanized settings should provide safe, efficient, smooth travel opportunities while offering interesting experiences. Wherever possible, trails in urban corridors should take advantage of opportunities for users to experience unique or pleasant natural features such as tree groves, viewpoints, historic and cultural features, wildlife habitats, open spaces and interpretive opportunities. Corridor trails also should provide connections into neighborhoods, business centers, public transit connections, schools and neighborhoods. Wherever possible, they should create opportunities for trail loops and connections.

In contrast, trails in natural areas provide minor routes that give users an opportunity to enjoy and experience wildlife habitats, stream corridors and floodplains while protecting and preserving them.

2.4 Assess Zoning and the Review Process

Before starting, check with the local municipality and other entities (regional, state and federal) with jurisdiction in the vicinity to learn what standards and guidelines will apply. Having this information at the outset of the project will save time in the long run, and there is a likelihood that it will provide value to the project as well. Refer to Chapter 6 for more information on environmental permits.

2.5 Plan a Process to Involve the Interested and Affected Public

Before investigating potential trail alignments at the site scale, discuss the potential trail with trail advocates and other stakeholders who will be affected by trail-routing decisions. Fully engaged communities that have shared in the deliberations leading to decisions regarding trails often become the strongest advocates of the trail.

Public outreach can be managed in many ways, depending upon complexity, the scale of the project and resources involved. Planners can use existing neighborhood groups in the local area, or create new ones to discuss the need for the trail. If possible, make sure to involve people who can represent user groups of all ages and abilities, such as equestrians and bicyclists, who have particular needs for trail surfacing and trail networks.

Following are some techniques for involving the public in the trail planning process:

Identify stakeholders. Public outreach, regular meetings, citizens' advisory committees, community design workshops, integrated committees, news stories or features, and media coverage all help involve the community and build consensus about and support for the trail.

Involve community stakeholders. Consider establishing a citizen advisory committee at the outset of trail planning or use an existing committee to serve as an advisory board. As work progresses, the committee may expand to include people who live near areas that become designated as potential trail routes. Their concerns are likely to become the focus of trail design solutions.

Involve users of the trail. Potential users such as cyclists and equestrians can help identify what initial and future demand there will be for the trail. This information is essential to determine the locations and amenities of trailheads, the width of the trail and its surface materials, and the trail's gradient and design speed. This input will influence the selection of potential trail routes, so they need to be considered early on.

Distribute newsletters and surveys. Surveys can be used to make sure all community concerns are identified. Newsletters (electronic or printed) can be used to share information and to conduct surveys about the trail. Project web sites have become popular and effective ways to communicate information to and garner input from the public.

Develop a plan. Having a public information strategy from the inception of the project to the grand opening could help garner popular interest, involvement and support. The trail should be named early in the planning process. Planned public events also foster community "ownership" of the proposed project.

Integrate committees. It is important to integrate the work of staff planners and technical advisors with the citizen advisory group. Everyone gets a chance to understand the issues that influence technical recommendations, and this tends to result in favorable decisions for all on the committee.

Many regional trail projects will require multi-level inter-governmental participation to maintain the trail vision; initiate legislative and funding processes; assure access across railroads, highways, bridges, waterways and other barriers; and to develop consistent policies that will protect the trail in the future.

2.6 Identify Appropriate Uses and Intensity of Use

The needs of trail users for connections at both neighborhood and regional scales will affect decisions about the types of trails that will be built, how wide they will be and what kinds of surfaces they will need to have. The range of groups expected to use the trail – hikers, walkers, wheelchair users, naturalists, cyclists, runners, skaters, equestrians – and their desired destinations also will affect decisions about trail type. Trail planners also should be aware that trail widths and surfacing materials are specified by local code in some municipalities.

Very low	Less than 25
Low	25-100
Moderate	100-200
High	200-400
Very high	More than 400

Table 2-1 Number of users per busy day. (Table excerpted from Trails Design and Management Handbook, Open Space and Trails Program, Pitkin County, Colo., 1994)

Trails used by only a few people will require a different design approach and materials for construction than trails that will have a very high level of use. Table 2-1 provides a way to categorize the intensity of existing or expected trail use. This information is essential for selecting appropriate trail widths and curve radii, as well as surface materials.

Trails with very high uses that serve many different groups – such as bicyclists, families with strollers, in-line skaters and people in wheelchairs – are almost always constructed with very durable surfaces that can stand up well to heavy wear and last a long time. Multiple-use trails that are used less could be constructed with softer surfaces such as well-graded crushed rock or bark chips. These materials allow rain to soak into the ground and can be constructed in riparian areas where impacts should be as minimal as possible. Such trails tend to be narrow and serve very low numbers of people. Natural surface trails serve people on foot in various modes. Properly designed, they also could serve people in wheelchairs. Table 2.2 gives examples of trail surfaces for different groups and levels of use. Refer to Chapter 8 for more information on trail surfaces.

Multiple-Use Hard Surface	Crusher Fines or Other Unpaved Surface	Natural Surface
Baby carriages	Baby carriages +	
Bicyclists (mountain bikes)	Bicyclists (mountain bikes)*	Bicyclists (mountain bikes)*
Bicyclists (road bikes)	Bicyclists (road bikes)+	
Equestrians**	Equestrians *+	Equestrians*
Hikers**	Hikers	Hikers
In-line skaters		
Joggers**	Joggers	Joggers
Runners**	Runners	Runners
Walkers	Walkers	Walkers
Wheelchair users	Wheelchair users +#	Wheelchair users +#

* May or may not be permitted depending on the site, design, structure and surface of the specific trail.
** Best on adjacent soft-surface trail.
\+ Use may or may not be suitable depending on the site, design, structure and surface of the specific trail.
+# Indicates a possible but not optimized use. Site, structural and management elements of the specific trail determine, create or improve access.

Table 2-2 Trail types and users. (Table excerpted from Trails Design and Management Handbook, Open Space and Trails Program, Pitkin County, Colo., 1994)

2.7 Establish an Interdisciplinary Technical Team

It may be useful to use an existing interdisciplinary team or establish one to assist with natural resource planning. Smaller municipalities with limited funds could consider inviting other public-sector natural resource scientists and transportation, development and infrastructure planners to assist on a limited or as-needed basis.

Design professionals, planners, transportation engineers, infrastructure planners and park maintenance specialists should be included on the planning team. Their knowledge of costs, policies, regulations, performance, equipment, public safety, permitting and environmental regulations will help the planning team make informed decisions about trail location and design.

Fish and wildlife biologists could provide information about fish and wildlife that need to be protected in the project area and recommend methods to avoid or minimize impacts. Further, they could collaborate on the design of trail facilities to minimize impacts to habitats and provide early input that can help with permitting.

Hydrologists, soil scientists, geologists and geomorphologists could interpret hillslope, channel and floodplain dynamics for the planning group. They could identify and interpret phenomena at the landscape scale that give rise to springs, slope instability and other conditions that could affect public safety and the condition of future trails. These physical scientists also could interpret geologic mapping and other studies to recommend routes at least risk of failure due to earthquakes, landslides and other geologic hazards. Further, they could help minimize impacts to trails by recommending appropriate designs in challenging physical settings.

2.8 Identify Natural Resource Opportunities and Challenges

Options for trail alignments in urban areas often are dictated by narrow existing corridors and by long-established land ownership and uses. It is essential for the alignments of these high-use trails to take advantage of available scenic, aesthetic, cultural and interpretive opportunities.

In natural areas, alignment options may be less constrained by development patterns, but instead influenced by the locations of streams, wetlands, floodplains and other water resource areas and by the habitats of threatened, endangered and sensitive species. As a general principle, trails should avoid (or minimize) crossing streams and wetlands, floodplains, steep slopes, high groundwater sites and other conditions that can result in failure of or damage to the trail or the safety of trail users. Trails in natural areas should be aligned at habitat edges or in existing disturbance corridors such as utility line easements and old road and rail beds. Chapters 3 and 4 provide guidelines for assessing natural resource conditions to make decisions about trail locations.

Plants and water provide the basic elements of wildlife habitat.

2.9 Identify Access Needs and Constraints

The type of trail to be built depends on use, needs, source of funds and sensitivity of the environment. In some instances, there are great opportunities to build trails that will allow those of differing abilities, such as wheelchair users, the elderly or people with other disabilities, to get out into natural areas. Trails often are the only way people with disabilities can gain access to natural areas. Thus, trails can become critically important for these users. While many trails are not easily conducive to equal access (due to steep slopes or other geographic constraints), and compliance with the Americans with Disabilities Act (ADA) may not be possible, it is important to take advantage of the areas where conditions lend themselves to accessibility and to design trails accordingly. Further, some trails, while not ADA-compliant, may still provide barrier-free or accessible opportunities. Look for opportunities to provide barrier-free trails in high recreation opportunity areas as well as in more challenging terrain. Minor side trails may provide more challenging barrier-free opportunities.

In addition, trails that receive federal transportation funds – an important source of funding for bicycle and pedestrian routes everywhere – need to be accessible to all age groups and physical abilities. These trails should be able to serve people with a range of abilities, including limitations to sight, hearing, movement and ability to judge and respond to hazards.

There are well-established standards for accessible or barrier-free trails. New standards allow flexibility in this area. These standards concern surface materials, maximum trail gradi-

ADA design standards assure equal access to natural areas on Fanno Creek Greenway Trail.

ent and cross-slope, minimum width and accessibility of trail infrastructure such as signs, resting areas and stream-crossing structures. In the pre-planning phase, it is essential to establish the degree to which the trail will meet ADA standards. When designing trails to meet accessibility needs, involve people with disabilities in the planning process.

2.10 Identify Broad, Tentative Route Possibilities

At this stage in trail pre-planning, the interested and affected community and the technical team should review both goals for habitat and connectivity at the landscape scale to identify several potential trail routes that appear to meet these goals. It is important to remember that the lines on the map at this phase of planning are conceptual. They are not alignments, but broad swaths in which trails might be located, depending on the outcome of further analysis.

2.11 Identify Costs of Building and Maintaining Trails

Before making a final decision on trail location, size and materials, it is a good idea to review construction and maintenance activities and costs. The team should have a clear idea about the costs of preparing the site for construction and the equipment and materials needed to build the trail. At this point, it also is a good idea to determine the long-term cost of maintaining the trail, including labor, equipment and time. "Long-term" means measuring costs at five-, 10- and 15-year intervals for resurfacing, bridge repair, replacement and other such costs. Determining these costs will help the team choose a trail type that can be constructed and maintained within the proposed budget and with available personnel. If the desirable level of maintenance cannot be provided, it may be prudent to construct a more durable, lower-maintenance trail.

2.12 Long-term Management

Difficult management issues should be identified before trail routes are approved. Public use rules and enforcement measures also should be determined in the planning stage. Trail management responsibilities and partnerships should be identified at this time. Trail users should be invited to contribute their insights about trail management and should be encouraged to become partners in stewardship of the trail.

What should we consider when planning the trail?

3.1 Introduction: Site Assessment in Urban and Natural Areas

Trail planners think about two fundamentally different settings when determining the location and design of trails: natural areas and linear urban corridors. The two settings require different approaches so that realistic natural resource goals can be established, according to the degree of existing disturbance. The existing degree of disturbance refers to the quality of habitat for wildlife and fish (see Figure 3-1). Typically, urban landscapes are heavily disturbed and need to be restored. In more pristine settings, preserving what is there and minimizing impacts may be the major goals.

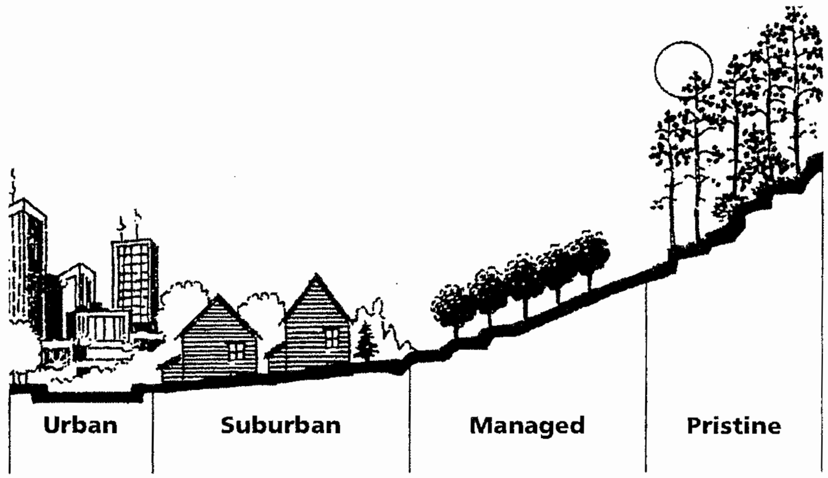


Figure 3-1 Natural resource protection goals for trails reflect trail setting and degree of disturbance. (Planning Trails with Wildlife in Mind: A Handbook for Trail Planners, 1998)

An early step in preliminary trail planning would be to evaluate the existing degree of disturbance in the setting in which a trail is being considered. Following are guidelines developed by Colorado State Parks for assessing the degree of habitat modification in natural area settings:

- determine the kind and condition of wildlife habitat present
- determine whether the plants and animals typically associated with the habitat are present, or whether the ecosystem has been simplified
- determine the nature of past and present human impacts to the habitat
- evaluate the surrounding land uses and their proximity to and impacts on the habitat
- identify roads that bound the habitat to determine whether they pose obstacles to wildlife movement
- determine how well the habitat is protected from external impacts
- determine what opportunities there are to improve habitat on the site.

Following are some additional principles to keep in mind when assessing potential trail corridors in urbanized settings:

Best case: Look for long-established routes or boundaries that may already have become trail routes, such as fence lines, old trolley lines, railroad lines, social trails (also known as demand trails) and utility corridors.
Next best case: Use an alignment or a human imposed "edge" between two adjacent different land uses such as the boundary between a developed area and an adjacent natural area.
Last resort: Use a right of way along an established transportation corridor.

The remainder of this chapter provides information about how to find and evaluate a wide range of information during site analysis. The kind of trail, the setting in which it is proposed and the permits required will determine the extent of information to be gathered and analyzed.

3.2 Site Analysis

Site analysis involves research, inventory, field analysis and mapping to gain an overview of physical, biological and cultural conditions that present both opportunities and constraints to potential trail routes. Because trails will be incorporated into existing and future land uses, trail planners will need to review zoning, local and regional trail plans and municipal street and utility plans in addition to natural resource information. Many areas already have been studied for other purposes, so start by researching existing information. By reviewing available information, planners will be able to prioritize and expedite planning for potential trail routes.

Existing site uses. Whether considering a trail system for an urban corridor or a natural area, it is important to understand how pedestrian needs are met and identify ways to improve them. A study of existing uses helps clarify how they relate to the surrounding transportation system and existing roads, trails and utility corridors. It also can reveal what is needed to improve pedestrian routes. Examine overhead and underground utility corridors and other rights of way because these often serve as informal trail routes or connectors and can be important links in both local and regional trail systems.

Planners from different jurisdictions get together to look at improving pedestrian access by examining existing roads, proposed and existing trails and utility corridors.

Evaluate existing use information to identify opportunities and constraints. Another important step is to identify current and future uses. Both of these uses have their opportunities and constraints.

- identify existing uses and needs for student walking routes, walk-to-shop routes, bike routes, pleasure walking routes and crossings
- identify opportunities to enhance such routes
- identify conflicting needs and uses
- identify negative impacts of existing uses and potential negative impacts of increased uses (see Chapter 4 for ideas about how to avoid impacts, and chapters 5, 6 and 8 for information about how to minimize them).

For sources of information about existing site uses, refer to Appendix B.

Natural area management plans. Management plans exist for many natural areas such as Government Island, Forest Park, Smith and Bybee Lakes Wildlife Area and the Sandy River Delta. In all likelihood, natural resource inventories were undertaken to develop management plans for each natural area. The trail-planning team should review the plans for special management areas in which trails are being considered because careful planning and coordination may already have taken place to determine trail locations. Information about habitats for sensitive species may be included in the plans.

Evaluate natural area plans. Discuss the natural area plan with the area manager. Learn if trails are consistent with habitat goals. If trails are compatible with natural area goals, learn the appropriate level of use to determine the user group, width of trail, surface materials, signing and connections to other trails.

For sources of natural area plans, refer to Appendix B.

Regional and municipal trail maps. The 27 municipalities of the region have developed a coordinated, regional transportation plan, the 2000 Regional Transportation Plan. This plan includes both bicycle and pedestrian systems and a regional trail network. Analyze potential trail routes with the connections of neighborhoods to the regional trail network in mind.

Evaluate information about municipal and regional trails. Learn how the area in the vicinity of the new trail will be developed in both the short and long terms to determine the connections users will need to other trails and public transportation.

Number and type of trail users. The type and number of users expected for the new trail segment will affect the design width, gradient and travel speed of the trail, its surfacing materials, the extent of vegetation clearing, management of the trail edges, and the location and level of development of trailheads and related facilities. User safety and the accessibility of the trail to emergency and maintenance vehicles will affect trail design and location. Potential impacts of trail users on water resources and wildlife habitats also will affect these decisions.

For sources of information about municipal and regional trails, refer to Appendix B.

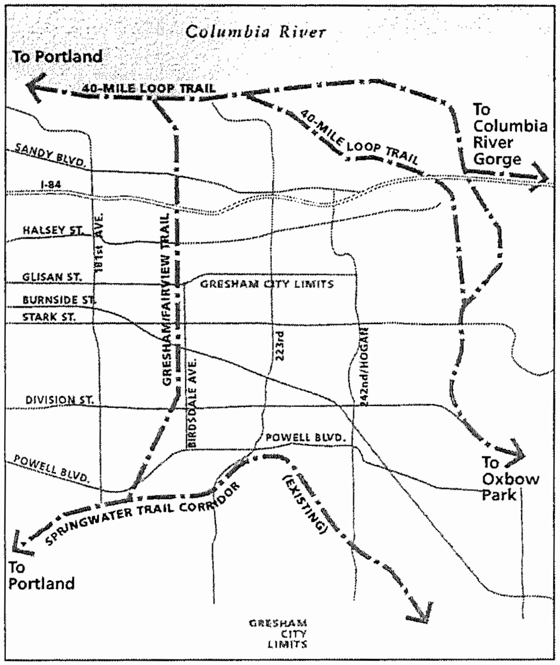


Figure 3-2
Potential new trails provide links and connections to local and regional trails and transportation routes. (Gresham Trails Master Plan, 1997)

Municipal zoning and comprehensive plans. City and county zoning ordinances regulate uses allowed in the areas that will be considered for trails. There may be requirements regarding trail location and width, limitations on what may be constructed, requirements for setbacks, and specifications for construction and plant materials. Many municipalities, for example, are requiring permeable trail surfacing for trails in riparian areas.

Sources of information about zoning, permits and requirements. Trail managers can learn precisely what will be required by requesting a pre-application meeting with the permitting agency. In addition to learning what the local municipality will require, the applicants also may learn what local, state and federal permits will be needed. See Chapter 6 for additional information on getting permits. Trail planners should expect to spend two to 12 months in the permit process.

Evaluate information about zoning, permits and requirements. By making a few changes to the preliminary trail route, it may be possible to meet local zoning code exemptions, avoid certain permit processes or design requirements, become eligible for grant funds and eliminate potential opposition or gain the support of important stakeholders in the trail.

Vegetation and wildlife habitats. Plants and water provide the basic elements of wildlife habitats. The amount and variety of native plants and the structural diversity of plant associations provide both food and cover, and reflect habitat types. Because plants also reflect elevation, aspect, weathering processes, soil depth, soil moisture conditions and disturbance regimes, a great deal about habitat type and quality can be interpreted from low-elevation aerial photos of vegetation. Even if the vegetation of the site under consideration has been photographed and/or mapped for various studies and master plans, it may still be necessary to check the information in the field.

Sensitive species. Trail planners should particularly seek information about the locations of habitats of sensitive species – those that are listed as threatened, endangered under the Endangered Species Act, or for which the need for concentrated conservation actions are noted. Forty-five vertebrate species that inhabit the metropolitan region are designated as sensitive, threatened or endangered by federal and state fish and wildlife organizations. These species are listed in Appendix C of this guidebook.

When trails pass through sensitive areas, planners should consider trail location, design and materials.

Water resource areas are especially rich in wildlife values. Special consideration is needed for trails in these areas.

Habitats in decline. Some sensitive species inhabit habitats that are declining. The Willamette Restoration Initiative (2001) and other regional initiatives have identified the following habitats in decline:

- riparian habitats and bottomland forests
- upland and wet prairie
- upland forests
- oak woodlands and savannas
- wetlands, springs and seeps
- off-channel or alcove habitats.

Other habitats. Other habitats in decline in the metro area may be key to the preservation of certain wildlife associations. For example, colonial nesting birds such as great blue herons depend on river islands and deltas, which are habitats in decline. Wildlife corridors take on added importance in urban areas where connections between natural areas are the only way for wildlife to travel from one place to another.

The presence of habitats for sensitive wildlife provides trail planners with interpretive opportunities. By contacting the Oregon Department of Fish and Wildlife, the U.S. Fish and Wildlife Service and National Oceanic and Atmospheric Administration Fisheries (NOAA Fisheries), trail planners can learn what state and federally listed species may be present and how to protect them by means of trail alignments, design features and management measures.

For more information about wildlife habitat and trails, refer to Chapter 4 and Appendix B.

Fish habitat. Salmonids and other native fish species require cool, clean flowing water with a high level of dissolved oxygen clean gravel in streambeds for reproduction, a variety of in-stream cover, a sufficient food source and unimpeded access to and from spawning areas and the ocean. Four important factors influence streams as habitat for salmon: water quality, (temperature, dissolved oxygen level, turbidity) stream flow, physical structure of the stream and food supply.

For more information about fisheries and trails, see Chapter 4 and Appendix B.

Water resources and hydrology. Trail planners should review the hydrologic systems of watersheds traversed by potential trail routes by reviewing existing watershed/hydrologic maps. Trail planners who know about the locations of headwaters, seeps and springs, wetlands, streams, riparian areas and

Threatened and endangered salmonid populations have habitat in or migrate through rivers and streams in the Portland metropolitan region.

floodplains, and the hydrologic regimes that sustain them will be better able to frame constraints and opportunities for siting the trail with least impacts to water resource areas. They also will gain information about future runoff conditions that will result from development and can incorporate this information into decisions about trail design and location to improve management and longevity of the trail.

Evaluate water resources and hydrology. Trail planners should consider rarity, quality and disturbance when considering potential trail routes. This can help focus decisions about whether a resource should be avoided completely, or whether minimal impact will be acceptable. Consider the following conditions:

- existing and potential disturbance (by people, dogs, trampling, dumping, hunting, social trails, compaction and erosion, noise, littering, off-road-vehicle use, adjacent development) on hydrology, native vegetation and wildlife habitat

- the unconstrained function of floodplains, including over-bank flows and sediment deposition
- the function of riparian areas in providing shade, organic materials, nutrients, bank stabilization and sediment control, flood storage and microclimate
- changes, such as increased imperviousness and stormwater runoff from adjacent development that are affecting or are likely to affect the water resource.

Soils and geology. This region's geologic history has produced a variety of local conditions that can present challenges for construction and long-term stability of trails. For this reason, a geotechnical engineer should provide input to trail routes under consideration. Trail planners who are aware of these conditions can make informed decisions about trail locations, designs and construction budgets. Some of these conditions are summarized:

Loess soils. The region was blanketed with very fine rock powder at the end of the last ice age. This wind-deposited rock powder, or loess, is highly erodible and does not make an enduring earthen trail surface. The resulting soils absorb moisture very readily and dry out quickly. They tend to be dusty in summer and soft in winter. Earthen trails in these soils tend to require special attention to drainage, and, depending on intensity of use, surfacing.

Clay-rich soils. Floodplain dynamics and soil weathering processes have produced clay-rich soils in some areas of the region. In general, a little clay in soil helps to bind the materials of the trail surface. But high clay content can make a soil so moisture-sensitive that, like the loess soils, it can become too wet to support a firm trail surface in the winter. In summer, such a soil can become dusty. Structural support, drainage and surfacing are special concerns for these soils.

It is challenging to place a trail in natural areas dominated by boulders.

Bouldery and rocky conditions. Soils in low-lying areas of the region, particularly near the Columbia Gorge, contain large boulders that were deposited by large floods at the end of the Ice Ages. Excavation of the boulders is expensive. Rock frequently needs to be imported to fill the voids left by the boulders and to provide a cushion, or tread surface. In other locations, poorly cemented ancient river gravels (for example, the Troutdale Formation in Eastern Multnomah County) may make hillslope trails unstable and expensive to construct.

Perched groundwater. Many upland soils in the region have seasonally perched groundwater. This is a regional anomaly that is not common in other areas. In certain soils, weathering has created a shallow hardpan, usually within 20 inches of the soil surface, that concentrates groundwater during the wet months. When a slope is cut to create a "bench" for a trail, this groundwater can rush out to the surface and create cut slope instability, trail slumping and seasonal problems of erosion and wetness on the trail. The lower third of slopes, particularly on north aspects, and the contact zones between geologic units are also prone to chronic wetness and should be avoided.

Shallow debris slides. Shallow debris slides commonly occur in the region during very wet periods due to saturation of soils on disturbed or convex slopes, undercutting of slopes by roads, building pads or streams, and in the inner gorges of streams and rivers. Some geologic materials are prone to ravel, which can result in continual maintenance and safety problems for trails.

Liquefaction. Extensive areas close to the Columbia and Willamette rivers are subject to liquefaction, or sudden collapse and spreading during an earthquake due to the increase of soil pore water pressure during ground shaking. Many relatively flat areas close to these large rivers are coded as high hazard areas on regional earthquake hazards maps. Most are intensely developed, and, with their views of the river, are popular locations for trails. Trail planners should refer to municipal planning departments to learn what uses are allowed in these zones and what construction standards apply.

Evaluate soils and geologic data. When reviewing data about soils, floodplains and geology, trail planners should try to avoid locating trails in geologically dynamic or hazardous conditions. Some of the indicators of unstable settings include:

- A history of rockfall, landslides, slumps or low-angle earth flows in a particular area.
- Soil types rich in silt-to-clay-sized materials. Because of their capacity to absorb water, some clay-rich soils can become wet and soft during the wet season and will not provide support to the trail.
- The presence of loose rock materials. Loose or poorly cemented rock materials, particularly those that are rounded, may not provide adequate support to the trail. By avoiding these materials, trail planners may be able to save time, effort and money on design and engineering.
- Downslope-orientation of planes of weakness in bedrock where there is danger of earth slippage or rockfall.
- Slope undercutting from both natural and cultural causes. Undercut slopes may be subject to failure.
- The likelihood of intense rainfall on sensitive or exposed slopes.
- The presence of fill or spoils materials that exceed the angle of repose, or the presence of fill materials not properly keyed or compacted, on slopes.
- Fill material at risk of settlement or failure due to the decomposition of organic material in it.
- Steep slopes greater than 25 percent.
- Conditions in which altered or increased drainage affect slope stability or local drainage.
- The presence of saturation and drawdown conditions, for example, in reservoirs where water levels are manipulated or along rivers that experience tidal fluctuations.
- Flooding and/or dynamic bedload deposition.
- Presence of high erosion hazard, shrink-swell soils, soils with poor bearing strength and soils with hazard of freezing.

For sources of information about soils and geology, refer to Appendix B.

Figure 3-3 Topographic map of a section of the Clackamas River

Topography. Trails fare best in the long run if they are located on moderate cross slopes of 25 percent or less, where they can be easily drained, are not subject to flooding and the ground is likely to be relatively stable. Trails on flat ground may be subject to drainage problems. Conversely, trails in steep areas with switchbacks may invite short cutting. A review of topographic information about the trail routes under consideration can provide useful information about both favorable and unfavorable trail alignments.

Evaluate topographic information.

- Try to find routes that avoid ground flatter than 5 percent of gradient and steeper than 25 percent.
- Avoid or minimize impact to floodplains, wetlands and stream headwater zones and intact habitat.
- If stream crossings cannot be located with existing disturbances, choose stream crossing sites located at natural pinch points (naturally confined channel locations) located downstream of meadows and wetlands, where spans footings can be located outside the floodway and their footings constructed on native rock.

3.3 Natural Resource Restoration

Trail planners should seek information about potential restoration projects where trail routes are being considered. Bringing a new trail into an area can provide access and opportunity to restore a disturbed area. If the restoration opportunities are

Bringing a new trail into a disturbed area can open up opportunities to restore native habitat.

identified, it is possible that the projects can be undertaken as mitigation for unavoidable impacts elsewhere. Examples of restoration projects include:

- removing exotic plants and re-planting with native vegetation
- storm-proofing, decommissioning or retrofitting old farm and forest roads in urban greenspaces so that they do not discharge directly into streams
- rehabilitating wet meadow systems in urban greenspaces whose hydrology is affected by old roads
- removing stream crossing structures (culverts and fill) if they impede fish passage, and replacing them with bridges
- retrofitting stream crossing structures for better fish passage
- providing for wildlife passage structures on roads that fragment their habitat
- removing hazardous materials and contaminants from trail routes and rights of way.

3.4 Cultural Resources

Many developed and undeveloped landscapes contain historic districts, sites, structures, buildings and objects of significance to Native American history, American history, architecture, culture or archeology. Check the local library and contact history groups and the Oregon Historical Society. To learn whether any site in the vicinity is listed as an historic resource, check with the Oregon Historic Preservation Office at the Oregon Parks and Recreation Department in Salem. City and county offices also maintain records of some of this information. The city of Portland has specific cultural resource protection regulations that apply in certain areas along the Columbia Slough in Portland. If an historic resource is present, find out what measures must be taken to protect the resource, and what the cultural interpretation opportunities may be.

3.5 Viewpoints and Interpretive Opportunities

Just as trails enhance the character of a place, so does the character of a place enhance trails. As much as possible, trail routes should meet goals for users' aesthetic experience. A good trail location is a balance between where users want to go and where managers want them to be. If the trail does not satisfy users' desires, they will pioneer their own routes.

People are intrinsically interested in the landscapes trails traverse. They enjoy the contrast of a trail that moves from shade to sunlight, forest to meadow, wet to dry, hillslope to river, high to low. A trail that visits a grand viewpoint between points A and B will be a popular trail. A trail that curves can have the effect of slowing down the pace at which people use the trail and enhancing their experience.

People like the opportunity to interpret natural or cultural history along the way. As much as possible, potential trail routes should include landscape contrast, viewpoints, points of interest, interpretive opportunities and scenic overlooks.

How can the trail preserve sensitive natural resources?

4.1 Introduction: Avoiding Natural Resource Impacts

After learning about the natural resources of the study area, the technical team should discuss its findings with residents, the resource agencies and the trail-planning group so that everyone has the same information and criteria can be developed for selecting general trail routes.

Before field-locating the routes, review the guidelines in this chapter and in Chapter 5 that highlight best practices for siting and designing green trails. The guidelines will help the group evaluate alternative alignments and select the best location for the desired kind of trail. This chapter provides background information on the needs of wildlife and fish and discusses general principles for avoiding impacts to fish and wildlife.

4.2 Vegetation and Wildlife Habitat

Wildlife species function within a home range that varies according to the size and needs of the animal, the season and the quality of the habitat. Home range is where the animal lives a major part of its life – including feeding, breeding and wintering over. Human activities may impact some species more than others. Some species such as crows thrive in the presence of humans; others such as pileated woodpeckers prefer habitats away from humans. It has been shown that disturbance by humans can cause nest abandonment, decline in parental care, shortened feeding times and lowered reproductive success in some birds.

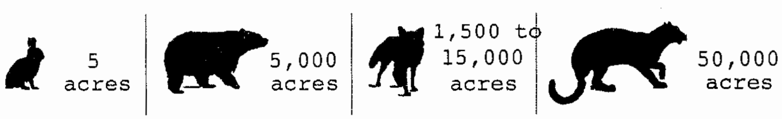


Figure 4-1 Habitat edges can accommodate trails with least disturbance to wildlife. (Adapted from Planning Trails With Wildlife in Mind: A Handbook for Trail Planners, 1998)

In particular, there seems to be an increase in conflict between humans and wildlife in riparian areas. Most humans like to recreate near streams. In response, planners have increasingly placed trails in riparian corridors. Most species of wildlife, including nearly half of all birds and 45 percent of all non-fish vertebrates in the Portland metropolitan area, use riparian areas for breeding, feeding, moving and dispersing. Ninety percent of all terrestrial species in North America depend on riparian corridors to travel from one end of their home range to another.

Following are general principles to consider when planning for trails in natural areas.

Keep trails to a minimum. If the area being considered for trails contains a sensitive natural resource, has high quality or restorable riparian or upland habitat and is home to many species, trails should be avoided in the area or there should be insurance that impacts are minimized. Studies have shown that initial human disturbances may have more impact on wildlife than continuing disturbance. This suggests that trails should avoid high-quality resources and be located where uses can be concentrated in areas that have habitats of lower quality.

Use existing disturbance corridors. Align trails along existing disturbance corridors when possible and, if appropriate, to reduce their long-term environmental impacts. Examples of disturbance corridors include:

- existing or abandoned rail lines
- corridors for overhead power lines
- old farm or forest roads
- social trails

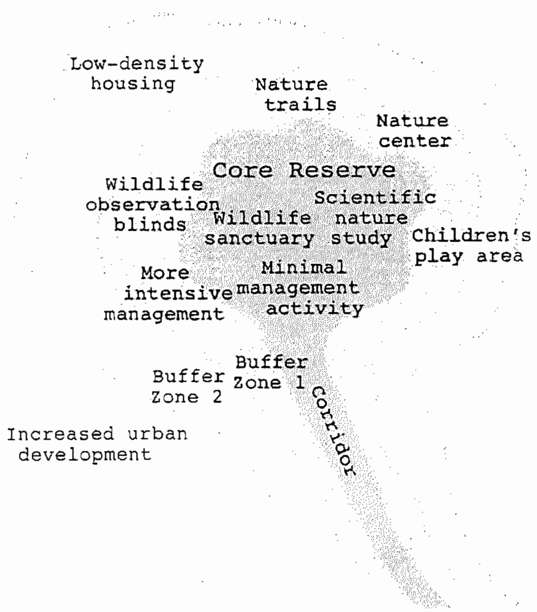


Figure 4-2 Low-impact trails in set-backs from core wildlife areas can provide users with opportunities to observe wildlife from overlooks and blinds. (Wildlife Reserves and Corridors in the Urban Environment, 1989)

- rights of way corridors
- swaths adjacent to roadways
- construction routes over buried sewer lines and other utilities
- utility maintenance access routes
- routes to quarries or borrow pits.

Trail stream crossings can be aligned to take advantage of sites where utilities cross streams. By carefully locating and aligning a trail, trail planners can subtly discourage off-trail uses and preserve sensitive resources from trampling.

It will be important to assess existing disturbance corridors, particularly those in wetlands, riparian areas or deep within habitat patches, to ascertain whether they should become trail alignments or be put to bed, abandoned or decommissioned (see Chapter 10: Trail Maintenance). The scale of the trail will play a large role in this decision. In some instances, the corridor may have become an important habitat for some species or it may retain relic habitats that have largely disappeared in the developed landscape. Restoration opportunities, such as improvement of fish and wildlife passage or removing invasive exotic vegetation, also should be identified during the corridor assessment.

Locate trails at habitat edges. Vegetation changes at habitat edges often are tension zones where opportunistic plant and animal species can thrive. Invasive exotic plants also may thrive here. Aligning trails in these locations provides an opportunity to remove the exotic plants from the corridor and replace them with natives that are better food sources for wildlife. The restored plant community also can serve as a transition zone between the trail and the intact habitat.

Keep trails out of core habitat areas and avoid fragmenting sensitive or significant habitats. In general, habitats occur in patches. Since the greatest species diversity and presence of sensitive areas is usually associated with the largest habitat patches, trails should avoid fragmenting large, intact habitats (see Figure 4-2). Because the greatest habitat impacts of trails occur with the first disturbance, the highest quality habitats should be avoided altogether and recreation uses should be concentrated where other disturbances already are present.

Maintain habitat connectivity. Access, seasonal availability and diversity of water resources are major factors contributing to the quality of wildlife habitats. Wetlands and streamside environments provide a variety of plant food and cover for wildlife, and wildlife use of these areas is disproportionate to other habitats in the landscape. Where a water resource is present, wildlife use of a corridor may be especially high. Trails should avoid stream and wetland crossings, if possible, and avoid posing a wildlife barrier between main channels and temporary wetlands.

Avoid small patches of high-quality connector habitat. Small habitat patches should be avoided, particularly if they contain unusual, sensitive or threatened and endangered species or rare habitats. Not all small habitat patches need to be connected in order to be significant. For example, many isolated hilltop forests of the region provide important stopovers for migrating neotropical birds. In other instances, physical connection of patch habitat to nearby habitats is essential. An example is the use of intermittent headwater streams by mainstem amphibians for reproduction and rearing.

Avoid habitat for threatened, endangered and sensitive species. Future trail routes should avoid the habitats of threatened, endangered and sensitive species. Each species responds to disturbance differently, so wildlife biologists should be consulted to help with preliminary planning and precise trail location.

4.3 Fish Habitat

Trails should be located outside the riparian corridor to protect stream banks from erosion, conserve riparian shade and allow recruitment of large woody debris to the stream. Only as a last resort should trails be placed in riparian areas.

Twelve threatened and endangered salmonid populations have habitats in or migrate through rivers and streams in the Portland metropolitan region. Salmon require cool, clean flowing water. Riparian habitat is very crucial for salmon and 70 other fresh water and estuarine fish species in the Pacific Northwest.

Riparian habitat provides shade, large woody debris and stabilizes stream bank and sediment. It shades streams and helps maintain cooler temperatures in the summer, which is critical to the survival of cool water fish such as salmon and trout. Elevated water temperature affects the metabolism and alters the feeding activity of fish. The roots of riparian vegetation such as trees and shrubs anchor soil and stabilize the banks. Major disruptions such as urbanization result in sediment delivery exceeding natural levels of suspended sediment. This increase in sediment lowers water quality and contaminates salmon gravel and spawning beds. If unchecked, stream bank erosion can increase sediment in the water, along with an increase in stream width, allowing more solar radiation and increasing water temperatures.

Social trails and improperly constructed trails and trail crossings placed close to streams and wetlands result in trail compaction, in some cases destroying the soil profile through loss of vegetation. This can result in an increase of erosion and delivery of sediment to nearby water bodies.

4.4 Water Resources

Avoid crossing streams, wetlands and floodplains. Trails can interfere with floodplain dynamics, groundwater movement, and stream transport of large wood and bedload. Care should be taken to avoid the impacts of trails on these resources by avoiding wet areas, springs, floodplains, stream corridors, wetlands and the lower portions of slopes, especially those that face north. The lower portions of north-facing slopes tend to be wet for two reasons. Groundwater moving downslope in the soil horizon tends to come to the surface at the toe of the slope. This condition is commonly expressed as springs or wet areas at the break in slope. The northerly aspect receives less direct sunlight than other slope exposures, and these areas generally remain wetter than south, east or west slopes.

4.5 Runoff and Erosion

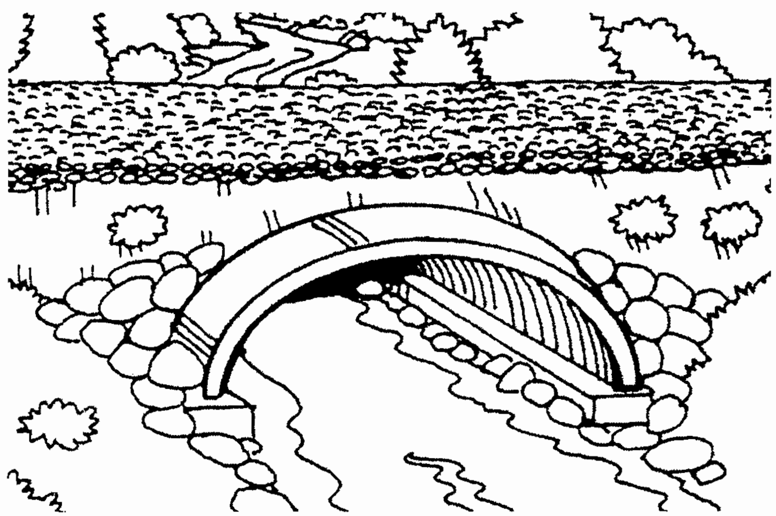


Figure 4-3 By crossing the stream on an existing structure (such as a road), new trails avoid creating new stream corridor disturbances. (Low-Volume Road Engineering Best Management Practices Field Guide, 2001)

Avoid steep trail pitches. Avoid creating even short segments of the trail that have a gradient steeper than 10 percent. It is very difficult to control drainage on steep trails, and erosion of steep earthen trails is expensive to repair. Also, runoff has a greater chance of becoming concentrated on steep trails. This can create erosion problems at the site where the water runs off the trail.

Encourage infiltration. Select trail designs and materials that facilitate infiltration rather than runoff of stormwater. Before selecting trail designs and materials, evaluate trail location and width, anticipate levels of use and the range of user groups expected so that drainage and infiltration can be fine-tuned. Also refer to Chapter 8 and Appendix E of this guidebook for more detailed discussions about trail drainage and infiltration-friendly materials.

Don't let watercourses run down the trail. Align trails perpendicular to the slope to prevent water from running down the trail surface. Trails should not be aligned "with" the slope. Trail routes should descend to water crossings from both sides of the channel so that high water does not result in the stream flowing down the trail. To avoid sediment from trail runoff entering the watercourse, it may be necessary to armor the trail with rock in the section that dips down to the crossing.

Avoid long sustained grades. Avoid long, sustained grades that can concentrate runoff on trails. Install rolling dips or grade breaks to get runoff off the trail and to allow users a rest.

Avoid flat ground and steep cross-slopes. In general, trails should be constructed on minimum cross-slopes of 5 percent and maximum cross-slopes of 25 percent. As a rule, trails on flat ground do not drain well. Trail widening is a common problem due to "walk-arounds" at wet areas on trails on flat ground. Trails on very steep slopes require larger excavations to create a level travel surface. There is an increased potential for sloughing, ravel, erosion and mass wastage of cut banks on steep cross-slopes. These dynamics can encourage the formation of bypass trails and can increase maintenance costs.

Avoid discharging trail runoff onto fill slopes and unprotected soils. Concentrated runoff from trails can cause damage to fill slopes and to unprotected soils adjacent to the trail. Discharge sites for trail runoff need to be carefully selected so that runoff velocity is slowed and sediments can settle out. Fill slopes should be armored where runoff is discharged onto them, or the runoff should be conveyed in a down drain such as a pipe to a location where sediments can be deposited and the flow infiltrated.

Avoid discharging trail runoff into streams and wetlands. Trails (and roads used as trails) have the capacity to change the timing, quantity and quality of the natural hydrologic system by delivering both sediments and runoff directly to streams, wetlands and riparian resources.

Avoid removing trees and shrubs at stream crossings.

Use existing roads and bridges wherever possible to refrain from removing trees and shrubs at crossings and to avoid new stream corridor disturbances.

Route selection and trail design should consider how trail drainage will be accomplished without affecting these water resources. Measures to avoid such impacts include:

- encouraging filtration on site as much as possible to avoid concentrating flows
- spreading crushed aggregate on earthen trails in locations where they can drain to streams or wetlands
- providing more frequent drainage relief for trails in these sensitive areas
- making trails as narrow as possible, and using existing disturbance corridors.

Avoid stacking switchbacks and climbing turns. Trail switchbacks and climbing turns need to be carefully sited so that their locations do not invite cut-throughs. When more than one switchback is necessary, they should not be inter-visible, particularly in winter, when many plants do not have leaves. Switchbacks should be offset from one another, and they should take advantage of natural benches, slope breaks and natural screening to prevent cut-throughs and short-cuts.

To further discourage cut-throughs, grades leading immediately into switchbacks and out of switchbacks can be increased, and brush or log barriers can be installed in the turn. Often it is necessary to field design an earth-retaining structure in the turn. For an informative video, "Constructing Trail Switchbacks," contact the U.S. Forest Service Technology and Development Program and request 2300 Recreation video, 00-02-MTDC.

What are some practices for minimizing the natural resource impacts of trails?

5.1 Introduction: Minimizing Natural Resource Impacts

This chapter focuses on strategies for minimizing the environmental impacts of trails. By integrating the practices summarized in this chapter with knowledge about site natural resources, trail planners can develop specific, environmentally friendly low-impact trail routing and drainage alternatives at the site scale.

In addition, there is much published information available to help accomplish these goals, and there is an extensive list of additional resources in the topical bibliography section at the end of this guidebook.

5.2 Protecting Vegetation (Wildlife Habitat)

Try to determine where people want to go, and then give them an easy way to get there that avoids the sensitive resource.

Techniques for limited access areas. If sensitive habitat cannot be avoided, try to find a way to place the trail at the habitat edge. Use an elevated trail or trail construction type that allows for low-impact access that encourages trail users to stay on the trail. Create a spur to a point of interest such as a wildlife-viewing area or scenic overlook. If possible, establish vegetative screening.

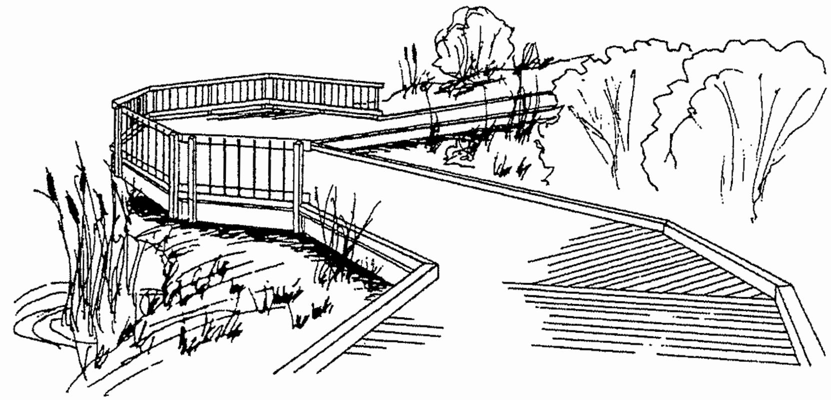


Figure 5-1 A boardwalk allows access to a wetland while encouraging users to stay on the trail. (Trails Design and Management Handbook, Open Space and Trails Program, Pitkin County, Colo., 1994)

If a trail is not designed to accommodate large numbers of users, its entry point might be made obscure and/or a proper trailhead may be omitted. The angles of trail intersections can be subtle ways of influencing the direction of travel on particular trail segments. A raised trail in a wet area – be it a bog bridge or a boardwalk – always keeps people on the trail.

Vegetative screening. To protect sensitive species from trail disturbances, establish native vegetation buffers of appropriate widths and densities to screen the trail.

Selected thorny native plants can be placed in some settings to discourage off-trail uses. However, more substantial barriers may need to be constructed to discourage off-trail uses. For example, to discourage cyclists from venturing onto wet or natural area trails, the first segment of a trail might be constructed as a stairway, perhaps flanked by thorny plants.

Trails in the Smith and Bybee Lakes Wildlife Area in Portland, Ore. are designed and sited to protect sensitive species such as the Western painted turtle.

Setbacks for threatened, endangered and sensitive species. Establish setbacks from habitats of threatened, endangered and sensitive species and water resources, including wetlands, streams, meadows, riparian corridors and ponds (see Appendix C). For example, don't encircle a pond with a trail, but identify low-impact opportunities for trail users to view the pond while leaving a majority of the area in its natural state. After an office and field inventory is completed to identify sensitive wildlife habitat in an area, an alternative analysis should be done to place the trail in an area where it will have the least impact on habitat.

If a threatened, endangered or sensitive species is using the site, follow appropriate measures after consultation with regulatory agencies. For example, if bald eagles are observed foraging or perching in the vicinity of a project site, keep activity and noise levels to a minimum to reduce the potential for disturbance. If nest sites are observed or known to occur within a quarter mile of a project site and work is proposed during the nesting season (Jan. 1 through Aug. 15), activities must be carried out at a distance greater than 800 meters (in line of sight) and 400 meters (out of line of sight) from eagle use areas to minimize the potential for disturbance. Construction work should be scheduled outside wintering period (Oct. 31 through March 31) and/or the nesting period (Jan. 1 through Aug. 15). Screening activities from view (i.e. through vegetation or topography) can also minimize disturbance.

Trail closure. The posting of signs let users know that a trail will be closed during breeding season for a sensitive species, either fish or wildlife. If trails will be closed to protect wildlife, the times and method of closure should be known at the time the trail is planned, and notification and enforcement strategies should be developed.

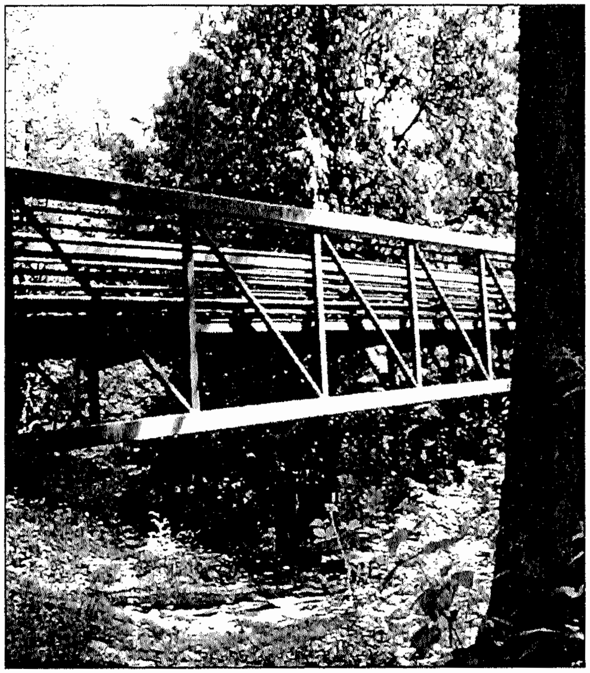
5.3 Minimizing Impacts to Fish Habitat

The following steps are recommended if an office or field inventory indicates that a trail will be near a native fish-bearing stream.

Use appropriate setbacks for trails near fish-bearing habitat. To protect fish and water quality, researchers have recommended riparian area setbacks from 50 feet to 200 feet from the top of bank, depending on the stream to protect fish and water quality (see Appendix C).

Trail closure. Closing a trail during key spawning times may help alleviate disturbance if users understand and agree with the rationale behind the restriction. Tools to educate the user could include signs, outreach activities and pamphlets.

Work windows for threatened, endangered and sensitive species. If a trail is constructed near a riparian corridor, associated in-stream work must be scheduled to occur within work periods established by the Oregon Department of Fish and Wildlife. Depending on location, the work window extends from as early as June 1 to as late as Oct. 10 (see www.dfw.state.or.us/ODFWhtml/infocntrhbt/0600inwtrguide.pdf).



This pedestrian bridge over Butler Creek in Gresham completely spans the 100-year floodplain.

Stream crossings. City and county zoning codes include specific regulations for setbacks from streams and other water bodies. If a trail must cross a stream, the trail-planning team's hydrologist, geomorphologist and fisheries and wildlife biologists can help determine whether a bridge or a culvert will provide the best solution for fish and wildlife passage. All culvert sizes for stream crossings should be prescribed by a fish passage engineer based on the size and conditions of the contributing watershed, the passage needs of fish and stream corridor wildlife, the dynamics of the stream and the best hydrologic data available. Some common prescriptions by ODFW and Washington Department of Geology include:

- In order of preference, use bridges, bottomless arches (see Figure 5.3), partially buried culverts or other similar structures
- Do not substantially alter water velocities and especially do not create excessive velocities. Keep culvert velocities to those navigable by fish.

Examples of fish-friendly designs

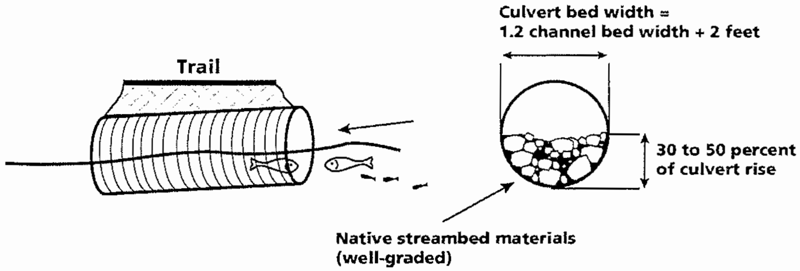


Figure 5-2 Easy passage. (Fish Passage Design at Road Culverts – Washington Department of Fish and Wildlife)

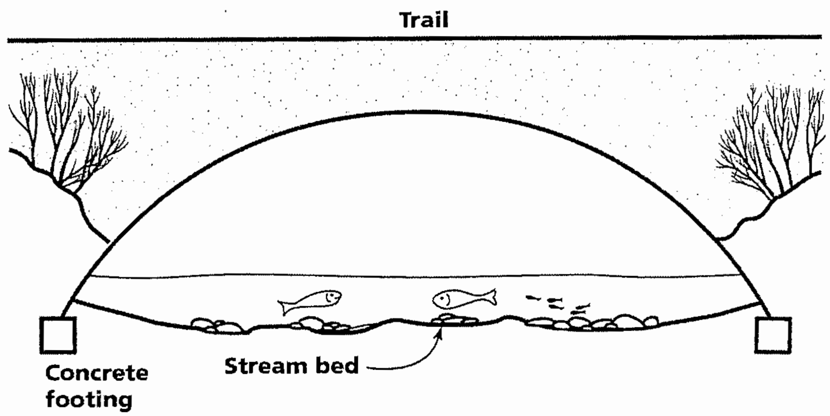


Figure 5-3 Bottomless arch culvert

- Do not create adverse water depths. Keep culvert flow depths comparable to the associated stream channel (see Figure 5-2).
- Provide resting pools at culvert inlet and outlet for culverts installed across streams with high channel gradients.
- At stream crossings, select a culvert size where there will be no abrupt change in gradient and the upstream and downstream channel alignments are as straight as possible for 50 feet in either direction.

- Fill slopes that drain to the stream should be trimmed to stable angles and vegetated or bioengineered or armored with rock.
- Pipes and culverts should be sized for the expected 100-year flow event in streams with habitat for sensitive species such as salmon. This design is intended to minimize channel erosion and deposition influenced by the crossing.

There are many excellent references to help with design of spans and culverts, and some are listed in the bibliography of this guidebook, under *Fish and Fish Passage.* For a thorough reference on designing culverts for fish passage, see www.wdfw.wa.gov.

5.4 Protecting Water Resources (Streams, Wetlands, Floodplains and Riparian Corridors)

Minimize stream corridor crossings. Trails should not cross streams more often than necessary and should not cross the same stream more than once if crossing cannot be avoided. Metro's Green Streets guidelines recommend stream crossings be no more frequent than about ¼ mile apart. Stream crossings should be as narrow as possible, and trails approaching bridges should become narrower where they cross in order to minimize the impacts of the crossing.

Trails should not be located in long stretches of riparian or streamside areas, but should cross them on short, direct routes. Crossings should take advantage of landscape settings where streams are naturally confined by hillsides, and ideally, crossings should be located downstream of floodplains. Trails in water resource areas should be surfaced with materials that allow infiltration of rainfall and that will not be washed by runoff into the water resource area.

One way to avoid constructing additional riparian corridor crossings is to use existing roads or utility crossings as crossing points for trails. Another is to use very long spans whose footings are outside the floodway (see Figure 5-4).

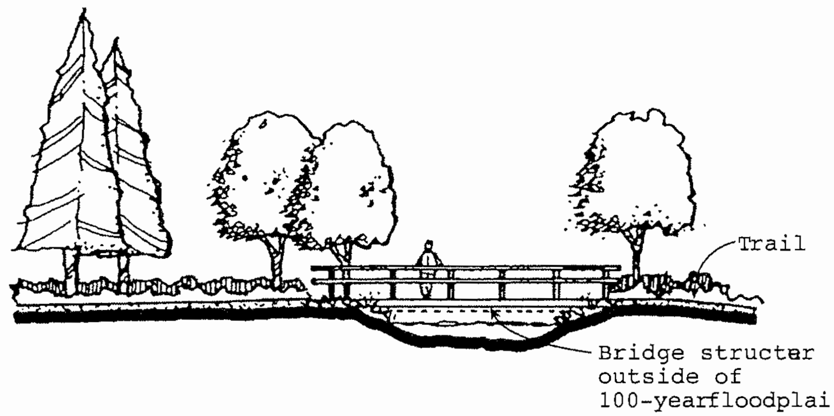


Figure 5-4 Locate footings outside of stream channel at top of bank (Trolley Trail Master Plan, Metro, 2003)

Fords, bog bridges, causeways and boardwalks. Each of these construction types enables trails to be constructed in wet ground:

Fords. Fords are installed where it is not feasible to construct a bridge or to install a pipe culvert, i.e., where streams have no, or low, banks (see Figure 5-5). Approaches to fords and low water crossing should be low gradient, armored with rock to prevent erosion and placed where bottom material is firm and erosion is minimal. Don't locate a ford in a spawning area, and make certain the ford does not become a passage problem for fish.

Bog bridges. Managers of natural areas, sensitive habitats and wetlands like to use bog bridges when low-use trails must pass through wet areas. There are many styles of construction, but all create a narrow pathway that spans between low supports that are laid on the ground. Traditionally, native wood puncheons and planks were used. Other materials such as plastic lumber might be used today. Typically, bog bridges do not have railings because they are low to the ground, but they may be constructed with low curbs. This kind of trail should not be used where flooding is expected.

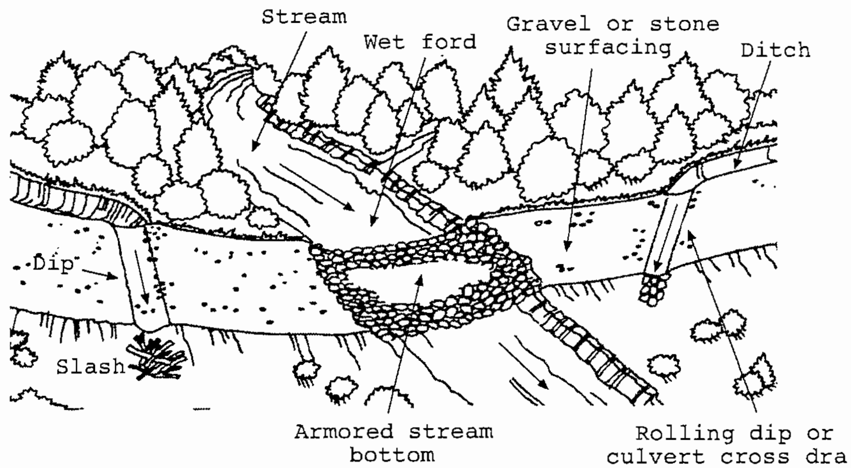
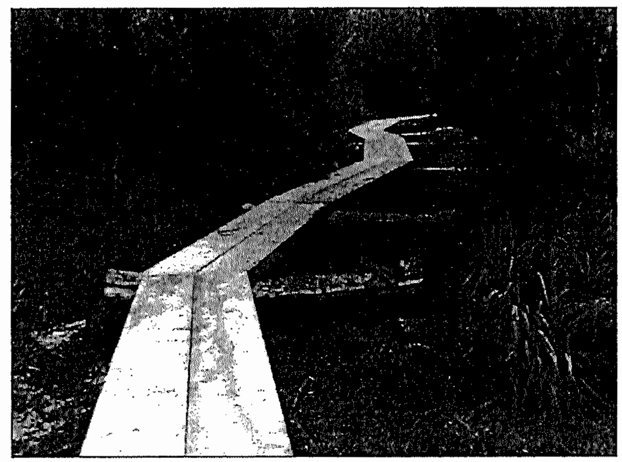


Figure 5-5 Simple ford design in an area with no fish spawning or fish passage problems. (Low-Volume Roads Engineering Best Management Practices Field Guide, 2001)



Log supports laid flat on the ground provide a foundation for a low-use bog bridge while limiting disturbance to a fragile wet area. (Wetland Trail Design and Construction, 2001)

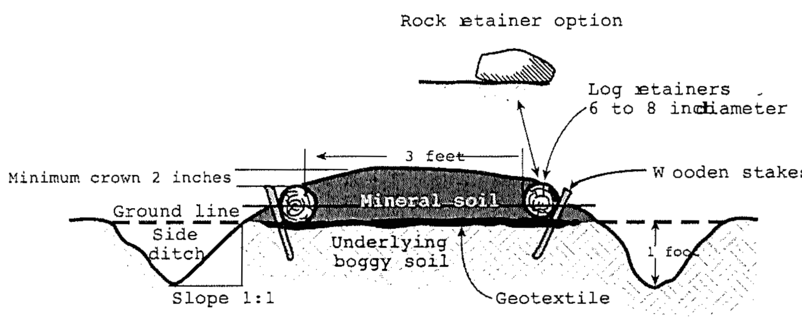
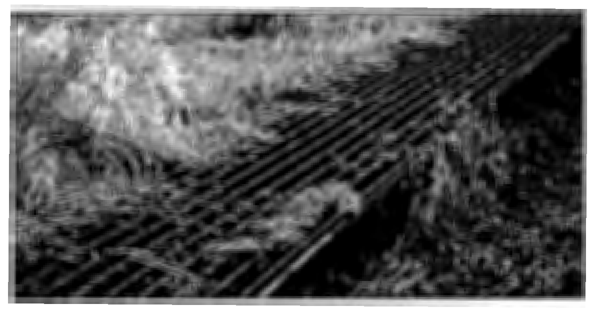


Figure 5-6 Cross-section of causeway construction. (Hesselbarth, W. 2000. Trail Construction and Maintenance Notebook. United States Forest Service.)

Causeways. Causeways (see Figure 5-6) are a time-honored way to elevate a trail tread above a wet section of trail. They encourage trail users to stay on the elevated trail instead of walking around a wet spot. There are many different techniques for constructing causeways and they all provide a filled, elevated, drained surface and a means to let groundwater and surface water pass under the trail at grade. They no longer are commonly used in wetlands because of the potential effects of ditches on groundwater conditions. They can be an effective way of elevating a trail through a wet spot.

Another way to provide a dry trail through a wet section is to use a cellular confinement system, a duck board or a metal grate. A cellular confinement system is a rigid mat with honeycomb-like cells that can be laid over the geotextile and backfilled with gravel to provide tread support through the wet area (see Figure 5-7). A duck board elevates the tread surface above a wet area by means of boards.

A duckboard elevates the tread surface above a wet area.



Metal grates can provide a dry trail through a wet section.

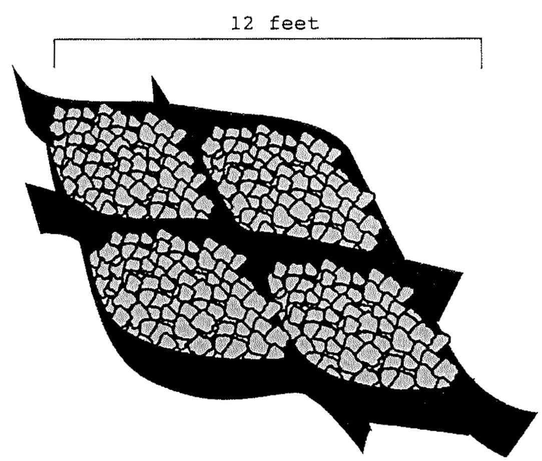


Figure 5-7 Cellular confinement system. Rigid cells filled with aggregate can provide support to a trail in a wet spot. (Hesselbarth, W. 2000. Trail Construction and Maintenance Notebook. USDA Forest Service.)

Elevated trails and viewing platforms. Viewing platforms can provide exciting ways for people to see wildlife in natural areas without disturbing their habitat. When a well-used or multi-use trail must pass through a wetland, an elevated trail can minimize impacts by raising the tread and traffic above these sensitive resources (see Figure 5-8). The tread, preferably made of synthetic lumber or metal grating (not galvanized), is supported on steel foundation pilings sometimes called "screw piles." Screw piles have been noted to resist sinking in some conditions that cause boardwalks on wooden pilings to sag over time. Plastic lumber often is used for railings and non-structural elements of boardwalks. Some structurally reinforced plastic lumber is beginning to be available as well.

Viewing platforms can be great destination points along trails, and they provide opportunities for interpretive education. For safety reasons, structures that are 30 inches or more above the ground must have railings. Biological conditions may require platforms be located so they don't shade sensitive resources and that trail treads allow light to penetrate to vegetation under the trail. Metal grating allows light penetration and provides a non-slip surface. Because smooth trail surfaces can become slippery during the wet season, roughened tread surfaces, open grating or grit-treated mats can be used to combat this safety problem.

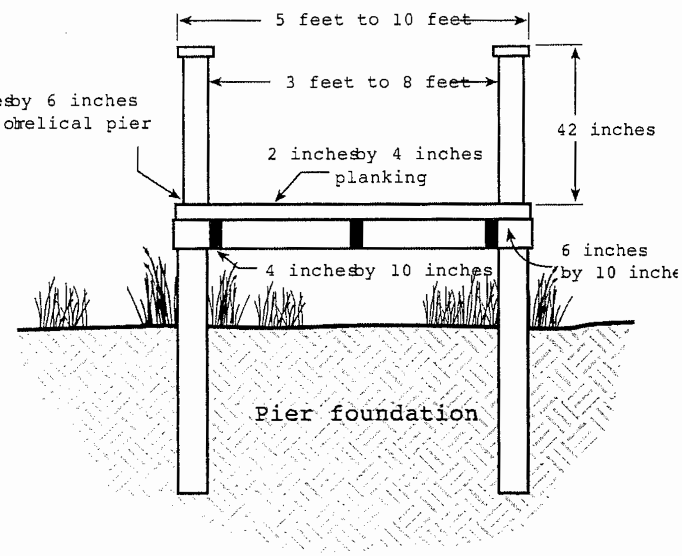


Figure 5-8 Elevated trails do not disrupt ground or surface water movements and they allow for wildlife passage. (Wetland Trail Design and Construction, 2001)

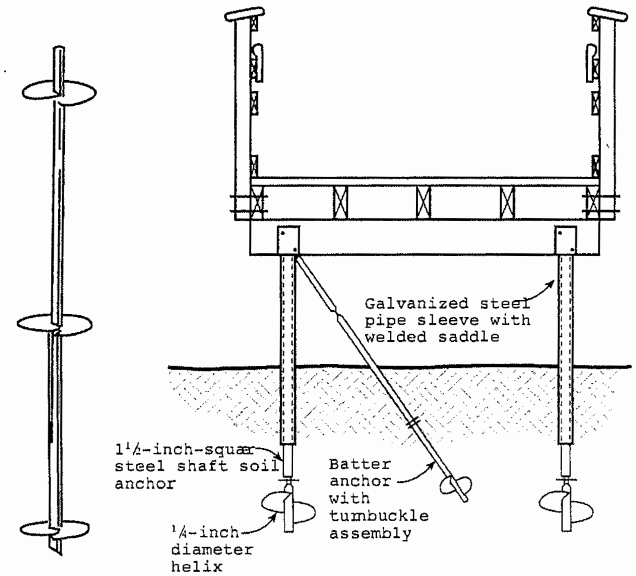


Figure 5-9 Metal screw piles can give reliable support to boardwalk structures in soft ground and do not need to be driven as deeply as traditional log pilings. (Wetland Trail Design and Construction, 2001)

Geotechnical exploration is necessary to determine how deeply boardwalk and viewing platform supports must be driven into soft sediments (see Figure 5-9). Screw piles require special equipment to install, but in some cases, do not need to be driven as deeply as traditional pilings. Screw piles do not require the careful attention to environmental protection that is needed when working with treated wood products. For more discussion on this topic, see the section on treated wood products in Chapter 8 and Appendix F. Connecting hardware for elevated trails should be corrosion-resistant. Wood that has been treated with waterborne preservatives containing copper must use galvanized connecting hardware.

5.5 Preventing Erosion

Unsurfaced trails are subject to erosion, as are some trail surface materials. Both natural and constructed trail surfaces can generate concentrated runoff, which can increase erosion, affect water resources and damage trails. By being aware of the kinds of problems that can be created or invited by trails in and near water resource areas, trail planners can work to avoid them through alignment, design and surfacing decisions. Solutions that can be implemented in the planning phase include trail siting, alignment and the use of vegetated setbacks. Solutions that can be implemented in the design phase focus on drainage design approaches, drainage templates and surfacing.

Techniques for the planning phase

Identify water resources at risk of receiving trail runoff and sediments. It is important to know the locations of water resources within about 200 feet of each proposed trail alignment. The location of these potential "receiving" water resources relative to the trail will help planners make decisions about trail type and siting, placement of trail drainage structures, designs for interception and infiltration of trail runoff and design of the cleared right of way. The proximity of water resources also should influence the selection of trail maintenance equipment, the season when certain maintenance work will be done, and even the disposal of earth materials generated during construction and maintenance activities.

Vegetated setback for trails. Researchers have recommended riparian setbacks for development ranging in distance from 33 to 250 feet from top of bank to minimize the impacts to water quality and to protect the full array of riparian functions (see Appendix C). Local governments have adopted ordinances to protect water quality and setbacks range from 50 feet to 200 feet depending upon slope.

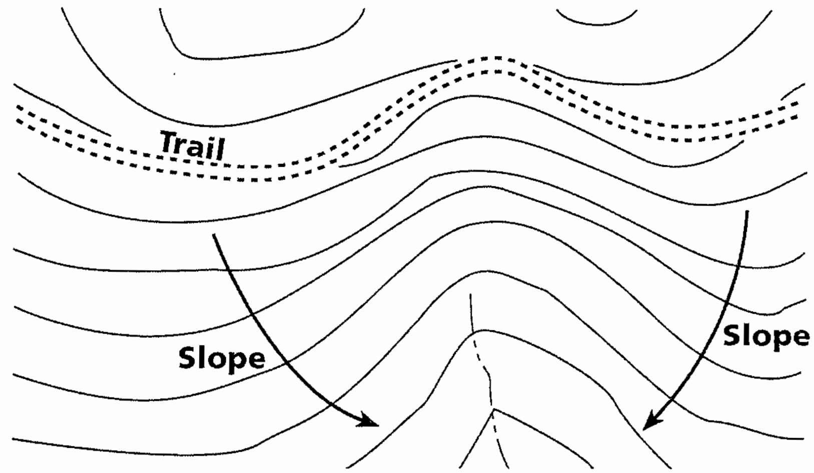


Figure 5-10 When trails traverse slopes instead of plunging directly up or down them, they are easier to maintain in good condition. (Low-Volume Roads Engineering Best Practices Field Guide, 2001)

Minimize trail width. Most municipalities in the region prescribe a vegetated setback between water resources and trails. Within these setbacks, trail width should be kept to a minimum and trail drainage should be managed for complete infiltration of runoff and immediate deposition or filtering of sediments in trail runoff. Runoff is less of a concern on trails in dense coniferous forests because the canopy intercepts much rainfall. For road-to-trail conversions, excess width can be ripped, sloped to drain and seeded to reduce the amount of bare earthen surface exposed to erosion.

Align the trail parallel to contours. This will discourage water from running down the trail surface (see Figure 5-10). Consider stairs where slopes are steep. Switchbacks can be another solution, but they require careful location, design and construction to remain stable and to discourage short cutting.

Plan ahead for construction in sensitive ares. Develop a plan for preventing erosion and controlling sediments in or near sensitive areas. Chapter 9 provides some guidelines on this topic. Cities have their own erosion control measures. For example, Portland's Erosion Control Manual includes best management practices for construction in sensitive areas.

Strategies for drainage design

Make sure to involve the appropriate specialists in decisions about types of trail surfaces, construction planning, trail drainage designs, drainage ditches, pipes and culverts. Some general design approaches for avoiding concentrated flows and erosion follow:

Trail surfaces for water resource areas. Use permeable surfaces and design stormwater infiltration to reduce the risk of trail runoff discharging directly into water resource areas.

Trail construction techniques. Adequate preparation of the sub-grade and base are necessary to support a stable, structurally sound trail, particularly in wet spots or wet conditions. Without this support, trails can become soft and muddy, which can encourage off-trail uses and erosion. Trails that will be used by maintenance vehicles need to be designed for this purpose to assure that rutting and erosion do not result.

Trail drainage templates. Trails should be sloped in cross section so that their surfaces shed water. Favorable drainage cross-gradients are achieved by in-sloping, out-sloping and crowning (see Figure 5-11). By controlling the nature of the trail cross slopes, trail designers control erosion of earthen trails and determine where runoff will be directed. Drainage designs also determine how much water will be present in trailside ditches and runoff discharge points. Hydrologic calculations are necessary to determine whether the ditch will need to be armored (protected with rock), how large and deep the rock should be and how frequently drainage relief will need to be provided. As a general principle, it is best to avoid inside ditches when possible to avoid ongoing maintenance needs.

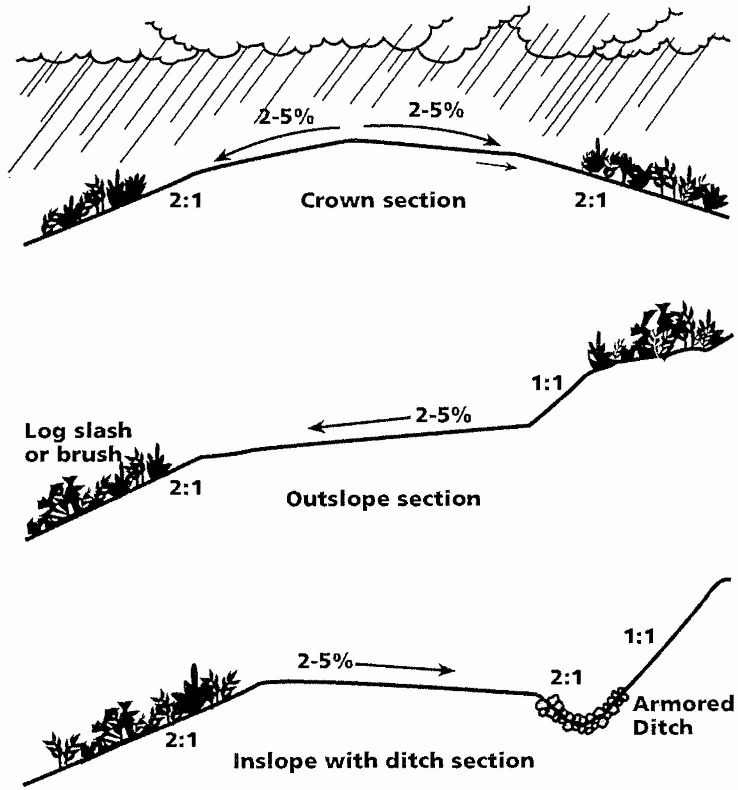


Figure 5-11 Typical trail drainage templates. (Low-Volume Roads Engineering Best Management Practices Field Guide, 2001)

Minimize runoff. Manage runoff in small quantities close to where it is generated so that risk of drainage system failure is low and runoff is concentrated as little as possible. Provide out-sloped drainage of at least 3 percent for earthen trails where possible so that runoff will sheet evenly off the outside edge of the trail. Out-sloping trails with constructed surfaces also can reduce the amount of concentrated runoff and minimize erosion that can be generated by discharge of concentrated runoff (see Figure 5-12). Out-sloping trails can eliminate or reduce the need for water quality facilities. Out-sloping also reduces the need for inside ditches and trail cross-drains (under-trail drain pipes), which frequently require greater maintenance to prevent erosion.

Planting trees and shrubs to create dense vegetative cover near the trail also can minimize runoff. The leaves of the overhanging plants will intercept much of the rainfall so that less of it falls directly on the trail. Leaf litter on the ground near the trail will absorb much of the rainfall, and the roots of plants in the vicinity of the trail will aid in both infiltration and uptake of water in the soil.

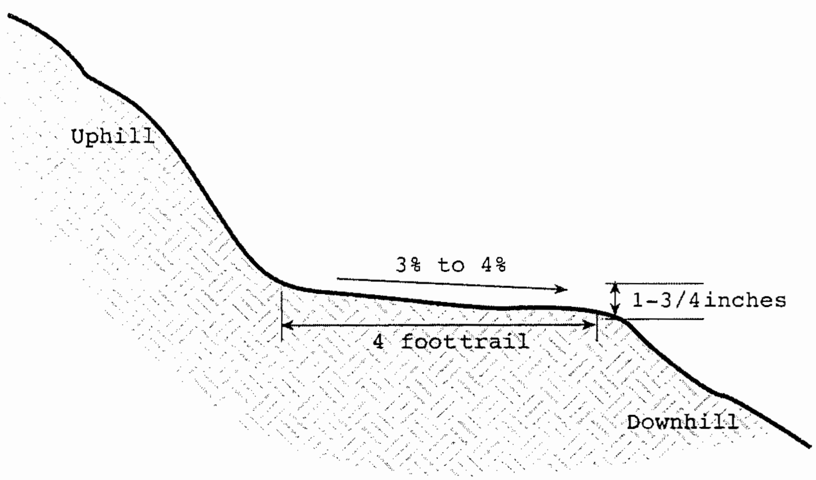


Figure 5-12 Outslope cross section. (Adapted from California State Parks and Recreation)

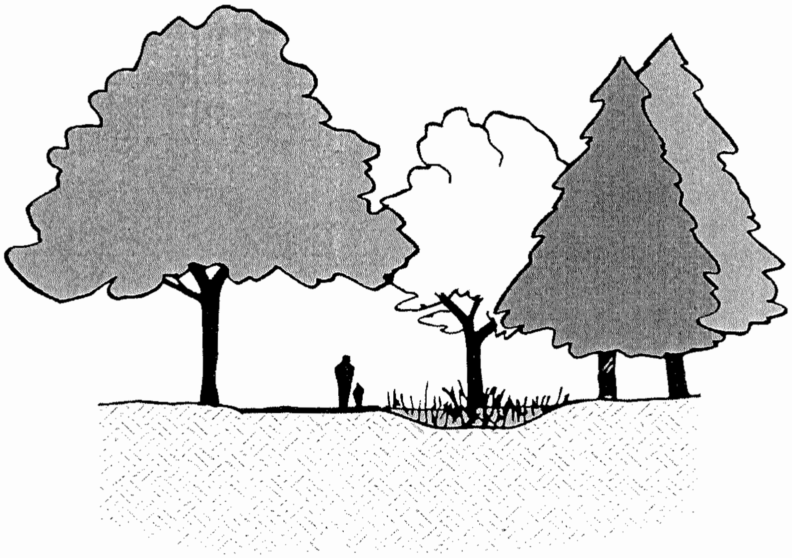


Figure 5-13 Bio-filtering swale. (Green Streets: Innovative Solutions for Stormwater and Stream Crossings, 2002). Vegetation in trailside ditches and swales can slow and filter trail runoff, providing important water resource protection.

Vegetative filtering. Trails can be designed to slope to adjacent vegetated areas so that diffuse runoff can be immediately filtered, level spread and infiltrated (see Figure 5-13). Locations selected for this purpose require sufficient light to support a dense growth of ground cover. Where concentrated flows cannot be avoided, treatment can be provided in created grassed swales, created ponds or other passive trailside facilities.

Drainage from trails should be treated before release to water resource areas. In settings where trail runoff must be concentrated and conveyed to a suitable discharge area, look for opportunities to combine this water with other runoff to create a treatment wetland or pond that offers a seasonal or perennial source of water for wildlife. It is important that trail drainage discharged from such created facilities does not change the hydrology of natural wetlands in the vicinity.

Metro's Green Streets: Innovative Solutions for Stormwater and Stream Crossings has many ideas for dispersing runoff and integrating it into the adjacent landscape. Many techniques explained in the publication such as filter strips and swales, permeable pavements and level spreading are applicable to multiple-use trails and should be considered. The city of Portland's Stormwater Management Manual also provides useful suggestions about appropriate vegetation for managing stormwater.

Limit sustained grades. Limit sustained grades to less than 10 percent to control erosion of the trail surface and to provide the majority of users with a trail gradient that they will find pleasant. A 10 percent sustained gradient is the steepest gradient commonly acceptable for moderate-to-challenging trail use by hikers, equestrians and long-distance mountain bikers.

Prevent erosion at outlets of rolling dips and culverts. Drainage outlets from trails should be protected to prevent erosion of the runoff discharge area. Often, a small armored earthen basin is constructed beside the trail to dissipate flows at runoff discharge points and to facilitate the deposition of sediments (see Figure 5-14). Such basins usually have sufficient volume to hold runoff for a time and encourage infiltration. For a minor outlet, brush or native organic debris can be spread to slow the velocity of the runoff. Major outlets should be armored with rock. Adequate armoring generally consists of two layers of angular rock sized to withstand movement by "worst-case" flows. To design an armored outlet that will last, a hydrologist can calculate the runoff expected in a 50-year storm or greater and select the rock size to resist this flow. Sometimes it is necessary to place brush at outlet of such basins where they overflow to break up concentrated flow and prevent erosion.

Use of drain pipes. When drainage from a trail interrupts surface or groundwater, a drain pipe or culvert should be used. Pipe-sizing calculations often must take into account the contributing watershed, its size, the nature of vegetation or disturbance, and how future development in the contributing watershed may affect groundwater or surface runoff that drain to the ditch. Rainfall and soil characteristics also are to be considered.

Finally, a decision must be made about the "design storm" each culvert must be capable of passing. In some jurisdictions, the design storm may be a storm with a 15-year recurrence frequency. Many jurisdictions are upgrading the design storm for which pipes are sized, recognizing that in urbanizing areas, runoff amounts can subject pipes to failure if they are not adequately sized. The selection of a larger pipe may contribute to a more stable trail drainage system that requires less maintenance in the long run.

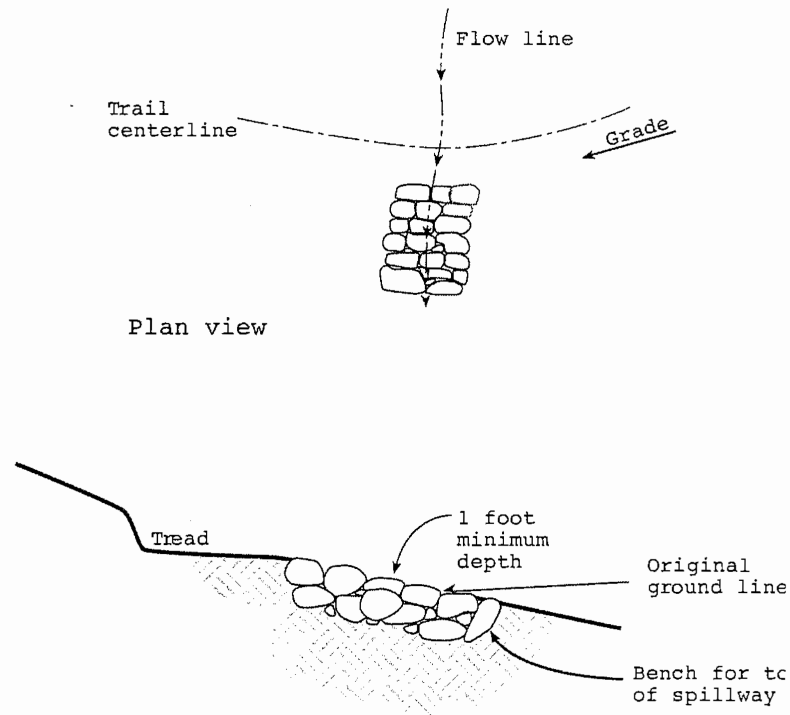


Figure 5-14 Rock-armored outlet, also known as drainage dissipation apron. (U.S. Department of Transportation. 2001. Gravel Roads Maintenance and Design Manual.)

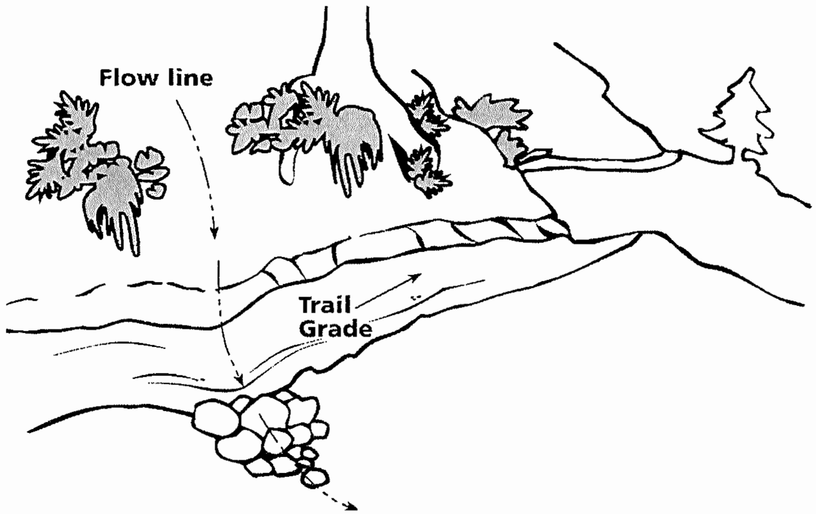


Figure 5-15 Runoff is directed from the trail to a rocked discharge area that protects the slope below from erosion.

Provide frequent drainage relief. Trail designers need to determine how every segment of each trail will be drained (see Figure 5-15). Frequent drainage relief is essential to minimize runoff and related erosion. Greater frequency of drainage relief is needed when trails are steep, constructed in erodible materials or near water resources, so that runoff discharge volumes and velocities remain low. To create rolling dips, the trail is designed so that the longitudinal profile is undulated frequently (this also is called rolling or breaking the grade) to disperse water from the tread (see Figure 5-16). The dips route runoff off the trail before rilling (erosion deeper than 1 inch) can occur. Spacing depends on gradient and the erodibility of the native earth materials. Some managers recommend more closely spaced drainage relief for urban-area trails, due to other factors that contribute to increased runoff.

The spacing of drainage features is related to both trail grade and materials. Steeper trails require more frequent drainage relief. Sandy, rocky and gravelly soils require less frequent drainage relief because runoff drains quickly into the soil and because these large, heavy materials are not easily moved by runoff. Silts, which are characteristic upland soils in much of this region, easily erode. Silty trail surfaces require more frequent drainage relief to resist erosion. The spacing suggested in Table 5-1 is a starting point for minimum drainage frequency. Aspect, position on slope and gradient of the cross-slope also influence the spacing between drainage features. The trail-planning team's soil scientist and geotechnical engineer can help with this.

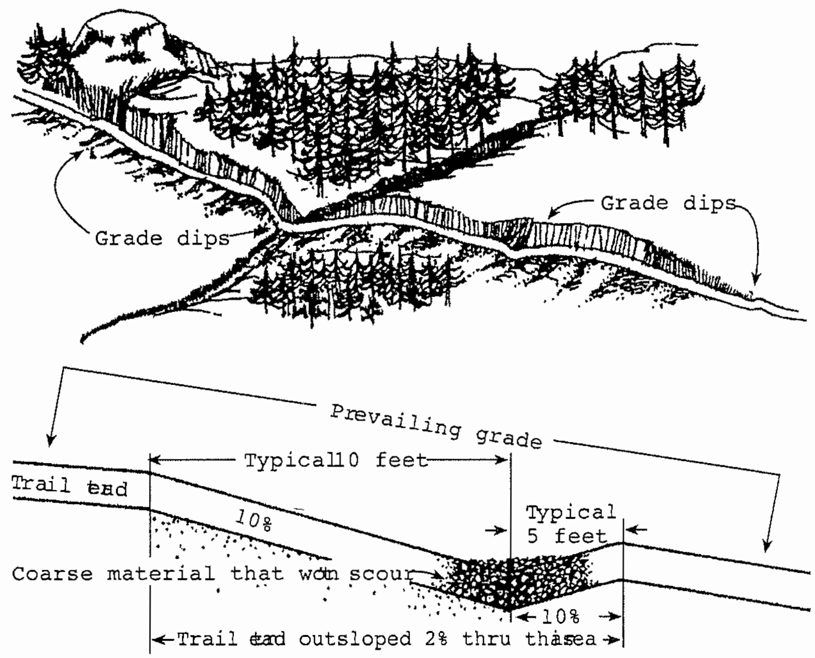


Figure 5-16 Subtle drainage features such as these rolling dips are incorporated into the trail so that runoff does not concentrate and is quickly routed off the trail. (Hesselbarth, W. 2000. Trail Construction and Maintenance Notebook. USDA Forest Service.)

Trail grade	Coarse, rocky gravelly materials (in feet)	Gravelly sands, silty sandy gravels, coarse extrusive volcanics (in feet)	Silty clays, clays, fine sandy silty clay, weathered volcanics (in feet)	Friable silts, fine silts and sands, fine decomposed granitic soils (in feet)
2 %	300	160	136	100
4 %	280	145	121	85
6 %	250	140	113	75
8 %	230	135	106	70
10 %	200	125	97	60
12 %	175	115	80	50

Table 5-1 Recommended frequency or spacing of rolling dips and water bars to prevent rill erosion by runoff on earthen trails. (Adapted from Geotechnical/ Materials Engineering Training Session, USDA Forest Service, 1982, 2002)

Table 5-2 shows recommendations about culvert spacing. Some managers prefer to space cross-drains closer on trails in urban settings due to a number of factors that can increase expected runoff. In Portland's West Hills, for example, or in the East Buttes (Boring Lava Domes in East Multnomah County), it is important to plan for drainage of perched groundwater that trail excavation captures. Increased use of earthen trails can also generate more runoff.

It is not always easy to determine how erodible a soil is by looking at it. For this reason, the soil scientist on the trail-planning team should evaluate soil erosion hazards along the trail route and provide recommendations about drainage features and spacing.

A note about drainage features and bicyclists. Rolling dips must be "transparent" to a bike wheel – that is, elongated so that riders roll smoothly through them – and the dips must be angled at 45 degrees or so to the travel direction. They must fall at about 20 percent of slope so that they are self-cleaning, meaning that sediments moving in runoff from the trail will be transported off the trail in runoff from the dip. For longevity, particularly to withstand wear by mountain bikes, both the mound and dip should be armored with gravel or rock.

Trail or road grade	Soils with low to moderate erosion hazard (in feet)	Soils with high erosion hazard (in feet)
0-3 %	500	325
4-6 %	400	230
7-9 %	325	160
10-12 %	280	130
12+ %	245	100

Table 5-2 Recommended distance between culvert cross-drains. (Adapted from Low-Volume Road Engineering Best Management Practices Field Guide, USDA Forest Service, 2001)

5.6 Working With Steep Slopes

Steep cross slopes (greater than 25 percent slope) present special challenges for trails, trail designers and trail users. A steep earthen trail that descends "with" the slope can develop severe erosion problems that are difficult to fix and may affect water resources. Small rock fragments on steep, hard, earthen or bedrock trails can be very treacherous for users. The danger of slipping on small rolling rocks or a slick section of trail often results in the development of numerous side trails where people can get a foothold on vegetation. If a steep trail is too demanding, users may choose another route. Steep trails may invite unwanted uses (such as cross-country bicycling) that are not conducive to natural resource protection goals. The need to protect public safety as well as water resources and wildlife habitats requires special approaches to the design of trails if steep terrain cannot be avoided.

Climbing turns. On moderate slopes (less than about 15 percent), it may be possible for a trail to gain elevation by means of a broad climbing turn (see Figure 5-17). The steepest part of the turn may be steeper by a few percentage points for a short "pitch" than the steepest sustained grade on the trail.

Figure 5-17 Climbing turns sweep gently upslope, minimizing the portion of the trail that runs "with" the slope and keeping gradient low. (Hesselbarth, W. 2000. Trail Construction and Maintenance Notebook. USDA Forest Service.)

Switchbacks. Switchbacks provide a way to gain or lose elevation on steep slopes greater than about 15 percent by means of slope traverses with periodic reversals in trail direction (see Figure 5-18). A person with trail engineering skills should design the switchback's "hairpin" turn because earth cut and fill are necessary. The area where earth materials will be placed as fill needs to be properly prepared before the fill is placed in compacted layers. This means that vegetation and organic debris should be stripped from the "fill" site and all roots grubbed out to a depth of about 1 foot. The fill layers should be "keyed" into one another. These details are essential for the fill section of the trail to have structural integrity.

A person with field engineering skills should oversee the construction. The turn often requires an earth retaining structure with large rock or wood material placed on it to keep it from being short cut. In wildland settings, the materials for the retaining structure and its protective "armoring" are frequently scavenged from the surrounding woods, but in urban natural areas, may need to be brought in. Native vegetation can often be installed in the retaining structure to visually screen the switchback and prevent users from developing switchback short cuts.

Switchbacks can be problematic where there is shallow soil over bedrock and where they are likely to capture groundwater. Natural "benches" or flattish spots in the landscape are ideal places to construct switchbacks. Avoid inter-visible switchbacks as they may be used as short cuts by users.

The trail segment going into the switchback from above should have a drainage feature that protects the turn from erosion and does not discharge onto the trail segment below it. The outside edge of the switchback also should have a drainage feature. Some designers increase the gradient of the trail segments leading into and out of the switchback to prevent short-cutting.

Stairs. Stairs have a number of advantages in steep terrain.

Switchback with retaining wall

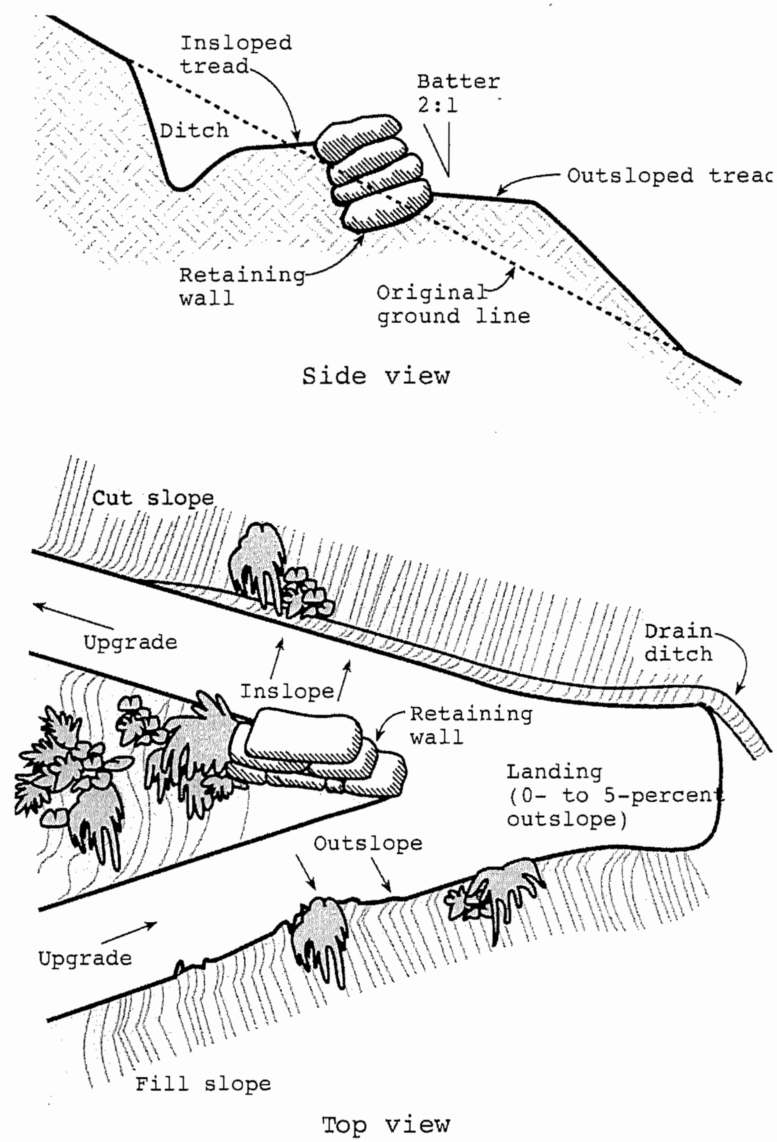


Figure 5-18 Switchbacks allow the trail to ascend a steep slope by traversing and changing directions while maintaining a reasonable gradient. (Hesselbarth, W. 2000. Trail Construction and Maintenance Notebook. USDA Forest Service.)

They can go directly up or downslope in locations difficult to fit with traverses and switchbacks. They can encourage people to stay on the trail in steep terrain and they can discourage non-pedestrian uses. Make sure to design stairs that do not create a blockage for wildlife movement. Stairs can be elevated above the ground to minimize ground disturbance and to allow passage of wildlife. In urban settings, planners often specify dense or thorny vegetation at stair edges to discourage bicyclists from going down beside the stairway. Stairs may be made of stone, concrete, wood or aggregate-filled wooden cribs. Specifications should be used to assure that proper anchoring and pinning provide stability to the stair and safety for the user. An important design detail for safe and usable steps concerns the ratio of riser to tread. See Glossary for information about determining this ratio.

A word about groundwater. Where a slope cut will be

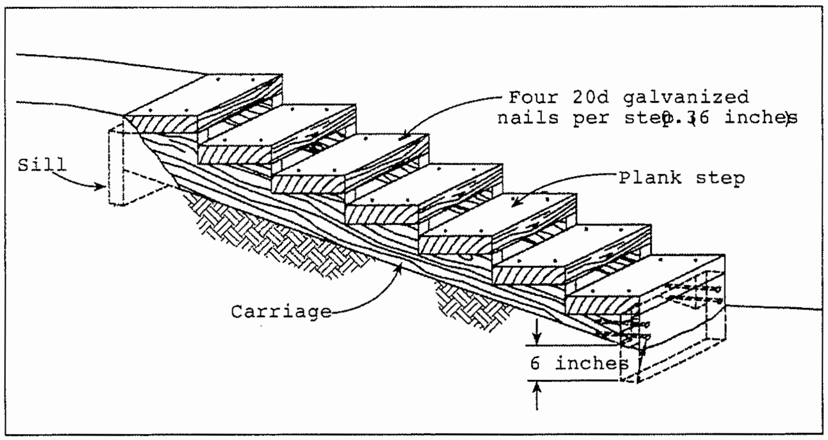


Figure 5-19 Plank stairway. (Jackson, B. 1993. Recreation Site Design)

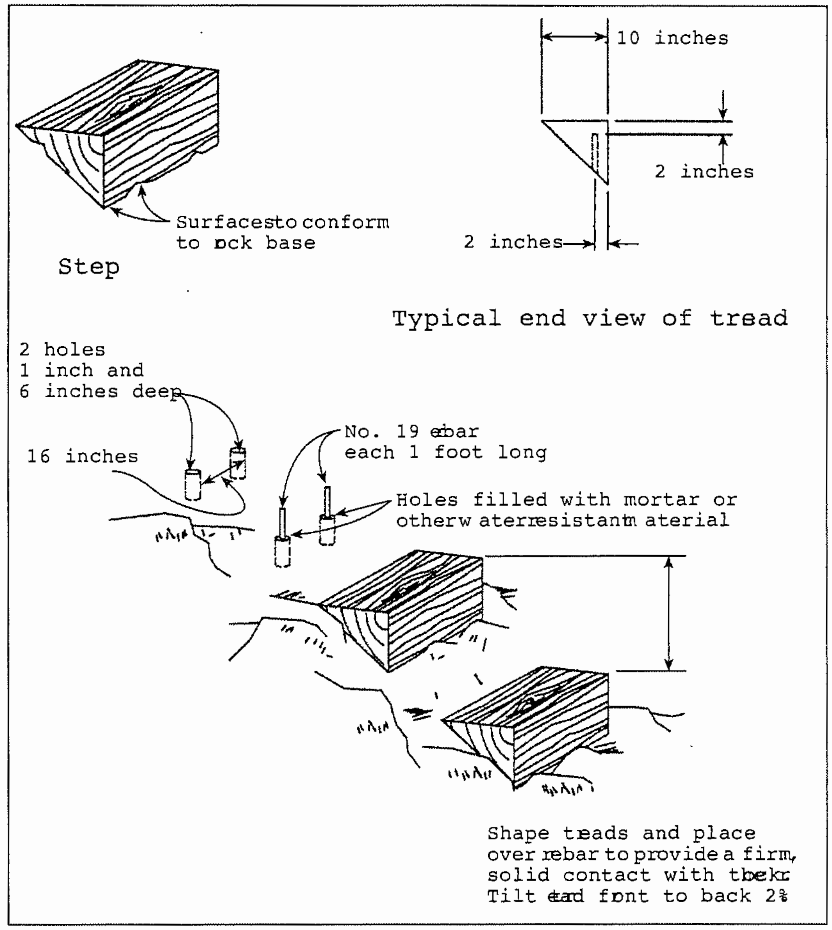


Figure 5-20 Pinned stairway. (Jackson, B. 1993. Recreation Site Design)

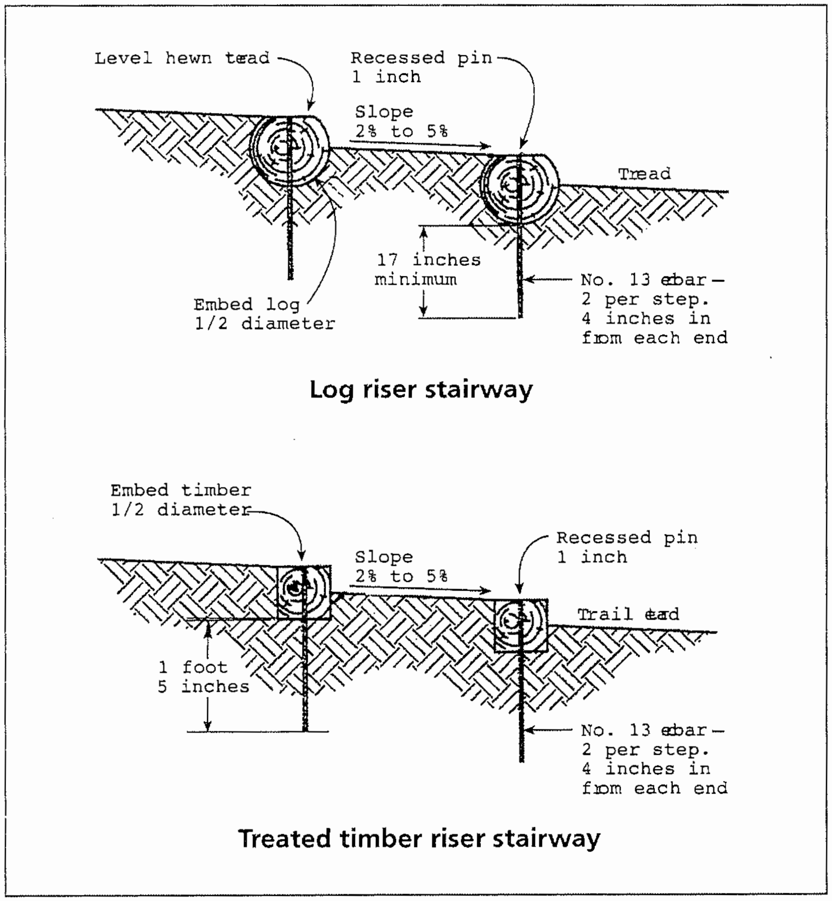


Figure 5-21 Log and treated riser stairways. (Jackson, B. 1993. Recreation Site Design)

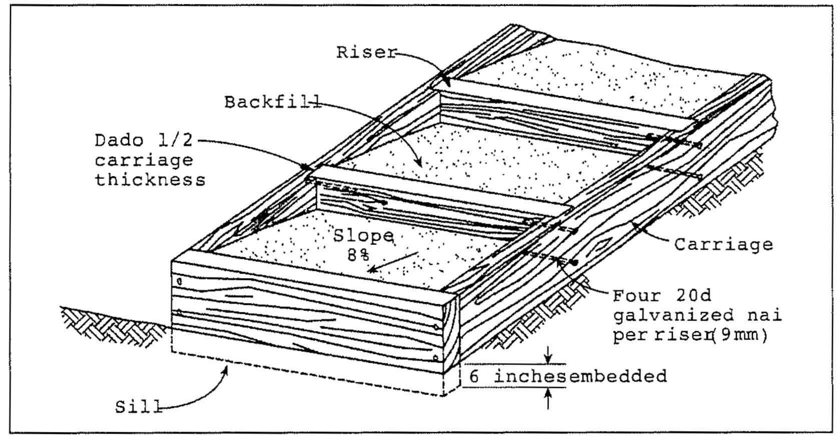


Figure 5-22 Crib ladder stairway. (Jackson, B. 1993. Recreation Site Design)

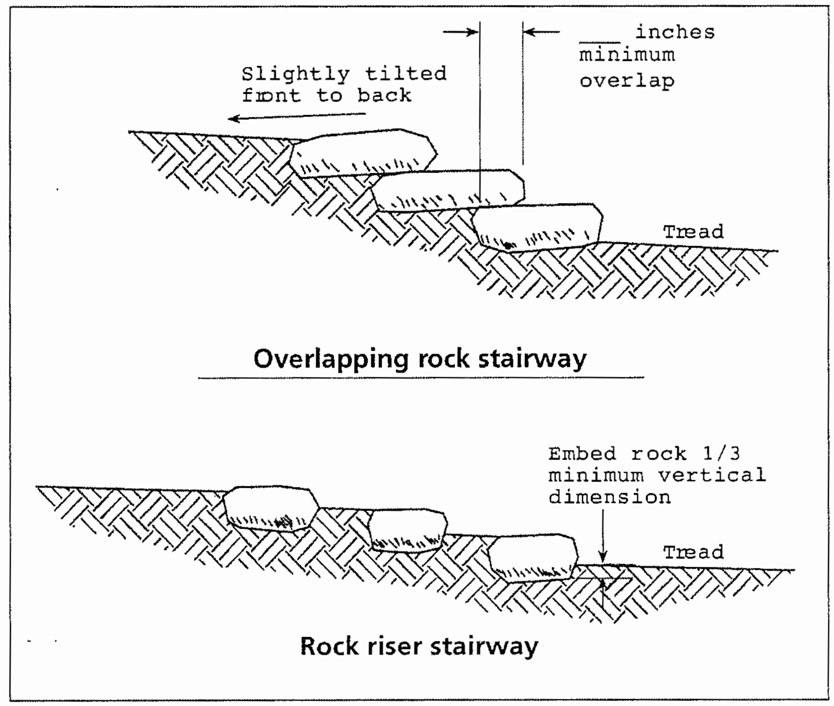


Figure 5-23 Rock stairways. (Jackson, B. 1993. Recreation Site Design)

made for stairs, a switchback or a climbing turn, it is important to plan for groundwater that may be intercepted by the cut. One technique is to construct a drainage ditch at the uphill edge of the trail. This is lined with geotextile fabric, backfilled with crushed rock in which a perforated pipe has been placed and covered (see Figure 5-24). Groundwater that is intercepted by the cut flows into this system and is discharged by the pipe to passive water quality facilities in the vicinity of ephemeral streams near the trail. Periodic risers provide access for pipe clean-out.

Trail planners who understand the natural resources of the area and who are familiar with techniques for siting and designing environmentally friendly trails can embark on the exciting work of locating test alignments. Some techniques for locating and evaluating potential trail alignments are discussed in the next chapter.

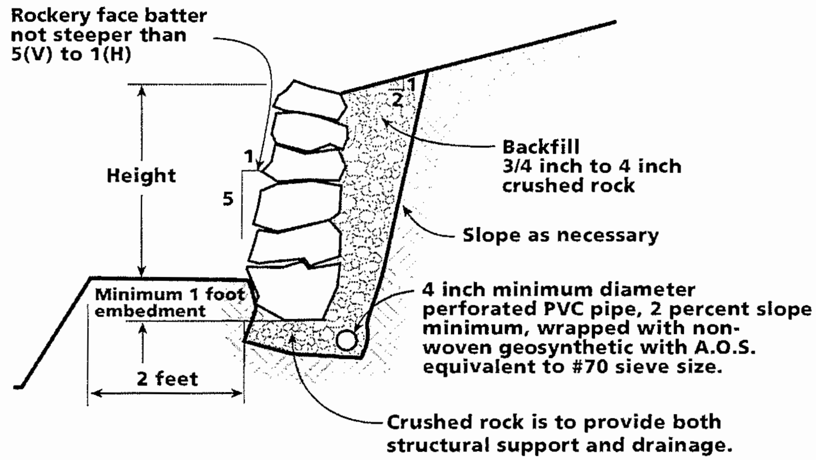


Figure 5-24 Perched groundwater that "daylights" in the trail cut drains to a gravel-bedded pipe behind this dry wall. It is then conveyed to a discharge area. (Gresham Saddle Trail, David Evans and Associates)

What environmental permits will we need?

6.1 Introduction

Permits ensure that projects will comply with federal, state and local environmental standards. Environmental permits are required for actions that will disturb vegetation, move soil, enter environmental or natural resource zones or have the potential to cause impacts to wetlands, water bodies or endangered species. Because regulatory programs change, it is always wise to check with local government and state and federal permitting agencies in the early phases of project planning.

6.2 Municipal Natural Resource Codes and Standards

As required by Statewide Planning Goals 5, 6 and 7, and other local zoning and code requirements, cities and counties implement protections for natural resources such as fish, wildlife, wetlands, steep slopes, streams and floodplains by means of local policies, codes and standards. One permit application may result in the need for another. For example, in Portland, if a trail will be in a zone designated "P" for protection or "C" for conservation, the project will require a land-use review. The land-use review triggers the need for a site-development permit, which is likely to require detailed drawings of grading, drainage, erosion control and construction management activities. A pre-proposal conference with the municipal planning and development office will provide project planners with information about the codes and standards the project must meet. This knowledge can expedite the issuance of permits, saving projects time and money.

Alternatives analysis. If a proposed trail will pass through a regulated natural resource (as delineated on a local map), an analysis of alternatives may be required. This analysis will determine if there are other routes that could result in lesser impacts to the resource. If no alternatives are available, steps may need to be taken to minimize (Chapter 5) and mitigate impacts of the trail. Each local government oversees codes and requirements that vary from one jurisdiction to another, so trail planners should be aware of these nuances.

6.3 State and Federal Environmental Permitting

Following are federal and state agencies with regulatory responsibility for a range of activities likely to be associated with trail projects. A majority of these permits reflect federal regulations outlined in the Clean Water Act (1972), the River and Harbor Act and the Endangered Species Act (1973). Refer to Appendix D for a checklist of permits required to construct a trail.

Federal agencies and acts

US Army Corps of Engineers (COE). This agency administers permits for activities regulated through Section 404 of the Clean Water Act and Section 10 of the River and Harbor Act. The goal of the act is to maintain and restore the physical, chemical and biological integrity of waters of the United States. Under the Clean Water Act, Section 404 regulations apply to discharges of dredged or fill material into the waters of the United States. Section 404 permits trigger Section 401 of the act, administered by the Oregon Department of Environmental Quality. Section 401 of the act includes regulations to protect and enforce water quality standards.

Because many activities require certification, and many others are permitted under 40 different nationwide and general permits, trail planners should always check with the COE to learn what permits will be required for particular conditions and circumstances. Trail planners working on projects along waterways will be especially interested in the provisions of the Nationwide Permit 42 for recreational facilities. For more information, call the Corps' Portland district office at (541) 465-6877 or visit www.nwp.usace.army.mil/.

Section 10 of the River and Harbor Act (1899) requires that any work in or over navigable waters of the United States or that affects the course, location, condition or capacity of such waters receive approval from the COE.

Following is a partial list of activities that can trigger the need to apply for COE permits:

- dredge and fill activities in the waters of the United States, regardless of the amount of area affected by the activity and the amount of fill used (waters of the United States include designated wetlands, lakes, rivers, streams and tributaries)
- removal or alteration of material in wetlands, streams, lakes and other waterways
- discharge of a pollutant in violation of state water quality standards
- obstruction or alteration of navigable waters of the United States, including structures below the mean high-water mark
- restoration or enhancement of wetlands, or fish habitat enhancement.

U.S. Fish and Wildlife Service (USFWS) and National Oceanic and Aeronautic Association (NOAA Fisheries) administer the Endangered Species Act. When there's a federal nexus such as a regulatory trigger, federal funds or federal lands involved in a project, this triggers Section 7 of the Endangered Species Act requiring consultations if protected species may be affected, the National Environmental Policy Act, the National Historic Preservation Act, and possibly other requirements such as Level 1 contaminant surveys. However, the lead federal agency for the project is responsible for compliance in those cases.

When there is not a federal nexus, Endangered Species Act regulations still apply and the non-federal entities are required to get "take" coverage if listed species may be affected. If additional information is needed on wildlife, including federal status and other relevant information such as obtaining a species list for an area, refer to the U.S. Fish and Wildlife Service Oregon web site at oregonfwo.fws.gov/EndSpp/EndSpp_home.html.

NOAA Fisheries has jurisdiction over listed threatened and endangered fish species. The agency has delineated their evolutionary significant units in the Portland metropolitan area and also will be designating critical habitats in the region. All of these species migrate as adults and juveniles through the metropolitan area in the Columbia River and its tributaries. Others also spawn and/or rear in metropolitan area streams. If additional information is needed on the status of fish species and ESA regulations and habitat sensitivity, refer to the NOAA Fisheries web site at www.nwr.noaa.gov/1salmon/salmesa/index.htm.

NOAA Fisheries also is responsible for implementing the Magnuson-Stevens Act "essential fish habitat" provisions. Essential fish habitat is broadly defined as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." Portions of essential fish habitat are present in the Portland metropolitan region and provide important habitat for salmon and other species; visit www.nmfs.noaa.gov/sfa/magact/ or talk to a NOAA Fisheries staff person for more information about this regulation.

State agencies

Oregon Division of State Lands (DSL). This agency reviews Section 401 and 404 permits jointly with the COE and is the lead state agency responsible for managing wetlands, submerged lands in the state's navigable water ways, and wetland fill and removal. The division implements erosion control and fill and removal permits. Oregon's Removal-Fill Law requires the DSL to oversee a removal-fill permit program to conserve, restore and maintain the health of Oregon's waters. The division's jurisdiction extends to the ordinary high water or high tide line, or to the line of non-aquatic vegetation- whichever is higher. If the activity involves filling or removing less than 50 cubic yards and is not in an area determined to be Essential Salmonid Habitat or a State Scenic Waterway, a state permit is not required. The division also oversees permitted fish habitat enhancement projects and wetland restoration and enhancement projects. Call (503) 378-3805 or visit http://statelands.dsl.state.or.us/todolist.htm if the project includes any of the following:

- building a pond
- constructing a marina or a dock
- removing gravel or rock from uplands, wetlands or water ways
- controlling streambank erosion
- building in a wetland
- construction of a large or small dam
- any work that will affect the bed or banks of a water way
- enhancing or restoring wetlands or fish habitat.

Oregon Department of Fish and Wildlife (ODFW). This agency comments on project activities and operations, and reviews structures such as bridges, wharves and culverts in and over water. The ODFW does not issue permits but provides input to assist project designs and construction activities to comply with in-water work requirements and to recommend measures to protect fish and wildlife. These protections concern salmon, steelhead, trout, warm water game fish, state and federally listed threatened and endangered species, and other native species. The ODFW also maintains a list of Oregon waters, their fish species and the recommended time periods for in-water work that are most compatible with fish and wildlife needs. If trail planners seek input early in project planning, the department can provide valuable input on the "permit-ability" of project components, including mitigation. Call (503) 872-5255 or visit www.dfw.state.or.us/ for assistance and information on in-water work windows and permit requirements under any of the following conditions:

- work is proposed in or over a water way
- dams, in-stream culverts, or spans or bridges over water are proposed
- the project will take place in or near a wildlife conservation area, floodplain or stream
- to learn whether federal or state-protected species are present in the project area.

Oregon Water Resources Department. Projects that will use, divert or store water generally require a water right certificate or permit from the department. For example, if water from a stream will be pumped to provide temporary irrigation for trailside plants, a permit will be needed. The department provides technical assistance on water-related projects, and can advise applicants on the likelihood that a permit can be obtained. For more information, contact the Water Rights Division in Salem at (503) 378-3741 ext. 499. The department administers the following permits:

- instream water rights certificate
- limited water use license (e.g., for temporary irrigation)
- permit to appropriate surface water
- permit to construct a reservoir
- permit to store water (e.g., in a pond)

- water diversion structure permit (e.g., to facilitate in-stream work).

Oregon Department of Environmental Quality (DEQ). This agency implements protections for land, air, groundwater and surface water in Oregon. DEQ reviews permit applications submitted to the U.S. Army Corps of Engineers under Section 401 Clean Water Act. Section 401 requires DEQ to certify that the proposed activity does not endanger Oregon's streams and wetlands and to confirm that the plan meets water quality laws and standards. Once this is confirmed, the DEQ issues a water quality certification.

Contact the Northwest Office of DEQ at (503) 229-5263 or 1-800-349-7677, or visit www.deq.state.or.us/wq/permitcorner/ for information about permits, particularly if any of the following actions are planned:

- land disturbance, grading or clearing vegetation on one acre or greater, including all project phases
- generation of waste water, for example, a drain field for a restroom or a drinking fountain at a trailhead
- dewatering of pits or trenches under certain circumstances
- construction activities near a water quality limited stream
- disposal of stormwater in an underground injection system
- wetland fill/removal.

6.4 Application Fees and Turnaround Times

Application fees generally must accompany local permit applications when they are submitted. Depending on the scope and scale of the project, the fees can be considerable. Make sure to research the costs of permit applications and build these into the project budget.

Planners should be prepared for permitting on long trail alignments in sensitive habitats to take at least 12 months. The range of permits and their applicability in specialized planning, engineering and environmental fields underscores the need for trail planning by an interdisciplinary team.

6.5 Useful Contacts

Municipal planning departments

Counties

Clackamas County	(503) 655-8581
Multnomah County	(503) 823-4000
Washington County	(503) 846-8611

Cities

Beaverton	(503) 526-2222
Durham	(503) 639-6851
Cornelius	(503) 357-9112
Fairview	(503) 665-7929
Forest Grove	(503) 992-3200
Gladstone	(503) 656-5225
Gresham	(503) 618-3000
Happy Valley	(503) 760-3325
Johnson City	(503) 655-9710
Hillsboro	(503) 681-6100
King City	(503) 639-4082
Lake Oswego	(503) 635-0270
Milwaukie	(503) 786-7555
Oregon City	(503) 657-0891
Portland	(503) 823-7526
Sherwood	(503) 625-5522
Tigard	(503) 639-4171
Troutdale	(503) 665-5175
Tualatin	(503) 692-2000
West Linn	(503) 657-0331
Wilsonville	(503) 682-1011
Wood Village	(503) 667-6211

More information

Topic	Agency or Department	Contact
Wetland maps	Oregon Division of State Lands Municipal planning departments (see page 65) Oregon Department of Fish and Wildlife US Fish and Wildlife Service Metro's Data Resource Center	(503) 378-3805 (503) 872-5255 (503) 231-6179 (503) 797-1742
Wetland permits (Section 404)	US Army Corps of Engineers Oregon Division of State Lands USDA Natural Resources Conservation Service (for information about wetlands on agricultural lands) Municipal planning departments (see page 62)	(503) 326-6995 (503) 378-3805 (503) 222-7645
Water quality permit (Section 401)	Oregon Department of Environmental Quality Municipal planning and permit offices (see page 62)	(503) 229-5279
Water rights and certificates	Oregon Division of State Lands	(503) 378-3741 or (503) 378-3741 ext. 499 or 1-800-624-3199
Trail construction along levees	Multnomah County Drainage District	(503) 281-5675
Comments on proposed projects	Oregon Department of Fish and Wildlife US Environmental Protection Agency	(503) 872-5255 (503) 326-3250
Erosion and sediment control	Oregon Department of Environmental Quality, Water Quality Division Portland Bureau of Environmental Services Clean Water Services, Inspection Services Clackamas County Surface Water Management Natural Resources Conservation Service	(503) 229-5279 (503) 823-7740 (503) 846-8621 (503) 353-4567 (503) 222-7645
Fish and wildlife conservation areas and information about threatened, endangered and sensitive species	Municipal planning departments (see page 65) Oregon Department of Fish and Wildlife Oregon Natural Heritage Program Bonneville Power Administration (GIS data base on resident and anadromous fish) US Fish and Wildlife Service NOAA Fisheries	 (503) 872-5255 oregonstate.edu/ornhic/ORNHP.html nppc.bpa.gov (503) 231-6179 (503) 230-5425

How do you site a potential trail route?

7.1 Evaluate Trail Routes in Natural Areas and Restricted Urban Corridors

In natural area settings, it is of primary interest for trail routes to avoid negative impacts to wildlife habitats and water resources. This is achieved by routing the trail around these resources. If this cannot be done, a route and trail materials should be selected that will minimize the impacts. But in densely developed urban areas, there often are not trail routing alternatives, and trail routes may be restricted to urban corridors (for example, utility easements, street rights of way, abandoned trolley and rail lines, vacated streets and along streams). In these locations, limitations such as gradient or soil conditions often can be compensated through design.

The following techniques for route selection may not be applicable to all trail types or to all areas. Nonetheless, they can be useful tools for decision-making, provided that trail planners recognize that many limitations, particularly for multiple-use trails in restricted urban corridors, can be overcome through design.

7.2 Set Control Points and Plot Test Alignments

Before going to the field to flag test alignments, set control points for each potential trail route on maps and aerial photographs. Control points are critical locations the trail should connect, avoid or pass through. For example, the trail may need to be set back from a heron rookery, pass above or below a rock outcrop, avoid a property, cross a stream at a particular spot or switch back at a break in slope on a steep hill. The trail needs to begin and end at points that are complementary to the network of trails and transportation system with which it is connected. Zoning, municipal transportation plans, permitting requirements, rights of way in vehicular travel corridors and potential funding sources are among the many additional factors that will influence preliminary trail routes. Each known condition that can affect major trail alignment decisions should be plotted.

Plot test grades for potential routes. The next step is to connect the dots by plotting test grades and alignments on a topographic map. If the trail will serve multiple uses, try to keep the test grade less than 5 percent. If an earthen trail is planned, the gradient may be steeper, but as a general rule, should not exceed 10 percent.

Grades of 10 percent and 5 percent are relatively easy to plot with a pair of dividers. Here's how: Find the scale and contour interval (the number of vertical feet between contour lines) on the map. Let's say the contour interval is 40 feet. To test a 10 percent gradient, set the dividers for 10 times the contour interval, or 400 feet. Start at the first control point and step the dividers from one contour line to the next all the way to the second control point. To test a 5 percent gradient, step the dividers two times between each contour line. If the potential route on grade cannot span between the two control points without exceeding the test gradient, the route can be dropped from consideration, or an alternative route can be tried. The workable routes should be plotted on the map using dashed lines.

To keep the test alignment from exceeding the gradient being tested, the trail may have to swing out and double back on itself to reach the next control point. The precise location for the turn will have to be worked out later on the ground, when a preliminary flag line is tied. Field conditions often result in the actual alignment being as much as 5 percent to 10 percent longer per mile than the dashed line on the map. In some cases, stairs may be an appropriate way to solve a gradient problem.

7.3 Identify Existing and Planned Infrastructure

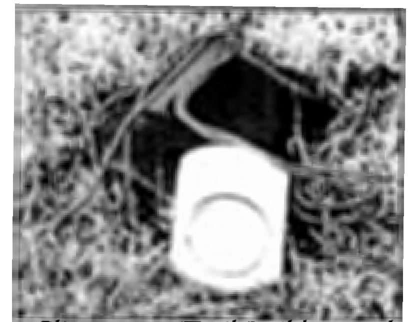
In urban areas, it is essential to investigate how a future trail alignment will work with existing and/or future infrastructure. Property boundaries, easements and rights of way must be known and the locations of public utilities must be determined. This information can disclose opportunities and constraints for future trail alignments.

By Oregon law, all local governments are required to have long-range transportation and growth management plans. These plans designate the type, density and location of future development, and the future locations of sewer lines, wastewater treatment plants and stormwater management facilities. Municipal engineers, infrastructure planners and land use planners on the trail-planning team can help find and interpret this information. They also can plot relevant items on maps and aerial photos in relation to test alignments and help determine if permissions must be granted for the trail to cross or use particular easements and rights of way. It is essential to learn whether these permissions will be granted before putting much additional effort into aligning the trail and making pre-design decisions.

7.4 Field-locate Alternative Alignments

Once all alternative alignments are plotted, gather tools for a field check. These include:

- topographic map
- aerial photo
- field notebook (to record observations and data)
- flagging (to mark points in the field)
- altimeter (to check elevations)
- clinometer (to check slope percentages)
- Global positioning system (to set points in the field)
- compass (for orientation to the site, the map and the aerial photos).



Clinometer. (Trail Building and Maintenance – Building Better Trails, IMBA Resources)

Begin by ground-truthing the start and end points for the trail to make sure they will accommodate the uses stated in the goals for the trail. If start and end points must be relocated, find more suitable locations, make sure to plot them on the aerials and map, and make a note regarding the reason for the change. Finalizing start and end points for trails often requires complex coordination with state highway departments, railroads, local transportation planners, infrastructure planners, safety and security personnel and engineers. Many issues concerning public safety, travel and stopping speeds, signage and security need to be resolved.

The next step is to test the grades by walking a rough route between control points, observing and recording conditions on the way. Shoot spot grades with the clinometer and try to stay roughly on or slightly less steep than the test gradient. Don't flag this route, but do flag and number the control points and record them in the field notebook If the test grade between control points is successful, note this. If the test route would need to be longer or the gradient steeper in order to connect the two control points, make a note of this but don't correct the grade line at this time. Continue walking a rough route to the next control point, staying at or slightly less steep than the test gradient, observing and recording conditions.

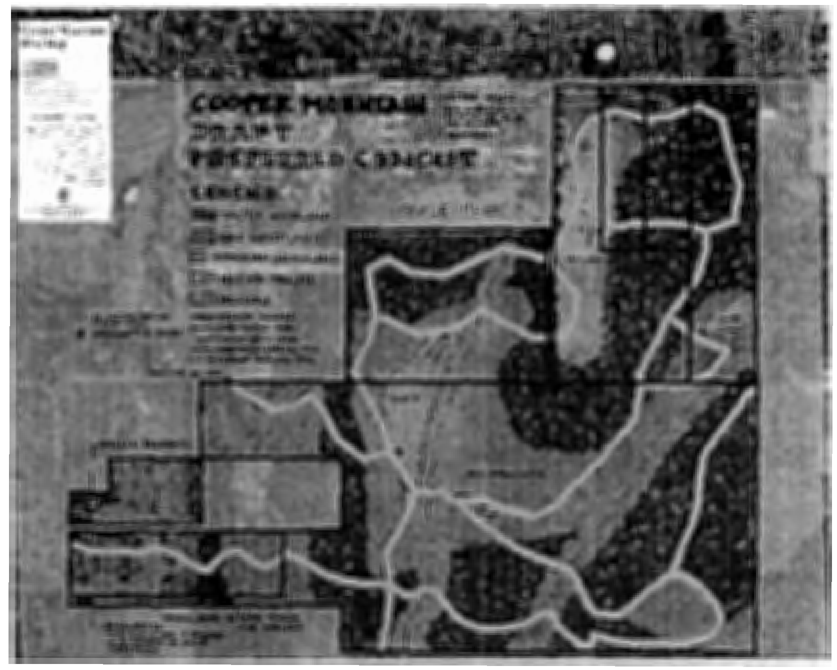
There almost always are conditions on the ground that cannot be anticipated by studying an aerial photo and a topographic map. The test alignment may encounter small seasonal drainages, rock outcrops, wildlife travel corridors, seeps and springs or special habitats that the trail should avoid. It may have to lose or gain grade in order to bypass such conditions or to create a setback for sensitive species. It may be necessary to drop back and lift a long section of trail up and around an area to be avoided, or to increase the gradient to drop below it. Some control points, such as suitable stream crossing points, may need to be scouted out on the ground. Make detailed notes about the locations of the control points and the needed grade adjustments, but do not fine-tune the precise alignment during this phase of fieldwork. This phase is primarily to find out if a route is feasible. Before determining this, re-evaluate each potential trail segment with respect to seasonal wildlife habitats and groundwater conditions.

If the test alignment between beginning and ending points hits the control points and stays reasonably within grade limits, and meets all the criteria for route selection, this route may be a candidate for more precise route location.

7.5 Identify Areas Where There Are No Alternatives (Restricted Urban Rights of Way)

Some potential trail routes are so defined or constrained that there are no reasonable alternative alignments for a future trail in the vicinity. In these cases, trail planners should identify the restricted rights of way in the planning zone and highlight them as potential routes or linkages in the future trail system. For example, old railroad beds and trolley line rights of way provide trail routes and important connections to neighborhoods and significant transportation corridors. The cleared easements for overhead and underground utilities (power lines and sewer lines) can make useful trail routes. In urban settings, trails often can be accommodated in the spacious rights of way beside county and state roads. Former streets that have been abandoned by municipalities, and platted but unbuilt streets also can become valuable trail linkages.

These opportunities are especially significant in fully developed areas where land uses are long established, and little, if any, opportunity for new trail alignments exist. Another advantage of using such routes is that municipalities may be able to avoid the costly and time-consuming process of acquiring land, parcel by parcel, along a favored trail route.



Trail planners used topographic maps, sensitive habitat information and interpretive and scenic vistas to draw this conceptual trail map for Cooper Mountain, Ore. (Metro, 2004)

7.6 Identify Areas Where Users Want to Go

Trail users enjoy the opportunity to experience the unique features of distinctly different landscapes. Planners should identify the significant scenic, interpretive and cultural opportunities associated with potential trail routes. A new trail is all the more attractive when it can take people to view spots, allow them to get close to wildlife, give them an opportunity to see historic features or stop at a local park. Trail planners should look for ways to provide these experiences along the trail and incorporate them whenever possible. If striking opportunities are not available, planners can look for ways to make the route interesting by taking advantage of different vegetation, moisture and light conditions along the way. If there is contrast along the trail – steep and not-so-steep, light and dark, wet and dry, remote or close to civilization – and an opportunity to experience the contrasts will make the trail pleasurable.

7.7 Identify Current and Future Public Uses at the Site

Trail planners must also estimate trail use. They need to understand how people currently use the site, how the trail will affect site uses and what off-site uses may occur because of the trail. Each of these scenarios has the potential to influence both trail alignment and design. Neighborhood residents and the citizens committee could review potential trail routes on the maps and in the field to help determine the final trail alignment. If they have been involved in this process, they are likely to understand the solution and support the ultimate alignment.

Some trail alignments have management consequences that can be solved through trail design landscaping, design of the trailhead or entryway, or by signage. The trick is to anticipate what human behaviors the trail will elicit. Seasoned trail managers can provide important input to decisions about trail alignments, designs and facilities. Their experience and ability to predict trail users can be used to good advantage as the planning committee begins to focus on particular alignments and design concepts.

7.8 Refine Each Test Alignment

To evaluate the remaining routes, tie a test flag line at grade between each control point. If it is to be an earthen trail, tie the line at 1 or 2 percentage points less than the desired maximum gradient of the trail. This will create slack in the gradient so designers can adjust the grade as needed to design drainage. Drainage will be designed later, if the route is selected. It will be important for field and office trail personnel to have expertise in trail drainage and know how to manipulate trail gradient to facilitate drainage. Typically, a corridor along the selected route is surveyed. Designers use topographic information in this corridor to fine-tune the micro-site location and gradient of the trail.

Before selecting a final route, it is important to note that if federal funds or federally managed properties are involved, the potential route will need to be assessed in compliance with the National Environmental Protection Act and the National Historic Preservation Act. If threatened and endangered species or their habitat could be affected, then compliance with the Endangered Species Act is essential. Many municipalities contract this work to consulting firms, whose inventory protocols and knowledge of environmental permitting processes can provide valuable, repeatable and defensible results on which to base future planning, permitting and design.

Consider the impacts of the favored alignment, based on disturbance levels for sensitive fish and wildlife species and their habitats. Based on these findings, adjust the flag line to avoid or minimize these impacts and to incorporate the municipality's setback and buffer standards for habitats of sensitive species.

7.9 Select the Best Route That Avoids or Minimizes Impacts

If trail gradients are still favorable, select the route with least environmental impacts. If impacts are unavoidable and no other route is feasible, the best route can be the one that also offers opportunities for restoration, and for which measures to minimize impacts can be funded and are likely to succeed.

7.10 Re-evaluate Goals for the Trail Use, Scale, Materials, Connections or Location

If irreversible impacts cannot be avoided, trail goals should be re-evaluated. The intended users of the trail, its width and surfacing can be adjusted. Instead of the route serving multiple users, having direct connections to regional multi-use trails and a high level of amenities, perhaps the route can accommodate a more modest, local trail. Or perhaps a multi-use route can stay out of the resource area but offer a scenic view of it or have a narrow, pedestrian spur into a part of it. Such a trail might have a specially engineered segment such as a boardwalk, or a section built on cantilevers to minimize resource impacts. Solutions such as these might enable the route to avoid or minimize impacts to sensitive natural resources.

7.11 Identify Potential Stewardship and Maintenance Partners for the Alignment

Trails that have been "adopted" by local residents and user groups tend to fare well. When people support a trail, they turn out for work parties and help with outreach education. Volunteer stewardship groups often provide a friendly presence to the public and an essential liaison to the municipality. Neighborhood and "friends" groups should be identified early in the trail planning process and encouraged to participate in every aspect of trail planning. Their involvement will create powerful stewardship bonds and lasting community support for the trail. They also are the first line of defense in preventing vandalism.

Trails, like rivers, cross many political boundaries. For example, a trail may traverse the right of way of a state transportation corridor, be located in an easement across private land, follow a utility corridor, or be part of a local or state park. It may traverse a busy public street, a river levee or descend deep into an undeveloped natural area. As a future trail alignment is resolved, a trail management team also begins to emerge, composed of many public and private land and resource managers.

What resource-friendly trail materials are available?

8.1 Introduction: Fitting the Trail and Materials to the Setting

As the trail route takes shape, planners will narrow the options for trail dimensions and materials based on the user types expected, the level of use anticipated, the environmental settings and degree of disturbance to natural resources already present along the route.

Trail width may range from 18 inches for little-used earthen walking paths to 10 feet or more for paved multi-use trails. In general, trails should be narrower and permeable to rainfall in water resource areas, which include streams, wetlands, riparian areas and floodplains. One important consideration in deciding about trail surface is that trails need to be pervious to stormwater. In some cases, earthen trails, if heavily used, may compact over time and may not retain their permeability to stormwater. Trail design is site specific and will depend on environmental conditions, level of use and stormwater drainage capability. This chapter explains the basic materials used to construct trails and provides guidance on how to select them for site conditions and uses.

8.2 The Anatomy of Trails

Whether they are large or small, most multiple-use trails have three basic parts: the sub-grade, the base and the surface. The sub-grade consists of the native earth materials under the trail. The base consists of materials placed over the sub-grade to make a stable foundation for the trail surface and support the weight of trail uses. In general, earthen trails do not have a base, unless needed for support through wet areas. The surface is the tread, or the part of the trail contacted by feet, wheels and hooves. The shoulder (or verge) is part of the constructed and cleared trail corridor that begins at the edge of the tread and extends a few feet outward (see Figure 8-1).

Most people think of the trail surface when they think of a trail. But in trail design, a lot of attention is paid to the ground underneath the trail surface. It must be properly prepared so that the tread surface will remain stable. In fact, among the most important decisions affecting the longevity of trails are the geo-technical and engineering decisions that bear on sub-grade and base treatments. A summary of some considerations regarding these treatments follows, with the caveat that trail planners should always rely on engineering input to prescribe these treatments.

A stable, well-built trail – be it a narrow earthen trail or a wide, paved multiple-use trail – is likely to be an environmentally friendly trail. A stable, properly drained trail keeps people on the trail, particularly through wet areas where poor drainage might cause go-around trails that damage vegetation and create wide mucky areas with little vegetation. Most likely, a stable trail also uses good drainage designs, which frequently route small amounts of water off the trail into trailside environments (see Chapter 5 for more details on drainage). Those good designs minimize trail failures and maintenance needs.

Constructed trails. For trails that will have sub-grade and base treatments, the sub-grade is cleared of organic materials. After vegetation and leaf litter have been cleared, roots and fibers are grubbed from the soil so that their decay will not cause later deterioration of the trail. Clearing and grubbing usually extend for at least several feet beyond the tread to include the shoulder and the hillslope under the future fill, where feasible (see Figure 8-1). The sub-grade needs to be well drained so that it will support the base materials (rock) that transfer weight to the sub-grade.

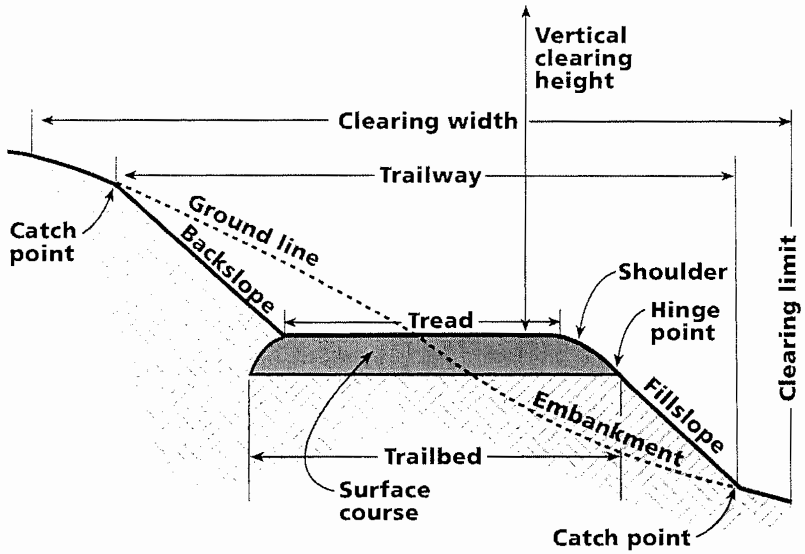


Figure 8-1 Trail structure terminology. (Hesselbarth, W. 2000. Trail Construction and Maintenance Notebook. United States Forest Service.)

Before the base rock is placed, the prepared sub-grade is usually compacted. If the sub-grade is wet or moist for even part of the year, drainage needs to be provided and/or a moisture barrier of some sort placed between the sub-grade and the base materials. Typically, a geotextile fabric can provide this barrier, although additional drainage measures may need to be designed. When a layer of large angular rock is placed on top of the fabric, the fabric keeps the rock from sinking into the yielding, wet soils.

However, sometimes the wet soils must be removed and replaced with angular rock. It is important to first know for certain whether a wetland fill/removal permit will be needed to remove wet soils or to place base rock in wet settings (see Chapter 6 for information about environmental permits). It also is important for an engineer to prescribe how to prepare the ground on which fill material will be placed and the thickness and compaction necessary for each layer of fill (see Figure 8-2). An engineer can determine whether it will be necessary to

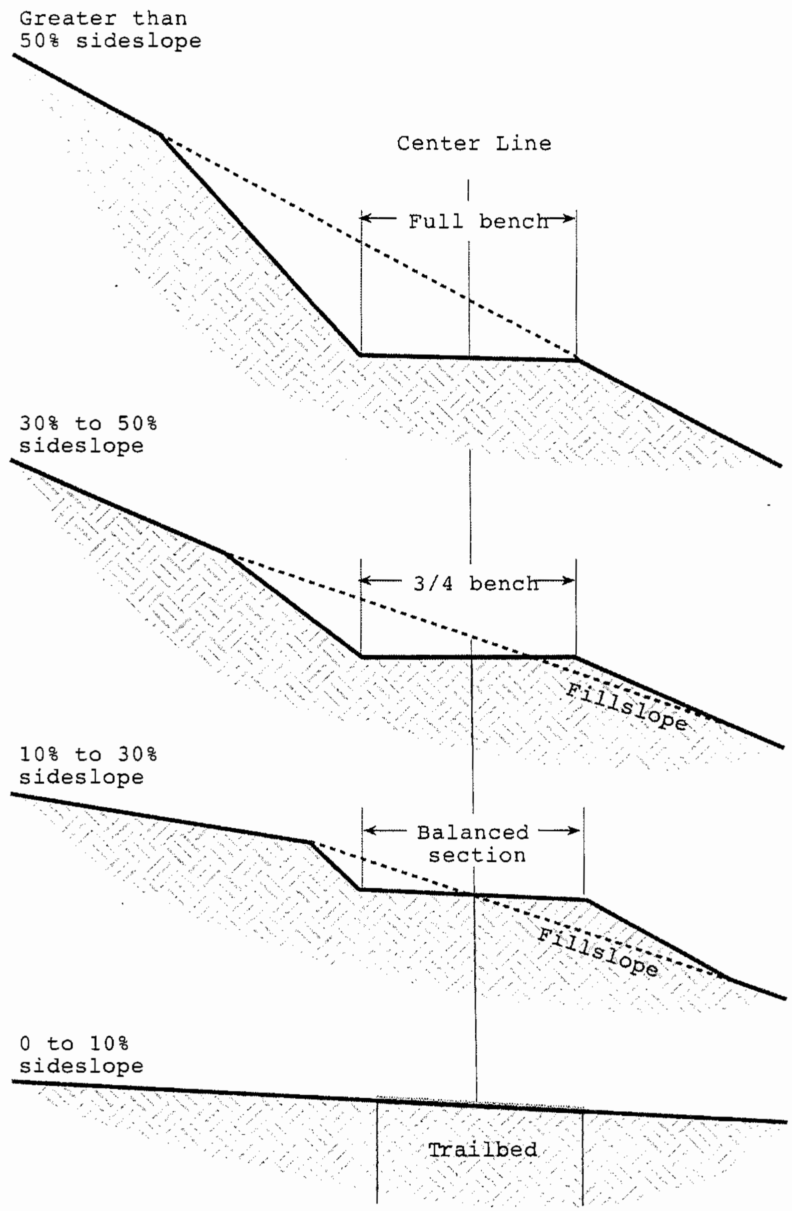


Figure 8-2 Typical trail cross sections. (Trail Construction and Maintenance Notebook, 2000)

excavate wet soils and what kind of geotextile fabric to use. An engineer also can determine compaction standards and the size and thickness of base materials (rock). These decisions are based on sub-grade conditions as well as the highest expected loads expected for the trail. For many trails, these loads will be maintenance and emergency vehicles.

Earthen trails. Earthen trails typically do not have constructed base layers and surfaces. However, these treatments are often necessary where earthen trails traverse moist ground. In urban settings where many earthen trails receive high use, are used by horses and/or bikes or are used during the wet season, sections of earthen trails often require improved drainage and sub-grade, base and surface treatments. Make sure to check on wetlands regulations when considering upgrades to trails in wet conditions. It may be more effective to re-route the trail away from problem sections.

Drainage considerations. An environmentally friendly trail is stable in the context of the water present in the trail environment and prevents impacts to natural resources due to runoff or off-trail uses. Drainage considerations play a large part in the selection of trail surfacing materials. Keeping water away from the sub-grade, the base, the surface and the edges of the trail is important to the longevity of both earthen and constructed trails. Water can cause problems for trails in many ways:

- Moisture from a wet sub-grade can migrate into the trail base and weaken its ability to support trail uses.
- Trailside drainage ditches can allow water to stand next to the trail and saturate it, deteriorating the trail surface and the base materials.
- Runoff from the trail surface can erode the trail and embankment.
- Stormwater from neighboring streets, parking lots, roof-drain pipes and other sources can affect the trail and trailside environments.
- Water that freezes in the base or sub-grade can cause gradual weakening of the subsurface layers that support the trail. Freezing in some semi-permeable trail surfaces can degrade these materials to the point that they will not support the uses the trail is designed for. Freezing in the base or sub-grade may cause the hard surface of the trail to crack.
- Perched groundwater that is "day-lighted" by an excavation can result in water pouring onto the trail and eroding it.
- Groundwater that is "captured" by storm drain or utility pipe trenches near the trail can saturate or undermine trails. Water leaking from underground water or sewer lines under or near a trail also can affect the structural integrity of the trail.

Geotextile fabrics. There are many kinds of geotextile fabric, each made to perform a particular role in a particular setting. Geotextiles function to separate materials, reinforce and provide drainage. Also known as filter cloth, geotextiles let water pass through them, promoting the movement of groundwater but keeping the soil in place. They are particularly useful in fine-grained soil such as loess, found in much of the region's uplands. Some geotextiles are woven, some are welded and some are made of millions of tiny strands pressed together to form a felt-like material.

Geotextiles are distinct from geo-nettings, which are constructed like a sandwich, having an internal layer that collects water and allows it to drain out to the edges. Each kind of geotextile comes in several grades. Many geotextiles will degrade with exposure to sunlight and require careful storage. It is important to select the right kind of fabric for the job. An engineer or manufacturer's representative can provide excellent information about the kinds and grades of geotextiles appropriate for particular projects. Many manufacturers like to partner with local governments on demonstration and research projects and can provide discounted materials for this purpose.

8.3 Preparing the Ground

Trail designers need to be aware of conditions that will require sub-grade and sub-base preparation. If trails must traverse loess soils, clay-rich soils, rocky, bouldery soils, wet soils or areas prone to debris slides, extra effort may be necessary to create a stable trail. A stable trail in difficult soils or terrain is less likely to be the source of unacceptable impacts to natural resources. Some soils or geologic problems can be ameliorated by removing native materials and replacing them with rock, coarse-grained or granular materials, by providing better drainage, by elevating the trail surface above the ground or by providing an engineered structure. Each of these alternatives generally involves greater construction expenses, and sometimes can require greater maintenance. Civil engineers, geotechnical engineers and geologists can evaluate relative costs for routes that will require engineered solutions versus routes that don't.

8.4 Resource-Friendly Materials

Preferences for and application of different trail surfaces vary among cities, counties, park districts, trail designers, engineers, permit reviewers and trail settings. The remainder of this chapter addresses a range of environmentally friendly trail surface types, from natural to highly constructed. Additional comments on material durability, maintenance, susceptibility to vandalism, functionality, adaptability to ADA standards and cost are provided in Appendix E.

Natural and native trail surfaces. Natural trail surfaces include in-situ rock, grass, sand and packed soil. A survey by Oregon State Parks found that trail users vastly prefer earthen and natural-surface trails. Many such natural-surface trails may start out as narrow stringer trails that become wider with increasing use. In forested locations, annual leaf and needle fall may provide natural mulch that protects the trail surface from excessive wear and erosion. If trails begin to erode, widen, bog down or ravel, they require a surface treatment that can with-

Trail surface of wood chips.

stand the increased traffic. Often, a change in surface type will require changes to the trail base and/or subgrade. Some options for soft-surface trails constructed with native materials are discussed below.

Native trails surfaces include those constructed of various shredded wood products and gravel or crushed rock. Trails with these surfaces retain a great deal of the "soft" feel of natural trail surfaces, and for this reason are second to earthen trails in popularity among trail users.

Shredded bark, wood chips or hog fuel. Many trail managers and trail friends' groups top-dress trails with a 3-inch-to-4-inch layer of shredded bark, wood bark chips or hog fuel. These materials are aesthetically pleasing and make nice walking surfaces. The job of spreading is usually labor intensive. In general, these materials need to be replaced every year because they are trodden into the trail surface, get flicked off the trail by trail traffic and decompose due to wetting and drying. Bicycles and horses can wear these materials down very quickly.
Although these woody materials can absorb a lot of moisture and allow for infiltration, they also are susceptible to being

washed off the trail by cross drainage and at rolling grade dips. Larger diameter bark chips are more subject to washouts than finer chips, and are not as likely to be stable at steeper grades.

These materials should not be used in the floodway, in stream approaches or on portions of the trail with surface cross-drainage. They should not be used in any location where over-bank flows or trail drainage would transport them to channels or wetlands. This is because their decomposition in water can lower dissolved oxygen levels, contribute harmful tannins and perhaps cause or exacerbate other water quality problems.

Most trail designers prefer to provide base and sub-grade treatments to enhance the longevity of bark chip trails. These typically include installation of geotextile fabric over a properly prepared subgrade, followed with a layer of angular base rock. This treatment provides both support and drainage and retards the ability of vegetation to grow up in the trail.

Hog fuel consists of bark and wood or wood wastes that have been mechanically processed and sometimes mixed with sawdust, shavings, sludge and/or other materials. It is often used as fuel but sometimes is used as a trail or playground surfacing material. Because inorganic contaminants may be present, it is important to know the source and composition of the material, particularly if it is to be used in playground or habitat areas or near water resources. It should not be placed directly on the ground but be separated from the subgrade by geotextile fabric and base rock. Many trail managers prefer shredded long and stringy cedar because it resists weathering longer than other materials.

Pea gravel. Pea gravel, a by-product of aggregate crushing, is tiny quasi-rounded rock material that can be treacherous on trails with any gradient. Most designers and trail managers do not recommend its use anywhere on trails. However, the availability and low cost of pea gravel can make it tempting to use. Some managers have found that pea gravel may drain well if fines and organic materials can be kept out of it. Others say it has useful applications in level areas, particularly if adequate base support is present, subgrade separation is provided with geotextile fabric, and the material can be contained with curbs. Maintenance of the curbs can be problematic. Proper sub-grade preparation is necessary to keep vegetation from growing up in the trail.

Crushed aggregate. Well-graded, compacted 1-inch minus crushed rock can provide a durable surface for hiking and biking trails. "Crushed" means that the rock has angular surfaces. "Well-graded" means that the rock contains a gradation of material sizes, from very small to very large. Rock that is not well graded generally does not compact well and thus has limited viability and durability as a trail surface.

When the crushed rock is spread at a thickness of 4 inches or so, and compacted to 95 percent at the right moisture content, the fine materials will form a tight matrix around the coarser ones to create a durable surface. The angular shapes of the coarser materials cause them to lock together when compacted. The surface is crowned or sloped to drain at 3 percent to 5 percent. This surface may both shed water and allow some infiltration. A "cushion" layer of well-graded 3/8-inch rock can be applied and compacted as a top dressing. Equestrians and pedestrians alike may favor this somewhat-softer surface.

Proper sub-grade preparation is necessary to keep vegetation from growing up in aggregate-covered trails and to prevent the aggregate from sinking into the subgrade. Crushed aggregate should be graded, placed and compacted per engineering specifications. Clean aggregate (not well-graded) and aggregate merely placed on trails, particularly trails having any cross-slope or gradient, is likely to migrate quickly into trail-side areas unless it can be contained.

A containment strategy for aggregate is to place it in over-excavated trail segments, separating it from the properly prepared and compacted sub-grade by means of geotextile fabric. The excavated area is typically 4 inches to 5 inches deep, and is designed so that it does not trap water. The aggregate is raked in to a depth an inch or so greater than the desired final surface elevation. Compaction of the subgrade and the aggregate can be achieved with a mini-roller. The surface should be crowned or outsloped so that water will flow off the trail. Cross-drainage must be provided in order to maintain a suitable percentage of fines in the aggregate. Drainage should be designed and installed prior to placing the aggregate.

Crusher fines. Various mixtures of very fine material and small angular or sub-angular crushed rock can be moistened and compacted to very durable surfaces. The mixture is placed about 7 inches to 8 inches thick in an excavated trench of 5 inches to 6 inches over a properly prepared and drained sub-grade. If the sub-grade is wet or moist, a geotextile fabric should first be installed. After placement, the crusher fines are compacted. Sometimes, a "cushion" of crusher fines is placed over crushed aggregate to make a more hospitable surface for horse hooves, bike tires and bare feet. This surface may both shed water and allow some infiltration. The color of the mixture depends on the color of the source rock. To avoid a bright trail surface or one that does not blend in with the surroundings, managers can specify the source rock.

Limit the gradient on which crusher fines trails are constructed. Make sure to provide for cross drainage (under trail). Material should be angular and well graded. Expect to do spot repairs. Depending on use, climate and drainage conditions, the surface will need to be re-graded periodically, additional stones and fines added, and the surface sloped or crowned and re-compacted. Turn radii must not be too sharp or bicycles may skid.

Hardeners for natural and native trail surfaces. In some conditions, trails with natural and native surfaces can be hardened by the addition of various binders to make them more durable.

Soil binders. Soil binders can be useful means for hardening trail surfaces in difficult-to-access locations, sensitive sites where a light touch or inert materials are required or in circumstances where rock is not available or its use is not practical.

Resin-based binders. Various organic resins can be combined to bind soil, well-graded aggregate or small stones to create an enduring hard surface in locations where site or environmental conditions dictate. Care must be taken to prepare the subgrade properly. After application, the mixture is rolled and compacted. Trail sections subject to freezing may be damaged by frost heave if moisture is present, so it is very important to properly prepare the sub-grade and install a moisture barrier (geotextile fabric) and adequate drainage (angular base rock).

Soil cement. If rock is not available, pulverized native soil can be mixed with Portland cement to make a hard trail surface. A thickness of about 4 inches is poured, rolled and compacted on prepared sub-grade. The surface and the sub-grade must be sloped to drain. The trail cross-slope should not exceed 4 percent and sheetflow should not occur on slope segments steeper than 4 percent. The trail gradient should not exceed 8 percent. Vegetation may grow through or in the trail surface. The surface will show wear with use by bicycles or horses.

Permeable surfaces. When both durability and permeability of the trail surface are desired, permeable pavers or confined cellular systems may be appropriate.

Permeable pavers. These are manufactured porous, concrete-like paving units set in sand over properly drained and prepared sub-grade. This pavement system allows rainwater to infiltrate into the sand layer, then into the sub-grade. The

Sand set permeable pavers.

paving units are held in place by countersinking them into the trail bed so that their surfaces are flush with the surface of the surrounding undisturbed soil. Grade and curves are limitations. Some sources recommend that permeable pavers be restricted to slopes no greater than 5 percent. Some types of permeable pavers are favored for trails in water resource protection areas because of their ability to infiltrate precipitation.

Confined cellular systems. These honeycomb-like systems can be anchored in place and back-filled with aggregate or a soil mixture to create enduring, porous and plantable retaining walls, armored slopes or reinforced trail surfaces. Anchoring can be tricky, particularly on slopes. These systems come in many materials and dimensions. Installations must comply with manufacturers' requirements.

Porous concrete. When the finest portion of rock ingredients is reduced or eliminated from a concrete mixture, the resulting material has many small voids through which water can pass. Some managers note that porous concrete resists plant growth better than porous asphalt and is more water permeable.

Recycled materials. Trail designers can choose other permeable surfaces in addition to gravel and crushed rock. Many recycled materials are available for use as trail surfacing, including shredded car tires, crushed pottery and glass, plastic, Styrofoam and recycled asphalt. Climate, site conditions, use, preparation and application methods, and other factors may influence how these materials perform. Many trail managers recommend testing materials before using them on an entire project. Others warn that recycled materials should not be used where they can be washed into streams or wetlands.

Railroad ballast. The coarse angular rock of in-situ railroad grades may make excellent, well-drained support for a trail. A geotechnical engineer should evaluate foundation soils and base materials to determine their behavior under different moisture conditions and loads. Sometimes base materials need to be removed and replaced because they will not provide adequate structural support, or due to soil moisture conditions. This material should be checked for environmental contaminants. "Tie memory," a condition in which the rock retains the impression of the railroad ties, will need to be remedied by removing, replacing and compacting the upper layer of rock.

Re-screening or re-processing base material can be done on site with a portable rock crusher. Before replacing the rock, improved sub-drainage or cross-drainage may need to be provided so that the sub-grade and base will support the trail and the trail surface will wear well. Sometimes a moisture barrier will need to be installed. This may reduce the necessary thickness of the base layer. A geotextile also can prevent vegetation from growing up in the trail.

An engineer should calculate the maximum load and speed of the largest emergency or maintenance vehicle expected on the road to determine whether a geotextile should be used to promote the structural stability of the trail.

A serviceable temporary surface cushion of crushed aggregate can be placed on the reconditioned railroad grade. But for maximum utility for a wide range of users, a final hard surface of asphalt or concrete will provide the best and most enduring surface.

On rail-to-trail conversions, equestrians prefer a soft-surface trail beside the hard one. The horse trail can be earthen, or it can be constructed of well-graded, compacted 3/4-inch minus angular crusher fines. The placement of horse paths on former railroad grades is very sensitive to the structural integrity of the materials comprising the grade. A horse path at the edge may be less desirable from a structural standpoint than one set back from the edge or in the center.

Hard surfaces. Both asphalt and concrete are used when durable surfaces are desired. These materials differ in their costs, longevity and maintenance needs, so each is used in different settings for different performance. (See Table 8-1).

Asphalt (macadam, tarmac). Asphalt, or "asphaltic concrete," is a somewhat plastic medium that can create a very smooth surface attractive to in-line skaters, wheelchair users, stroller pushers, skateboarders and bicyclists. It is composed of graded aggregate mixed with a binder of bituminous oil. If made with coarse aggregate, it is more porous than asphalt composed of smaller rock fragments. The coarser grades are somewhat permeable, if the base and subgrade are designed to drain. The expected life span of asphalt is seven to 10 years.

Asphalt conforms to the ground surface and is stable on both steep grades and horizontal surfaces if properly mixed and applied, and the sub-grade is properly prepared. It is generally installed in a 2-inch layer, then smoothed and compacted by the asphalt machine and rollers (see Figure 8-3). Favorable drainage cross-slopes may be as little as 2 percent. Sometimes

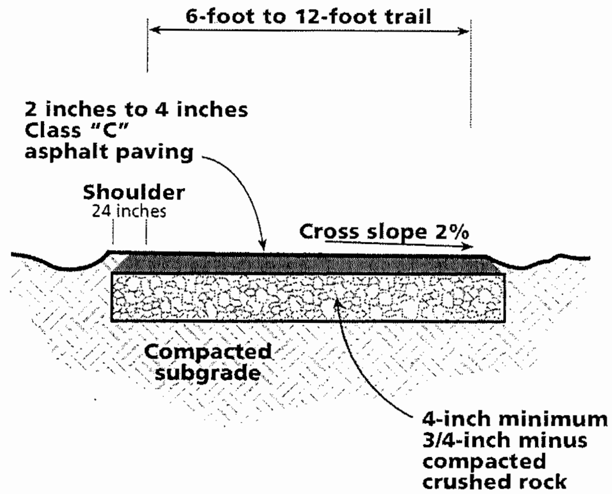


Figure 8-3 Typical cross section of an asphaltic concrete surface. (Trail Master Plan, Tualatin Hills Park and Recreation District, 1998)

a fresh asphalt surface will be dusted with sand or a porous fine material to stabilize excess oils. However, this treatment can diminish permeability. This, and other considerations of pavement design, are the province of civil and geotechnical engineers.

Asphalt is not a favored trail surfacing material in settings where the base or subgrade are susceptible to moisture or where the trail surface is subject to freezing. These conditions, particularly in the absence of a "live" traffic load, can contribute to heaving and cracking of asphalt-surfaced trails. Additionally, asphalt is easily distorted by tree roots. For these reasons, asphalt is not appropriate for wet areas. However, asphalt has its place as a trail-surfacing material on dry, well-drained, rocky, south-facing hillslopes with little clay or plastic material in the soil.

Table 8-1 A comparison of asphalt and concrete for trail surfacing. (Adapted from Trails Design and Management Handbook, Open Space and Trails Program, Pitkin County, Colo.)

	Asphalt	Concrete
Material qualities	• Plastic, malleable	•. Very strong, brittle, durable
Initial cost	• Subgrade preparation costs can be high • Site prep costs can be high • Installation costs generally less than for concrete	• Marginally higher installation cost than asphalt, but maintenance costs are lower • Subgrade preparation costs are lower
Life span	• 15 to 30 years • Sealing in the second year greatly prolongs the life span of asphalt	• High: 30 to 50 years, particularly with proper preparation of subgrade and base, proper mix, application, finishing and curing
Installation	• Can be applied on uneven surfaces • Can be applied at steeper gradients than concrete • Sensitive to soil type (coarse and well-drained subgrade is optimum)	• Can be installed in wet areas, on curves, and with precision • Requires forms and internal structural support • Requires skilled contractors • Proper design for crack control is critical
Resurfacing needs	• Edges tend to crumble over time • Prone to cracking, doming, heaving and settling • Life span can be greatly prolonged if sealed in the second year • Must be sealed or chip-sealed every 5 to 10 years	• No resurfacing needed for decades; surface grinding may refresh traction surface after decades of wear
Suitability in natural resource protection areas	• Not suitable for wet areas • Will deform to accommodate tree roots • Porous grades can be used to facilitate infiltration	• Holds up well in wet areas • Not as prone to buckling from tree roots as asphalt • Bridges imperfections that may develop in the subgrade
Susceptibility to moisture and temperature extremes	• Prone to drawing moisture to the subgrade and base, and subsequent freezing and deterioration • Dark surface warms quickly, facilitating snowmelt • High temperatures can facilitate deformation	• Performs well at high and low temperatures
Construction season or limitations	• Cannot lay asphalt below 35 degrees farenheit.	• Newly poured concrete must not freeze during initial hydrating period • Care must be taken in wetland and aquatic environments
Preference by users	• Preferred by runners for its greater resiliency than concrete	• Consistent, smooth surface for all users • Broom finish makes skid resistant
Ease and expense of spot repairs	• Easier to remove and replace deteriorated sections than concrete	• Spot repairs can be made flush with surface

Chip seal. An asphalt surface can be refreshed by application of a surface emulsion of tar or oil. Sand or rock chips are added to the oil and rolled to provide a fresh wearing surface. Researchers have found that hydrocarbons in runoff affect aquatic invertebrates making asphalt near water resources cause for concern. To be safe, it is best not to apply chip seal near water resources due to the potential for excess oil to be washed off the trail surface. However, proper proportions of sand or rock chips and proper application and rolling will prevent excess oil. Managers can reduce the chance of poor chip seal workmanship by pre-qualifying bidders and equipment. Some users report that chip sealed surfaces are rougher and slower. Others warn that in some settings and applications, chip seal may not withstand concentrated flows of water and can erode.

Concrete. Concrete, or Portland cement, is tough but brittle. It is the material of choice in settings with severe climate changes and the heaviest uses. In addition to requiring proper structural support from base and sub-grade, it must be reinforced with wire or fabric mesh and jointed to control cracking. It is commonly placed 4 to 6 inches thick and can be colored to blend with surrounding materials. It can be scored or rough-finished to reduce slipperiness. The use of concrete can be limited by site access.

The pH of water may increase when it comes in contact with fresh concrete, causing problems for salmon and trout. For this reason, the state of Oregon regulates how concrete work is managed in streams and lakes. Trail planners should explore options for trail materials and trail construction methods when planning multi-use trails in and near water resources.

See Appendix E for more information about trail surfaces for high and low use.

8.5 A Note About Equestrian Trails

For durable, all-season urban equestrian trails, plan a 2-foot to 4-foot-wide tread surface[1] to accommodate single-file use. One way of constructing an equestrian trail includes:

- moisture-barrier geotextile, as specified by an engineer for the site
- base rock
- additional geotextile layer, if needed
- 3/4-inch minus, well-graded, compacted aggregate
- compacted cushion layer (should be angular rock, 1/4-inch minus, not larger).

Horses tend to favor the outside edges of narrow trail treads. An engineer or geotechnical engineer can recommend proper placement and compaction of fill material at trail edges required for equestrian safety. This is of special concern at the edges of trails constructed on pre-existing fill whose materials and construction methods are not known.

8.6 Trail Materials for Wet Areas and Wetlands

Native local wood. Traditionally, trail managers have felled trees near trails to build needed trail structures. This has been a cost-effective way to get construction materials to the sites where they are needed, particularly on remote, narrow earthen trail systems. But today, many managers are balancing the decision to use local native materials against the need to maintain

[1] Seasoned horses and riders can negotiate the narrower trail treads of more primitive settings, provided there is adequate overhead clearing (10 feet) and that the width of the cleared trail corridor is sufficient to accommodate horse, rider and packs. However, there can be safety hazards for riders and horses that are not experienced in pivot turning on narrow trails, particularly on steep cross-slopes.

park landscapes that support long-term ecosystem needs. Managers should weigh the need to use standing trees, hazard trees or wind-thrown trees for trail structures against the long term ecosystem needs for these logs as snags, downed wood or as future woody debris for streams and important wildlife habitat features. A hazard tree that must be felled is a logical choice for creating lumber or puncheons for trail structures. But if the species is not resistant to rot, it may be better to top the hazard tree and leave it as a wildlife snag, or fell it and let it decompose on the forest floor for other wildlife species.

Locally, the most rot-resistant wood comes from the heartwood of cedars. Douglas fir logs do not contain the rot-resistant tannins that are present in Western red cedar heartwood, but the density of the wood does repel some fungus and insects. These two local species are good local candidates for making lumber and puncheons for on-site construction of wooden trail structures. If non-treated rot-resistant lumber is desired, consider obtaining boards from cedar.

Treated wood products. See Appendix F for best management practices for the use of treated wood products.

Plastic lumber. Plastic lumber looks like wood and can be worked in much the same ways as wood. Its smooth wood-like surface does not get slippery during the wet season, and it does not catch fire. It can be colored or painted to blend into natural environments and does not raise the concerns of environmental contamination that come with treated wood products. But it is heavy, expensive, low in strength and resilience, and is weathered by sunlight. Strength limitations mean that it may be more appropriate for decking than joists, beams or posts. However, new technologies are continuing to improve the looks, strength and performance of plastic lumber and it is certainly well worth considering for use in sensitive areas.

Plastic lumber can be used in much the same way as wood.

Selection of trail materials in water resource areas. Permit applicants for trails near essential habitat for salmonid species listed under the Endangered Species Act should be aware that if there is federal review, trail materials are likely to be restricted within 100 or more feet of these habitats. Guidelines for trail materials for the most sensitive water resource areas follow.

- If trails have hard surfaces, keep them away from streams.
- If trails must get closer than 100 feet to streams, construct them with permeable surfaces (see Figure 8-4). Bark should not be placed in locations where it can wash into streams.
- Consider rock-filled geocells or gabions to avoid placing fill in wetlands.
- Avoid using galvanized metal where runoff from galvanized materials can be delivered to water resources.

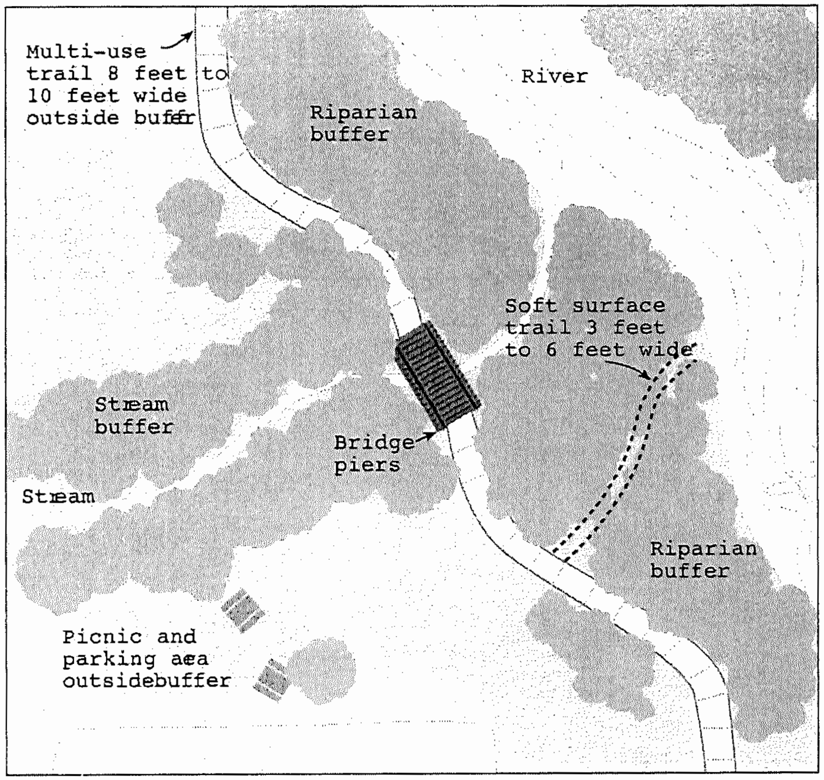


Figure 8-4 The riparian corridor should remain free of impervious surfaces, structures and recreational amenities, including multi-use trails.

8.7 Summary: Choosing Trail Materials, Widths and Surface Types

Trail surface materials reflect the kind and intensity of use expected and the environmental sensitivity of the site.

Choices for width and materials of the trail should reflect users' needs and their expected level of use. Safety and environmental impacts are serious concerns for trails that are too narrow, particularly if crowding forces users onto trail shoulders and verges. Refer to Table 8-2 to match users, level of use and trail types.

The surface materials of trails passing from uplands into riparian areas or floodplains need to be permeable to rainfall. This design detail minimizes runoff in water resource areas and protects them from trail impacts. Surface materials for trails in natural areas and urban corridors are given in the Table 8-3.

Table 8-2 Selecting trail width and surface material based on level of use. (Adapted from Trails Design and Management Handbook, Open Space and Trails Program, Pitkin County, Colo.)

Trail type	**Very low** (<25)	**Low** (25-100)	**Moderate** (100-200)	**High** (200-400)	**Very high** (>400)
Multiple use hard surface	8 feet	8 feet	8 feet	10 feet***	10 feet***
Crusher fines surface, bikes	4-5 feet	6 feet	8 feet	8-10 feet	7-10 feet
Natural surface	18 inches-2 feet*	2-3 feet*	3-5 feet*	4-6 feet**	5-7 feet**

* Construction and maintenance can be expensive (and the natural appearance of the trail compromised) if the cross slope of the hillside is less than 10 percent (15 percent if the trail width is more than 2 feet). Consider using crusher fines on at least the parts of the trail with a hillside cross slope of less than 15 percent.

** Often requires high and expensive maintenance. Maintenance can be minimized in well-drained, cohesive (i.e., not sandy) mineral soil where hillside cross-slopes are less than 20 percent. If these conditions cannot be met, a crusher fines surface is recommended.

*** Or up to 12 feet or more, where practicable, as used in the Portland metropolitan area.

Table 8-3 Trail Surface Types in Relation to Environmental Settings

Setting	**Uplands**			**Riparian areas**			**Floodplains**		
	Natural	Permeable	Hardened	Natural	Permeable	Hardened	Natural	Permeable	Hardened
Natural area	◆	◆		◆	◆		◆	◆	
Urban linear corridor			◆		◆**	◆	◆**	◆*	

* If soft/permeable trails are in the path of floodwaters, they may be a source of scour erosion. This can damage both the trail and floodplain and increase sediment loading to the stream. Instead, hard and soft surface can be combined and short soft surface spurs can be created to floodplains to provide trail users a satisfying experience of the river or stream. Good places for location of trail are (1) downstream end of the floodplain, (2) perpendicular to the stream, (3) upslope edge of the floodplain, (4) edge of existing disturbance corridor.

** If use of trail is very low to low (see Table 8.2). If use of trail is high, other surfaces may need to be considered.

What are some resource-friendly construction techniques?

9.1 Introduction

Like other construction projects, trail projects can be organized and managed in ways that encourage sustainable practices and minimize environmental impacts. This chapter describes strategies for setting up a trail construction project so that the contractor or project team is encouraged or required to use environmentally friendly construction practices.

Virtually all of the strategies discussed here are based on natural resource protection requirements already in place in the regulatory permits and contract documents issued for typical trail construction projects. The strategies highlight these natural resource requirements for typical trail construction projects.

This chapter discusses strategies for procurement, communications, construction staging and site management, quality assurance and quality control, schedule, and post-construction monitoring and maintenance. These topics reflect issues trail managers encounter in managing trail construction to protect natural resources.

9.2 Procurement

A procurement strategy determines how environmentally friendly services, materials and equipment for a trail project will be purchased. Part of the strategy is to ensure that natural resource protection requirements are defined as separate bid items that can be enforced.

Identify natural resource protection measures as separate bid items. Even if natural resource protection measures such as tree protection, replanting, erosion and sediment control and hazardous material management are incidental to another bid item such as earthwork, they should be clearly and fully described on the bid form. In some cases, trail designers and project managers may decide to list them as separate items on the bid form. These measures can be broken down further, so that individual activities and materials are listed as separate bid items. Again, using erosion and sediment control as the example, this would mean listing separate bid items for installation, inspection and record keeping and maintenance.

It is important to create a balanced approach so that an excessive number of separate bid items does not result in unreasonably high bids and unreasonably increased costs for construction and maintenance. A properly balanced procurement strategy will require the contractor to take natural resource protection measures seriously in order to be paid for them. It also will give the trail project manager leverage to ensure that complete and adequate protections are carried out for the duration of construction.

Provide descriptions of bid items for natural resource protection. Trail designers and project managers should include explicit descriptors in bid items. If biodegradable erosion control materials are desired, insert the term "biodegradable" in the item description rather than depending on the contractor, subcontractors and suppliers to notice that key word in the specifications. If a certified weed-free seed mix is desired, insert those key words in the bid item description. If a certain brand of product is needed, specify it by name in the bid contract.

Identify pre-qualified designers and contractors. Standard practice is to accept design proposals and construction bids from all who meet minimum requirements for registration, licensing, bonding and insurance. However, it is increasingly common for project managers to require bidders to demonstrate their specific qualifications and experience. Trail project managers can use this approach to identify designers and contractors who have trail experience and are knowledgeable about environmentally friendly construction practices. There are many approaches to pre-qualifying bidders but all require the same basic information:

Firm profile. Information provided for pre-qualification should include staff size and resources, organizational structure, equipment and relevant experience with environmentally friendly construction practices.

Qualifications and experience of key team members. Information about the role and availability of key team members also should be provided.

References. At least two to three references should be listed to check on past work products.

Project approach. Pre-qualification applications should include a description of how the bidder intends to execute the trail project and provide the natural resource protection measures.

Establishing a pre-qualified pool of proposers/bidders can be done in conjunction with an individual project or an ongoing program. For example, a trail project manager can pre-qualify contractors before accepting their bids on a specific trail project. Alternatively, a land management entity, such as a park district, may wish to establish a pre-qualification list from which project managers can invite individual firms to submit proposals or bids as new projects are implemented. Pre-qualification lists also can be borrowed from other agencies. As always, project managers must take care not to create such restrictive requirements that the pool of providers is unnecessarily limited.

Consider alternatives to the traditional design-bid-build process. The traditional process of designing a trail project and then seeking the lowest bid may not result in environmentally friendly construction. Alternative project delivery methods can help trail project managers achieve the desired results and still stay within the budget. Alternatives include:

Guaranteed-maximum-price agreements, under which a contractor agrees to deliver a completed project for a lump-sum price that will not be exceeded.

Design/build, which typically involves the general contractor retaining the design team.

Construction manager/general contractor, under which a contractor may negotiate an agreement with the project owner to deliver a finished project and then solicit bids from subcontractors.

Sustainable purchasing. More and more jurisdictions, including Metro, the city of Portland and Multnomah County, are now implementing sustainable purchasing requirements. Examples are purchasing and using recycled materials and certified wood products.

In practice, elements from each of these approaches usually are combined to create a project delivery method that is uniquely suited to the requirements of the project and owner. For example, guaranteed-maximum-price and construction manager/general contractor provisions almost always are combined when they are used in public agency contracts. Many organizations that own trail systems have procurement departments and procedures that can be valuable resources for project managers who need to purchase design and construction services.

The use of guaranteed-maximum-price, design/build and construction manager/general contractor contracts is allowed by state law but the local agency's contract review board must approve these types of contracts.

Use a qualification-based selection process. Public agencies in Washington and, increasingly, in Oregon may select designers and contractors based on their qualifications and value of the services they offer. This allows agencies to select contractors on the basis of highest quality work at the most reasonable price. Depending on the circumstances, quality of work may be more important than price. In other cases for some agencies, the lowest bid may be taken into consideration.

Requests for proposals and negotiated bids are sometimes used by federal agencies, but state and local agencies are not always allowed to use these procurement methods. Agency procurement departments and procedures should be consulted before using a quality-based selection process. Professional organizations such as Associated General Contractors and the American Council of Engineering Consultants have well-developed positions on legal and ethical considerations associated with quality-based selection and alternative project delivery.

Require pre-qualified construction equipment. A contractor's choice of trail construction equipment can have profound effects on natural resources. For example, oversized excavating equipment can damage a swath of vegetation that is wider than the trail construction corridor. It also can permanently compact the soil in areas outside the intended limits of disturbance, yet many contractors do not own equipment suitable for low-impact trail construction.

Pre-qualifying construction equipment requires the trail designer or project manager to take a balanced approach. In some cases, the trail project manager will be able to specify a type or model of equipment known to be environmentally friendly. The key is to insert the words "or approved equal" after the requirement. This will avoid claims of bias.

In other cases, it will be more appropriate to define the desired performance criteria and ask the contractor to submit a list of proposed equipment for approval prior to awarding the contract or proceeding with construction. This approach will avoid requirements that bidders perceive as unduly restrictive.

Public works agencies have used these approaches for many years and can provide valuable advice and information. Equipment providers can provide performance and production statistics. Some can provide sample specifications that define how their equipment can get the job done with minimum impact on natural resources.

Provide contingency rock and material quantities for the contractor to bill against. The trail designer cannot always know in advance whether a certain construction item will be needed or how much of it will be needed. For example, it is not always possible to predict the need to drain and stabilize areas of wet soil.

One way to address these uncertainties is to include an allowance in the bid form for a certain quantity of an item that may be needed, making it clear that only the amount that is actually used will be paid for. As an example, if wet or unstable soil is suspected but cannot be verified or quantified until construction has begun, the designer can include an allowance for a specific amount of stabilization rock of a specific size. That way, the trail project manager can be assured of receiving the rock at a pre-determined price without making a commitment to actually purchase a specific amount.

9.3 Communications

A communication strategy can determine how the trail project team will be informed about resource-protecting construction practices. Many instances of construction-related environmental damage are the result of uninformed workers. Other difficulties with natural resource protection during trail construction are the result of conflicting expectations between the contractor and the project manager. Requirements for natural resource protection are usually in place in the regulatory permits or the contract documents but must be highlighted for the construction team.

Construction drawings and specifications. Requirements for natural resource protections, such as coffering, filtering and preservation of vegetation, should be integrated into the construction drawings and specifications, rather than stated only in a separate document. Site-specific instructions are most appropriately placed on the construction drawings. Most workers, suppliers and subcontractors will see the construction drawings; few will see the regulatory permits or environmental reports.

Training for contract managers. Staff who will be managing trail construction contracts should receive training in all aspects of contract management. Project managers with appropriate experience and contract management skills should be selected.

Worker education. It is not always enough to require natural resource protections in the plans and specifications. The trail project manager may decide to conduct a training session to inform the project team about specific natural resource protection requirements. Alternatively, the contractor can be required to do this. The pre-construction conference, weekly project meetings and daily "tailgate" meetings can provide good opportunities for worker education.

9.4 Construction Staging and Site Management

Trail construction plans and specifications focus on how specific trail elements will be built. However, it is also necessary to consider how work will be staged and how the project site will be managed. These requirements are set forth in regulatory permits or environmental reports, and relate to keeping construction materials and staging areas away from sensitive environmental areas including riparian zones, floodplains and wetlands.

To implement a unified natural resource protection plan, information on construction staging and site management must be made easily accessible for the entire project team. This can be done in several ways:

On the construction drawings. For example, construction limits should be shown adjacent to the trail alignment.

On a separate plan. This approach can be used to show activities that occur away from the trail alignment, such as material storage.

On a plan developed by the contractor. This approach can be used when the contract document sets forth general requirements for natural resource protection, such as protection of vegetation in material storage areas. The contractor's plan shows specific "means and methods" for protecting vegetation.

On the ground. Construction limits, vehicle maneuvering areas and staging areas should be indicated with flagging, markers or, in critical areas, orange construction fencing. Silt fences double nicely for erosion control and setting disturbance limits.

The following discussions provide examples of staging and site management issues that warrant special attention. Which issues are given priority and how they will be handled will depend on the site conditions and the specifics of construction.

Construction boundaries. The boundaries of construction areas, resource protection areas, construction access and vehicle maneuvering areas and staging areas for material and equipment must be marked and, in some cases, fenced. Construction workers often are focused on convenience and efficiency. Their awareness of natural resource impacts cannot be assumed. Project managers can work with construction managers to designate project boundaries in order to ensure compliance.

Protection of trees and other plants in the construction zone during project activities must be made very clear, both in the plans and construction drawings, and on the ground. If it is not an option for contractors to remove plants that are in the way, even if they intend to replace them, this information needs to be clearly communicated.

Erosion control and water resource protection. Good erosion and sediment control begins with good planning. Erosion and water resource requirements are usually set forth in the regulatory permits. Protection measures are set forth in the contract documents. Contractors can be asked to contribute information about the following:

Prevention. Identify strategies for sequencing and managing construction activities to minimize exposure of disturbed earth during the wet season and near sensitive water resources. Identify strategies for inspecting and maintaining construction site erosion control during inclement weather especially at night, on weekends and during holidays.

Contractors also can be asked to identify typical erosion conditions that can develop under construction conditions, and list typical mechanisms that they might use to control them. For example, covering an earthen stockpile with plastic will probably prevent the pile from eroding during heavy rainfall conditions. However, water shed from the plastic covering may become an erosion agent and contractors can be asked to further identify how they would prevent erosion in this situation.

By considering potential erosion scenarios and their solutions, contractors can arrive at realistic costs for project erosion and sediment control activities. By considering worst-case potentials, they can evaluate the costs of applying costly measures and heroic efforts versus making changes in project schedules.

The trail project manager must ensure that the contractor applies erosion and sediment control measures effectively in the field. To accomplish this, it is usually necessary to modify or refine the measures shown on the construction drawings.

The trail project manager must reach an agreement with the contractor on how refinements or modifications to the natural resource protection plan can be implemented within the existing budget. Finally, the project manager must have documentation showing that resource protections are being monitored, maintained and modified to meet changing conditions.

Potential worst case runoff scenarios. Contractors should be asked to identify where construction site runoff will flow and the resources at risk in the event of unexpected or unusually intense rainfall.

Emergency response. They also can identify typical personnel, equipment, materials and communication strategies for quick response to emergency runoff situations.

Management of excavated and stockpiled soil and rock. Often the project documentation will not provide comprehensive guidelines for handling excavated or stockpiled soil and rock. However, the trail project manager must have a clear agreement with the contractor on how these materials will be handled in an environmentally friendly manner.

Typical issues include:

Disposal of organic materials generated in clearing and grubbing. In many cases it is acceptable, economical and even environmentally beneficial to "lose" or scatter these materials in the project area rather than disposing of them off-site. However, this activity must be planned and executed carefully.

Disposal of construction waste. Construction waste should be recycled or disposed of at an approved site.

Storage and re-use of excavated soil. This may include material that will be used as fill or topsoil that will be used for re-vegetation. In either case, stockpiles should be protected against erosion. Topsoil stockpiles should be limited in height in order to retain air content and avoid creation of anaerobic conditions.

Delivery, storage and transport of gravel, crushed rock and other construction materials. The trail-project manager should have a clear agreement with the contractor on how and where each of these operations is staged so that natural resources will be protected.

Management of fuels and toxic materials. Depending on materials, topography and proximity to water resources, it may be necessary to provide spill protection or containment facilities. These range from berms and pumps to diapering of equipment. If a spill occurs, a contingency plan must be in place for dealing with it. Equipment fueling and washout should occur off-site or in designated, properly protected areas away from drainages and streams. As noted, it is often best for the trail designer or project manager to set forth performance and protection criteria and then require the contractor to develop and execute a protection plan. Project managers should always specify that the contractor have spill response supplies on the job site.

Management of treated-wood construction materials. Many trail facilities and structures, such as bridges and retaining walls, are constructed with wood products that have been chemically treated to resist rot. Treated wood construction debris can be a source of pollution if not managed properly. Examples of management considerations include:

Training employees. Personnel who will work with these products need to be taught proper methods for storage and handing of treated wood products.

Documentation. The contractor may be required to show receipts for delivery of hazardous materials, such as sawdust, shavings, trimmings and used absorbent pads, to garbage transfer stations.

Off-site fabrication. The contractor may be required to provide facilities for off-site fabrication.

Management of concrete in streams and lakes. The pH of water may increase when it comes into contact with fresh concrete. This can be a problem for cold-water species such as salmon and trout, which are sensitive to pH and to dissolved solids. The state of Oregon regulates how concrete work is managed in streams and lakes. Contractors will be required to provide temporary cofferdams around concrete work areas in bodies of water. They must be able to show records that these have remained in place until the concrete has dried and they may be required to show evidence that their concrete trucks were rinsed at appropriate off-site facilities.

9.5 Quality Assurance and Quality Control

A quality assurance plan sets goals for protection of specific vegetation, habitats and water resources. A quality control plan identifies specific checks and procedures to ensure that quality assurance goals are being met. Specific quality control procedures should be set for each project and should identify specific methods for ensuring that natural resource protection goals are being met. These methods include observation, monitoring, inspection, testing, maintenance and documentation.

As a general approach, quality assurance/quality control procedures that have been developed by public transportation agencies for road projects can be used to manage construction of wide hard-surfaced multi-use trails. The construction processes are the same for roads and trail projects of this nature. Trail managers should take maximum advantage of the extensive body of knowledge available about road construction and should spend time in the field on quality control and quality assurance during trail construction unless there are other inspectors available.

Construction observation and inspection. The trail owner and/or designer must observe the construction enough to know that the trail is being built in accordance with the plans and specifications, and that natural resource protections are in place and operational. Construction inspection entails more in-depth investigation, measurement and testing of the contractor's work to ensure conformance to the contract documents. The trail designer or project manager must determine what level of observation and inspection will be needed and assign responsibilities accordingly.

Observation and inspection records. All construction observations and inspections should be recorded in a daily report. This responsibility can be shared among the owner, designer and contractor. However, specific roles and responsibilities should be assigned to each party. Records should conform to a standard format and should include a section for natural resource protection. Additional documentation may include:

Contractor requests for information from the owner or designer.

Material submittals from the contractor, including test reports or brochure information to demonstrate that construction materials conform to the contract documents and are environmentally friendly. Contractors also may provide shop drawings, showing how they propose to construct specific details.

Contractor's point person for natural resource protection. The trail contractor should designate a single point of contact for natural resource protection, including erosion control. Usually this contact will be the same person responsible for other quality assurance/quality control compliance.

9.6 Schedule

Schedule and time management are essential to any construction project. Typically the emphasis is on efficiency, convenience and following the shortest path to completion. Trail projects are the same except that the construction schedule often must revolve around the timing of events in the natural world.

Seasonal work windows. Seasonal work "windows" specify when certain types of construction may or may not be done. Work windows may be imposed to avoid disruption of wildlife migrations, fish runs, periods for nesting or rearing young, or to avoid erosion and stream sedimentation due to heavy rains.

In-water work windows may affect the construction of bridges and stream crossings. In-water work windows typically occur in late summer and early fall, when stream flows are at their lowest level. This means that construction in or near the water must be deferred to low-flow periods. However, current regulatory policy is such that any work in or near fish-bearing streams is unlikely to be permitted unless it can be shown that there is no other reasonable alternative and an overriding public benefit will be provided. The best strategy for trail designers or project managers is to contact regulatory agency representatives during the planning process and integrate their requirements into the project from the earliest stages.

Work windows also may be imposed when the rainy season leaves soils too wet to be worked. Different soils have different "liquid limits" for the amount of moisture they can absorb and still remain workable. Typically, soils with high silt or clay content have lower liquid limits. Granular or rocky soils are less sensitive. Many trail construction activities must be carefully planned so they can be completed before the onset of the rainy season. If work is stopped because of weather, measures such as seeding or installation of barriers should be taken to stabilize and protect sites until the project starts up again.

However, trail work does not necessarily have to stop when soil moisture is high. In some situations, a layer of crushed rock may be used to protect moisture-sensitive soils. While grading or earthwork may not be possible when soil moisture is high, other operations such as brush clearing may still be practical. General information on soil capabilities can be obtained from county soil surveys. Geotechnical engineers should be consulted for specific recommendations on large or sensitive projects.

Duration, sequence and phasing. The length of time needed for each construction activity should be indicated in the schedule. Among other things, this will assure the project manager that preparatory work will be completed in advance of seasonal work windows. The construction sequence also should be indicated so the project manager knows that the contractor has thought through the construction process and will avoid repeated disruption of natural resources.

It may be necessary to identify project phases that are based on natural resource issues. For example, pruning or felling of certain trees must be delayed until birds that nest in them have hatched and fledged their young. Tree removal should be scheduled outside the wildlife nesting season (April 15 to July 15).

9.7 Post-Construction Monitoring and Maintenance

Trail-project managers should consider strategies for ensuring that environmental protection measures remain effective after trail construction has been completed. Public agency construc-

Contractors need to maintain and monitor the site after construction is completed.

tion contracts typically obligate the contractor to a one-year maintenance and warranty period. During this time, the contractor must keep the project in a condition that conforms to the contract requirements. On trail projects, vegetation monitoring and maintenance typically are problematic. The contractor should hand over "as built" drawings and specifications to the owner. The drawings will specify the actual construction of the trail. The project specifications should include detailed requirements for watering, removal of unwanted vegetation and desired plant survival rates. If these rates are not achieved, additional plants must be installed. Monitoring of new trails' drainage features during the first year after construction is covered in the Chapter 10.

After a year (or as agreed by the contractor and owner), ongoing trail maintenance and operation typically become the responsibility of the owner. Ongoing natural resource protection typically is focused on habitat and water resources. Periodic monitoring and maintenance are necessary to ensure proper drainage, prevention of erosion and re-establishment of native vegetation or non-invasive cover plantings. The transfer of maintenance responsibility from contractor to owner should include a transfer of information on what the contractor has learned about maintaining the project. This will give the trail owner's staff a head start as they assume responsibility.

How should we take care of the trail?

10.1 The Goals of Resource-Friendly Trail Maintenance

Most park managers agree that there is a lot more to trail maintenance than meets the eye. A trail that looks inviting on a sunny afternoon also must be safe during wet and cold conditions. The pungent gold cottonwood leaves that light up trails in fall need to be raked out of bio-swales. Plants next to the trail must be pruned so that people can pass safely. Hazard trees must be pruned or removed, signs replaced, litter picked up and glass swept. Workers and volunteers need to be trained, equipment maintained and the trail surface repaired.

A resource-friendly green trail maintenance program provides care to the trail surface and its drainage system before normal wear and weather can create problems that affect water resources and fish and wildlife habitats. The maintenance schedule is sensitive to the seasonal needs of fish and wildlife. It enhances and preserves wildlife habitats in the trailside environment, creating opportunities for trail users to enjoy nature at its best.

Environmentally friendly trail maintenance begins in the trail-planning phase by anticipating trails' future maintenance needs and influencing decisions about trail location and design. This chapter highlights maintenance actions that support environmentally friendly trails. These actions begin in administration of the maintenance program and extend to inspection and record-keeping, routine upkeep and repairs, retrofitting and upgrades.

10.2 Administering a Trail Maintenance Program

Administrative practices establish a maintenance program for trails. They assure that maintenance activities are scheduled, budgeted, tracked and properly executed before resource degradation can occur. Some of the items to take into consideration are listed below.

Develop an overview of maintenance activities

Annual, seasonal, occasional and emergency inspections are important to maintaining trail systems in good condition. A typical schedule of maintenance includes the following:

Annual/seasonal activities.

Readiness for winter. Trail drainage systems should be inspected and maintained before the onset of the wet season.

Storm response. Trails should be inspected and necessary maintenance provided after high winds, freezing rain, unusually intense rainfall or flooding.

Mid-winter. A good time to check on the functioning of trail drainage systems is after soils are saturated.

Winter's end. Inspection and maintenance should be provided to make sure the trail and its drainage features are in top shape before the beginning of the high-use season.

High-use season. Wear and tear on the trail can affect both natural resources and public safety. Inspections and maintenance throughout the high-use season can prevent degradation of the trail and wildlife habitats in the trailside environment. Also check for presence of social trails.

New trails. For additional information about maintenance schedules for new trails, refer to the inspection section of this chapter.

Light seasonal maintenance. Inspectors should carry hand tools that enable them to take care of light tasks such as cleaning plugged drainpipes and trimming vegetation. This work should be noted on the inspection forms to support the forecasting of maintenance requirements for each trail segment. More time-consuming maintenance work that can be accomplished by hand crews should be prioritized and completed as soon as possible after seasonal inspection.

Medium-duty seasonal maintenance. Activities that may need to be scheduled include:

- spot-improvements to drainage features
- clearing wind-throws
- repairing informal detour and cut-off trails
- assessing and removing of hazard trees, particularly at trailheads and gathering points
- cleaning major drainage system and making repairs that are important to prevent water resource or habitat impacts, and/or trail damage
- cleaning boardwalks and bridges
- placing seasonal "hop-across" materials in small pedestrian water crossings, if they will keep the trail passable for users and help prevent further damage by detour trails.

Occasional inspection. Trails and their surfaces, furnishings and drainage facilities need occasional upgrading to maintain functionality, public safety and appearance. For example, a failing trail segment in a wet area may need to be reconstructed or a trail surface and base treatments may need to be upgraded to accommodate increased trail use. To address these and other occasional needs, trail managers need to have a broad view of trail lifespans, future trail upgrades and typical reconstruction scenarios.

Emergency inspection. Drainage problems that result in impacts to receiving water resources or fish and wildlife habitats should be taken care of as soon as they are discovered. Other repairs may need to wait until soils are firm enough to support repair vehicles, if needed. It may be necessary to install temporary stabilization until environmental windows are favorable for sensitive species or in-water work.

Develop a multi-year budget

It is essential to budget for both regular (seasonal and annual), occasional (repairs and reconditioning) and long-term maintenance needs (projected for five, 10, 15 and 20-year horizons). Because not all of these activities will be necessary on each trail segment in each year, the budget should reflect varying activity levels across time and should include line items for big jobs: storm damage response, major reconditioning, realignment or replacement of structures or jobs that require large equipment.

Develop tracking methods

Maintenance activities such as inspection, repair and emergency response should be tracked with inventory forms, field notes and other records. Written inspection records for each trail segment should be logged. These records will become the basis for budget and labor forecasts, equipment purchases and schedules for improvements all vital to the health of the maintenance program.

Provide training for staff

Maintenance crews tend to change with the changing seasons and shifting assignments. Therefore, education in environmentally friendly maintenance practices is an on-going need in most maintenance departments.

Develop a program of environmental improvements

Many trail managers must maintain trail systems that were constructed in ways or settings that do not reflect current thinking about natural resource protection. By identifying trail segments that result in chronic functional problems and unacceptable impacts to fish or wildlife, or to water resource areas or their functions, managers can develop programs of environmental improvements and budgets and schedules to accomplish them. Inspection and assessment of existing trails may reveal opportunities to minimize or eliminate these impacts.

Potential remedial actions include:
- retrofitting bridges and culverts for fish and wildlife passage
- replacing culverts with spans
- upgrading trails to reduce impacts in or restore functions to wetlands and floodplains
- realigning or reconstructing trail segments where erosion has been a long-standing problem
- abandoning or decommissioning trails in sensitive species habitats
- upgrading drainage on roads and trails to stop chronic delivery of trail runoff and sediments to streams, wetlands or riparian areas
- removing exotic vegetation from trailside environments and replacing it with native plants
- providing improved wildlife passage
- dealing with long-standing social trails.

Note that these remedial actions likely will require city, county and state permitting if located in environmentally sensitive areas. More information about assessing existing trails is provided further on in this chapter.

Develop resource-friendly contracting practices

When maintenance activities will be accomplished under contract, natural resource protection practices need to be specified in the contracts and approved in the field.

Following are examples of practices to include:
- Contractors should attend a pre-work site meeting and provide input into maintenance contracts.
- Contractors should participate in identifying places where and how excess earth materials can be disposed in the field (not in wetlands, near streams or in other sensitive locations).
- Contractors should be experienced in particular techniques such as herbicide application and have certified workers.
- Maintenance plans should contain special directions for contractors to follow under worst-case conditions. For example, contractors might be required to stockpile bio-filter bags to install in ditches in the event there is a rainstorm during reconditioning of a trailside drainage ditch.
- Earth-disturbing activities such as blading and shaping dirt roads and cleaning ditches with equipment should be paid by clearly marked segments, not by lineal feet (a practice that encourages over-maintenance and unnecessary exposure of disturbed earth to erosion and transport to water resources).
- As with construction, erosion prevention and sediment control practices are part of all maintenance practices that disturb ground. Erosion control practices are inspected and maintained daily while maintenance work is being completed. Measures such as seeding or mulching for erosion control are inspected by the contractor during the rainy season until the project manager finds that the disturbed earth has been stabilized.
- Controls for sensitive area protection are installed before maintenance activities begin. These can include erosion and sediment controls, designation of areas for equipment maneuvering and parking, areas for storage of equipment and materials including soils stockpiles, and limits on removal of organic matter.
- Ground-disturbing work is delayed in wet weather.
- Contractors provide project schedules showing how they will accommodate working windows for sensitive species.
- There is daily inspection of work that can affect water or other sensitive resources, and a written record of inspections and follow-up actions.

10.3 Inspecting Trails

Inspection and maintenance are important elements in resource-friendly sustainable trails. A regular trail inspection program is an insurance policy for taking care of conditions before they result in impacts to water resources or fish and wildlife habitats. For example, a clogged culvert inlet might be spotted during routine inspection. The few minutes the inspector takes to remove the debris could prevent the trail from washing out and sending sediment to downslope water resources. Timely inspection and follow-up also protect the trail itself from damage by wear and weather.

First-year inspection for new trails.[1] New trails need to be closely monitored in the first year after construction so problems can be corrected before they cause damage and become more costly to fix. A typical inspection schedule for the first and successive years is provided in Table 10-1.

Long-term inspection. After the first few years of rigorous inspection and maintenance, any trail problems should have been identified and solutions implemented. Inspection and maintenance of drainage systems should continue as before. As drainage swales age, they may require additional maintenance such as reshaping, cleaning out or reestablishing of vegetation. The trail structures also will begin to require more attention as they weather, settle and wear. Vandalism may take its toll on signs and structures, and solutions will need to be found to control off-trail uses.

Inspecting asphalt and concrete. Asphalt surfaces will need to be re-sealed (see Chapter 8). "Alligatoring," or a pattern of small cracks in asphalt, can indicate moisture in the base or sub-grade. This condition may require reconstruction of a section of the trail.

Type of trail	Item	Suggested frequency
New hard and soft trails	Note drainage design including ponding, gullying and wash outs	After the first heavy rains
	Drainage should be repaired, trail structure inspected and check for presence of social trails	Two months or after several moderate rains
	Joint inspection with contractor to inspect trails including structure, surface, drainage and vegetation	Four to six months after the trail is completed. Soft surface trails require greater attention than hard surface trails
	Spot improvements of trails for handling wet weather or worst case runoff	End of the first year prior to rain
Existing trails and newly built trails (ongoing maintenance)	Weed control	Seasonal
	Water plants (newly established trails) and remove exotics	As needed
	Mow the edges where applicable	Biannual – fall and spring
	Prune trees/shrubs	Five months to one year
	Clear drainages including smaller pipe inlets, outlets for sediment, leaves and blockages	Annually, especially after a large water event (late spring) or fall after leaves are down and before rains
	Clear vegetation along ditches	Every two years
	Trail sweeping	Regular schedule
	Trash disposal	As needed

Table 10-1 Maintenance recommendations for green trails.

When concrete surfaces have been properly constructed, they should require virtually no maintenance. Cracking of concrete surfaces can indicate that scoring patterns were not properly spaced. Cracks should be filled to prevent moisture damage to the base and sub-grade.

A word about earthen and soft-surface trails

The same general schedule of inspection and maintenance applies to soft-surface trails. Newly constructed earthen and soft-surface trails should also be monitored closely in the first year. The tread surfaces of earthen trails generally require greater attention than constructed trail surfaces, particularly if use is high. Because elements of trail drainage are present in the tread surface of earthen and soft-surface trails, special attention is given to them in the following maintenance practices.

10.4 Maintaining Trails

Drainage features

Many of the drainage features discussed are common to earthen and constructed trails. However, one of these features, the rolling dip, is almost exclusive to earthen trails.

Rolling dips and sediment traps. Water running down the surface of an earthen trail almost always pulls a little sediment with it, no matter how perfectly spaced drainage features may be. The function of rolling dips is to catch the runoff and sediment and route them off the trail in a leadoff ditch (see Figure 10-1). But this does not always occur as neatly as planned, and someone has to come along with a shovel and clear out the collected sediment – both in the dip and in the leadoff ditch. This operation needs to be done every one to three years, depending on soils, vegetation, use and other conditions (rolling dips on

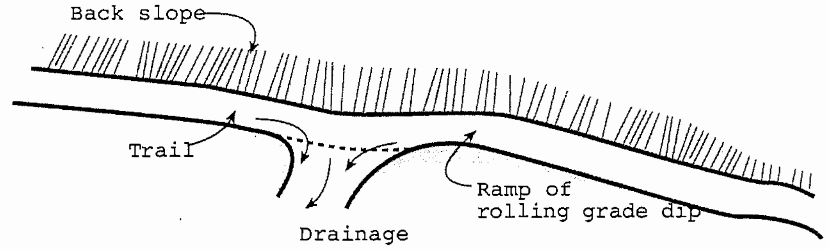


Figure 10-1 Schematic of a rolling grade dip. (Trail Building and Maintenance: Rolling Grade Dips – Erosion Control, IMBA Resources)

earthen trails under full conifer canopy may require less frequent maintenance). Depending on the scale of the project, large equipment may be needed to rebuild and reshape the dips, or to reshape the leadoff ditch and dissipation apron and sediment deposition area.

Dissipation aprons ("catch basins"). When concentrated stormwater is discharged over the side of a trail, the energy of the falling water may rapidly erode the discharge area. This may be particularly true where the trail incorporates a drainage system to capture groundwater and route it under the trail. To avoid erosion at the discharge point, the site typically is armored with cobbles and boulders, which slow the water and sometimes, level-spread it into the surroundings. Despite this, discharge sites frequently sustain erosion anyway, and the discharge apron needs to be maintained every few years. This entails bringing in more rock or coarse woody material, perhaps from the immediate area, and placing it where it will help to dissipate the energy of the runoff and allow settling of sediments. An engineer or qualified designer typically selects the rock type, shape, size, weight and armor thickness.

Culverts. Culverts are pipes that route water under the trail for discharge on the downhill side of the trail. They typically have an inlet basin and an outlet, or dissipation basin. Woody debris and buildup of sediments can clog culverts. Inspectors can clear them with shovels and handsaws during inspection. Both inlets and outlets should be cleaned. Work with power saws in natural areas should be deferred until a favorable work window that reflects fish and wildlife needs.

Ditches. Ditches route water alongside or away from trails until it can be discharged. Whether they are maintained by hand or by machine, ditches require regular maintenance. Their neglect can cause serious consequences – when, for example, runoff that should have been contained in the ditch overflows on the trail and gullies it or washes it out, then flows to the nearest receiving water. Sediments can clog ditches and should be removed if they interfere with conveyance of runoff. However, maintenance can result in bare ditches, which are vulnerable to erosion. It may be necessary to add roughness elements (such as rock) to prevent ditch erosion. Major work on ditches should be done during the dry season, and erosion and sediment control should be provided on bare ditches. Many managers use bio-filter bags – net bags filled with chipped bark. These can be staked to the ground and are removable. Some are biodegradable.

Trail-side vegetation

Brushing and pruning. Low-intensity and narrow pedestrian trails should be hand-pruned annually to keep them open (Figure 10-2 and 10-3). Due to declining budgets for trail maintenance, many trail managers schedule trails for vegetation maintenance every two to five years. Because of this, trail friends' groups have become vital components of many trail maintenance programs.

The vegetation should not pose a hazard to trail users or restrict their movement (see Figure 10-4). It is critical to maintain sight distance at trail intersections with streets, roads and railroads so that trail users have unobstructed views at pedestrian crossings and intersections.

Both city and county zoning codes regulate cutting and spraying of native vegetation. Trailside pruning should take place after the nesting season. Consideration should be given to avoiding or minimizing pesticides (see the last section of this chapter, Integrated Pest Management). The potential impact of chainsaw noise on sensitive wildlife species also should be considered. Pruned material can be lopped and scattered near the trail but not in or adjacent to the trail's clearing limits.

Mowing. Increasingly, trail managers are mowing less frequently and deferring mowing until late spring to avoid disturbing wildlife. Others are converting to slow-growing, heterogeneous lawn mixes or "eco-lawns" as no-mow alternatives to turf.

Clearing vegetation from ditches. Vegetation growing in trailside ditches can impede water flow and cause sediment build-up. If vegetation causes water to stand in the ditch and saturate the trail foundation, the trail can be damaged. On the other hand, ditch vegetation can be effective in the uptake of nonpoint pollutants associated with runoff. Therefore, its removal should be carefully considered.

On wide high-use trails, ditches are usually "cleaned" or "pulled" every two years or so. This operation is done with a backhoe bucket that scoops out the sediment and the vegetation in the ditch (i.e., typically weeds, willows, alder and other wet-loving plants). Ironically, this often leaves the ditch bare and susceptible to erosion by the runoff that flows into it. Therefore, ditch cleaning should occur after the spring rainy season so that annual vegetation can re-establish before the onset of fall rains. Biofilter bags or straw wattles are usually staked at intervals in the ditch to filter sediments if the ditch should flow.

If the ditch discharges directly to a stream or wetland, erosion of the bare ditch can be a problem and the ditch may need to be maintained by hand. In this case, plants should be cut and sediments removed with a shovel.

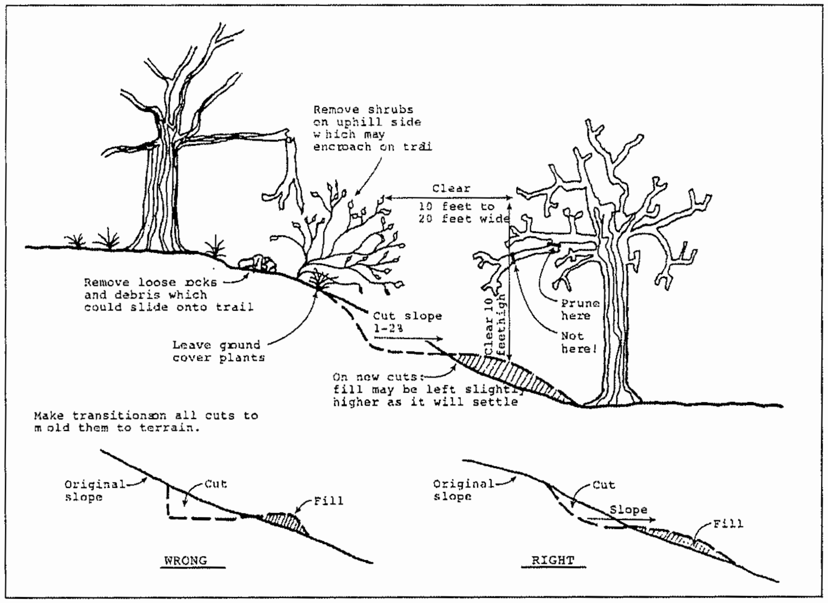


Figure 10-2 Make transitions on all cuts to mold them to terrain. (Trails Manual, 1995)

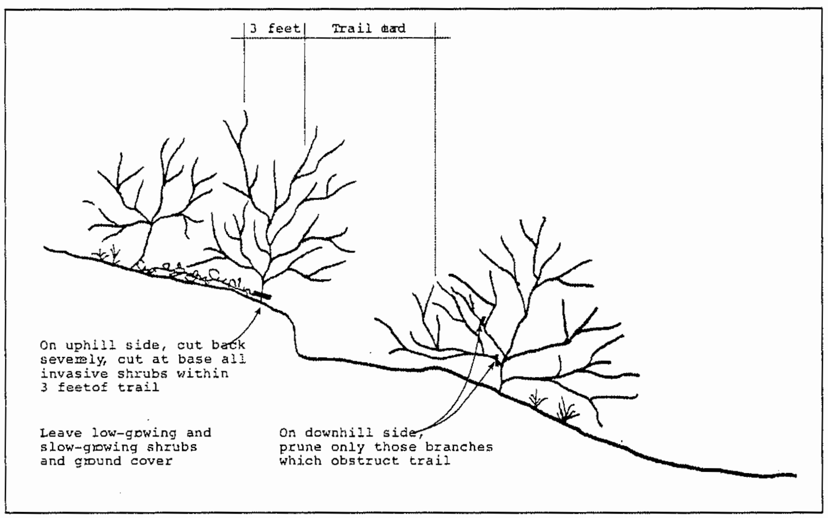


Figure 10-3 Typical vegetation clearing from slide slopes. (Trails Manual, 1995)

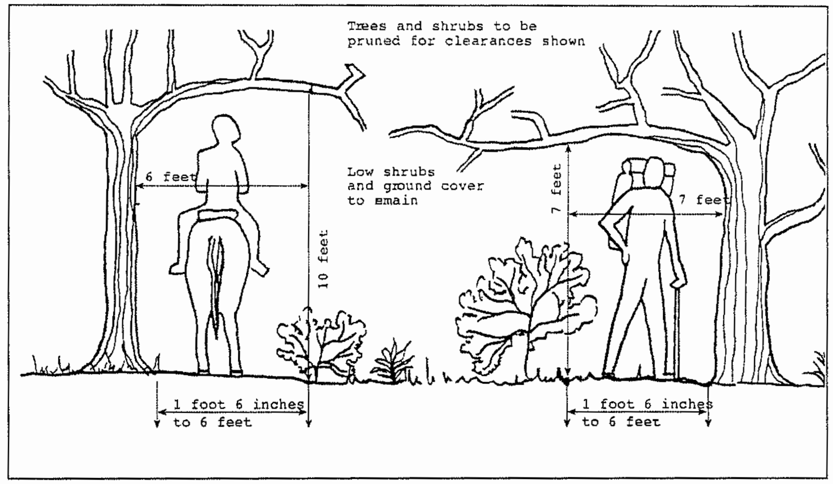


Figure 10-4 Typical vegetation clearing for hikers and horses only trails. (Trails Manual, 1995)

Bio-swales. The drainages that flow to swales should be inspected regularly to make sure that erosion from upstream stream or drainage facilities are not loading the swales with sediments. If eroding up-line ditches are found to be a source of sediments, roughness elements such as rock and coarse wood may need to be added to the ditches to slow the flow and reduce erosion. If flow volumes are too high and ditch erosion cannot be controlled, the flow may need to be split so that it is received by two swales, instead of one. Annual leaf-fall should be removed from swales when possible, to improve their efficiency. Sediments that accumulate in swales should be removed periodically, so that the swale is capable of holding runoff from larger storms. This may necessitate removal and re-establishment of vegetation.

Seasonally closed trails

Inspect closed trails to make sure drainage is in good order, closure signs are up and/or gates are locked.

Unsurfaced gravel park roads

Unsurfaced park roads are often used as trails. Vehicular traffic on unsurfaced park roads during the wet season can degrade the road surface and generate sediments in runoff. If water stands on the roadway and/or the surface becomes soft and muddy, pedestrians, equestrians and bicyclists may create detour trails. Routine inspection and maintenance can prevent detour trails.

The following steps could be taken to maintain unsurfaced gravel park roads:

- Use seasonal closures if needed but allow access for seasonal drainage inspection.
- Before winter, install seasonal waterbars, check or install trash racks, clean culvert inlets and outlets, gate and close to non-essential traffic.
- Reduce or minimize hauling and grading during wet weather conditions.
- Grade only when and where needed and only when moist, not wet, after rainy season.
- Don't disturb sections of the roadway that don't need maintenance while repairing, blading or grading sections that do.
- Don't blade, grade or drag in rain or freezing temperatures.
- Avoid work near streams during the rainy season.
- Don't blade surface materials when they are dry (contributes to loss of fines and subsequent washboarding.)
- Don't blade ditch spoils back onto the road surface, but dispose of them in a pre-determined area.
- Control dust in summer to conserve fines in the road surface. Place a layer of well-graded aggregate on the road and compact it at the proper moisture content. If the road has already been rocked, sometimes ripping and re-compacting will be sufficient to reduce dust problems. Sometimes, it is necessary to adjust the percentage of coarse to fine materials. If aggregates are not desired, organic lignins can be applied by spray to reduce dirt.

10.5 Evaluating Existing Trails

Existing trails can be evaluated to ascertain what impacts they may be having on water resources and wildlife habitats. Trails that affect the hydrology of water resources or chronically discharge stormwater or sediments to them are cause for concern. Following are several indicators to keep in mind when assessing the impacts of trails on wetlands, wet meadows and streams.

Trails that do not function properly may show some of the following characteristics:

- Deep trenching – trail is sunken because of poor drainage and berming of the outslope and sediment build up.
- Short cuts – many users take short cuts because they are the shortest distance between two points. These short cuts are referred to as social trails and can damage vegetation, habitat and water bodies. Often shortcuts are developed by users to avoid wet, muddy segments of trails.
- Impacts to natural resources such as trail runoff to meadows and wetlands and issues with culvert crossings.

Other characteristics of poorly functioning trails include widening of the trail, increase in tripping hazards because of exposed tree roots and steep trails or people avoiding these trails because of their danger. The main cause of poorly functioning trails is the movement of water, which can cause erosion and deep entrenchment. Other causes are poor initial trail design and placement, and inadequate maintenance.

A social trail leading to the stream is obliterated by placing big boulders at the end of the steep trail.

Social trails

Social trails can be obliterated by following the following steps:

- Cover the trail with duff, topsoil, plants, woody debris, grasses or small trees, where feasible.
- As a long-term strategy, thorny native shrubs should be planted because they are hard to navigate.
- Large boulders or large woody debris can be placed on the trail in areas that are steep or hard to revegetate.

Trails in wet meadow and wetlands

- A culvert that is set below grade in a meadow can cause incision of the meadow, increasing erosion and disturbing native plant and wildlife habitats there. Incision can dewater the wet area as groundwater levels adjust to the lowered drainage point at the culvert. This can lead to a change in species in the wet meadow or wetland. If culverts are set below grade, they should have stable drop inlets to prevent incision.
- When concentrated runoff from a trail is directed and into a meadow or wetland it can cause channelization, increase erosion and disturb hydrologic regimes needed to support native vegetation. Trail runoff should be diffused and trail ditches should have frequent turnouts and plugs to prevent channelization of trail run-off.
- Presence of trails can facilitate invasion of exotic species and upland plants into meadows, causing rapid ecosystem changes. Mowing, removal or spot treatment by appropriate chemicals may be needed to reduce invasions by exotic species especially along trail edges.

Signs of erosion caused by runoff from trails

- Erosion and raveling of cut and fill slopes
- High use of earthen trails results in sediments being delivered to water resource areas.

In the Western Cascades, research shows that trail drainage will not impact the water area if there is at least a 200-foot set back from a watercourse.

Refer to Chapter 5 for additional cautionary notes on culvert crossings of streams.

If chronic problems are identified, the trail system may be a candidate for reshaping, upgrading, storm proofing or decommissioning.

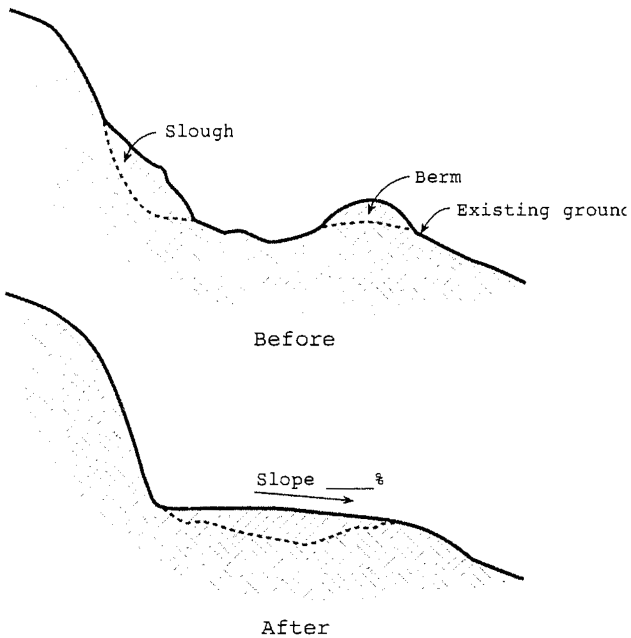


Figure 10-5 Restoring existing trails.

Reshaping the trail template

Earthen trails may begin to develop low spots in the center where use is concentrated, and the trail template may need to be re-shaped (see Figure 10-5). This may entail knocking down the outside edge of the trail with hand tools, spreading this soil across the trail and compacting it, or using equipment to re-grade and compact the trail. In problem situations, a more durable surface may need to be installed or more frequent drainage relief constructed. Sometimes a degrading trail segment may need to be retrofitted with stairs.

Upgrading. In this approach, engineered changes are made to the trail base, drainage template, or drainage features to reduce sediment generated from the trail. For example, a crushed aggregate surface may be applied to reduce erosion from runoff on the tread surface. Alternately, additional drainage features may be constructed on the trail.

Storm-proofing. Stream-crossing fills and pipes are removed and the exposed edges of the trail are laid back to a stable angle and vegetated or armored with rock. This treatment lowers the risk of the trail "blowing out" at the pipe. Storm-proofed trails should be inspected after major storms to make certain that conditions are still stable.

Decommissioning. Options range from blocking the problem trail or obliterating it and re-establishing the pre-trail topography and vegetation.

Conversion. An earthen trail that is too wide may become a chronic source of sediments, which can be problematic if the trail drains to a water resource. Such a trail may be made more stable by outsloping it, narrowing the tread surface and planting vegetation in the area that will not be used for the tread.

In this road to trail conversion a former forest road was ripped, reshaped and seeded. (Heavy Equipment Operator's Guide to Road Rehabilitation, Casaday and California Department of Parks)

10.6 Planning for Trail Upgrades

Successful upgrades of earthen trails start with understanding how sub-grade and base conditions can affect the trail. Problems often arise when concrete or asphalt are placed over earthen trails without proper sub-grade and base preparation. The surface may begin to deteriorate and cracks may appear because foundation support and a moisture barrier are missing. Similar problems can occur when gravel is placed directly on the surface of a boggy trail without the benefits of improved drainage or a moisture barrier. The gravel shortly migrates down into the muck and will need to be applied again.

If an upgrade from an earthen trail to a constructed surface trail is planned for the future, it will be necessary to make the appropriate upgrades to both the trail sub-grade and the base (see Figure 10-6). These actions are vital to assure a solid foundation for the trail and to preserve the trail surface from degradation due to settling or moisture. Upgrading a railroad bed to a gravel, asphalt or concrete trail also may require sub-grade and base treatments, particularly if there are poorly graded materials in the railroad grade and/or moisture conditions affecting the sub-grade or sub-base. As with many other things in life, investment of initial effort can save future labor and maintenance costs.

10.7 Using New Trail Alignments to Accomplish Natural Area Restoration

An exciting opportunity is presented when a new trail traverses an area that has a high potential for restoration. Such areas might have been tiled for agriculture, have infestations of non-native plants, contain hazardous materials or abandoned roads that affect wildlife habitat use, fish passage or ground- or surface-water hydrology. There might be an opportunity to convert an old road into a trail, re-establish a wetland or create a special habitat. Plan to take advantage of restoration opportunities that can be accomplished in conjunction with new trail

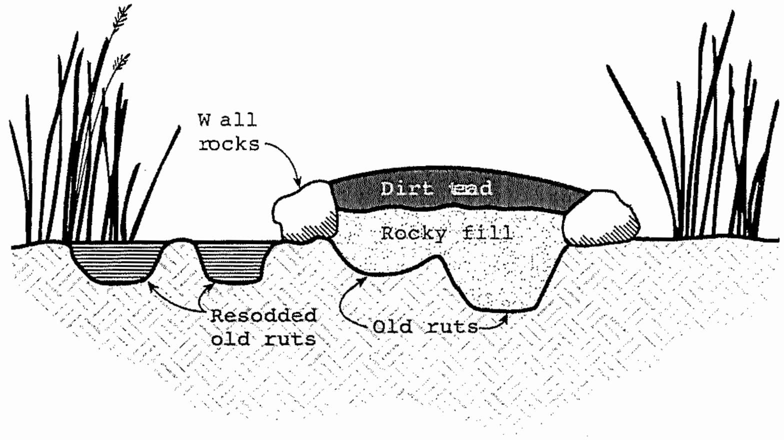


Figure 10-6 An old decomissioned roadway was converted to provide dry trail passage through a wet spot. (Hesselbarth, W. 2000. Trail Construction and Maintenance Notebook, USDA Forest Service)

development.

It will be worthwhile to explore several grant programs to help with restoration costs. These include Greenspace Program restoration grants from the U.S. Fish and Wildlife Service and Metro, funds from the Oregon Watershed Enhancement Board, and others. In Portland, trail proponents may be able to share costs with the Bureau of Environmental Services Watershed revegetation program.

10.8 Integrated Pest Management

In the mild, wet Pacific Northwest where plants seem to thrive unbidden, invasive vegetation control is a fact of life for trail managers. The amount of vegetation control that must take place along trails may not be evident to the young family taking a half-mile nature hike or to a cyclist riding the entire length of the Springwater Corridor. Yet mowing, weeding, hoeing, pruning, clearing and spraying vegetation along trail corridors can be major maintenance tasks in manicured parks as well as in primitive settings. These tasks keep tree branches from overhanging trails, blackberries and other vegetation from taking over trail rights of way, trees from becoming established where they shouldn't and exotic plants from spreading. Vegetation maintenance keeps bio-swales operating properly, provides sight distance at intersections and curves, allows for maneuvering of maintenance and emergency vehicles, and provides a measure of safety and security along trails.

Most natural area managers recognize that careful consideration should precede the selection of chemical methods, or herbicides, to control vegetation. This is because some herbicides have the potential to affect people and wildlife that come into contact with them in the trail corridor. Runoff carrying herbicides to streams and water resource areas can affect wetland and aquatic life as well. For these reasons, most herbicides are restricted for general use and can only be applied by trained and certified applicators. Any herbicide use near a stream that may affect listed fish may directly or indirectly trigger ESA regulations.

Park districts regularly provide their maintenance people with up-do-date education about handling herbicides. Yet, having a reliable method to determine when to use herbicides judiciously can be a bit of a challenge. This section summarizes the components of an integrated pest management program and strategies for developing such programs for trail systems.

Integrated Pest Management Defined (IPM). Integrated pest management is a sustainable approach to managing pests that combines biological, cultural, physical and chemical controls in ways that minimize economic, health and environmental risks. IPM is a least-risk approach that relies on information-gathering and informed decision-making to control pests. The U.S. Environmental Protection Agency promotes a graduated scale for making IPM decisions.[2]

Set action thresholds. Before taking any pest control action, set an action threshold, a point at which pest populations or environmental conditions indicate that pest control action must be taken. An understanding of the level at which pests will either become an economic or environmental threat is critical to set action thresholds.

Identify and monitor. Not all insects, weeds and other living organisms require control. Many organisms are innocuous; some are even beneficial. Pests should be identified so that appropriate control decisions can be made in conjunction with action thresholds. Monitoring can remove the possibility that pesticides will be used when they are not really needed.

Prevent. As a first line of pest control, find ways to manage an area to prevent pests from becoming a threat. This may mean using cultural methods, such as selecting pest-resistant varieties, and planting pest-free rootstock. These methods can be effective, cost-efficient and present little or no risk to people or the environment.

Control. Evaluate control methods for both effectiveness and risk. Choose effective, less risky pest controls first. These might include the use of highly targeted chemicals, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring, identifications and action thresholds indicate that less risky controls are not working, then additional pest control methods can be used, such as targeted spraying of pesticides. Broadcast spraying of non-specific pesticides is a last resort.

Strategies for avoiding risky pest controls. The following strategies are used to avoid the need for chemical pest management:

Planning. A least-risk approach should be used during conceptual trail design when a new planting is being considered. Evaluate site conditions, site uses, vegetation management capabilities and goals, and the sensitivity of adjacent resources when selecting plants. The goal is to avoid disturbing intact habitats so non-native nuisance species are not favored, and to select vegetation that will thrive in the environment with the least care, and require little or no herbicides, pesticides or fertilizers. By the time design documents are being prepared, the future management program for the vegetation should already be known.

Use of native plants. Make sure to select plants that will do well in site-specific conditions of aspect, light, moisture, soil type and other conditions.

Improving soil conditions. Chances are that native plants will naturally re-establish themselves along narrow, new trails that traverse relatively undisturbed native habitats. This is because the soil seed bank is likely to be intact if the original topsoil is present and the soil microorganisms are relatively undisturbed. These conditions favor the reestablishment of the native flora.

However, when large-scale excavation has taken place and the resulting planting medium consists of low-organic, compacted sub-soil, more ruderal or "weedy" species are likely to flourish. These conditions also can favor exotic plants. Whenever possible, save and stockpile topsoil from earthwork and reapply over final grade. Improving soil conditions can enhance survival of native plants in trailside environments. This may involve ripping or tilling to loosen and aerate the soil, and addition of mulch to add organic materials, retain soil moisture and discourage weeds.

Occasionally, other soil amendments are needed. Landscape architects or horticulturists who specialize in native plants can have soils tested, interpret test results and specify soil treatments and amendments. Plants should not be selected that require regular amendments, particularly fertilizers.

Avoidance of actions that degrade soils. Trail alignments, dimensions and construction plans should be carefully selected and designed to avoid degrading trailside soils.

Use of existing disturbance corridors to site trails. This approach avoids attracting pests and unwanted plants to undisturbed sites by siting trails in pre-existing linear routes as discussed in Chapter 4 and other sections of this guidebook.

10.9 Strategies for Minimizing Risky Pest Controls

Restore native plants. Exotic plants or plantings that require regular applications of pesticides should not be considered for replacement, particularly if there are concerns about human exposure, sensitive habitats, or water resources. Care should be taken to select native species that will be able to shade out, or otherwise out-compete, invasive or exotic plants.

Rethink turf and turf mixes. Vegetation for corridors along multiple-use trails does not always need to be a dense, non-native grass. Heterogeneous, low-growing ground covers may provide many of the same benefits as turf in these settings. For example, a substitute seed mix for pure turf might include a native herbs and grasses and forbs that can do well in the site's soil and light conditions.

Consider alternatives to aggressive non-natives in stormwater swale and erosion control plantings. Exotic grasses can provide quick cover for erosion control plantings as well as dense stems and root masses for passive runoff treatment swales. However, some non-native grasses used for such purposes can spread quickly into wildlife habitats and become nuisances that require aggressive controls.

Many seed supply companies specializing in grasses can help formulate seed mixes that will be effective for erosion control treatments but not spread aggressively. It can be worthwhile to make a few calls and give the sales representatives a summary of site conditions and the desired performance of the future planting. Many companies specialize in native and local seed. There also is a sterile grass "regreen" that could be used as an interim erosion control measure.

Use a zoned approach to pest control. Some municipalities classify their park and greenspace landscapes according to the level of use and management they receive. For example, the Portland Parks uses the following classifications:[3]

- highly managed area
- intermediate managed area
- impacted natural area
- intact natural area.

Within these zones, the following conditions are distinguished:

- buffer zone for wetland, pond, lake or waterway
- wetland, pond, lake or waterway.

The city has developed pest management objectives and specific actions for each type of area in each of its parks and greenspaces. In addition, site-specific guidelines are provided for the use of pesticides and fertilizers in the buffer zones of waterways. These guidelines are based on levels of management and/or maintenance, and restoration goals or activities. Management practices within bodies of water, biofilters and wetlands also are specified. Finally, special exception areas (such as golf course streams and park turf behind seawalls) and their pest management needs and practices are identified.

Portland applies several integrated pest management practices to all areas. These include:

- use of low-pressure, low-volume, hand-held spraying, injection, daubing, painting and wiping equipment and drop-spreaders
- management of drift by means of nozzle size, pressure regulation, height of spray wand and restrictions to spray application in buffer areas when wind speed is greater than 5 mph or when wind direction would carry spray toward open water
- listing of all post-emergent and pre-emergent pesticides allowed in buffer zones, and all pesticides allowed in certain circumstances in aquatic sites
- formal review of policies each two years
- provision for collaboration with the National Marine Fisheries Service in the event of need for emergency application of actions not already approved
- strict adherence to state and federal record-keeping requirements and mixing, handling and disposal protocols
- rigorous training and licensing of grounds maintenance personnel who will apply pesticides.

Endnotes

[1] Adapted from Pitkin County, Colorado Open Space and Trails Program, Trails Design and Management Handbook. 2000, by Troy Scott Parker.

[2] Items in italics are summarized from the U.S. Environmental Protection Agency's web site, www.epa.gov/pesticides/citizens/ipm.htm, accessed on July 21, 2002.

[3] Summarized from www.portlandparks.org (accessed on April 26, 2002). NOAA Fisheries Division has approved the Integrated Pest Management Program developed by Portland Parks and Recreation. However, other jurisdictions are not covered by this program. A summary of the program is provided here.

Glossary

Angle of repose: The maximum angle of slope (measured from a horizontal plane) at which loose, cohesionless material will come to rest on a pile of similar material.

Armor: Rock placed in a ditch, catch basin or dissipation apron to protect it from erosion by concentrated flows of water. Typically, rock for armoring is sized to resist the greatest flows expected and is placed at a depth corresponding to twice the diameter of the average stone. Rock sizes typically are determined by an engineer or qualified designer. Also see "riprap."

Base course (base): This is the main load-spreading layer of the constructed trail and is normally constructed of crushed stone.

Bedload: Sediment that slides, rolls or bounces along the bottom of the streambed due to flowing water.

Best management practices (BMPs): Practical guidelines that can be used to reduce the environmental impacts of land uses or operations by means of careful planning, location, design, construction, management and maintenance.

Bog bridge: A pathway elevated above wet soils by means of planks or puncheons laid across wooden supports, such as logs, that are laid on the ground.

Catch basin, sediment catch basin: The excavated or constructed basin at the inlet of a culvert cross-drain pipe used to collect water and direct it into the culvert pipe. Catch basins or "sumps" also may serve to slow the velocity of moving water, thereby encouraging sediments to drop our of the flow before entering the pipe. Also see "drop inlet."

Causeway: A pathway elevated above wet soils by means of earthen fill placed between retainers, such as logs or large rocks that are countersunk or pinned to the ground. Crushed stone is frequently used as a top dressing to "cushion" the tread. The earthen fill is separated from the wet ground beneath it, either by over-excavating the wet soil and replacing it with base rock, and/or by means of geotextile fabric. Causeways typically include design details that provide ways for groundwater and surface water to pass at grade beneath or through the structure.

Concrete: A mixture of crushed stone or gravel, sand, cement and water that hardens as it dries.

Cross-drain: Installed or constructed structures such as culverts and tolling dips that move water from one side of the trail to the other.

Cross-section: A drawing depicting a section of the trail sliced across the width.

Cross-slope: The gradient of the hillslope as measured directly down the fall line.

Cut-and-fill: A method of trail construction in which the trail is built by cutting into the hillside and spreading and compacting the spoil materials in nearby low areas.

Ditch: A low point adjacent to the trail intended to collect runoff from the trail and adjacent land for transport to a suitable point of disposal.

Dividers: A simple drafting tool, somewhat like a compass, for marking off distance on a map or aerial photo.

Down-drain: An enclosed pipe that leads concentrated stormwater away from a slope before discharge to the ground. Down-drains protect slopes from erosion.

Drainage dissipation apron ("catch basin"): A catch basin is an area designed to receive and dissipate concentrated storm-water discharges. Typically, the basin is armored with rock and sized to encourage energy dissipation and sediment settling before discharge of stormwater to the ground.

Drain rock: This term usually refers to the class of rock used in leach fields. Typically, it is angular clean 2-inch to 4-inch rock. If alluvium (rounded rock, also known as wash rock) is used for drainage, some sources recommend that it be slightly larger and well graded. Problems may ensue if rounded rock is used in the trail base or subgrade or if trail retaining structures are constructed on top of rounded drain rock. A civil engineer or qualified design professional should specify rock, whether it is needed for drainage or support.

Drop inlet: A masonry or concrete basin, or a vertical riser on a metal culvert inlet, usually of the same diameter as the culvert, and often slotted, to allow water to flow into the culvert as water rises around the outside. Drop inlets are often used on ditch relief culverts where sediment or debris would plug the pipe. A drop inlet also helps control the elevation of the ditch.

Floodplain: A level low-lying area adjacent to streams that is periodically flooded by stream water. It includes lands at the same elevation as areas with evidence of moving water, such as active or inactive flood channels, recent fluvial soils, sediment on the ground surface or in tree bark, rafted debris and tree scarring.

Floodway: Narrowly interpreted, the floodway is the area near waterways where the Federal Emergency Management Agency has prepared detailed engineering studies to designate where the water is likely to be deepest and fastest. It is the area of the floodplain that should be reserved (kept free of obstructions) to allow floodwaters to move downstream. Placing fill or structures in a floodway may block the flow of water and increase flood heights. Depending on many variables, the floodway is typically the portion of the floodplain within a stream or river's present-day meander belt.

Focal species: A species whose habitat needs represent the range of needs for an entire group of wildlife that uses a specific habitat type. Focal species are numerous enough to be monitored and are at least moderately well studied.

Ford: An unimproved route across a stream usually selected for its wide, shallow character, and, usually, a cobble or firm rock bottom. Also see "low-water crossing."

Geotextile or filter fabric: Textile made from synthetic fibers, usually non-biodegradable, to form a blanket-like product. Geotextiles can be woven or non-woven and have varying degrees of porosity and strength. In trail construction, they are used as moisture barriers, for separation or reinforcement of soils, filtration and for drainage.

Grade, gradient: The slope of the trail along its alignment. The slope is expressed in a percent ratio, or the ratio of elevation change compared to the distance traveled (rise over run). Also see "sustained grade" and "pitch."

Inlet: The opening in a drainage structure of pipe where the water first enters the structure.

Inslope, insloped, insloping: A trail cross-section that is sloped 3 percent or more into the hillside. In-sloped trails drain to parallel ditches that collect water, which is periodically conveyed, sometimes in culvert pipes under the trail, to suitable discharge areas.

Inside/outside: Refers to the inside of the trail (typically the cutslope or back slope), or the outside of the trail (typically on the fill slope or down-slope side.

Lead-off ditches (turnouts): Excavations designed to divert water away from a trail or trail-side ditch in order to reduce the volume and velocity of trailside ditch water.

Level-spread, level-spreading, level-spreader: Level-spreading is a way of preventing concentrated flows and erosion by maintaining runoff as sheet flow and dispersing it, usually in dense groundcover, for filtration and infiltration.

Liquefaction: The sudden collapse and lateral spread of sediments due to loss of cohesion because of increased pressure of soil water during ground shaking during an earthquake.

Loess: In the Portland metropolitan area, loess soils consist predominately of silt, and were deposited by wind. They are common in uplands. Loess soils are generally highly erodible because they lack binding colloids.

Low-angle earth flow: Slow-motion ground movement that can occur in areas with little to no slope due to a combination of factors.

Low-water crossing: A low-water crossing is a constructed feature that creates a temporary stream crossing that is expected to wash out during high water. Also see "ford."

Mass wastage: The various means by which earth material moves downslope under the influence of gravity.

Outlet protection: Devices or material, such as a headwall or riprap, placed at the outlet of pipes or drainage structures to dissipate the energy of flowing water, reduce its flow velocity and prevent channel or bank scour.

Outslope: A slight cross-ways tilt of the trail tread (typically 3 to 5 percent) in the direction hillslope's fall line to facilitate efficient movement of runoff across the trail and off it.

Pitch: A short section of trail that is steeper than the maximum design grade.

Porous concrete: A concrete mix that is lean in fines, resulting in many small voids, through which water can pass.

Puncheon: A short, heavy piece of roughly dressed timber. Puncheon also refers to a level tread surface for a bridge or trail created by smoothing one face of a log.

Ravel: Constant surficial movement of loose or coarse material on a slope in poorly cemented material. Also, a process where the coarse material on a trail surface comes loose and separated from the trailbed because of lack of binder or poor gradation of material.

Retaining structure: A structure designed to resist the lateral displacement of soil.

Rill, rills, rilling: Rills indicate that sheetwash has begun to concentrate. When rilling is observed, significant erosion has already taken place. Erosion up to 1 inch deep is considered rilling. Gullies are considered to have developed when rills coalesce and erosion is deeper than 1 inch.

Right of way: Legally, it is an easement that grants the right to pass over the land of another. Also see "trail corridor."

Riprap: Well-graded, durable, large rock, ideally with fractured surfaces, sized to resist scour or movement by water and installed to prevent erosion of native soil material.

Rolled trail grade: On a climbing trail, a rolled trail grade is one that levels off periodically (depending on trail gradient, width and soils) to allow runoff to be routed off the trail, usually by means of a rolling dip (see next definition).

Rolling dip: Water running down the surface of an earthen trail almost always pulls a little sediment with it, no matter how perfectly spaced the trail's drainage features may be. The function of rolling dips is to catch the runoff and sediment and route them off the trail. The dip is a subtle "hump," usually in an outsloped earthen trail, that serves as a velocity stop for trail runoff and routes it off the trail. The frequency of rolling dips is based on trail width, gradient, surface type, soil erodibility and the proximity and sensitivity of trailside areas that will receive the runoff. A qualified professional should specify the frequency of rolling dips and the angle at which they are placed relative to the tread. Some general guidelines follow:

Rolling dips on earthen trails should be "transparent" to a bike wheel – that is, elongated so that riders roll smoothly through them – and the dips must be angled 45 degrees or so to the travel direction. They must fall at about 20 percent of slope so that they are self-cleaning, meaning that sediments moving in runoff from the trail will be transported off the trail in runoff from the dip. For longevity, particularly to withstand wear by mountain bikes, both the mound and the dip can be internally reinforced with rock and/or armored. General guidelines for spacing of rolling dips are given in the adjacent table.

Scale: Scale is the proportion that a map or aerial photograph bears to the ground it represents. This is usually stated as a ratio. The scale of 7.5-minute topographic map, for example, is 1:24,000, or one map inch represents 24,000 inches on the ground. To be more meaningful, ground inches can be converted to feet or miles. One inch on a 7.5-minute topographic map represents about 2,000 feet on the ground.

Trail grade	Coarse, rocky, gravelly materials	Gravelly sands, silty sandy gravels, coarse extrusive volcanics	Silty clays, clays, fine sandy silty clay, weathered volcanics	Friable silts, fine silts and sands, fine decomposed granitic soils
2%	300 feet	160 feet	136 feet	100 feet
4%	280 feet	145 feet	121 feet	85 feet
6%	250 feet	140 feet	113 feet	75 feet
8%	230 feet	135 feet	106 feet	70 feet
10%	200 feet	125 feet	97 feet	60 feet
12%	175 feet	115 feet	80 feet	50 feet

Recommended spacing of rolling dips or water bars on earthen trails in different materials. (Adapted with permission from the author from Geotechnical/Materials engineering Training Session, by Keller and Vandhurst, USDA Forest Service, Region V., 1982, 2002).

Sediment catch basin: A constructed basin designed to slow water velocity and trap sediment as it settles out of the water. Also see "catch basin."

Sensitive species: A species that is listed under the Endangered Species Act as threatened or endangered, candidate or proposed by the Oregon Department of Fish and Wildlife or is a species of concern for listing.

Shoulder: The surfaced or unsurfaced width of a trail next to the tread, or traveled way.

Stairs: A series of risers and treads used to ascend a slope where a trail on grade would be too steep. A common formula to determine ratios for outdoor stairways is 2R + T = 26 inches to 27 inches, where R = riser and T = tread. This ratio should be held constant for the entire stairway or set of stairs. Rounded stair edges and beveled risers are important for trip avoidance.

Subgrade: The surface of trailbed upon which the base course is constructed.

Sustained grade: A trail grade that is more or less consistent between two points.

Test gradient: A trial gradient that can be plotted between two points by referring to map scale and using dividers.

Trail corridor: The strip of land in which trails and other facilities such as roads and utility lines are built. This includes the tread itself, the shoulder or verge, and the cleared areas beside the trail.

Tread: The portion of the trail that is contacted by feet, wheels and hooves.

Turnpike: A structure that elevates the trail above wet ground on earth fill. Turnpikes can be distinguished from causeways in that ditches are constructed on one or both sides of the trail to provide localized drainage of groundwater. Because such drainage features have the potential to change the groundwater conditions in wetlands, they are no longer favored. Also see "causeway."

Underdrain: A buried trench, filled with coarse aggregate, coarse sand or gravel and typically placed in a ditch line along a trail, which acts to drain subsurface water from a wet area and discharge it in a safe and stable location. Underdrains may use a uniform size or rock, be wrapped in geotextile and have a perforated drain pipe in the bottom of the trench.

Waterbar: A feature placed in earthen trails, typically using mounded earth or countersunk stone or wood, whose purpose is to intercept runoff and route it off the trail. Care must be taken that such features do not pose barriers or safety hazards to users. Typically, waterbar materials are countersunk in the earth, sometimes with a geotextile to prevent undercutting, seepage or piping from undermining the waterbar's stability. Also see "rolling dip."

Selected references
Where to get more detailed information

Contents

- General references on trail planning
- Trail design, construction, materials
- Wildlife and trails
- Fish and fish passage
- Trail access and multiple use
- Policy and regulatory context for environmentally friendly trails
- Environmental permits
- Trail construction and materials for wet areas
- Trail maintenance and management
- Native plant landscaping/xeriscaping/integrated pest management
- Assessment, maintenance and decommissioning of unsurfaced park roads and roads used as trails
- Evaluating erosion and slope stability

General references on trail planning

British Columbia Ministry of Environment. Department of Fisheries and Oceans, Vancouver, B.C. 1997.
Access Near Aquatic Areas: Guide to Sensitive Planning, Design and Management

City of Portland, Ore., Bureau of Parks and Recreation, Bureau of Planning and Development Commission.
1993.
Columbia South Shore Slough Trail Master Plan
1993.
Recommended Draft Natural Resources Protection Plan for the Columbia South Shore
1995.
Columbia South Shore Slough Trail Permit and Contstruction Handbook

Cole, D. N., M. Peterson and R. Lucas. 1987.
Managing Wilderness Recreation Use: Common Problems and Potential Solutions
U.S. Department of Agriculture, Forest Service Intermountain Research Station.

Cole, D. N. 1989.
Low-Impact Recreational Practices for Wilderness and Backcountry
U.S. Department of Agriculture, Forest Service Intermountain Research Station.

Cole, D. N. 1993.
"Minimizing Conflict between Recreation and Nature Conservation"
In Ecology of Greenways: Design and Function of Linear Conservation Areas
D.S. Smith and P.C. Helmund, eds.

East Bay Regional Park District, Oakland, Calif.
1996.
Master Plan for East Bay Regional Park District
1997.
Existing and Potential Parklands and Trails

Flink, C. A., and R. M. Searns and L. Schwartz. 1993.
Greenways: A Guide to Planning, Design and Development
Island Press.

Flink, C. A., and K. Olka and R. M. Searns. 2001.
Trails for the Twenty-First Century: Planning, Design, and Management Manual for Multi-Use Trails
Island Press.

Geunther, K. 1999.
Low Maintenance Roads for Ranch, Fire and Utilities Access
Wildland Solutions Field Guide Series.

Harris, C. and N. T. Dines. 1997.
Time-Saver Standards for Landscape Architecture
McGraw-Hill.

Kurahashi Associates, Inc., Adolfson Inc., M. G. Wilson, A. Shilisky, M. Hayes et al. 1996.
Ancient Forest Preserve Master Plan
Metro Regional Parks and Greenspaces Department, Portland, Ore.

Mertes, J. D. and J. R. Hall. 1996.
Park, Recreation, Open Space and Greenway Guidelines
Alington, Va.: National Recreation and Park Association

Oregon State Parks and Recreation Department. 2003-07.
Oregon Statewide Comprehensive Outdoor Recreation Plan

Otak, Inc. and DKS Association. 2002.
Gresham-Fairview Trail Master Plan
City of Gresham, Ore., Parks and Recreation Division.

Parker, T. S. 1994. Open Space and Trails Program, Pitkin County, Colorado.
Trails Design and Management Handbook 1.1

Stankey, G. H., D. N. Cole, R. C. Lucas, M. E. Petersen and S. S. Frissell. 1985.
The Limits of Acceptable Change (LAC) System for Wilderness Planning
U.S. Forest Service, Intermountain Forest and Range Experiment Station. January 1985.

U.S. Department of Agriculture, Forest Service. 1991.
Forest Service Handbook 2309.18-91-2, Trails Management Handbook.

U.S. Department of Agriculture, Forest Service, Technology and Development Program. 2000.
Trail Construction and Maintenance Notebook
Constructing Trail Switchbacks
In cooperation with U.S. Department of Transportation, Federal Highway Administration

Trail design, construction, materials

Bachensky, L. 2002.
Building Crusher Fines Trails
On American Trails' web site at www.american trails.org/resources/trailbuilding/BuildCrushFinesOne.html
U.S. Forest Service, Rocky Mountain Region.

Bergmann, R. 2000.
Soil Stabilizers on Universally Accessible Trails
00231202
San Dimas, Calif. U.S. Department of Agriculture, San dimas Technology and Development Center.

Birkby, R. C. 1996.
Lightly on the Land. The SCA Trail-Building and Maintenance Manual.
Published by The Mountaineers, Seattle, Wash.

City of Portland, Ore., Bureau of Parks and Recreation. 1992.
Springwater Corridor Trail Surfacing Test Sections

Demrow, C. and D. Salisbury. 1998.
The Complete Guide to Trail Building and Maintenance
Published by Appalachian Mountain Club Books. Boston, Mass.

Metro, Portland, Ore. 2002.
Green Streets: Innovative Solutions for Stormwater and Stream Crossings

Parker, S. T. 2004.
Natural Surface Trails by Design – Physical and Human Design Essentials of Sustainable Enjoyable Trails
Naturescape, Boulder, Colo.

Riter, J. and M. Riter. 2000.
Trailbuilding Basics
International Mountain Bicycling Association.
Online at www.imba.com/resources/trail_building/index.html.

U.S. Department of Agriculture, Forest Service, Technology and Development Program. 2000.
Constructing Trail Switchbacks (video)
2300 Recreation, 00-02-MTDC.

U.S. Department of Agriculture, Forest Service, Technology and Development Program. 1998.
Handtools for Trail Work
2300 Recreation. 8823-2601-MTDC.

U.S. Environmental Protection Agency, Office of Water. 1999.
Stormwater Technology Fact Sheet: Porous Pavement
Online at www.epa.gov.owmitnet/mtb/porouspa.pdf.

Wildlife and trails

Adams, L. W. and L. E. Dove. 1989.
Wildlife Reserves and Corridors in the Urban Environment: A Guide to Ecological Landscape Planning and Resource Conservation
Published by the National Institute of Urban Wildlife.

Cole, D. N. 1993.
"Minimizing Conflict between Recreation and Nature Conservation"
In Ecology of Greenways: Design and Function of Linear Conservation Areas
D.S. Smith and P.C. Helmund, eds.

Cole, D. N. and M. Jeffery. 1988.
Recreational Impacts in Some Riparian Forests of the Eastern United States
Environmental Management 12 (1) pp. 99-107.

Duerksen, C. J. et al. 1997.
Habitat Protection Planning: Where the Wild Things Are
American Planning Association. Planning Advisory Service Report 470/471.

Gaines, W. L, P. H. Singleton and R. C. Ross. 2002.
Assessing the Cumulative Effects of Linear Recreation Routes on Wildlife Habitats on the Okanogan and Wenatchee National Forests
U.S. Department of Agriculture, Wenatchee National Forest.
Online at www.fs.fed.us/r6/wenatchee.

Hellmund, P. C. 1998.
Planning Trails with Wildlife in Mind: A Handbook for Trail Planners
Colorado State Parks, Boulder, Colo.

Leedy, D. L., R. M. Maestro and T. M. Franklin. 1978.
Planning for Wildlife in Cities and Suburbs
U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services. FWS/OBS – 77/66.

Miller, S., Knight, R. and C. Miller. 1997.
Influence of Recreational Trails on Breeding Bird Communities
Ecological Applications: Vol. 8, No. 1, pp. 162-169.

Oregon Historical Society. 2000.
Wild in the City: A Guide to Portland's Natural Areas
Michael C. Houck and M. J. Cody, editors.

U.S. Fish and Wildlife Service and National Marine Fisheries Service. 1998.
Endangered Species Consultation Handbook: Procedures for Conducting Consultation and Conference Activities Under Section 7 of the Endangered Species Act
Online at endangered.fws.gov/consultations/s7hndbk/s7hndbk.htm.

U.S. Forest Service, San Dimas Technology Center et al. 2004.
Wildlife Crossing Toolkit
Online at www.wildlifecrossings.info/beta2.htm.

Washington County Soil and Water Conservation District. 1999.
Enhancing Wildlife Habitat: Tips for Small Acreages in Oregon

Fish and fish passage

Adamson, B. 1998.
Erosion and Sediment Control Practices for Construction Activities at Water Crossings
Ontario Ministry of Natural Resources, Canada.

Bradbury B. and W. Nehlsen, et al. 1995.
Handbook for Prioritizing Watershed Protection and Restoration to Aid Recovery of Native Salmon
Online at www.usbr.gov/mp/regional/battlecreek/bradbury.pdf

Carrasquero, J. 2001.
White Paper: Over-water Structures: Freshwater Issues
Submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology and Washtington Department of Transportation. Hererra Environmental Consultants, Seattle, Wash.
Online at www.wa.gov/wdfw/hab/ahg/finalfrs.pdf.

Castro, J. 2002.
Geomorphic Impacts of Culvert Replacement and Removal
U.S. Fish and Wildlife Service, Portland, Ore.

Robison, G. E., A. Mirati and M. Allen. 1999.
Oregon Road/Stream Crossing Restoration Guide
Online at www.nwr.noaa.gov/1salmon/salmesa/4ddocs/orfishps.htm.

Vaughn, D.M. 2002.
Potential Impact of Road-Stream Crossings (Culverts) on the Upstream Passage of Aquatic Macroinvertebrates
Report submitted to USDA Forest Service San Dimas Technology and Development Center.

Washington Department of Fish and Widlife, Habitat and Lands Program, Environmental Engineering Division. 1999.
Fish Passage at Road Culverts: A Design Manual for Fish Passage at Road Crossings
Online at www.wa.gov/wdfw/hab/engineer/cm/fpdrc.pdf.

Trail access and multiple use

Alta Transportation Co. 2001.
Rails-with-Trails: Best Practices. Phase I: State of the Practice
Prepared for U.S. Department of Transportation.
Online at www.greenways.org (go to technical assistance/online references).

American Association of State Highway and Transportation Officials. 1999.
Guide for the Development of Bicycle Facilities

Beneficial Designs, Inc., Peter W. Axelson, Denise A. Chesney, Dorothy V. Galvan et al.
1999.
Designing Sidewalks and Trails for Access: Part I of II Review of Existing Guidelines and Practices
2001.
Designing Sidewalks and Trails for Access: Part II: Best Practices Design Guide
U.S. Department of Transportation, Federal Highway Administration.
The Universal Trail Assessment Process
Online at www.beneficialdesigns.com/trails/utap.html.

Evans, D. and Associates. 1997.
Gresham Trails Master Plan
City of Gresham, Ore., Parks and Recreation Division.

Moore, R. L. 1994.
Conflicts on Multiple-Use Trails: Synthesis of the Literature and State of the Practice
Technical Report No. FHWA-PD-96_031.

Rails to Trails Conservancy and the Association of Pedestrian and Bicycle Professionals. 1998.
Improving Conditions for Bicycling and Walking, A Best Practices Report
Published by Federal Highway Administration.
Online at www.apbp.org/intro.pdf.

U.S. Department of Transportation, Federal Highway Administration and the National Trails Advisory Committee. 1994.
Conflicts on Multiple-Use Trails: Synthesis of the Literature and State of the Practice

Policy and regulatory context for environmentally friendly trails

Metro, Portland, Ore. 2003.
Revised Draft: Metro's Technical Report for Goal 5

State of Oregon. 2000.
A Guide to Oregon Permits Issued by State and Federal Agencies with a Focus on Permits for Watershed Restoration Activities
Oregon Plan Implementation Team.
Online at www.oweb.state.or.us/pdfs/permitguide.pdf.

U.S. Department of the Interior, U.S. Fish and Wildlife Service, Office of Legislative Services. 1992.
Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service
Online at laws.fws.gov/lawsdigest/indx.html.

U.S. Environmental Protection Agency. Major environmental laws:

- *The National Environmental Policy Act.* 1969.
- *The Endangered Species Act.* 1973.
- *The Clean Water Act.* 1977 Amendment.
- *The Pollution Prevention Act.* 1990.

Online at www.epa.gov/epahome/laws.htm.

U.S. Fish and Wildlife Service and National Marine Fisheries Service. 1998.
Endangered Species Consultation Handbook: Procedures for Conducting Consultation and Conference Activities Under Section 7 of the Endangered Species Act
Online at endangered.fws.gov/consultations/s7hndbk/s7hndbk.htm.

Environmental permits

Adamson, Bruce. 1998.
Erosion and Sediment Control Practices for Construction Activities at Water Crossings
Ontario Ministry of Natural Resources, Canada.

City of Portland, Ore., Bureau of Environmental Services. 1996.
Erosion Control Handbook
Online at www.bds.ci.portland.or.us/inspect/sitedev/Erosion%20Control%20Manual.pdf.

City of Portland, Ore., Bureau of Environmental Services. 1997.
Portland Environmental Handbook

Castro, J. 2002.
Geomorphic Impacts of Culvert Replacement and Removal
U.S. Fish and Wildlife Service.

Oregon, State of. 2001.
The Oregon Plan Toolbox, Watershed Restoration Box
In *The Oregon Plan for Salmon and Watersheds*

Robison, G. E., A. Mirati and M. Allen. 1999.
Oregon Road/Stream Crossing Restoration Guide.
Online at www.nwr.noaa.gov/1salmon/salmesa/4ddocs/orfishps.htm.

Trail construction and materials for wet areas

Bachensky, L. 2002.
Building Crusher Fines Trails
Online at www.americantrails.org/resources/trailbuilding/BuildCrushFinesOne.html.

Hutton, K.E. and S.C. Samis. 2000.
Guidelines to Protect Fish and Fish habitat From Treated Wood Used in Aquatic Environments in the Pacific Region
Habitat and Enhancement Branch, Fisheries and Oceans, Canada.

Lebow, S. T. and M. Tippie. 2001.
Guide for Minimizing the Effect of Preservative-Treated Wood on Sensitive Environments
U.S. Department of Agriculture, Forest Service, Forest Products Laboratory and National Wood in Transportation Information Center in cooperation with the U.S. Department of Transportation and the Federal Highway Administration. General Technical Report FPL-GTR-122.

Monlux, S. 2000.
Geosynthetics for Trails in Wet Areas
U.S. Department of Agriculture. 0023-2838MTDC.
Online at www.fhwa.dot.gov/environment/fspubs/00232838.

Nightengale, B. and C. Simendtad. 2001.
White Paper: Treated Wood Issues Associated with Overwater Structures in Marine and Freshwater Environments
Submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology and Washington Department of Transportation by the University of Washington, School of Aquatic and Fishery Sciences.
Online at www.wa.gov/wdfw/hab/ahg/overwatr.htm.

Steinholtz, R. and B. Vachowski. 2001.
Wetland Trail Design and Construction
U.S. Department of Agriculture. 0123-2833MTDC.
Online at www.fhwa.dot.gov/environment/fspubs/01232833.

Western Wood Preservers Institute and Canadian Institute of Treated Wood. 1996.
Best Management Practices for the Use of Treated Wood in Aquatic Environments
Online at www.wwpinstitute.org/pdffiles/bmpsinaquatic2.pdf.

Trail maintenance and management

Bachensky, L. 2000.
Maintenance Management Systems for Trails
U.S. Forest Service, Rocky Mountain Region.
Online at www.americantrails.org/resources/ManageMaintain/BuildMaintSys.html.

City of Portland, Ore., Bureau of Parks and Recreation. 2001.
Pest Management Program, Waterways Policy
Online at www.portlandparks.org/hort.

East Bay Regional Park District. Undated.
Volunteer Trail Safety Patrol
Online at www.parkpatrol.org.

Hesselbarth, W. 2000.
Trail Construction and Maintenance Notebook
U.S. Department of Agriculure Forest Service.
4E42A25 - Trail Notebook

Neiger, M. 2004.
A Rucksack Primer on Trail Building and Maintenance
Online at therucksack.tripod.com/trailbuilding.htm

U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center. 2002.
Forest Roads and the Environment
Video set (5)

Native plant landscaping/xeriscaping/ integrated pest management

Hirose, J., M. McPhee, P. Van Vlack and S. Weston. 1993.
Naturescaping: A Place for Wildlife
Oregon Department of Fish and Wildlife.
ISBN 0-9635088-4-9.

City of Portland, Ore.
2004.
Portland Plant List
Bureau of Planning.
Online at www.planning.ci.portland.or.us/lib_plantlist.html.
2004.
Integrated Pest Management
Bureau of Parks and Recreation.
Online at www.portlandparks.org/hortservices/ipm.htm.

Assessment, maintenance and decommissioning of unsurfaced park roads and roads used as trails

Casaday, E. and D. Beer. 2000.
Draft Heavy Equipment Operator's Guide to Road Rehabilitation
North Coast Redwoods District of the California Department of Parks and Recreation.

Coffin, B., S. Defoe and C. McKeone. 1999.
Road Decommission Monitoring Report
USDA Forest Service, Gifford Pinchot National Forest, Mt. Adams Ranger District.

Environmental Protection Agency. 2000.
Recommended Practices Manual: A Guideline for Maintenance and Service of Unpaved Roads
Produced by Chocatawatchee, Pea and Yellow Rivers Watershed Management Authority.
Online at www.epa.gov/owow/nps/unpavedroads.html.

Keller, G. and J. Sherar. 2001.
Draft: Low-Volume Road Engineering Best Management Practices Field Guide
USDA Forest Service and USAID.
Online at ntl.bts.gov/lib/24000/24600/24650/Index_BMP_Field_Guide.htm

The Mattole Restoration Council. 1989.
Elements of Recovery: An Inventory of Upslope Sources of Sedimentation in the Mattole River Watershed, with Rehabilitation Prescriptions and Additional Information for Erosion Control Prioritization
California Department of Fish and Game.
Online at www.krisweb.com/biblio/mattole_mrc_xxxxl_1989_elementsrecov.pdf

Mendocino County Resource Conservation District. 1982.
Road Building Guide: Planning, Constructing and Maintaining Ranch, Farm and Homesite Access Roads

Merrill, B. R., and E. Casaday. 2001.
Field Techniques for Forest and Range Road Removal
California State Parks, North Coast Redwoods District, Department of Roads, Trails and Resources Maintenance.

Oregon Department of Forestry. No date.
Road Hazard Inventory Version 1.03
Forest Road Management Guidebook: Maintenance and Repairs to Protect Fish Habitat and Water Quality

Swanson, F., J. Jones, B. Wemple, and K. Snyder. 1999.
Roads in Forest Watersheds – Assessing Effects from a Landscape Perspective
Proceedings of the Seventh Biennial Watershed Management Conference, Charles W. Slaughter, editor.
Water Resources Center Report No. 98, University of California, Davis.

U.S. Department of Agriculture. 1996.
Managing Roads for Wet Meadow Ecosystem Recovery
Publication PB97-116008.

U.S. Department of Agriculture, Forest Service, Northeastern Area, Department of State and Private Forestry. 1998.
A Landowner's Guide to Building Forest Access Roads
NA-TP-06-98.

U.S. Department of Transportation, Federal Highway Administration, South Dakota Local Transportation Assistance Program. 2000.
Gravel Roads Maintenance and Design Manual

U.S. Environmental Protection Agency. 2001.
National Management Measures to Control Nonpoint Source Pollution from Forestry
EPA 841-D-01-002.
Office of Water, Washington D.C.

Washington Department of Ecology. 1999.
Effectiveness of Forest Road and Timber Best Management Practices with Respect to Sediment-Related Water Quality Impacts
Publication 99-317.

Weaver, W. E., and D. Hagans. 1994.
Handbook for Forest and Ranch Roads: A Guide for Planning, Designing, Constructing, Maintaining and Closing Wildland Roads
Pacific Watershed Associates for the Mendocino County Resource Conservation District.

Evaluating erosion and slope stability

Balster, C.A., and R.B Parsons. 1968.
Geomorphology and Soils, Willamette Valley, Oregon
Corvallis, Oregon State University, Agriculture Experiment Station Special Report 265.

Beeson, M. H., T. L. Tolan and I. P. Madin. 1991.
Geologic map of the Portland quadrangle, Multnomah and Washington Counties, Oregon and Clark County, Washington
Oregon Department of Geology and Mineral Industries Map GMS-75, Scale 1:24,000.

Hall, D.E., Long, M.T., Remboldt, M.D., editors. 1994.
Slope Stability Reference Guide for National Forests in the United States
Publication EM-7170-13. Washington, DC: U.S. Department of Agriculture, U.S. Forest Service, Engineering Staff. 3 volumes, 1091 p.
Online at forest.moscowfsl.wsu.edu/engr/ssg/.

Hofmeister, J. R., Y. Wang and D. Keefer. 2000.
Earthquake-Induced Slope Instability: Methodology of Relative Hazard Mapping, Western Portion of the Salem Hills, Marion County, Ore.
Oregon Department of Geology and Mineral Industries Special Paper 30.

Mabey, M. A., G. L. Black, I. P. Madin et al. 1997.
Relative Earthquake Hazard Map of the Portland Metro Region, Clackamas, Multnomah and Washington Counties, Ore.
Oregon Department of Geology and Mineral Industries. Interpretive Map Series 1, issued by State of Oregon.

Mabey, M.A., I.P. Madin, T.L. Youd, and C.F. Jones. 1993.
Earthquake Hazard Maps of the Portland Quadrangle, Multnomah and Washington Counties, Oregon, and Clark County, Washington
Oregon Department of Geology and Mineral Industries. Geological Map Series 79, issued by state of Oregon

Multnomah County Department of Sustainable Development. 2002.
Emergency Management Planning
Online at www.co.multnomah.or.us/dscd/emergency/current%20issues.shtml.

Proctor, R., E. B. Nuhferand and P. H. Mosier. 1993.
The Citizens' Guide to Geologic Hazards
American Institute of Professional Geologists.

Pacific Watershed Associates. 1998.
Aerial Reconnaissance Evaluation of Recent Storm Effects on Upland Mountainous Watersheds of Idaho – Wildland response to recent storms and floods in the Clearwater, Lochsa and Boise River watersheds, Idaho

State of Oregon Land Board. 1988.
Oregon Natural Heritage Plan; Geologic Natural Heritage Features

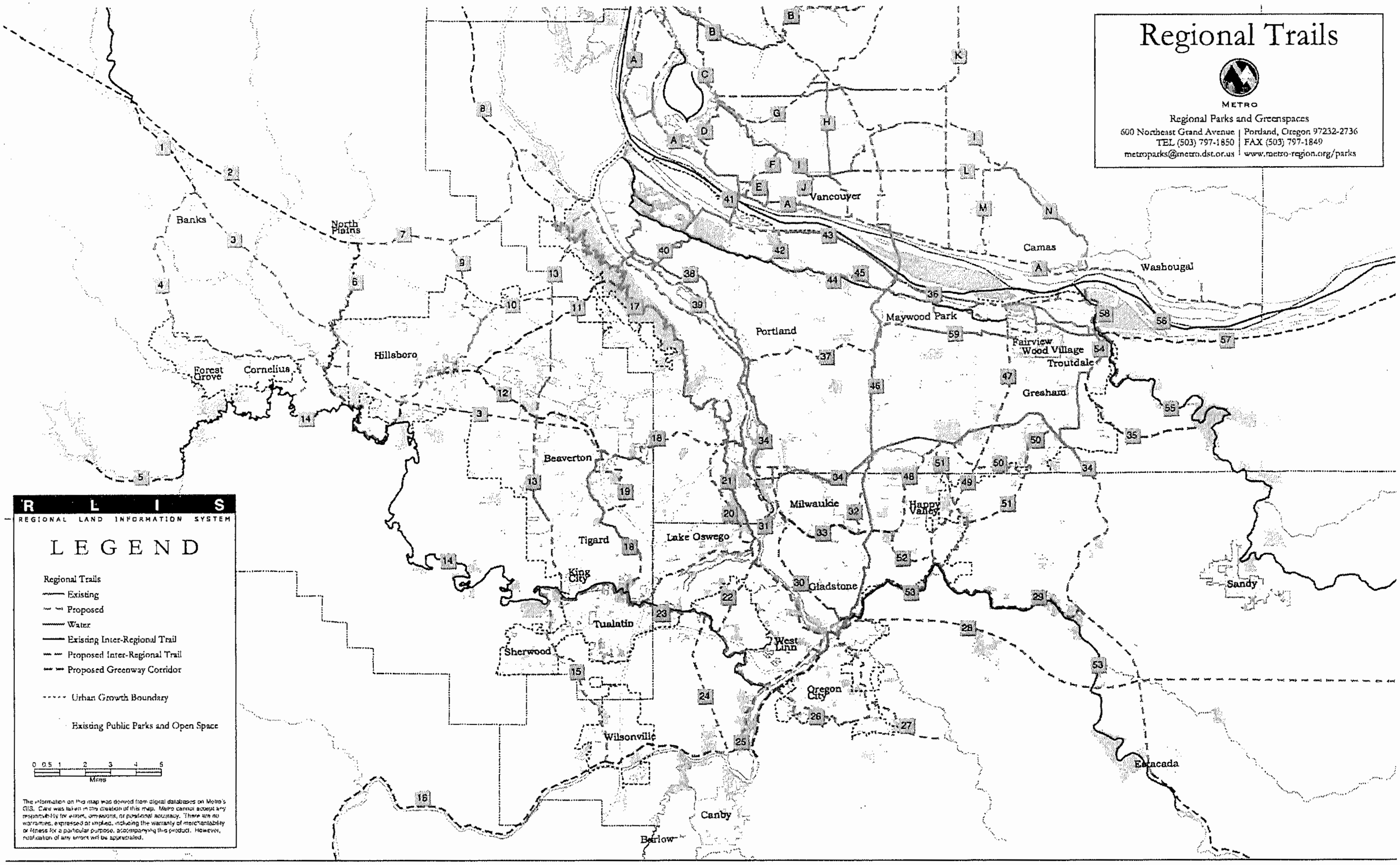
State of Oregon. 1997.
IMS-1: Relative Earthquake Hazard Map of the Portland Metropolitan Region
Department of Geology and Mineral Industries.

Transportation Research Board. 1996.
Landslides: Investigation and Mitigation.
(Special Report 247)
National Research Council. Turner, Keith A. and Robert L. Schuster, editors.

U.S. Department of Agriculture, Soil Conservation Service, West Technical Service Center, Portland, Ore. January 1982.
Geomorphic Surfaces and Soils in Multnomah County

Weaver, W. and D. K. Hagans. 1996.
Aerial Reconnaissance Evaluation of 1996 Storm Effects on Upland Mountainous Watersheds of Oregon and Southern Washington: Wildland response to the February 1996 storm and flood in the Oregon and Washington Cascades and Oregon Coast Range Mountains
Prepared for The Pacific Rivers Council, Eugene, Oregon.

Appendix A – Regional Trails



Appendix B – Sources of Information for Trail Planning

Existing site uses

Sources of information

Neighborhood associations, schools, homeowner associations, youth groups and local walking groups often can provide information about:

- school bus stops and student walking routes
- walk-to-shop routes
- local bike routes
- local walking loops and destinations
- needs for connections and safe crossing sites.

Natural area management entities such as The Nature Conservancy, Port of Portland, municipal parks departments, U.S. Fish and Wildlife Service, Metro's Regional Parks and Greenspaces Department, watershed and friends-of-streams groups and others can provide information about:

- type and season of use
- popular trailheads (and trailhead problems)
- the needs and problems of existing trails.

Municipal public works departments, utility providers and departments of transportation can provide information about utility corridors and rights of way and easements. In some instances, the local community, including watershed groups, could provide information on right of way and local trail access needs.

Natural area plans

Sources of information

Many entities have special natural resource management areas, including:

- U.S. Forest Service
- Bureau of Land Management
- Oregon Parks and Recreation Department
- city, county and regional planning and park departments
- The Nature Conservancy preserves (for example, Camassia Preserve, the Diack Tract in the Sandy River Gorge, etc.)
- Columbia Gorge National Scenic Area
- Port of Portland
- U.S. Army Corps of Engineers
- universities and colleges (for example Reed College's old-growth study site on the Sandy River)
- corporate campuses (for example, Dawson Creek Parkway)

Regional and municipal trails

Sources of information

- Metro's Regional Parks and Greenspaces Department (see especially Metro's 2002 regional trail map)
- Metro's Planning Department and Data Resource Center
- city and county departments of parks, recreation, planning, and transportation
- chambers of commerce and visitor information centers
- Portland Office of Transportation
- Oregon Parks and Recreation Department
- Mt. Hood National Forest
- Bureau of Land Management
- Mazamas, SW Trails (explorepdx.com/swtrails.html), SW Neighborhood, Inc.
- outdoor recreation stores, including REI and Oregon Mountain Community
- map supply stores, including Powell's Travel Store, Oregon

Existing trails

Offering a glimpse of things to come, these regional trails are at least partially completed and open to the public (as of July 2003). They connect neighborhoods, schools, parks and jobs and provide access to nature and opportunities to hike, bike, walk, run and roll. For more information about these trails, visit the Metro web site at www.metro-region.org/parks and click on "regional trails and greenways."

10. *Rock Creek Trail.* From the Tualatin River, this trail parallels Rock Creek and heads northeast through Hillsboro, eventually connecting to the Beaverton Powerline Trail. Several segments are complete.

13. *Beaverton Powerline Trail.* An electric powerline corridor owned by PGE and BPA, this trail route runs from the Tualatin River near the Tualatin Wildlife Refuge north to Forest Park. Currently, some portions of the trail are complete, totaling more than 2 miles of the 16-mile trail.

17. *Wildwood Trail.* This soft-surface pedestrian trail runs the length of Forest Park south to Hoyt Arboretum and Washington Park. From the Vietnam Veterans Memorial near the Oregon Zoo, it continues south as the Marquam Trail to Council Crest Park, Marquam Nature Park and Terwilliger Boulevard. Forest Park's Leif Erikson Drive offers 11 miles of rugged all-weather bicycling.

18. *Fanno Creek Greenway Trail.* This trail begins at Willamette Park on the Willamette River Greenway, just south of downtown Portland. It stretches 15 miles to the west and south through Beaverton, Tigard and Durham, and ends at the Tualatin River in Tualatin. Approximately half of the trail is complete; additional sections are under construction.

21. *Terwilliger Trail and Parkway.* Running along Terwilliger Boulevard in Portland's southwest hills from Duniway Park to Oregon Health and Sciences University campus and George Himes Park, this trail heads south to Lake Oswego and ends at Highway 43 near the Willamette River Greenway.

34. *Springwater Corridor.* The metro area's premier multi-use regional trail. Currently, the improved portion of the Springwater is 17 miles long starting near OMSI and extending along the Willamette River and Oaks Bottom to the Sellwood Bridge. Most of the rest of the route parallels Johnson Creek east to the Clackamas County line in Boring.

38. *Willamette Boulevard Bikeway.* From the Peninsula Crossing Trail in North Portland, this bike trail heads south and east to North Killingsworth Street. The bike lanes are on the bluff above Mocks Bottom and the Willamette River.

40. *Peninsula Crossing Trail.* This 4-mile trail, completed in 2002, crosses the North Portland Peninsula between the Willamette and Columbia rivers. The pedestrian and bike path connects urban neighborhoods to schools, workplaces and natural areas such as Smith and Bybee Lakes Wildlife Area.

41. *I-5 Bridge Trail Crossing.* This trail across the Columbia River connects the regional trail system with Vancouver and Clark County trails.

43. *Lewis and Clark Discovery Greenway Trail.* Marking the historical path of Lewis and Clark along the Columbia River, a vision for the Lewis and Clark Discovery Greenway Trail originated in 1965. Current plans encompass several existing and proposed trail segments on both sides of the Columbia River. On the south side, this includes the Marine Drive and Columbia River levee sections of the 40-Mile Loop. (For more information about this trail, see the "Vancouver/Clark County" section.)

46. *I-205 Corridor Trail.* Adjacent to I-205, this multi-use trail is a major north-south connection between Clackamas, Multnomah and Clark counties. The trail links Oregon City, Gladstone, Portland and Vancouver.

54. *Beaver Creek Canyon Trail.* Located on the east side of Troutdale in Beaver Creek Canyon, this trail traverses Mt. Hood Community College. Some sections of the trail are incomplete. A greenway connecting from the trail to Oxbow Regional Park is envisioned.

59. *I-84 Bikeway.* This bikeway runs along I-84 from I-205 to Fairview.

Proposed trails

Trail planners and community advocates have proposed several future trail projects that are a conceptual part of the regional trails and greenways system. Before decisions are made about trail alignment and appropriate use, there will be a master planning process and many opportunities for public involvement. For more information about the status of these projects, visit the Metro web site at www.metro-region.org/parks and click on "regional trails and greenways."

3. *Turf to Surf Rail with Trail.* This trail will run from downtown Lake Oswego to the Oregon coast. Connections to the coast could be made via the Fanno Creek Greenway Trail, the Banks-Vernonia Trail and/or other railroad corridors and river valleys.

4. *Council Creek Trail.* This trail is planned from the end of the westside MAX light-rail line in Hillsboro west to Banks via Cornelius and Forest Grove, with an additional short trail extension south connecting to the Tualatin River.

7. *Burlington Northern Rail to Trail.* This corridor was originally envisioned to provide public access from Sauvie Island just north of the island bridge, over the Tualatin Mountains to the Tualatin Valley. At this time, a trail option is not likely, since freight train service is currently offered in the corridor.

9. *Oregon Electric Trail.* A southern spur of the Burlington Northern Rail with Trail, this trail will head south to Hillsboro just north of US 26.

15. *Tonquin Trail.* This trail will run south from the Tualatin River National Wildlife Refuge through Sherwood and Wilsonville to the Willamette River Greenway.

19. *Washington Square Regional Center Trail.* This trail will provide a loop around Washington Square on the east side of Highway 217 with connections to the Fanno Creek Greenway Trail.

20. *Hillsdale to Lake Oswego Trail.* A pedestrian-only trail will run from the Hillsdale town center in South-west Portland to downtown Lake Oswego traversing Tryon Creek State Park along the way. It also will provide a connection to the Willamette River Greenway Trail.

22. *River to River Trail.* This trail will connect the Willamette and Tualatin rivers via Wilson Creek and/or Pecan Creek. The trail will begin in Lake Oswego and end in Tualatin.

23. *Lower Tualatin River Greenway Trail.* This trail will run along the Tualatin River from its confluence with the Willamette River west to the Tualatin River National Wildlife Refuge.

24. *Stafford Trail.* This trail will cut though the Stafford Basin from the Tualatin River (near Stafford Road) south to the Willamette River.

25. *Willamette Narrows Greenway Trail.* Part of the Willamette River Greenway vision. This trail will run along the west side of the Willamette River from the mouth of the Tualatin (south of Willamette Park in West Linn) to land purchased by Metro near the Canby Ferry.

26. *Oregon City Loop Trail.* This trail will create a loop around the perimeter of Oregon City. It will cut through Newell Creek Canyon, connect to the Beaver Lake Trail and skirt the southern edge of the city on its way back to the Willamette River across from its confluence with the Tualatin River.

27. *Beaver Lake Trail.* Beginning at the End of the Oregon Trail Center in Oregon City, this trail will head south on the east side of Newell Creek Canyon and east to Beaver Lake.

28. *Oregon Trail-Barlow Road.* This trail will follow the pioneer wagon train route from the Cascades west to the End of the Oregon Trail Center in Oregon City.

30. *Trolley Trail.* This trail corridor follows a former streetcar line extending south from Milwaukie through Gladstone. Metro and North Clackamas Parks and Recreation District acquired the 6-mile trail corridor and are currently planning trail construction.

31. *Willamette Shoreline Trolley Rail with Trail.* Part of the Willamette River Greenway vision. This trail will run along a former streetcar line corridor from Willamette Park in Portland to downtown Lake Oswego between Highway 43 and the Willamette River. The planned use for this right of way is a future rail transit project. Where there is room for both, the trail is proposed as a "rails-with-trail" project.

Water trails

Trails in rivers and other waterways offer a unique view of the nature of the region. Developing water trails means providing access points for canoes, kayaks, boats and rafts. To find out more about the status of these efforts, visit the Metro web site at www.metro-region.org/parks and click on "regional trails and greenways."

14. *Tualatin River Water Trail.* This water trail has become very popular during the past several years thanks, in part, to the efforts of the Tualatin Riverkeepers. Several excellent launch sites are operated by local jurisdictions: Rood Bridge Park in Hillsboro, Cook Park in Tigard and Brown's Ferry Park in Tualatin. Open space properties acquired by Metro along the Tualatin River will serve as additional future access points. This water trail runs from the Tualatin's confluence with the Willamette River west toward Hagg Lake.

44. *Columbia Slough Water Trail.* A water trail running from the confluence with the Willamette River east to Fairview Lake. Points of interest along the water trail include Kelley Point Park, Smith and Bybee lakes and Whitaker Ponds. Addi-tional launch sites will be developed.

53. *Clackamas River Trail.* A water trail running from Estacada west to the confluence of the Clackamas and Willamette rivers.

55. *Sandy River Gorge Water Trail.* This will be a trail on the water connecting Oxbow Regional Park and Dabney State Park with the Sandy River delta on the Columbia River at Lewis and Clark State Park.

56. *Lower Columbia River Water Trail.* The Lower Columbia River Water Trail encompasses the 146 free-flowing river miles of the Columbia River from Bonneville Dam to the ocean.

Greenways

Greenways generally follow rivers and streams and may or may not provide for public access. In some cases, greenways may be a swath of protected habitat along a stream with no public access.
In other cases, greenways may allow for an environmentally compatible trail, viewpoint or canoe launch site. For more information about these greenways, visit the Metro web site at www.metro-region.org/parks and click on "regional trails and greenways."

5. *Hagg Lake Greenway.* Beginning in the foothills of the Coast Range at Hagg Lake, this greenway will head east along Scoggins Creek connecting to the Tualatin River.

6. *McKay Creek Greenway.* From the confluence with the Tualatin River, this greenway runs north through Hillsboro to the confluence with Dairy Creek and continues to North Plains.

11. *Bronson Creek Greenway.* From the confluence with Beaverton Creek, this greenway heads east and crosses the ridge of the Tualatin Mountains linking with the trail system in Forest Park.

12. *Beaverton Creek Greenway.* From the confluence of Beaverton and Bronson Creek, the Beaverton Creek Greenway connects with the Fanno Creek Greenway Trail at Highway 217 near Southwest Allen Boulevard.

29. *Clackamas River Greenway.* This greenway will provide limited public access on the north side of the Clackamas River from the Willamette River east to Barton Park.

33. *North Clackamas Greenway.* Beginning at the Milwaukie waterfront, this greenway will generally follow Kellogg Creek and Mt. Scott Creek east to the I-205 Trail and end at the Mt. Scott Trail.

35. *Beaver Creek Canyon Greenway.* This greenway will follow Beaver Creek Canyon east from where the trail ends in Troutdale, toward Oxbow Regional Park.

58. *Sandy River Gorge Greenway.* This greenway will follow the Sandy River from Dabney State Park to its confluence with the Columbia.

Vancouver/Clark County regional trails

A growing network of regional trails is taking shape on the north side of the Columbia River in Vancouver and Clark County, Wash.
For more information about the Vancouver/Clark County trail system, visit www.ci.vancouver.wa.us/parks-recreation.

A. *Lewis and Clark Discovery Greenway Trail.* A multi-use trail stretching 38 miles along the Columbia River from Ridgefield National Wildlife Refuge to Steigerwald National Wildlife Refuge. Approximately 12 miles of trails are complete on the Washington side, including trails from Ester Short Park to Wintler Community Park and between the Columbia Springs Environmental Education Center and the I-205 Bridge. (For information about trails on the south side of the Columbia, see the "Existing Trails" section.)

B. *Salmon Creek Greenway and Trail.* This trail runs along the south side of Salmon Creek and the Salmon Creek Greenway to Klineline Pond and Salmon Creek Park and will continue east along the creek toward Battle Ground. The western portion of the trail is complete.

C. *Lakeshore Trail.* Lakeshore Trail parallels the northeast side of Vancouver Lake on Lakeshore Drive connecting Burnt Bridge Creek Greenway Trail and Fruit Valley Trail to Salmon Creek Greenway and Trail.

D. *Fruit Valley Trail.* This trail will make up part of the Vancouver Lake Loop. Located in the east Vancouver Lake Lowlands, this trail will connect Burnt Bridge Creek to the Lewis and Clark Greenway Discovery Trail.

E. *Discovery Historic Loop Trail.* This well-traveled urban loop trail connects Fort Vancouver National Historic Reserve, Officers Row National Historic District, Columbia River Waterfront, old downtown Vancouver and the I-5 Bridge.

F. *St. John's Trail.* This bike path or trail will connect Burnt Bridge Creek Trail to Central Park.

G. *Lewis and Clark Rail with Trail.* Envisioned as a rail-with-trail project, this trail will begin on the east side of Vancouver Lake at Burnt Bridge Creek north and east across the county to Chelatchie Prairie.

H. *Lieser/Andresen Trail.* This trail makes up a major north/south connection through Vancouver. Beginning at 88th Street, the northern portion follows along Andresen Road to David Douglas Park where it jogs east to follow Lieser Road to Lieser Point and the Columbia River. Major sections along Andresen Road are complete.

I. *Burnt Bridge Creek Greenway and Discovery Trail.* Starting on the east side of Vancouver Lake and running east along Burnt Bridge Creek. The western portions of the greenway trail are completed.

J. *Blanford Canyon Trail.* This trail will connect Burnt Bridge Creek Greenway to Evergreen Boulevard.

K. *164th Avenue Trail.* A major north/south connection, this trail runs along 164th Avenue from the northern side of Vancouver to the Columbia River. Major portions of the trail are complete.

L. *Bonneville Reach Discovery Trail.* This trail will connect Burnt Bridge Creek to Lacamas Heritage Trail by way of the 18th Street powerline corridor.

M. *Fisher Basin Trail.* This trail will run from the Bonneville Reach Discovery Trail to the Columbia River.

N. *Lacamas Heritage Trail.* This mostly completed trail runs adjacent to Goodwin Road from Lacamas Creek to the Washougal Greenway.

Inter-regional trails

The proposed inter-regional trails will connect the Portland metropolitan region to other areas, such as the Columbia River Gorge, Mt. Hood National Forest, Pacific Coast and Willamette Valley.

1. *Banks to Vernonia Trail.* This multi-use trail connects Banks and Vernonia. Managed by the state of Oregon, the trail is open to all non-motorized uses – horse-back riding, biking, walking, etc.

2. *Portland to the Coast Trail.* A long-range vision for a trail connecting the Portland metropolitan area to the Pacific coast.

8. *Pacific Greenway.* A long-range vision for a greenway connecting the Portland metropolitan area to the ocean at Astoria.

16. *Willamette River Greenway.* Part of the Willamette River Greenway vision. This segment of the trail extends well beyond the Portland metro area south to Eugene.

57. *Lower Columbia Gorge Trail.* A trail through the Columbia River Gorge from the Sandy River will connect to other trails and recreation opportunities at state and national parks in the gorge.

drologic unit code. Go to nppc.bpa.gov to review this data (further explanation under sources of data on hydrology and water resources).

- Clean Water Services has collected data on all the streams in its jurisdiction. Visit www.cleanwaterservices.org and follow links to the Healthy Streams Plan.
- Contact Metro's Planning Department for a list of culverts that are barriers to fish passage.
- Federal, state and some local departments of transportation have information about blockages to fish passage in their jurisdictions.
- The Student Watershed Research Project at Saturday Academy, Portland State University, has a network of member schools with sampling sites and years of data. Visit www.ogi.edu/satacad/. Also, the Northwest Region office of the Oregon Department of Environmental Quality may have prior years' data.
- Students in Mt. Hood Community College's Fisheries and Integrated Natural Resources Technology programs inventory various attributes of streams as part of the Watershed Research and Assessment Program. Visit summit-ecampus.org/watershed.
- Many watershed councils and friends of streams groups have commissioned studies of fish, instream habitats and stressors to them.
- The city of Portland and ODFW are cooperating in an ongoing study on how fish use the Willamette River in Portland. Data are available through the city of Portland's Endangered Species Program.
- Oregon Department of Environmental Quality (DEQ) maintains databases on macroinvertebrates in selected streams. The DEQ also has detailed information about selected stream segments that do not meet federal water quality standards. Also refer to the section in this chapter on hydrology and water resources.

Hydrology and water resources

Sources of data

- The U.S. Army Corps of Engineers maintains detailed mapped information about the location of the 100-year flood elevation for all major rivers and many major streams of the region. Floodplain maps also can be obtained from the Federal Emergency Management Agency at www.fema.gov.
- The U.S. Geologic Survey maintains watershed maps down to fifth-field hydrologic units, which are named using a hydrologic unit code, or HUC. The HUC identifies the basin, sub-basin, watershed and sub-watershed in which the drainage is located. Acreage for each hydrologic unit also is given, together with flow data, if available, and information about the presence of cold-water fish habitat in the system. This information is available online at the USGS web site at www.usgs.gov.
- The Oregon Department of Water Resources produces watershed maps down to the fifth-field hydrologic unit. For information about ordering, go to www.wrd.state.or.us.
- Metro has mapped watersheds (down to sixth field unit) and streams, wetlands and their associated riparian zones for the entire region. These can be accessed at www.metro-region.org/pssp.cfm?ProgServID=7.
- Clean Water Services has done extensive hydrologic and hydraulic modeling within its jurisdiction, and this data is available at www.cleanwaterservices.org.
- The Multnomah County Drainage District has hydrologic data for the Columbia Slough.
- Every few years, Bergman Photographic Services flies the Portland metropolitan region to produce a set of color infrared photos. These are especially helpful in distinguishing wetter areas from those that are better drained. Contact Bergman at www.mapps.org/capabilities/or.htm.
- The Port of Portland maintains extensive files on the type and location of wetlands at its holdings for air and sea terminals in the region.

Vegetation and wildlife habitat

Sources of data

- The Oregon Department of Fish and Wildlife, U.S. Fish and Wildlife Service and NOAA Fisheries maintain information about state and federally listed species.
- The Bonneville Power Administration maintains a web site (nppc.bpa.gov) that has a searchable database on habitat for resident and anadromous fish species where users may generate maps.
- Federal land management agencies such as the U.S. Forest Service, Bureau of Land Management, USDA Natural Resources Conservation Service and others such as the Port of Portland maintain aerial photo archives for their lands.
- Many watershed councils maintain aerial photo files.
- The US Army Corps of Engineers maintains photo archives of the region's major waterways and adjacent lands.
- If the site includes privately owned forestland, aerial photos and/or habitat maps might be available through the Oregon Department of Forestry.
- Metro's Data Resource Center has maps, aerial photos and GIS data such as a high-resolution set of aerial photos for Multnomah, Clackamas and Washington counties.
- Metro's Planning Department has mapped the location of sensitive wildlife habitat in the region.
- Metro's Regional Parks and Greenspaces Department maintains a library of management plans for selected regional greenspaces, for which habitat mapping may have been done.
- Clean Water Services has a database of vegetation and wildlife habitat information as part of the agency's Watersheds 2000 program.
- The city of Portland has inventoried natural resource areas and published this information in detailed reports that describe the functional values of the resource sites.
- Aerial photos and habitat maps for special studies and natural area management plans may available through the planning departments of counties and cities.
- Colleges and universities may have databases of vegetation and/or habitat information associated with long-term or special studies in particular areas.
- The Student Watershed Research Project through the Oregon Graduate Institute's Saturday Academy program has developed vegetation and habitat maps for a number of sites throughout the region.
- Bergman's, Northern Light, Spencer Gross and WAC are private sources of aerial photography.
- The Oregon Natural Heritage Program maintains information about the locations of threatened, endangered or sensitive plants at oregonstate.edu/ornhic/ORNHP.html.
- Willamette Basin Habitat Conservation Priorities maintains information about declining habitat in the Willamette Basin at www.oregonwri.org.

Fish habitat

Sources of data

Many factors influence fish and their habitats. The following organizations maintain data bases on habitat elements for fish:

- NOAA Fisheries maintains information on fish listings, maps of critical habitats and other updates on fish issues. Go to www.nwr.noaa.gov for this information.
- The ODFW maintains a regional fisheries database in GIS that can be accessed at oregonstate.edu/dept/nrimp/information/index.htm.
- The Oregon Natural Heritage Program also maintains data bases on sensitive species. Visit oregonstate.edu/ornhic/ORNHP.html.
- ODFW undertakes fisheries surveys of various kinds for many of the cities and counties in the region, so data on fish presence, spawning, habitat and macroinvertebrates is often available through local municipalities.
- The Bonneville Power Administration maintains a searchable, scalable database on the presence of anadromous fish in the region, which is accurate down the sixth-field hy-

- The U.S. Fish and Wildlife Service maintains mapped information about the presence and type of wetlands developed from high-altitude aerial photographs. This information is plotted on 7.5-minute U.S. Geologic Survey topographic maps. The maps can be ordered online through the Oregon Division of State Lands at statelands.dsl.state.or.us.
- More detailed information about wetlands is usually available at local planning departments, due to local studies undertaken to meet state requirements for local wetland planning.
- Stormwater system maps and specialized hydrologic studies also are available at city and county offices.
- The Oregon Department of Environmental Quality maintains a database of stream quality known as the 303(d) list. It is available at www.deq.state.or.us/wq.
- Stream gauge data is available from the Portland district office of the U.S. Geological Survey, and can be ordered at oregon.usgs.gov/pubs_dir/rptsinfo.html. Hard copies of Statistical Summaries of Streamflow in Oregon and Oregon Water Resources Data for the current water year can be picked up at the district's East Portland office at 10615 SE Cherry Blossom Drive.

Soils and geology

Sources of information

- The U.S. Geological Survey is a rich source of geologic studies and mapped geological information. Many documents can be downloaded at www.usgs.gov.
- The USDA Natural Resources Conservation Service has put its entire library of county soils surveys online at soils.usda.gov. Hard copies of county soils surveys can be obtained at the county offices of Soil and Water Conservation Districts.
- The USDA Forest Service has mapped the soils and geology of many watersheds and prepared special studies of selected sites.
- The Oregon Department of Geology and Mineral Industries has published earthquake and landslide hazard maps and other relevant geologic information of all types for the region. They can be purchased at the Nature of Oregon store in the Oregon State Building on Northeast Oregon Street, Portland.
- The Oregon Department of Transportation undertakes geologic studies for particular projects.
- The city of Portland has mapped potential landslide areas. This information is available on Portland's web site at www.portlandmaps.com.
- The Portland State University geology department maintains a library of geologic studies by students and professors.
- Maps designating natural hazard zones, steep slopes and floodplains are available in hard copy or electronically through county planning departments and Metro.
- Watershed councils are becoming repositories for this kind of data.
- Important information about soils and geology also can be interpreted from aerial photos and topographic maps.

Topography

Sources of information

- City and county planning departments have electronic databases of topographic information. The quarter-section maps maintained by many municipalities commonly show ground surface elevations at contour intervals of 1 to 10 feet.
- The U.S. Geological Service has 15-minute topographic maps at a scale of 2.6 inches to the mile. These can be ordered online at www.usgs.gov/.
- Metro's Data Resource Center also has topographic information for the region, which can be obtained as electronic files or printed maps.
- The Portland District of the U.S. Army Corps of Engineers

maintains flood hazard maps for the region.

- Municipal and state departments of transportation sometimes have topographic information for the surveyed rights of way of streets and highways.

Restoration

Sources of data

To identify restoration opportunities other than re-vegetation projects at the landscape scale requires data of the sort that many resource agencies may only be beginning to collect. However, some agencies have identified and prioritized restoration projects and they may administer federal, state or local laws specific to natural resource restoration.

Watershed councils increasingly are developing watershed plans and initiating studies to develop lists of potential restoration projects.

Metro has region-wide data about culverts that pose barriers to fish passage and wildlife crossing.

Clean Water Services' Watersheds 2000 stream inventory identifies sources that degrade streams.

Cities and counties with stormwater system licenses are required to identify non-point and point sources that degrade streams.

Oregon Department of Fish and Wildlife may have data about culverts that limit fish passage and about road segments with high mortality records for wildlife.

City, county and special recreation districts, parks and greenspaces managers may have identified restoration opportunities particularly in natural resource management plans.

Neighborhood, watershed and advocacy groups may have information about restoration opportunities in their areas.

U.S. Fish and Wildlife Service. The service manages several restoration grant programs, including the greenspaces program administered in partnership with Metro, and can provide technical assistance for restoration projects.

Oregon Watershed Enhancement Board has sponsored watershed improvement projects for many years and has developed a series of guidelines available in "The Watershed Toolbox."

Appendix C – Sensitive species list and riparian area widths

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8] WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
A	Cope's Giant Salamander	*Dicamptodon copei*	R	None	SU	G3/S2	2	XX	X		XX					
A	Columbia Torrent Salamander	*Rhyacotriton kezeri*	R	None	SC	G3/S3	2	XX			XX	X				
A	Cascade Torrent Salamander	*Rhyacotriton cascadae*	R	None	SV	G3/S3	2	XX			XX	X				
A	Clouded Salamander	*Aneides ferreus*	R	None	SU	G3/S3	3					X	X		X	X
A	Oregon Slender Salamander	*Batrachoseps wrighti*	R	SoC	SU	G4/S3	1	X			X	X				
A	Western Toad	*Bufo boreas*	R	None	SV	G4/S4	4	XX	XX	XX	XX	X	X	X	X	X
A	Tailed Frog	*Ascaphus truei*	R	SoC	SV	G4/S3	2	XX			XX	X				
A	Northern Red-legged Frog	*Rana aurora aurora*	R	SoC	SV/SU	G4T4/S3	2	XX	XX	XX	XX	XX	X	X	X	X
(A)	(Oregon Spotted Frog - extirpated)	*Rana pretiosa*	R	C	SC	G2G3/S2	1	(XX)	(XX)	(XX)	(XX)	(X)	(X)	(X)	(X)	
R	Painted Turtle	*Chrysemys picta*	R	None	SC	G5/S2	2	XX	XX	XX	X		X		X	X
R	Northwestern Pond Turtle	*Clemmys marmorata marmorata*	R	SoC	SC	G3T3/S2	1	XX	XX	XX	XX	X	X	X	X	X
R	Sharptail Snake	*Contia tenuis*	R	None	SV	G5/S3	4	X			X	X	X	X	X	X
B	Horned Grebe	*Podiceps auritus*	W / M	None	SP	G5/S2B, S5N	2	XX	XX	XX						
(B)	(California Condor - extirpated)	*(Gymnogyps californianus)*	R	LE	None	G1SX	1-ex	(X)			(X)			(X)		
B	Dusky Canada Goose	*Branta canadensis occidentalis*	W / M	None	None	G5T2T3/ S2N	4	XX	XX	XX	X				XX	
B	Aleutian Canada Goose (wintering)	*Branta canadensis leucopareia*	W / M	LT	LE	G5T3/S2N	1	XX	XX	XX	X				XX	
B	Harlequin Duck	*Histrionicus histrionicus*	W / M	SoC	SU	G4/S2B, S3N	2	XX	XX		XX					
B	Bufflehead	*Bucephala albeola*	W / M	None	SU	G5/S2B,S5N	4	XX	XX	XX	X					
B	Barrow's Goldeneye	*Bucephala islandica*	W / M	None	SU	G5/S3B,S3N	4	XX	XX	X						
B	White-tailed Kite (appears to be undergoing range expansion)	*Elanus leucurus*	W / M	None	None	G5/S1B, S3N	2	X			X	X		X	XX	
B	Bald Eagle[9]	*Haliaeetus leucocephalus*	S	LT[9]	LT	G4/S3B, S4N	2	XX	XX	X	X	X	X	X	X	X
B	Northern Goshawk	*Accipiter gentilis*	W / M	SoC	SC	G5/S3	2	X		X	X	X	X			
B	Merlin	*Falco columbarius*	W / M	None	None	G5/S1B	2	X	X	X	X	X		X	X	X
B	American Peregrine Falcon	*Falco peregrinus anatum*	N	None	LE	G4T3/S1B	2	X	X	X	X	X	X	X	X	X
(B)	(Mountain Quail - extirpated)	*Oreortyx pictus*	R / S	SoC	SU	G5/S4?	4	(X)			(X)	(X)	(X)		(X)	(X)
B	Band-tailed Pigeon	*Columba fasciata*	S	SoC	None	G5/S4	4	XX			XX	XX	XX		X	X
B	Northern Pygmy-owl	*Glaucidium gnoma*	R	None	SC	G5/S4?	4	X		X	X	XX	X		X	X
(B)	(Northern Spotted Owl - extirpated from Metro region)	*(Strix occidentalis caurina)*	(S)	LT	LT	G3T3S3	1					(XX)	(X)			
B	Common Nighthawk (nearly extirpated)	*Chordeiles minor*	N	None	SC	G5/S5	4	X	X	X	X	X	X	X	X	X
B	Lewis's Woodpecker (extirpated as breeding species)	*Melanerpes lewis*	W / M	SoC	SC	G5/S3B, S3N	4	X			X		XX	X	X	X
B	Acorn Woodpecker	*Melanerpes formicivorus*	R	SoC	None	G5/S3?	4						XX	X		X
B	Pileated Woodpecker	*Dryocopus pileatus*	R	None	SV	G5/S4?	4	X			X	X	X		X	X
(B)	(Yellow-billed Cuckoo; extirpated)	*Coccyzus americanus*	N	SoC	SC	G5/S1B	2	(XX)			(XX)					
B	Olive-sided Flycatcher	*Contopus cooperi (= borealis)*	N	SoC	SV	G5/S4	4	X			X	XX				
B	Willow Flycatcher (western OR race)	*Empidonax traillii brewsteri*	N	None	SV	G5TU/S1B	4	XX			XX	X	X		X	X
B	Streaked Horned Lark	*Eremophila alpestris strigata*	S	SoC	SC	G5T2/S2?	2							XX	X	X
B	Purple Martin	*Progne subis*	N	SoC	SC	G5/S3B	2	XX	XX	X	X	X	X	X		X
B	Western Bluebird	*Sialia mexicana*	S	None	SV	G5/S4B, S4N	4					X	XX	X	X	X
B	Yellow-breasted Chat	*Icteria virens*	N	SoC	SC	G5/S4?	4	XX			XX	X	X		X	
B	Oregon Vesper Sparrow	*Pooecetes gramineus affinis*	S / N	SoC	SC	G5T3/S2B, S2N	2							XX	XX	
B	Tricolored Blackbird	*Agelaius tricolor*	S	SoC	SP	G3/S2B	2	XX		XX		–	-		X	
B	Western Meadowlark (extirpated as breeding species)	*Sturnella neglecta*	W / M	None	SC	G5/S5	4	X		X				XX	XX	
M	Yuma Myotis	*Myotis yumanensis*	R / S	SoC	None	G5/S3	4	X	X	X	X	X	X	X	X	X
M	Long-legged Myotis	*Myotis volans*	R / S	SoC	SU	G5/S3	4	X	X	X	X	XX	X	X	X	X
M	Fringed Myotis	*Myotis thysanodes*	R / S	SoC	SV	G4G5/S2?	2	X	X	X	X	X	X		X	X
M	Long-eared Myotis	*Myotis evotis*	R / S	SoC	SU	G5/S3	4	X	X	X	X	X	X	X	X	X
M	Silver-haired Bat	*Lasionycteris noctivagans*	L	SoC	SU	G5/S4?	4	X	X	X	X	XX	X	X	X	X
M	Hoary Bat	*Lasiuris cinereus*	L	None	None	G5/S4?	4	X	X	X	X	X	X	X	X	X
M	Pacific Western Big-eared Bat	*Corynorhinus townsendii townsendii*	R / S	SoC	SC	G4T3T4/S2?	2	XX	XX	X	X	X	X	X	X	X
M	Western Gray Squirrel	*Sciurus griseus*	R	None	SU	G5/S4?	3					X	XX		X	X
M	Camas Pocket Gopher	*Thomomys bulbivorus*	R	SoC	None	G3G4/S3 S4	3							X	XX	X
M	White-footed Vole	*Arborimus (= Phemacomys) albipes*	R	SoC	SU	G3G4/S3	4	X			X	X				
M	Red Tree Vole	*Arborimus (= Phenacomys) longicaudus*	R	SoC	None	G3G4/S3S4	3	X			X	XX	XX			
(M)	(Grizzly Bear)	*(Ursus arctos)*	(R)	LT	None	G4/SX	2-ex	(X)			(X)	(X)		(X)		
(M)	(Columbian White-tailed Deer)	*(Odocoileus virginiana leucurus)*	(R)	LE	SV	G5T2QS2	1	(X)		(X)	(X)	(X)	(XX)	(X)	(X)	(X)

Sensitive Species List Key

*	Indicates species that are non-native (also known as alien or introduced) to the Metro region.
( )	Parentheses indicate a species that was historically present but was extirpated from the Metro region within approximately the last century.
1	Code (type of animal) **A** = Amphibians **B** = Birds **F** = Fish **M** = Mammals **R** = Reptiles
2	Migratory status (indicates trend for the majority of a given species in the Metro region) **A** = Anadromous (fish; lives in the ocean, spawns in fresh water) **C** = Catadromous (fish; lives in fresh water, spawns in the ocean) **M** = Migrates through area without stopping for long time periods **N** = Neotropical migratory species (birds; majority of individuals breeding in the Metro region migrate south of U.S./Mexico border for winter) **R** = Permanent resident (lives in the area year-round) **S** = Short-distance migrant (from elevational to regional migration, e.g., across several states) **W** = Winters in the Metro region
3	Federal status (based on current Endangered Species Act listings) **E** = Endangered. Endangered taxa are those that are in danger of becoming extinct within the foreseeable future throughout all or a significant portion of their range. **T** = Threatened. Threatened taxa are those likely to become endangered within the foreseeable future. **LE** = Listed endangered. Taxa listed by the U.S. Fish and Wildlife Service (USFWS) or the National Marine Fisheries Service (NMFS), as Endangered under the Endangered Species Act (ESA), or by the Departments of Agriculture (ODA) and Fish and Wildlife (ODFW) of the state of Oregon under the Endangered Species Act of 1987 (OESA). **LT** = Listed threatened. Taxa listed by the USFWS, NMFS, ODA, or ODFW as Threatened. **PE** = Proposed endangered. Taxa proposed by the USFWS or NMFS to be listed as Endangered under the ESA or by ODFW or ODA under the OESA. **PT** = Proposed threatened. Taxa proposed by the USFWS or NMFS to be listed as Threatened under the ESA or by ODFW or ODA under the OESA. **C** = Candidate taxa for which NMFS or USFWS have sufficient information to support a proposal to list under the ESA, or that is a candidate for listing by the ODA under the OESA. **SoC** = Species of concern. Former C2 candidates that need additional information in order to propose as Threatened or Endangered under the ESA. These are species that USFWS is reviewing for consideration as Candidates for listing under the ESA.
4	State status (based on current Oregon Department of Fish and Wildlife "Oregon Sensitive Species List," 2001) **SC** (critical) = Species for which listing as threatened or endangered is pending; or those for which listing as threatened or endangered may be appropriate if immediate conservation actions are not taken. Also considered critical are some peripheral species that are at risk throughout their range, and some disjunct populations. **SV** (vulnerable) = Species for which listing as threatened or endangered is not believed to be imminent and can be avoided through continued or expanded use of adequate protective measures and monitoring. In some cases the population is sustainable, and protective measures are being implemented; in others, the population may be declining and improved protective measures are needed to maintain sustainable populations over time. **SP** (peripheral or naturally rare) = Peripheral species refer to those whose Oregon populations are on the edge of their range. Naturally rare species are those that had low population numbers historically in Oregon because of naturally limiting factors. Maintaining the status quo for the habitats and populations of these species is a minimum requirement. Disjunct populations of several species that occur in Oregon should not be confused with peripheral. **SU** (undetermined status): Animals in this category are species for which status is unclear. They may be susceptible to population decline of sufficient magnitude that they could qualify for endangered, threatened, critical or vulnerable status, but scientific study will be required before a judgement can be made.

5	ORNHP Rank (ABI – Natural Heritage Network Ranks): ORNHP participates in an international system for ranking rare, threatened and endangered species throughout the world. The system was developed by The Nature Conservancy and is maintained by The Association for Biodiversity Information (ABI) in cooperation with Heritage Programs or Conservation Data Centers (CDCs) in all 50 states, in four Canadian provinces, and in 13 Latin American countries. The ranking is a 1-5 scale, primarily based on the number of known occurrences, but also including threats, sensitivity, area occupied, and other biological factors. On Metro's species list the first ranking (rank/rank) is the Global Rank and begins with a "G". If the taxon has a trinomial (a subspecies, variety or recognized race), this is followed by a "T" rank indicator. A "Q" at the end of this ranking indicates the taxon has taxonomic questions. The second ranking (rank/rank) is the State Rank and begins with the letter "S". The ranks are summarized below. **1** = Critically imperiled because of extreme rarity or because it is somehow especially vulnerable to extinction or extirpation, typically with five or fewer occurrences. **2** = Imperiled because of rarity or because other factors demonstrably make it very vulnerable to extinction (extirpation), typically with 6-20 occurrences. **3** = Rare, uncommon or threatened, but not immediately imperiled, typically with 21-100 occurrences. **4** = Not rare and apparently secure, but with cause for long-term concern, usually more than 100 occurrences. **5** = Demonstrably widespread, abundant and secure. **H** = Historical occurrence, formerly part of the native biota with the implied expectation that it may be rediscovered. **X** = Presumed extirpated or extinct. **U** = Unknown rank. **?** = Not yet ranked, or assigned rank is uncertain.

6	ORNHP List is based on Oregon Natural Heritage Program data. **List 1** contains taxa that are threatened with extinction or presumed to be extinct throughout their entire range. **List 2** contains taxa that are threatened with extirpation or presumed to be extirpated from the state of Oregon. These are often peripheral or disjunct species that are of concern when considering species diversity within Oregon's borders. They can be very significant when protecting the genetic diversity of a taxon. ORNHP regards extreme rarity as a significant threat and has included species that are very rare in Oregon on this list. **List 3** contains species for which more information is needed before status can be determined, but which may be threatened or endangered in Oregon or throughout their range. **List 4** contains taxa which are of conservation concern but are not currently threatened or endangered. This includes taxa that are very rare but are currently secure, as well as taxa that are declining in numbers or habitat but are still too common to be proposed as threatened or endangered. While these taxa currently may not need the same active management attention as threatened or endangered taxa, they do require continued monitoring.
7	Riparian association indicates use of any of the four water-based habitats. Single "X" in any habitat type (upland or water-associated) indicates general association; "XX" indicates close association, as per Johnson and O'Neil 2001.
8	Habitat types based on Johnson and O'Neil (2001). These habitats are described more fully within the text of the upland and riparian chapters. **WLCH** = Westside Lowlands Conifer-Hardwood Forest **WODF** = Westside Oak and Dry Douglas-fir Forest and Woodlands **WEGR** = Westside Grasslands **AGPA** = Agriculture, Pasture and Mixed Environs **URBN** = Urban and Mixed Environs **WATR** = Open Water - Lakes, Rivers, Streams **HWET** = Herbaceous Wetlands **RWET** = Westside Riparian-Wetlands

Range of functional riparian area widths for wildlife habitat

Terrestrial habitat			
	Function	**Reference**	**Recommended width *(each side of stream)***
Wildlife needs	Willow flycatcher nesting	Knutson and Naef 1997	123 feet
	Full complement of herpetofauna	Rudolph and Dickson 1990	>100 feet
	Belted kingfisher roosts	USFWS HEP Model	100-200 feet
	Smaller mammals	Allen 1983	214-297 feet
	Birds	Jones et al. 1988	246-656 feet
	Minimum distance needed to support area-sensitive neotropical migratory birds	Hodges and Krementz 1996	328 feet
	Western pond turtle nests	Knutson and Naef 1997	330 feet
	Pileated woodecker	Castelle et al. 1992	450 feet
	Bald eagle nest, roost, perch Nesting ducks, heron rookery and sandhill cranes	Castelle et al. 1992	600 feet
	Pileated woodpecker nesting	Small 1982	328 feet
	Mule deer fawning	Knutson and Naef 1997	600 feet
	Rufous-sided towhee breeding populations	Knutson and Naef 1997	656 feet
	General wildlife habitat	FEMAT 1993	100-300 feet
	General wildlife habitat	Todd 2000	100-325 feet
	General wildlife habitat	May 2000	328 feet

Acronyms

USFWS: U.S. Fish and Wildlife Service

FEMAT: Forest Ecosystem Management Assessment Team

Range of functional riparian area widths for fish habitat and water quality

Aquatic habitat			
Function		Reference	Functional width *(each side of stream)*
Temperature regulation and shade	Shade	FEMAT 1993	100 feet
	Shade	Castelle et al. 1994	50-100 feet
	Shade	Spence et al. 1996	98 feet
	Shade	May 2000	98 feet
	Shade	Osborne and Kovacic 1993	33-98 feet
	Shade/reduce solar radiation	Brosofske et al. 1997	250 feet
	Control temperature by shading	Johnson Ryba 1992	39-141 feet
Bank stabilization and sediment control	Bank stabilization	Spence et al. 1996	170 feet
	Sediment removal and erosion control	May 2000	98 feet
	Ephemeral streams	Clinnick et al. 1985	66 feet
	Bank stabilization	FEMAT 1993	1 SPTH
	Sediment control	Erman et al. 1977	100 feet
	Sediment control	Moring 1982	98 feet
	Sediment removal	Johnson and Ryba 1992	10 feet sand-400 feet clay
	High mass wasting area	Cederholm 1994	125 feet
Pollutant removal	Nitrogen	Wnger 1999	50-100 feet
	General pollutant removal	May 2000	98 feet
	Filter metals and nutrients	Castelle et al. 1994	100 feet
	Pesticides	Wenger 1999	>49 feet
	Nutrient removal	Johnson and Ryba 1992	33-141 feet
Large woody debris and organic litter	Large woody debris	Spence et al. 1996	1 SPTH
	Large woody debris	Wegner 1999	1 SPTH
	Large woody debris	May 2000	262 feet
	Large woody debris	McDade et al. 1990	150 feet
	Small woody debris	Pollock and Kennard 1998	100 feet
	Organic litterfall	FEMAT 1993	1 SPTH
	Organic litterfall	Erman et al. 1977	100 feet
	Organic litterfall	Spence et al. 1996	170 feet

Acronyms

USFWS: U.S. Fish and Wildlife Service

FEMAT: Forest Ecosystem Management Assessment Team

HEP: Habitat Evaluation Procedures

Appendix E – Trail Surface Materials Matrix*

Key			
Functionality		**Availability**	**Vandalism Susceptible**
B=Bicycle P=Pedestrian S=In-line skate	W=Wheelchair V=Emergency Vehicle	H=High M=Moderate L=Low	G=Graffiti M=Moved C=Cutting D = Deformation A=Arson

Product	Description/ Installation Method	Durability	Maintenance Description	Permeable	Functionality	ADA	MTIP Fundable	Availability	Vandalism Susceptible	Cost Per SF	2'-12'-2' section cost*
High-use multi-use trails											
Nike Grind – Atlas Tracks (Familian Product)	Prepare subbase, place geotextile, 6" aggregate base, apply Nike grind atlas track rubberized surface over base.	8-10 years	Reapply binding agent every 5-6 years. Keep surface clean, dirt and sand wear surface down, Full replacement needed after 10 years	Yes	Pedestrian only. Avoid heavy loads including equestrians, bicyclists, and vehicles	Yes	No	L – locally based but few installers	C, A, G	$12.50	$3,198,000
Nike Grind – Field Turf	Prepare subbase, place geotextile, 6" aggregate base, apply field turf surface over base, similar to laying a carpet.	8-10 years	Sweep regularly; keep free of organic materials as they will rot the surface. Replace surface after 10 years	Yes	Pedestrians only, too soft for bikes and wheels	No	No	L	C, A, G	$11.75	$3,006,120
Nike Grind – Rebound Ace	Prepare subbase, place geotextile, 6" aggregate base, pour concrete or asphalt base, apply rebound Ace surface directly over hard surface.	8-12 years	Replace topcoat after 10 years	No	B, P, W, S, but not tested, intended application is sport surfaces	Yes	Yes	L	C, A, G	$10.50	$2,686,320
Permeable Concrete	Prepared subbase, place geotextile, 12" depth aggregate base, Portland cement, coarse aggregate, water, 5" depth section	15 years	Vacuum sweep and pressure wash 4 times a year	Yes	B, P, W, V	Yes	Yes	M	G	$6.00	$1,535,040

* *From the Trolley Trail Master Plan, Metro, 2004*

Product	Description/ Installation Method	Durability	Maintenance Description	Permeable	Functionality	ADA	MTIP Fundable	Availability	Vandalism Susceptible	Cost Per SF	2'-12'-2' section cost*
Concrete	Prepared subbase, place geotextile, 6" agg. base, Portland cement, aggregate, sand, water 4" depth section	25 years	Periodic inspection for uplift and settlement, repair as needed	No	B, P, S, W, V	Yes	Yes	H	G	$4.75	$1,215,240
Permeable Asphalt	Prepared subbase, place geotextile, 12" depth aggregate base, emulsion and coarse aggregate 2" depth section	8 years	Vacuum sweep and pressure wash 4 times a year, patch any pot holes as needed	Yes	B, P, S, W, V	Yes	Yes	M	G	$3.50	$895,440
Glassphalt	Prepared subbase, place geotextile, 6" agg. base, asphalt with aggregate/glass, 2" depth section	7-10 years	Pothole patching	No	B, P, S, W, V	Yes	Yes	M	G	$2.75	$703,560
Reground Asphalt	Prepared subbase, place geotextile 6" aggregate base, emulsion recycled asphalt chips 2" depth section	7-10 years	Pothole patching	No	B, P, S, W, V	Yes	Yes	M	G	$2.75	$703,560
Asphalt	Prepared subbase, place geotextile, 6" aggregate base, emulsion, aggregate	10 years	Pothole patching	No	B, P, S, W, V	Yes	Yes	H	G	$2.75	**$703,560**
Poly Pave	Prepared subbase, place geotextile, 6" aggregate base, grade and shape, mix poly pave in top 2" of base, spray on two top coats of poly pave 2" depth section	5-10 years	Reapply Poly pave solidifier every 1-2 years depending on level of use. Make spot repairs as needed.	No	B, P, W, S, V	Yes	Unknown	L	G	$2.50	$639,600

Product	Description/ Installation Method	Durability	Maintenance Description	Permeable	Functionality	ADA	MTIP Fundable	Availability	Vandalism Susceptible	Cost Per SF	2'-12'-2' section cost*
Chip Seal	Prepared subbase, place geotextile, 6" aggregate base, emulsion, ½" – ¼" aggregate, two coat process	7-10 years	Pothole patching	No	B, P, W, V	Yes	Yes	M	G	$2.00	$511,680
Low-use trails											
Nike Grind – tlas Tracks (Familian Product)	Prepare subbase, place geotextile, 6" aggregate base, apply Nike grind atlas track rubberized surface over base.	8-10 years	Reapply binding agent every 5-6 years. Keep surface clean, dirt and sand wear surface down. Full replacement needed after 10 years	Yes	Pedestrian only. Avoid heavy loads including equestrians, bicyclists, and vehicles	Yes	Not as primary trail, ok as shoulder	L – locally based but few installers	C, A, G	$12.50	$1,200,600
Nike Grind – Field Turf	Prepare subbase, place geotextile, 6" aggregate base, apply field turf surface over base, similar to laying a carpet.	8-10 years	Sweep regularly; keep free of organic materials as they will rot the surface. Replace surface after 10 years	Yes	Pedestrians only, too soft for bikes and wheels	No	Not as primary trail, ok as shoulder	L	C, A, G	$11.75	$1,128,564
Nike Grind – Rebound Ace	Prepare subbase, place geotextile, 6" aggregate base, pour concrete or asphalt base, apply rebound Ace surface directly over hard surface.	8-12 years	Replace topcoat after 10 years	No	B, P, W, S, but not tested, intended application is sport surfaces	Yes	Yes	L	C, A, G	$10.50	$1,008,504
Pavers with Fines	Prepare subbase, place geotextile, 6" aggregate base, place plastic pavers over base, fill cells with 3/16" minus crushed rock.	15 years	Keep weeded, refill cells with gravel as needed	Yes	B, P, W, S, E, V	Yes	Yes	M	M	$4.50	$432,216
Wood Planner Shavings	Prepare subbase, place geotextile, 4" aggregate base, place 3" layer of wood planners shavings, add additional 3" layer after initial compaction	2-3 years	Add 2"-3" of new material annually	Yes	P, E	No	Not as primary trail, ok as shoulder	H	M, D, A	$2.60	$249,725

Product	Description/ Installation Method	Durability	Maintenance Description	Permeable	Functionality	ADA	MTIP Fundable	Availability	Vandalism Susceptible	Cost Per SF	2'-12'-2' section cost*
Crusher Fines/Gravel	Prepare subbase, place geotextile, 6" aggregate base, place 2" depth ½" minus over base, roll and compact	2-5 years, depending on maintenance	Sweep to fill voids from dislodged fines	Yes	P, B, V	No	Not as primary trail, ok as shoulder	H	M, D	$2.50	$240,120
Filbert Shells	Prepare subbase, place geotextile fabric, 4" aggregate base, then 3" layer of filbert shells	7-10 years	Keep shells in place by regular raking. Re-top every 5 years	Yes	P, E	No	Not as primary trail, ok as shoulder	M	M	$2.25	$216,108
Wood Mulch	Prepare subbase, place geotextile, 4" aggregate base, place 3" layer of wood mulch, rake and shape, apply second 3" layer after initial compaction and settlement	1-3 years	Top dress annually	Yes	P, E	No	Not as primary trail, ok as shoulder	H	M, D, A	$2.10	$201,700

*The cost for all hard surface options includes using 2' wide shoulders of ¾" minus gravel for a 6 mile trail..

* 6' width is used as an example and cost estimating purposes only. Other widths can be considered.

Appendix F – Notes and best practices for the use of treated wood products

Wood that will be used outdoors is frequently treated to withstand rot. Treated wood should not be used anywhere near aquatic environments. Two distinct wood treatment types are distinguished: oil-based and water-based. Each has many different processing methods. For the various combinations of treatment type and processing method, different environmental safety measures are used. These measures, or best management practices (BMPs), are intended to minimize leaching of treatment chemicals into the environment and to protect the health of the people who handle the treated products.

The treated wood products industry identifies sets of BMPs for each stage of manufacture of treated wood products and for ordering, receiving, storing and handling these materials. It is up to trail planners to specify the product and for trail construction managers to receive, inspect or reject, properly store the products and educate workers about safe ways to handle the products and construction waste. Some municipalities have discontinued the use of treated wood and are replacing it where it already exists. Some general BMPs for treated wood follow:

Design. Treated or untreated wood will last longer if it is not exposed to the ground and is allowed to dry out as the weather changes. Wood structures should be designed with this in mind.

Ordering. Before ordering, complete a site specific risk assessment to determine if and how well the water body flushes.

When ordering:

- Note whether the water flushes all the time, or with the tides, seasons or not at all.
- Specify the performance needed and note whether the product will be used in a wetland, in the water, over the water or in a splash zone.
- Note whether children will play on or around the treated wood.
- Don't ask for a rush order, as proper time for curing is essential for some processes and treatment types.
- Don't ask for over-treatment or re-treatment by the factory.
- Specify that no surface residues should be present.
- Ask for written documentation that treatments have been applied in accordance with the current standards of the Western Wood Processing Institute and Canadian Institute of Treated Wood.

Receiving. When the material arrives, the documentation should include a list of the best management practices used in manufacture and curing and a quality assurance identification mark that indicates third-party inspection. No surface residues should be visible and the lumber should not have an oily sheen.

Storage. Products should be stored on pallets or widely spaced 2 by 4s above ground in dry areas and covered. Some products need to be stacked so that there is ventilation under and between each piece.

Construction. Many managers rely on off-site construction of trail facilities made of treated wood products to lessen risks of worker and environmental exposure. Workers need to be trained in methods for handling specific products, including construction post-treatment and conditioning of sawn surfaces, bolt holes and the like. Working facilities need to be kept clean and wood dust and shavings collected and properly disposed.

Materials should be staged in small quantities for installation in the field. Fabrication that must be done in the field should take place over tarps so that sawdust and shavings can be collected. Outdoor work should cease in windy or wet weather. Field treatment of cuts and bore holes should be minimized. Field-applied chemical treatments should not be done over water. Disposable absorbent materials should be used to catch drips and to wipe excess chemicals from treated surfaces. These should be removed from the site and properly disposed. Field application of water repellants and stains is not recommended.

Exhibit 5

RTP Environmental Screening Form

Sponsor Name:
Metro Parks and Nature

Project Name:
Burlington Creek Forest Natural Surface Trails

Part I: Project Description: What will this grant fund?

On behalf of the public, Metro owns 1,300 acres of the North Tualatin Mountains which extend from the fringes of Oregon's Coast Range into the greater Portland metropolitan area. A public planning process was held over a two year period to identify desired activities and the most suitable location for public access to nature at four different sites within the North Tualatin Mountains properties. This grant request, if awarded, would fund the building of natural surface trails at one of those sites, Burlington Creek Forest.

New trails will provide public access to nature at one of Metro's newest Nature Parks, Burlington Creek Forest in the North Tualatin Mountains. This grant request would fund the construction of approximately five miles of shared use, natural surface, hiking and mountain biking trails, along with needed drainage crossing structures and wayfinding signs.

In keeping with its mission, Metro has completed extensive work to improve habitat and water quality at its four North Tualatin Mountains properties. Work has included 1.3 miles of stream restoration, 700 acres of forest thinning and the planting of 85,000 native trees and shrubs. Further planned restoration includes the decommissioning of three miles of existing gravel roads, culvert removal and replacement and continued forest management to improve water quality and wildlife habitat.

Proposed trails at Burlington Creek Forest are being designed sustainably and have been aligned to minimize impacts to natural resources. Sustainable trail design and construction techniques to be employed include: maintaining wide buffers from riparian corridors, minimizing the number of stream crossings, utilizing boardwalks and bridges to reduce impacts to riparian areas and minimizing erosion potential by aligning trails to follow contours, utilize grade reversals and to have outslopes that shed stormwater locally. Natural surface trails will vary in width, ranging between 24 and 36".

Part II: Alternatives to Proposed Action(s): Are there project Alternatives? If so, please describe.

A public master plan process was held over a two year period to determine the most feasible site for public access among the four separate sites that compose the 1,300 acre North Tualatin Mountains. A landscape scale assessment considered the habitat conservation value of each property based on key ecological attributes and a desired future condition scenario (see the attached 2016 Site Conservation Plan).

During the access planning process, two of the four sites, McCarthy Creek and Burlington Creek Forest, were selected for formal public access based on current conditions, conservation targets, habitat restoration goals, existing visitor use, feasibility and ease of public access. At North Abby Creek and Ennis Creek Forest, habitat and water quality will remain the priority along with a provision for a possible future Pacific Greenway Trail segment. A landscape scale assessment ~~considered the hab~~itat conservation value of each property based on key ecological attributes and a desired future condition ~~scenario (see~~ the attached ~~2016 Site Conservation~~ Plan).

Site alternatives explored different options for where formal public access and trails would be located as well as the most suitable places to protect land for conservation purposes. The alternative scenarios are attached and the 2016 adopted North Tualatin Mountain Access Master Plan is available at: www.oregonmetro.gov/north-tualatin-mountains-access-master-plan.

Utilizing public input, Burlington Creek Forest was selected for the first phase of development. Alternative concept plans explored opportunities to provide public access as well as places to protect core habitat areas.

Metro is committed to getting all people outdoors as a means to ensure a conservation ethic within our population. We enjoy a partnership with the non-profit Trackers Earth who actively accesses Metro properties within the North Tualatin Mountains for their camps and outdoor programming.

Furthermore, Metro focuses on providing opportunities for all our community members to experience nature close to home. It is only with ease of access and familiarity will people gain lifelong healthy habits and appreciation of nature. Metro does not intend to charge a fee to visit Burlington Creek Forest in order to avoid a potential barrier for community members of lower socio-economic status.

Participation in day hiking experienced a nearly 20% growth rate in Oregon between 1982 and 2009 (SCORP). Trail development at Burlington Forest would meet three of the top four identified community needs when asked about preferred activities: dirt walking trails and paths, nature and wildlife viewing and off-street bicycle trails and pathways.

An inventory of off-road cycling opportunities, completed by Metro in 2016, found a deficiency in opportunities to ride off-road bicycles in Portland Metropolitan area. Mountain biking is growing in popularity and is often cited by community members as their preferred way to exercise, enjoy a mental escape, socialize, and enjoy nature. Given the proximity to the City of Portland, off-road cyclists could potentially ride or take transit within riding distance of Burlington Creek Forest. Given the deficit of off-road cycling opportunities close to home, the addition of approximately five miles of trails is a significant increase for the region's community members.

While the majority of community members are enthusiastic to have another protected natural park in the region, some neighbors have expressed concerns. We have heard concerns about increased traffic on area roadways. The Burlington Creek Forest site, however, is an ideal option for development as park access is proposed just a quarter mile from a highway and Metro owns all the property on both sides of the road for that length. Others have concerns about the potential impacts to wildlife that may result from trails. Metro is a conservation organization with habitat and water quality protection at the core of its mission. The third essential piece of the mission is to provide public access to nature. We realize that some impacts to nature will occur and actively work to minimize these impacts. We view public access as critical to ensuring future conservation and protection of nature in our region.

An investment in Metro's nature parks ensures a public benefit to a wide array of diverse community members. Metro is proud to be recognized as a leader in advancing diversity, equity and inclusion in the region. This important work includes providing parks and natural areas that are welcoming to all people so that future park visitors reflect our region's growing diversity.

D. Archeological and Historical Resources:	Yes	No
1. Are there National Register-listed or eligible sites in the project area?		X
2. Would the project affect any listed or eligible sites?		X
3. Are the effects of the project adverse to listed or eligible sites?		X

4. If yes to any of the above, briefly summarize below and attach the following: survey report, accompanying determinations and concurrences from State Historic Preservation Office, and any agreement for resolution of adverse effects.

A cultural resource overview was completed by Archaeological Investigations Northwest in September of 2014. A review of archaeological records and a field review were conducted. The records search found no previously recorded cultural resource investigations and no cultural resources were found during fieldwork. Given the history of land use for agriculture, forestry, and (rarely) housing, few, if any, undisturbed portions of landforms were found. The landscape observed in all cases was highly undulating, likely due to the traverse of tracked vehicles. The undulations, along with the subsequent erosion, make the probability for cultural resources in the areas visited low.

E. Fish & Wildlife: Attach a completed and signed Intergovernmental Consultation Form from **Oregon Department of Fish & Wildlife.** (See Section 1.8 for instructions and Section 6.1 of the RTP manual for the form and contact information.)	Yes	No

5. Describe the impacts; attach supporting documentation and the Intergovernmental Consultation Form.

Two drainage crossing structures are proposed. The USGS National Hydrography Dataset classifies one drainage as a perennial stream and the other as an intermittent steam. The proposed structures are associated with trails and are expected to be approximately 5 feet wide by 18 feet long and four feet wide by 15 feet long. Designs have not been completed yet for the structures.

H. Oregon Coastal Management Program: Attach a completed and signed Intergovernmental Consultation Form from the **Oregon Department of Land Conservation and Development.** (See Section 1.8 for instructions and Section 6.1 of the RTP manual for the form and contact information).	Yes	No
1. Is the project within the Oregon Coastal Management Program boundary?		X

2. Describe the impacts; attach supporting documentation and the Intergovernmental Consultation Form.

I. Water Quality: Attach a completed and signed Intergovernmental Consultation Form from the **Oregon Department of Environmental Quality.** (See Section 1.8 for instructions and Section 6.1 of the RTP manual for the form and contact information)	Yes	No
1. Does the project affect a public or private drinking source?		X
2. Does the project affect a designated impaired water body?		X
3. Indicate how many acres of ground-disturbing activities will result from the project:	2.0 acres	
4. Is there a municipal separate storm sewer system (MS4) National Pollution Discharge Elimination System permit (NPDES) or will runoff be mixed with discharges from an NPDES permitted industrial facility?		X
a. If yes, provide NPDES permit #		

5. Describe the impacts; attach supporting documentation and the Intergovernmental Consultation Form.

Ground disturbing activities will include excavation for nearly five miles of natural surface trails. Trails are proposed to be approximately 30" wide.

J. Hazardous Waste:	Yes	No
1. Are hazardous wastes located within the project area?		X

2. Describe the impacts:

Part IV: Public Involvement: Describe how public involvement was solicited and attach copies of public notices, comments received and the responses to comments.

The central goal of the master plan development process was to identify the best locations for formalized recreation access and amenities. To help answer this question, Metro engaged community members and scientists in looking at the four individual sites that together comprise the North Tualatin Mountains. A Stakeholder Advisory Committee was established for the project, and met five times to share technical expertise and insights into community needs and desires. Committee meetings, four community events, conversations with community members, and numerous comments submitted online helped to identify places to provide access, and where to prioritize protection of undisturbed core habitat areas.

This process relied on available data, principles of landscape ecology, the expertise and experience of local natural resource scientists and wildlife biologists, and landscape-scale design strategies to determine the most appropriate opportunities for public access and connecting with nature.

The planning process followed a cyclical, four-step strategy involving a series of internal and external stakeholder meetings followed by Metro Council member updates and public open house events. A Stakeholder Advisory Committee was composed of local agency representatives, public officials, recreation advocates, environmental activists and residents. Internal coordination involved collaboration with Metro natural resource scientists, land managers, communications staff,

Part VI: Motorized Project Questions: Answer this section **only if** you have motorized recreation as part of your project scope.		
A. Air Quality:	**Yes**	**No**
1. Is the project area in a designated non-attainment or maintenance area for air quality? (Locations include: Portland, Salem-Keizer, Eugene-Springfield, Rogue Valley(Central Point to Ashland), Grants Pass, LaGrande, Oakridge, Klamath Falls or Lakeview)		
2. If yes, is the project listed on the exempt projects list (40 CFR 93.126)?		
B. Noise:	**Yes**	**No**
1. Is the project in an existing designated recreational land use area or park?		
2. Is the project located near any residential areas, campgrounds, wildlife refuges or wilderness areas?		
3. If yes to any of the above, describe the proximity to types of areas and describe noise impacts:		
a. What types and numbers of mechanized vehicles do you anticipate on the trail daily and seasonally? (Example: 30 snowmobiles day/winter and 30 OHVs day/summer-fall)		

Part VII: Applicant Certification:

I certify the information above was completed to the best of my knowledge to be accurate and correct:

Signature: ______________________________ Date:__________

Printed Name:______________________________

For Official Use Only

Land & Water Conservation Fund Act (LWCF), Section 6(f)(3):	Yes	No
1. Are Section 6(f)(3) properties affected by the project?		
2. If yes, will the use of the Section 6(f)(3) property constitute a conversion?		

☐ Further coordination not required ☐ Further coordination required

Approved:______________________________ Date:__________
LWCF State Liaison Officer

Trails Coordinator Certification:	Yes	No
Project qualifies as a Categorical Exclusion, per 23 CFR 771.117 and Stipulation 2 of the 2007 Programmatic Agreement between FHWA and OPRD. (If project does not qualify as a CE, consult with the FHWA RTP Manager)		

Certified:______________________________ Date:__________
Trails Coordinator

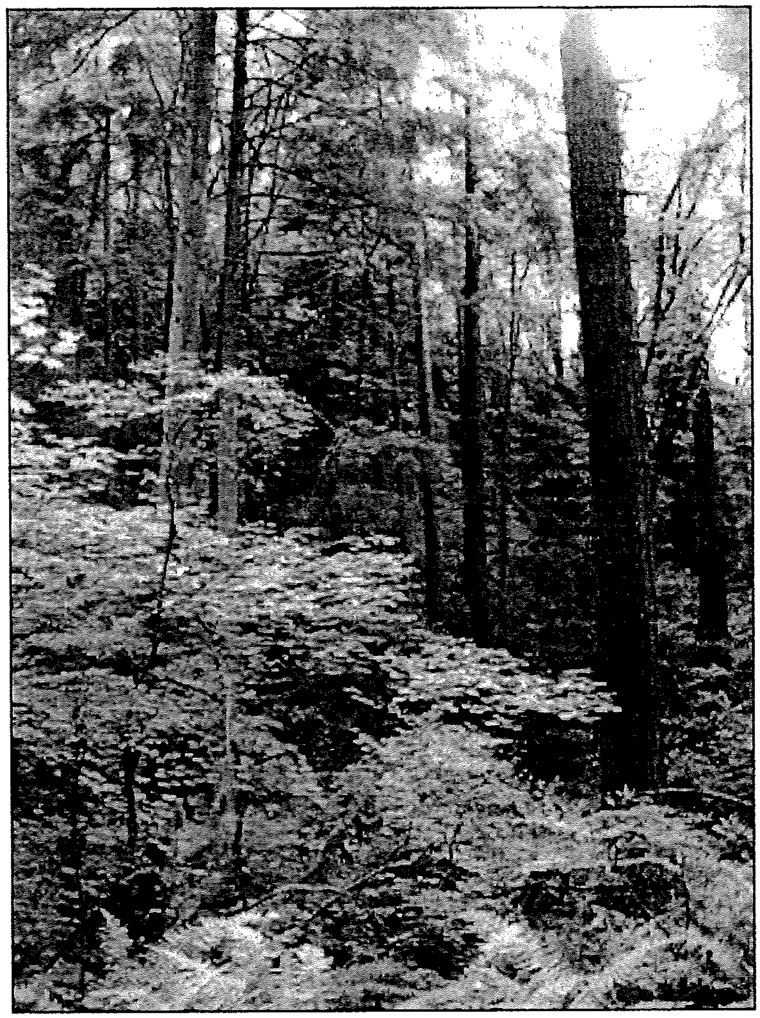
Federal Highways Administration Approval:

Accepted: ______________________________ Date:__________
FHWA Recreational Trails Program Manager

Exhibit 6

PORTLAND PARKS & RECREATION

Healthy Parks, Healthy Portland



Forest Park

Desired Future Condition

January 2011

Forest Park Desired Future Condition

January 2011

Portland Parks & Recreation Project Staff

David McAllister, Senior Manager/City Nature
Astrid Dragoy, Zone Manager/City Nature West
Dan Moeller, Zone Supervisor/City Nature West
Kendra Petersen-Morgan, Ecologist/City Nature West
Emily Roth, Natural Resource Planner/Planning
Josh Darling, GIS Specialist/Planning
Colleen Keyes, Editor/Communications

Cover photo: Forest Park

Portland Parks & Recreation
1120 SW Fifth Avenue, Suite 1302
Portland, Oregon 97204
503-823-PLAY
www.PortlandParks.org

Nick Fish, Commissioner
Zari Santner, Director

Introduction & History

Forest Park is an unparalleled natural resource; an oasis for plants, wildlife, and the urban explorer. Unique in the nation, Forest Park is the largest natural area within a city and provides a place for quiet reflection, passive recreation, environmental research, and educational discovery. With over 5,000 acres of undeveloped natural area, Forest Park is home to over 100 species of native birds and more than 50 mammals. The park includes Special Status Habitats, such as Interior Forest and Oak Woodlands (designated in the City of Portland Terrestrial Ecology Enhancement Strategy), and has documented flora and fauna that are unique within an urban setting.

Forest Park is an integral part of the wildlife corridor that connects the Portland Metropolitan area to the Coast Range through a series of undeveloped rural properties that are currently in a mix of private and public ownership. This corridor is believed to play a critical role in species dispersal throughout the region, providing an opportunity for recruitment of flora and fauna outside of the urban area (Houle, 1982).

The management of the park is provided by Portland Parks & Recreation (PP&R) and is guided by the *Forest Park Natural Resource Management Plan* (NRMP), adopted by City Council in 1995. The plan details specific actions for ecological restoration, recreation use, and operations and maintenance of the natural area. The Desired Future Condition (DFC) projects the plant community structure for the next 25 years. Both the plan and DFC provide guidance to staff for setting work priorities, making land management decisions, and informing the public about park management plans. The DFC is the means for setting goals for restoration activities. The term acknowledges that natural landscapes change over time and that humans play a key role in determining the degree and direction of that change. For an overview of how the DFC fits into PP&R's ecosystem management, refer to Appendix I.

The Desired Future Condition statement is designed to be complementary to the Forest Park NRMP; the two should be utilized as tools for comprehensive park management.

History

LAND USE AND DISTURBANCE

Plant communities in Forest Park have developed in response to past land use practices and natural disturbance. The following major events and activities shaped the current vegetation communities:

Disturbance Corridors

Eight public utility corridors exist in Forest Park. Each corridor has a 100-year easement which allows for vegetation management to maintain line function and hazard reduction. Depending upon specific power corridor management, mature trees may be left when they do not interfere with utility transmission.

Fire

There have been three stand replacing fires over the past 120 years. These fires resulted in over 1,400 acres within the park being impacted by fire.

- 1889 fire burned approximately 400 park acres
- 1940 "Bonney Slope" fire burned 170 park acres
- 1951 fire burned over 900 park acres

Infrastructure

Roads, water storage structures, fire hydrants, and culverts are located throughout the park. Many are obsolete and non-functional.

Invasive Species

Due to the park's location in an urban environment, the control of invasive species is likely to be an ongoing management challenge. While English ivy is the species most often associated as a problem in Forest Park, other invasive plants pose a threat to ecosystem health (See Appendix II).

Logging

Extensive logging, which included removal of dead trees and large downed wood, occurred throughout the park in the 19th and 20th centuries. Controlled fires were utilized to reduce slash and other materials deemed as hazardous. Additionally, the City of Portland utilized Forest Park as a wood cutting camp twice in the early 1900s to provide fuel and income to needy families.

Recreation

Recreation use and type has evolved over time. From youth camps of the 1950s to demands for increased cycling opportunities today, recreation impacts the park's natural resources (See Appendix III).

Reforestation

Following the 1951 fire, Forest Park managers planted thousands of trees in the 1950s throughout the central management unit near Saltzman Road. These areas are now evidenced by high densities of even-aged trees that are competing for space and light. Due to limited plant availability, these species included some not typically found in our region, such as Port Orford cedar *(Chamaecyparis lawsoniana)* and Eastern Ponderosa pine *(Pinus ponderosa)*.

Research

The proximity of Forest Park to Portland results in the convenient use of the natural area as a site for scientific inquiry. From environmental education field trips to long-term university research projects, the park serves to provide the community with valuable educational opportunities. Currently, permits are issued for all research activities to balance the value contributed against the impacts that result from this work in the park.

PLANNING

Forest Park Natural Resources Management Plan 1995

The Forest Park Natural Resources Management Plan (NRMP) adopted in 1995 provides the framework for managing the park. The NRMP details forest management actions that favor an old-growth conifer forest. The plan divides Forest Park into management units. These management units were created to provide a framework for resource protection standards and appropriate levels of recreation use. The management units are defined as follows:

- North Management Unit: Germantown Road to Newberry Road (1,558 acres)
- Central Management Unit: Firelane 1 to Germantown Road (2,247 acres)
- South Management Unit: Burnside to Firelane 1 (1,236 acres)

Portland Wildfire Fuel Reduction Project 2006-2010

In 2006 three City of Portland agencies (Portland Parks & Recreation, Environmental Services, and Fire & Rescue) received a grant from the Oregon Emergency Management (OEM) and the Federal Emergency Management Administration (FEMA) to create long and short term plans and projects to reduce the risk of wildfire in and around Forest Park (http://www.portlandonline.com/parks/index.cfm?c=43178). For Forest Park, the planning effort identified four main ecosystem types:

1. Grass and shrub communities along utility corridors
2. Oak woodlands along the east edge of the park, near Highway 30
3. Interior conifer and mixed conifer-deciduous forest
4. Edge area deciduous and mixed forest

With the greater recognition of the risk of wildfire in natural areas adjacent to homes, the report encourages a deciduous forest of bigleaf maples *(Acer macrophyllum)* and red alders *(Alnus rubra)* that are less likely to ignite and burn adjacent to structures. The deciduous forest retains vast amounts of moisture and lacks the volatile resins found in firs, hemlocks, and cedars. They can actually act as fire breaks if placed strategically in areas where fires are likely to start or spread.

The FEMA report evaluates Forest Park through the lens of wildfire risk reduction. This is an important component of managing a large urban forest, but is only one of the objectives used in developing the Desired Future Condition for Forest Park. **Ecosystem management, which is the foundation for how Portland Parks & Recreation manages its natural areas, involves developing strategies for conservation, restoration, and enhancement that promote wildlife habitat, biodiversity, and water quality.** Each of these elements was evaluated in crafting the Desired Future Condition.

Willamette Subwatershed Improvement Strategies

The City of Portland Bureau of Environmental Services (BES) is developing the Willamette Subwatershed Improvement Strategies (http://www.portlandonline.com/bes/index.cfm?c=31819). These strategies provide actions to improve watershed health. Seven of the subwatersheds are found within Forest Park. Balch and Miller subwatersheds are viewed as urban reference sites (City of Portland, BES, 2010a) because they are in relatively good condition. PP&R and BES will work together to identify and develop priority projects for the subwatersheds of Forest Park.

Forest Park

Natural Resource Inventory

GEOLOGY

Columbia River Basalt comprises the majority of the Tualatin Mountains and the bulk of Forest Park, measuring roughly 700 feet in depth below the West Hills. Remnant cinder cones from volcanic activity between two million until a few hundred thousand years ago, found near Skyline Boulevard, produced formations known as Boring lava that can be identified by a more gray appearance than Columbia River Basalt. In more recent geologic history, wind-deposited loess known as Portland Hills silt accumulated along the ridges of the West Hills in some areas up to depths of 55 feet at the crest of Forest Park.

Portland Hills silt, or loess, is strong when dry, but when wet or saturated it loses its strength and can result in instability especially on steep slopes (Burns, 1998). A study conducted for Metro Regional Government inventorying the number of landslides that occurred from February 1996 to May 1998 documented 73 landslides within the boundaries of Forest Park, ranging from 100-1000 cubic yards in volume. The largest of these was 8,875 cubic yards and occurred along Leif Erikson Drive.

SOILS

The dominant soil types found throughout Forest Park are classified by the USDA Natural Resources Conservation Service (formerly USDA Soil Conservation Service) as Goble Silt Loam, Cascade Silt Loam, and Wauld Very Gravelly Loam (Table 1). Cascade and Goble loams are often collectively referred to as Portland Hills silt.

Table 1: Dominant Soils in Forest Park

Soil Type	Location	Permeability	Erosion Hazard	Vegetation
Goble Silt Loam	Steep hillsides and ridges	Slow; rapid runoff	High	Douglas fir, bigleaf maple
Cascade Silt Loam	Ridgetops	Slow; poorly drained	High	Douglas fir, bigleaf maple
Wauld Very Gravelly Loam	Steep creeks and tributaries	Moderate; runoff is slow to medium	Slight to high	Douglas fir, bigleaf maple

TOPOGRAPHY

Elevations along the floodplain of the Willamette River range from 30 to 40 feet mean sea level (msl). As the land rises up to the Tualatin Mountain range elevations reach 900 to 1,180 feet msl (City of Portland, 1992) in the park. It has been estimated that 90 to 95 percent of the upland slopes in Forest Park exceed 30 percent (City of Portland, 1992) and therefore have severe landslide potential.

AQUATIC RESOURCES

Forest Park is located on the west side of the Willamette Watershed. Due to the steep slopes that are characteristic of the Tualatin Mountains, development occurred more slowly here than in other parts of the watershed (City of Portland, BES, 2004). As a result, the eastern face of the Tualatin Mountain range is unique in the Willamette Watershed due to the presence of open creeks and streams that flow northeast to the Willamette River.

Historically, the creeks and streams of the Tualatin Mountain Range flowed freely into an ecologically-rich mosaic of wetlands that were found along the historic floodplain of the Willamette River. Today the majority of creeks flow freely until they reach Highway 30 and St Helens Road, where they are piped through culverts until they meet the confluence with the Willamette River. While most of the creeks within Forest Park do not have the capacity to provide habitat to fish due to significant fish passage barriers between Forest Park and the Willamette River, these streams play a critical role in providing cold, clean water to the Willamette River.

Seven Willamette River subwatersheds are found within Forest Park. These subwatersheds are considered to be some of the most intact subwatersheds within the City of Portland (City of Portland, BES, 2010a). Within the boundary of Forest Park, streams are flowing through land with a relatively stable land use pattern and thus creeks such as Balch and Miller are viewed as urban reference sites (City of Portland, BES, 2010a). The general stream characteristics for each of these subwatersheds are listed in Table 2.

A recent declining water quality trend in Balch Creek has been identified through a synthesis of six years of water quality data (City of Portland, BES, 2010a). From this analysis, elevated ammonia levels were identified which were likely attributed to failing septic systems in the area. In addition, regression models suggest that total suspended solids in Balch Creek are increasing at a rate of 25% a year, while other westside streams are showing a slight decrease in this metric.

Table 2: Forest Park Subwatershed Characteristics

Subwatershed	Acreage	Percentage within Park	Mainstem Flow	Stream Type within Park	Fish- bearing
Johnson-Nicolai	1,200	3%	intermittent	open channel (headwaters only)	no
Balch	2,236	25%	perennial	open channel	resident cutthroat
Kittridge	1,221	50%	intermittent	open channel	no
Saltzman	1,079	58%	intermittent	open channel	no
Doane	1,302	66%	intermittent	open channel	no
Linnton	2,403	73%	intermittent	open channel	no
Miller	916	60%	perennial	open channel	cutthroat trout, Coho salmon, short-head cottid

Additional information about each of these subwatersheds can be found in the City of Portland, Bureau of Environmental Services Willamette Subwatersheds Characterization Report.

CURRENT VEGETATION COMPOSITION

Forest Park is located along the eastern edge of the Western Hemlock Vegetation Zone which is the most extensive vegetation zone in Western Oregon and Washington (Franklin and Dryness, 1973). While western hemlock *(Tsuga heterophylla)* is considered the climax species for this vegetation type, it is well documented that Douglas fir *(Pseudotsuga menziesii)*, a sub-climax species, dominates the landscape in this zone throughout the Pacific Northwest, even in old-growth stands. Forest Park is no exception to this pattern; multiple "stand replacing fires," and a history of extensive logging and disturbance have led to a forest composition that is typical to that found in a second-growth Douglas fir forest. As a result of this long history of disturbance, much of the forest is composed of relatively young trees that range in age from 50-100 years (Trout Mountain Forestry 2008). Aerial analysis shows that 99% of the park is forested, with a quarter of the park composed of conifer-dominated forest and three-quarters composed of mixed conifer-deciduous forest, which is largely comprised of bigleaf maple and red alder with a conifer component.

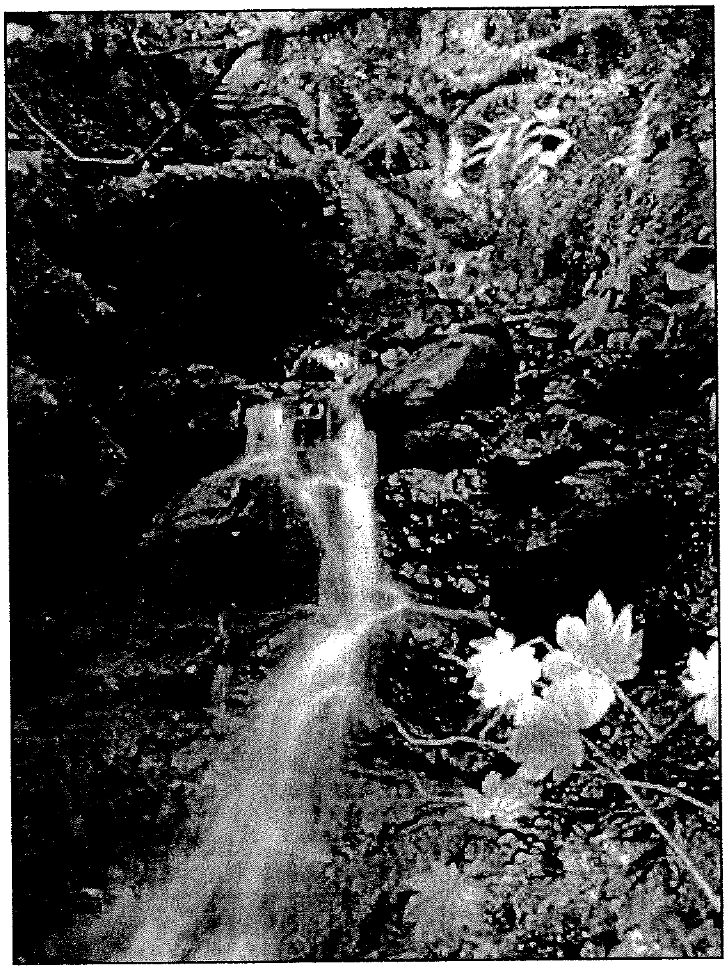
Due to Forest Park's location along the edge of the Western Hemlock Vegetation Zone, it is also influenced by the Willamette Valley Vegetation Zone. Dominant tree species include Douglas fir, grand fir *(Abies grandis)*, Oregon white oak *(Quercus garryana)*, Pacific madrone *(Arbutus menziesii)*, and bigleaf maple. All of these species can be found within Forest Park although Oregon white oak and Pacific madrone are restricted to the distinct portions of eastern slopes of Forest Park. A more complete understanding of the diverse composition of flora in Forest Park is achieved when viewed through the lens of influence of both the Western Hemlock and Willamette Valley Vegetation Zones.

SUCCESSIONAL STAGES IN THE PARK

Due to the complex history of past disturbance throughout Forest Park, a variety of vegetation types associated with successional stages is present throughout the park. An extensive classification of the park identified six distinct successional stages that are relevant for how the park is viewed today (Table 3).

Table 3: Successional Stages found throughout Forest Park (Houle, M. 1982)

Vegetation Type	Age Range Associated with Stand	Percent of Total Acres	Associated Alliance(s)
Grass-Forb	2-5	0.7%	Disturbance Corridor
Shrub	3-10 or 3-30 w/ no conifer regeneration	2.2%	Disturbance Corridor
Hardwood Young Conifer	10-35	19.0%	Bigleaf Maple Forest Bigleaf Maple Seasonally Flooded Forest
Hardwood Topped by Conifer	30-80	41.7%	Douglas Fir Bigleaf Maple Forest
Mid-Aged Conifer	80-250	24.6%	Douglas Fir-Western Hemlock Forest Douglas Fir Oregon White Oak Woodland
Mature Hardwood	30-100	11.3%	Bigleaf Maple Forest Bigleaf Maple Seasonally Flooded Forest
Old Growth	>250 years	0.5%	Douglas Fir Giant Forest



Forest Park

Desired Future Condition

Methodology

The Desired Future Condition (DFC) is defined by the vegetative community composition of the natural area. The natural area is subdivided into ecological units defined by plant alliances. An alliance is a vegetation category used by the National Vegetation Classification System (NVCS) that identifies a plant community type based on the presence of dominant and/or diagnostic species in the predominant or uppermost stratum. Typically, the alliance is named after the tree species that dominate the canopy. For example, the Douglas Fir-Western Hemlock Forest alliance (DF-WHF) has an upper tree canopy that consists mainly of Douglas fir and western hemlock. Physical characteristics such as hydroperiod are also used to name some alliances, e.g., Oregon Ash Seasonally Flooded Forest alliance (OASFF).

Occasionally, the NVCS does not include definitions that capture the dynamics of urban ecological management. Areas of permanent disturbance or portions of the landscape that have been modified to accommodate infrastructure will not achieve a typically defined vegetative community. In Forest Park, utility corridors are an area that experience disturbance through the removal of vegetation that may interfere with utility conveyance. In addition, managed buffers to address interface issues with private property, such as fire suppression, may be included to achieve management goals. In these instances, an appropriate vegetation alliance is assigned and defined by Portland Parks & Recreation staff.

While many portions of the landscape are managed for a late seral or climax successional stage, there may be times where the greatest ecological benefit is achieved through actively managing a landscape for an earlier successional stage. For example, oak woodlands were historically maintained through the repeated disturbance of fire; with the advent of fire suppression these rich and diverse habitats are developing into conifer dominated forests. Active management would be required to reset the conditions and structural complexity that constitutes oak woodland.

In a disturbed environment the benchmarks for achieving a later seral stage of succession may be so distant that they exceed planning parameters. The DFC is designed to be a planning document that forecasts conditions for 25 years. Long-term ecological objectives for the site may exceed this planning interval and will be utilized as a target for which to set interim benchmarks. The trajectory of management may be directed toward a later successional stage that resembles historic conditions, but intermediate goals may be defined based on the dynamic ecological conditions in the urban Portland environment. The DFC planning period was determined to provide an opportunity for review, a realistic timeframe for management activities, and the occasion to incorporate new science and enhanced understanding of ecological conditions into the planning process.

Desired Future Condition for Forest Park

The DFC for Forest Park is:

- a mosaic of evergreen-dominated and mixed deciduous forest
- oak woodlands along portions of the park's eastern edge
- a diversity of native shrubs and open meadows within the disturbance corridors

Structurally, the Desired Future Condition closely mirrors the current condition. It combines the recommendations from the NRMP and FEMA Wildfire Study to set a vegetation trajectory that includes moving towards old-growth forest and reducing fire risk at key interfaces. The alliances associated with the DFC are described with its corresponding successional stage. Alliances are sourced from Natureserve 2009 unless noted otherwise. Page 17 depicts a map of the geographic distribution of the DFC alliances. The methodology utilized to develop this distribution is discussed in Appendix IV.

Ecological Goals
Ecological goals are the foundation of ecosystem management. These goals are accomplished through management strategies achieved through project actions. Associated with each alliance is a management strategy identified to be critical to achieving the Desired Future Condition. These strategies will be accomplished through projects which have been identified in Appendix V. The ecological goals for Forest Park are as follows:

1. Protected Air and Water Quality
2. A Forest with Structural Complexity: Vertically (canopy, midstory and understory, snags and downed wood) and Landscape-Scale (mosaic of habitat types, natural gaps)
3. Floristic Native Biodiversity with Increased Habitat Opportunities for Target Wildlife Species and Avian, Terrestrial, and Aquatic Native Wildlife Corridors (within and surrounding Forest Park)
4. Intact Native Plant and Animal Communities with Minimal Disturbance from Non-native Species and Invasive Species Populations Controlled Through Management
5. Reduction of Catastrophic Fire Risk

Diversity of Shrubs and Open Meadows

SHRUBLAND/GRASSLAND ALLIANCE

This alliance (not an NVCS) is associated with the permanent disturbance corridors that provide access for public utility transmission. Characteristic species include vine maple *(Acer circinatum)*, western hazelnut *(Corylus cornuta)*, cascara *(Rhamnus purshiana)*, and serviceberry *(Amelanchier alnifolia)* along corridor margins or in areas with fewer height constraints. Mock orange *(Philadelphus lewisii)*, snowberry *(Symphoricarpus albus)*, red-flowering currant *(Ribes sanguineum)*, thimbleberry *(Rubus parviflorus)*, red elderberry *(Sambucus racemosa)*, blue elderberry *(Sambucus cerulea)*, and oceanspray *(Holodiscus discolor)* are all appropriate selections to create a shrub-dominated system on an exposed site.

Managing power corridors as shrublands enhances wildlife habitat diversity while reducing wildfire risk and allowing for infrastructure maintenance.

In addition to the disturbance corridors found throughout the park, there are several open meadows and roadsides that fit into this alliance. These are areas of historic disturbance from homesteads, grazing, mowing, and general park maintenance. These grassland edges are primarily composed of non-native grasses, but in areas where disturbance has been reduced, herbaceous native plants are beginning to colonize the edges. Changes in current management and the restoration of these areas with native forbs and grasses have the potential to provide significant pollinator habitat and biodiversity near disturbed edges of the park.

Funding provided through the FEMA Wildfire Risk Reduction Grant resulted in the treatment of invasive species within over 150 acres of power corridors throughout Forest Park. In 2009/10, following removal of invasives, over 20,000 native shrubs were planted to revegetate the treatment areas. These enhanced power corridors will require maintenance to ensure the survival and success of the plantings and could be utilized as a demonstration site for alternatives for utility corridor management.

While the FEMA funding provided an unprecedented opportunity to address wildfire risk reduction while improving habitat quality, there is additional work to be done. An additional 150 acres were identified for fuel load reduction by the Forest Park Wildfire Risk Assessment. Ongoing maintenance of the initially treated power corridors will be required to insure the original investment of time and resources in this area is supported. The level of maintenance necessary for these areas will require a funding source above and beyond Portland Parks & Recreation's Operating Budget.

Management Strategy

- Expand cover and diversity of native vegetation, manage for wildlife and address wildfire risk.

Mosaic of Evergreen-dominated and Mixed Deciduous Uplands

BIGLEAF MAPLE FOREST ALLIANCE

(Acer macrophyllum Forest Alliance)

Bigleaf maple is the dominant tree species with Douglas fir present in the 10-25% cover class range. Red alder and Pacific dogwood *(Cornus nuttallii)* are often found in association with this alliance. Red alder typically is not found in stands older than 60-70 years although individual plants occasionally persist for up to 100 years (City of Portland, 1995). Vine maple is a characteristic sapling found in association with this alliance. Additional shrub species include red elderberry, salmonberry *(Rubus spectabilis)*, thimbleberry, salal *(Gaultheria shallon)*, and dull Oregon grape *(Mahonia nervosa)*. Ferns dominate the herbaceous layer and include sword fern *(Polystichum munitum)*, lady fern *(Athyrium filix-femina)*, and brackenfern *(Pteridium aquilinum)*.

This alliance typically represents an earlier seral stage of succession and is usually found in the Western Hemlock Zone in areas that have been disturbed through fire, logging or landslides. The alliance may persist on wet sites. In some areas, individual bigleaf maple may reach ages that exceed 200 years (City of Portland, 1995).

The Forest Park NRMP recommends the thinning and/or removal of mature maples to release conifer seedlings or provide opportunities for conifer planting in the understory. The Wildfire Risk Reduction Assessment recommends maintaining a wildfire resistant forest by maintaining large areas of maple or a maple-fir mix. These two recommendations present divergent methods for managing this alliance type.

While this alliance has been evaluated to determine the function it provides to wildfire reduction, it has not been evaluated to determine its wildlife function in Forest Park. Bigleaf maple provide food for a variety of birds and small mammals which include squirrels, chipmunks, finches, and grosbeaks (Uchytil, 1989). This alliance will be monitored to evaluate the utilization of this vegetation alliance by wildlife, survey for any unique plant associations, and evaluate natural regeneration. Following this assessment, a portion of these acres may be underplanted with conifer species to facilitate the development of greater structural complexity.

Management Strategy

- Assess site to determine wildlife utilization, unique plant associations and natural regeneration. Utilize data to inform management needs to create greater structural complexity.

DOUGLAS FIR–BIGLEAF MAPLE FOREST ALLIANCE

(Pseudotsuga menziesii–Acer macrophyllum Forest Alliance)

This alliance is characterized by a diffuse canopy of deciduous and coniferous trees from 35-50 m high with over 60% cover. It is typical to have a two-tiered canopy with Douglas firs emerging through bigleaf maple. Shade-tolerant conifers, such as western hemlock, western red cedar, and grand fir may also be part of the stand composition depending upon the location, land-use history, and age of the forest stand. The shrub layer ranges in cover from 20-60%, is well-developed, and is comprised of a diversity of species. Shrub species commonly associated with this alliance include salmonberry, red elderberry, western hazelnut, vine maple, snowberry, and red huckleberry *(Vaccinium parvifolium)*. The herbaceous layer includes redwood sorrel *(Oxalis oregana)*, sword fern, western trillium *(Trillium ovatum)*, Pacific waterleaf *(Hydrophyllum tenuipes)*, and wild ginger *(Asarum caudatum)*.

This alliance is typically found in areas of disturbance that have been impacted by logging or historic wildfires. Over time these second-growth forests shift canopy dominance toward Douglas fir. In the wettest sites, bigleaf maple may continue to retain dominant canopy status.

Regionally, much of the land that this alliance comprises is composed of Douglas fir plantations and natural regeneration that followed logging operations. In Forest Park, plantations can be found that are comprised of even-aged trees that make up structurally simplistic stands. Competition for light and space in second growth stands will result in some trees dying to make space for the establishment of younger shade tolerant trees. Structural diversity of second-growth, heavily stocked Douglas fir stands may be managed through careful thinning which can accelerate the development of late-successional forest conditions and increase understory complexity (USGS, 2003). Any exploration of stand management must first evaluate the habitat criteria for specific wildlife species as research indicates that an increase or decrease in population due to thinning treatments is species specific.

The 2008 Forest Park Wildfire Fuel Reduction Project identified the areas of greatest risk within the park; they include the interface between private and public property particularly along the western edge of the park where housing density and dry season winds are the highest. Active management of this area is critical to reduce wildfire risk. Recommendations for this buffer area include maintaining a Douglas fir overstory of widely spaced firs interspersed with bigleaf maple. In stands with conifer dominance, fuel reduction work was recommended which could include pruning and the removal of ladder fuels contributed from invasive species.

Management Strategy

- Address wildfire risk. Evaluate habitat criteria for target wildlife to inform need to create greater structural complexity.

DOUGLAS FIR–WESTERN HEMLOCK FOREST ALLIANCE
(Pseudotsuga menziesii–Tsuga heterophylla Forest Alliance)

This alliance type is characterized by a mixed canopy of Douglas fir and western hemlock. Western red cedar is present in this alliance and may co-dominate on valley bottom sites with poorly drained soils. In the presence of disturbance, western red cedar and western hemlock may be missing from the canopy stratum. Grand fir is sometimes found in association with this alliance and a subcanopy of bigleaf maple is typical. Shrubs commonly associated with this alliance include vine maple, dull Oregon grape, salal, red huckleberry, western hazelnut, and baldhip rose *(Rosa gymnocarpa)*. In the presence of disturbance, such as logging or landslides, red alder may regenerate abundantly when mineral soil is exposed. The herbaceous layer is comprised of shade tolerant ferns and forbs such as brackenfern, swordfern, redwood sorrel, vanilla leaf *(Achlys triphylla)*, western starflower *(Trientalis borealis ssp. latifolia)*, inside-out flower *(Vancouveria hexandra)*, and western trillium.

Following disturbance, replacement of Douglas fir by western hemlock is variable dependant upon the moisture regime of the site. On very dry sites, western hemlock can be completely absent from the forest composition while on wet to very wet sites western red cedar will be present. Western red cedar is typically successionally intermediate between Douglas fir, an early successional species, and western hemlock, the climax species. Depending upon disturbance intensity and available seed sources, hemlocks may not make an appearance in a stand until the second century following disturbance (Van Pelt, 2007). In a Douglas fir forest, the presence of hemlocks of different sizes, including canopy trees, can be an excellent indicator of an old-growth conditions.

Management Strategy

- Foster succession to old growth.

DOUGLAS FIR GIANT FOREST ALLIANCE
(Pseudotsuga menziesii Giant Forest Alliance)

This community type has a multi-tiered canopy of Douglas fir, which often is 50 m or more in height. Other coniferous trees such as western hemlock and western red cedar may be present in the upper tree layer, depending upon location and stand history. Broad-leaved deciduous trees such as bigleaf maple and Oregon white oak are common associates. Western yew *(Taxus brevifolia)* may also be part of the subcanopy, particularly in moist ravines. The forest understory is usually species-rich and well-developed, and may be dominated by either shrubs or a mixture of ferns and forbs. Common shrub species include salal, oceanspray, dull Oregon grape, vine maple, snowberry, and western hazelnut. The herbaceous layer is usually dominated by shade-tolerant forbs and ferns, including vanilla leaf, starflower *(Trientalis borealis)*, wild ginger, western trillium, redwood sorrel, sword fern, and maidenhair fern *(Adiantum pedatum)*. Mosses and lichens may be abundant, covering trees, logs or the forest floor.

A small number of acres exhibiting these forest characteristics are found within the areas of Forest Park that were least impacted by fire and logging. In the absence of disturbance, this acreage will grow over the next centuries as second-growth Douglas fir stands mature and take on old-growth characteristics, eventually reaching a concentration and composition that achieves the criteria of a functional old-growth stand.

Management Strategy

- Monitor and maintain for health.

BIGLEAF MAPLE SEASONALLY FLOODED FOREST ALLIANCE
(Acer macrophyllum Seasonally Flood Forest Alliance)

This alliance is associated with riparian forests along streams, rivers, and creeks. Bigleaf maple is the dominant tree in the canopy, but red alder and black cottonwood *(Populus trichocarpa)* are also present to a lesser degree. A dense shrub community includes western hazelnut, salmonberry, thimbleberry, snowberry, and occasionally devil's club *(Oplopanax horridus)*. The herbaceous layer is comprised of ferns, redwood sorrel, western trillium, vanilla leaf, and fringe-cup *(Tellima grandiflora)*. The diverse shrub layer that is associated with this alliance contributes to bird species diversity (Houle, 1982).

Disturbance is often associated with this alliance type; presence of this alliance often indicates a history of selective logging of associated conifer species. Additionally, regular disturbance such as periodic flooding may result in the persistence of this alliance. In the absence of this disturbance, succession will result in the development of a conifer component.

Management Strategy

- Assess site to determine wildlife utilization, unique plant associations, and natural regeneration. Utilize data to inform management needs to create greater structural complexity.

Oak Woodlands

OREGON WHITE OAK WOODLAND ALLIANCE
(Quercus garryana Woodland Alliance)

This alliance is characterized by an open canopy of Oregon white oak found at lower elevations of the treeline where they transition upslope into forests dominated by Douglas fir. Historically, fire maintained this habitat type. Fire suppression near urban areas has resulted in the encroachment of Douglas fir into oak woodlands. This habitat type is now found only in small, isolated pockets throughout the valley (ODFW, 2006). The majority of remnant oak populations are found primarily at or below 300 feet throughout the city, likely reflecting a transition zone between the wetlands and riparian areas that lined the Willamette River and the conifer forests that dominated the higher slopes and crests of the Tualatin Mountain Range. In Forest Park, the remaining oak woodlands are found along the eastern boundary of the park's edge.

Shrubs associated with this alliance include poison oak *(Toxicodendron diversilobum)*, oceanspray, snowberry, serviceberry, vine maple, cascara, and western hazelnut. Sword fern, bracken fern, and a variety of native grasses are often associated with the relatively open cover of this alliance. In Forest Park, species that are not common throughout the Portland Metro area such as western black haw *(Viburnum ellipticum)*, western alum root *(Heuchera micrantha)*, and low snowberry *(Symphoricarpos mollis)* are found associated with oak woodlands.

Oak woodlands have been identified as an important habitat type by regional and state planning efforts (City of Portland, BES, 2010b and ODFW, 2006). The Oregon Conservation Strategy has identified this habitat type as a Strategy Habitat for the Willamette Valley. Oaks provide important structural habitat for wildlife. The acorns that are produced are important for winter survival and are utilized by a variety of species including California quail, varied thrush, acorn woodpeckers, Douglas tree squirrel, black-tailed deer, and mice (ODFW, 2006). Additionally, researchers in the Willamette Valley found a greater abundance of breeding neotropical migrants in Oregon Oak Woodlands than in coniferous forests (Gucker, 2007). In the absence of fire, selective removal of Douglas fir can help maintain this unique and biologically important habitat composition. While the current composition of the eastern edge of Forest Park is dominated by a Douglas fir-bigleaf maple alliance, pockets of remnant oak woodlands remain both within the park's boundary and on adjacent private property. These remnant oak woodlands must be assessed and prioritized for conifer removal to improve and maintain their habitat quality and composition.

Management Strategy

- Maintain and expand existing acreage through enhancement and/or acquisition.

Riparian Corridors and Aquatic Habitat

Forest Park plays a regional role in delivering clean, cold water to the Willamette River. Creeks and streams flow through each alliance type within Forest Park. While no one subwatershed is completely located within the boundary of Forest Park, management within the park can contribute to improved water quality conditions. Functioning riparian corridors with native vegetation, intact streambanks protected from erosion, and infrastructure that does not contribute to increased sediment load are all critical components of maintaining a healthy functioning system. Aquatic habitats that provide structure for fish, amphibians, and macroinvertebrates are critical for maintaining and improving populations of aquatic wildlife.

Management Strategy

- Enhance riparian buffer vegetation.
- Maintain or improve water quality to meet Federal standards.
- Increase channel complexity and fish habitat.
- Reduce adverse impacts to sediment load from failing infrastructure.

Wildlife Habitat

The diversity of wildlife species using Forest Park has been documented and to date includes more than 50 different mammals and greater than 100 bird species. Additionally, Forest Park is home to a variety of reptiles and amphibians including garter snakes, Pacific giant salamanders, rough-skinned newts, and red-legged and Pacific tree frogs, to name a few. The two perennial streams that flow through the park, Balch and Miller Creeks, have populations of cutthroat trout and Coho salmon; short-head cottids have been observed in Miller Creek. On occasion large mammals such as bear and elk have been documented in the park. The species diversity in Forest Park is largely due to its size and connection to the Oregon Coast Range through a wildlife corridor that functionally links the park to the rural Coast Range. This connection is critical to allow for seasonal and long-term dispersal of individuals which helps maintain genetic and biological diversity. The wildlife corridor is currently unprotected and in the ownership of a mix of private and public properties that span the jurisdiction of Multnomah, Columbia, and Clatsop counties. The preservation and management of the interior lands of Forest Park alone will not protect the species diversity found within the park's boundaries.

The City of Portland's Terrestrial Ecology Enhancement Strategy (TEES) was developed to identify habitat priorities for conservation and restoration. Forest Park has been identified by TEES as an anchor habitat for wildlife both on a local and regional scale. Through TEES, six unique habitat types have been identified as having special status due to their importance for wildlife habitat diversity throughout the state and within the Portland Metro area. Five of the habitat types are found in Forest Park:

- Herbaceous wetlands: Present to a small degree throughout the park.
- Oak woodlands: Patchy distribution along the eastern edge of the park. The most intact example of this habitat type is located near Harborton Road.

- Interior forests: Over 3,000 acres of interior forest are found in Forest Park, the largest acreage of this habitat type within the City of Portland.
- Late successional conifer forests: Total acreage is relatively small, but old growth individuals are found in both the north and south management units of the park.
- Bottomland hardwood forests and riparian habitats: Throughout the park along creeks.

In addition to identifying unique habitats, TEES has identified Special Status Wildlife Species. The TEES Special Status Wildlife Species List was developed to identify species of concern because they are rare, declining or of special interest. Appendices VI and VII list those Special Status Wildlife Species and identifies their known presence in Forest Park and their association with particular habitat types. These lists focus on Special Status Wildlife Species and are not comprehensive lists of all wildlife utilizing the park.

Management Strategy

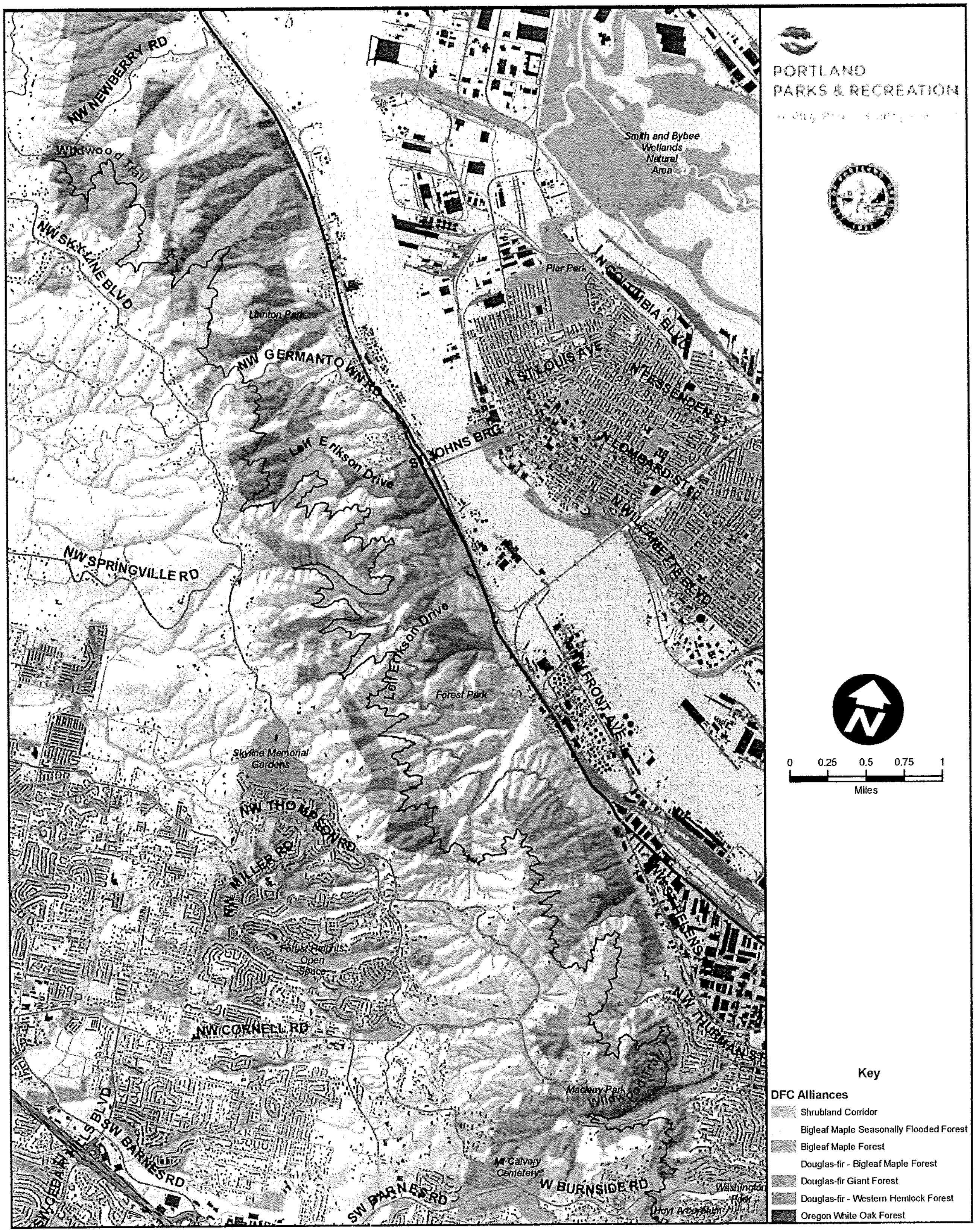
- Reduce existing invasive plant distribution and cover. Monitor and respond to new invasive plant and animal populations.
- Protect, enhance, and expand wildlife habitat features (natural and urban).
- Improve the understanding of wildlife utilization throughout the park and utilize this information to inform management decisions.

Conclusion

Forest Park represents an incredible regional resource for plant and animal biodiversity. Large tracts of interior forest and unique habitat types support a diversity of wildlife not typically found in an urban natural area. The implementation of the DFC will be to maintain, improve, and in some cases, expand the present habitat types. The continued health of Forest Park is dependent upon protection and management of the lands that buffer and influence the interior composition. Long-term management of the park must include:

1. Outreach to private property owners to address invasive species management and wildfire fuel reduction on their lands.
2. Cooperation with partners to protect aquatic resources that exist within and surrounding the park.
3. The establishment of a protected wildlife corridor that extends to the Coast Range.

These actions are critical for the continued health of the flora and fauna that depend upon the habitats and natural resources found in the park. Portland Parks & Recreation has the responsibility of managing Forest Park, but it is critical to engage partners to address these larger regional issues that extend beyond the boundaries of Portland Parks & Recreation management. The preservation of this great place is dependent upon strong partnerships that evaluate how the decisions that are made today influence the ecosystem health and integrity of the park tomorrow.


PORTLAND
PARKS & RECREATION
Smith and Bybee Wetlands Natural Area
Pier Park
N COLUMBIA BLVD
N ST LOUIS AVE
N FESSENDEN ST
N LOMBARD ST
ST JOHNS BRG
NW NEWBERRY RD
Wildwood Trail
NW SKYLINE BLVD
Linnton Park
NW GERMANTOWN RD
Leif Erikson Drive
NW SPRINGVILLE RD
Forest Park
NW FRONT AVE
Skyline Memorial Gardens
NW THOMPSON RD
NW MILLER RD
Forest Heights Open Space
NW CORNELL RD
NW THURMAN ST
Macleay Park
Mt Calvary Cemetery
W BURNSIDE RD
SW BARNES RD
Hoyt Arboretum
Washington Park
0 0.25 0.5 0.75 1
Miles
Key
DFC Alliances
Shrubland Corridor
Bigleaf Maple Seasonally Flooded Forest
Bigleaf Maple Forest
Douglas-fir - Bigleaf Maple Forest
Douglas-fir Giant Forest
Douglas-fir - Western Hemlock Forest
Oregon White Oak Forest

REFERENCES

Burns, Scott, W.J. Burns, D.H. James and J.C. Hinkle. 1998. Landslides in Portland, Oregon Metropolitan Area Resulting from the Storm of February 1996: Inventory Map, Database and Evaluation. Prepared for Metro Regional Government.

City of Portland. Bureau of Planning. 1992. *Northwest Hills Natural Areas Protection Plan.* Tim Brooks, Damian Syrnyk, Geoff Sauncy, and Jeff Mihelich. Ordinance no. 164517. Portland, Oregon.

City of Portland. Portland Parks & Recreation and Bureau of Planning. 1995. *Forest Park Natural Resource Management Plan.* Nancy Gronowski, Jim Sjulin, Tim Brooks, and Fred Nilsen. Ordinance no. 168509. Portland, Oregon.

City of Portland. Bureau of Environmental Services (BES). 2004. Willamette Watershed Characterization Report.

City of Portland, OR, Bureau of Environmental Services (BES). 2010a. Westside Streams Water Quality and Trend Analysis: Status Report 2002-2008.

City of Portland, Bureau of Environmental Services (BES). 2010b. Draft Terrestrial Ecology Enhancement Strategy: Special Status Wildlife Species. Portland, Oregon.

Franklin, J.F. and C.T. Dryness. 1973. Natural Vegetation of Oregon and Washington. PNW Forest and Range Experiment Station. General Technical Report. PNW 8. Portland, Oregon.

Gucker, Corey L. 2007. Quercus garryana. In: Fire Effects Information System. United States Department of Agriculture (USDA), Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. December 18, 2010. *(http://www.fs.fed.us/database/feis/)*

Houle, Marcy. One City's Wilderness: Its Wildlife and Habitat Interrelationships. 1982. Special Report for The Oregon Parks Foundation.

Natureserve. 2009. *(http://www.natureserve.org/explorer/)* Viewed February-April 2010.

Trout Mountain Forestry. 2008. City of Portland-Forest Park. Wildfire Risk Reduction Final Report.

Uchytil, Ronald J. 1989. Acer macrophyllum. In: Fire Effects Information System. United States Department of Agriculture (USDA), Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. December 18, 2010. *(http://www.fs.fed.us/database/feis/)*

United States Department of Agriculture (USDA), Soil Conservation Service and Forest Service, in Cooperation with Oregon Agricultural Experiment. 1983. Soil Survey of Multnomah County, Oregon. *(http://soildatamart.nrcs.usda.gov)*

United States Geologic Survey (USGS). 2003. Response of Birds to Thinning Young Douglas-fir Forests. Cooperative Forest Ecosystem Research.

Van Pelt, Robert. 2007. Identifying Mature and Old Forests. Washington Department of Natural Resources.

Appendices

APPENDIX I

Ecosystem Management Program

Portland Parks and Recreation's City Nature Group, utilizes an Ecosystem Management Program (The Program) to manage Natural Area properties. The Program utilizes a science-based approach to ecological management and includes six interrelated steps. Applied over time, the sequence of steps informs management and provides the feedback required to modify practices for the best intended outcome. This system is referred to as adaptive management.

The six steps of the Ecosystem Management Program are:

1. ***Inventory:*** An assessment of existing conditions.
2. ***Desired Future Condition:*** A planning goal that describes conditions land managers are attempting to achieve over a specified period of time in a defined area.
3. ***Assessment:*** A gap analysis that identifies the stressors contributing to the difference between the outcomes articulated in the Desired Future Condition and the existing conditions (Inventory).
4. ***Prescription:*** The development of project plans which include a project description, measure of success, budget and timelines for specific interventions to address stressors and achieve the Desired Future Condition.
5. ***Intervention:*** Implementation of the prescription.
6. ***Monitoring:*** Systematic observation and data collection utilizing established protocols to determine the efficacy of the intervention and inform the need to modify the prescription.

APPENDIX II

Invasive Species in Forest Park

One of the more identifiable disturbances in Forest Park is that of invasive species. English ivy *(Hedera helix)*, was introduced to the area at the end of 19th century as a horticultural plant and is identified as an escapee as early as 1929 (Christy, et al. 2009). As time has progressed, so has the distribution of this invasive species. In Forest Park, English ivy is dominant throughout the disturbed edges and entrances of the park. The South Management Unit of the park has the largest acreage with the highest percent cover of English ivy.

In 1994, in an effort to provide meaningful employment for local youth while raising the profile of English ivy as an invasive species, the No Ivy League was born with help various community partners. As a result of this group's dynamic leadership in invasive species removal and tireless efforts to educate and inform the public, many Portland residents often associate English ivy with Forest Park.

In 2004, the City of Portland conducted a vegetation inventory of the entire park; this survey revealed that over 2,300 acres or 49% of the park had no presence of English ivy (Table 1). Of the total acreage, approximately 1, 112 acres or 23% of the park included trace amounts of English ivy which is defined as less than 1 percent of a given area. From this analysis the conclusion can be drawn that over 70% of the park is not significantly impacted by English ivy. Table 1 displays the distribution (as measured by the cover class) of English ivy and its relative presence throughout the park. Cover class is defined as the percent of ground area covered by a vertical projection of the canopy of a species for the entire vegetation unit, an absolute value not relative to the other species present (City of Portland, 2004). Table 1 illustrates the distribution of ivy throughout Forest Park. The map on page 22 provides a visual representation of this distribution.

English ivy is a management concern in the most disturbed edges and entrances of the park. It is critical that its distribution be controlled to insure that the larger percentage of the park continues to remain free of ivy.

Table 1: Distribution of English ivy throughout Forest Park (PP&R Vegetation Survey 2004)

Cover Class	Relative Presence throughout park	
	Acreage	Percent of Park Surveyed
Not Found	2,383	49%
Trace (<1%)	1,112	23%
1% to 10%	770	16%
10% to 20%	271	6%
20% to 50%	260	5%
50% to 75%	58	1%
Over 75%	8	<1% (0.18)
Total	4,862	100%

While English ivy might be the most publicly recognizable invasive species in Forest Park, other species pose a threat to ecosystem health. In addition to English ivy and clematis *(Clematis vitalba)*, invasive tree species such as English holly *(Ilex aquifolium)*, non-native laurel *(Prunus lusitanica* and *P. laurocerasus)*, non-native cherry *(Prunus avium)*, English hawthorn *(Crataegus monogyna)*, horse chestnut *(Aesculus hippocastanum)*, and Norway maple *(Acer platanoides)* are found distributed throughout the park. Of particular concern is English holly as it is present in greater numbers than other invasive trees and was found to be the most widely distributed invasive species in Forest Park (City of Portland, 2004).

For the past three years, PP&R's Protect the Best crew has worked to remove invasive species from the most pristine areas in Forest Park. This program was designed to provide protection of the most ecologically intact natural areas within the PP&R Natural Area Portfolio from the threat of habitat degradation by invasive species. In Forest Park, the crew has worked predominately in the North Management Unit and along the west side of the park above Leif Erickson Drive. Due to the overall health of Forest Park, this crew has spent up to 75% of their working hours dedicated to removing invasive species in Forest Park. As a result, they have provided initial treatment to over 1,800 acres within the park and retreated over 800 of those originally treated acres as of the end of March 2010 (City of Portland, 2010). This body of work has resulted in over 2,400 English holly trees alone being removed from Forest Park.

Invasive species that have a smaller distribution but the potential for significant impact to the ecosystem of Forest Park are being identified and addressed as part of a citywide program of Early Detection Rapid Response. A coordinated campaign to address garlic mustard *(Alliaria petiolata)* throughout the Portland Metro area and in Forest Park has been ongoing for the past two years. In Forest Park, garlic mustard is found along roadsides and trails; it has been inadvertently distributed by park users and domesticated and wild animals. This particular species is of significant concern because of its documented ability to disturb woodland ecosystems. Garlic mustard exudes chemicals from its roots that may prevent other plants from thriving. As a result, it has the capacity to significantly alter the native woodland herbaceous plant community – reducing plant diversity, destroying palatable forage for wildlife, and reducing opportunities for pollinators.

The potential for the introduction of new invasive species to Forest Park due to the disturbed edge that exists along the park boundary and the proximity to residential properties is high. This requires constant vigilance and a quick response to new invasive plants as they appear. Portland Parks & Recreation is currently addressing several invasive species that have newly arrived to the park's perimeter, primarily through the illegal dumping of yard debris. These species include lesser celandine *(Ranunculus ficaria)*, yellow archangel *(Lamiastrum galeobdolon)*, butterbur *(Petasites japonica)*, and spurge laurel *(Daphne laureola)*. Long-term protection of the park from invasive species will require a significant outreach program to private property landowners to address invasive species control at the interface between public and private property.

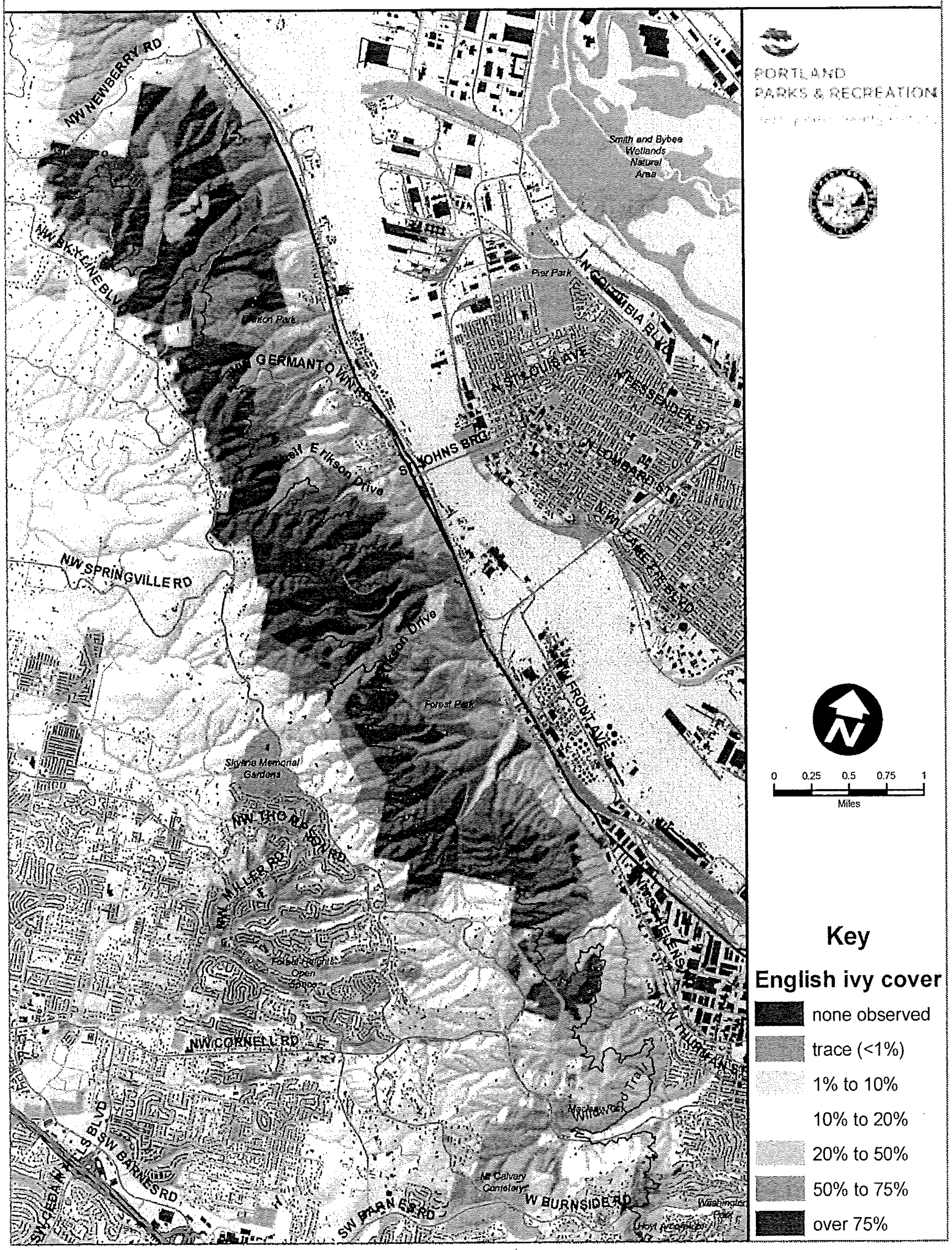
REFERENCES

Christy, J.A., A. Kimpo, V. Marttala, P.K. Gaddis and N. Christy. 2009. Urbanizing Flora of Portland, Oregon 1806-2008. Occasional Paper 3 of the Native Plant Society of Oregon.

City of Portland. Portland Parks & Recreation (PP&R). 2004. Natural Area Vegetation Inventory.

City of Portland. Portland Parks & Recreation (PP&R). 2010. Protect the Best Invasive Vegetation Management Program Report.

Forest Park English Ivy Distribution (surveyed 2004)



APPENDIX III

Recreation in Forest Park

Forest Park has experienced a marked increase in recreational use and transformation of recreational types since its inception. Prior to the declaration of the area as a park, recreation included walking, nature study, and picnicking (Munger, 1960).

Following the dedication of the area as Forest Park, the City of Portland allowed overnight camping for local youth during the summer months, developed bridle paths for horseback riding, and opened Leif Erikson and Saltzman Roads to one-way scenic drives. A lack of facilities to support these recreation activities, impacts to the park's natural resources, and an increase in use resulted in a modification of recreation over time. Horseback riding is permitted within the park on specifically designated trails only. Forest Park is now closed to overnight camping and vehicle access is restricted to park maintenance and emergency access vehicles.

Current recreation includes hiking, biking, running, dogwalking, and horseback riding. As in the past, park managers have to evaluate the impacts from recreation on the natural resource. Recreation demands can have significant adverse impacts to the natural resources of Forest Park. It is not uncommon to see park users walking with their dogs off leash in Forest Park, although City Code requires dogs be on leash at all times within the park. The 1995 Forest Park Natural Resources Management Plan identified the adverse impacts from dogs off leash to flora, fauna, and water quality. Increased erosion, trampled vegetation, reduced water quality, and disturbed wildlife are all evidenced impacts from dogs off leash. Beginning in 2006, the City of Portland began the Dogs for the Environment program which provided outreach to park users about following PP&R rules regarding having your dog on a leash at all times on park property unless the dog is in one of the City's 32 off-leash areas. This program has also provided education about the impacts from off-leash dogs and their unattended waste to wildlife, water quality, and other park users' experience and safety. Through this program an expanded ranger program has been funded in collaboration with the Bureau of Environmental Services to enforce leash and scoop laws.

Over time, recreation pressures change. Currently, in the City of Portland, a portion of community members expressed a desire to expand off-road cycling opportunities, specifically to provide additional single track cycling experiences. Single track cycling is defined as a trail with a minimum width of 18 inches and a maximum width of four feet (City of Portland, 2009). A group of stakeholders have convened to form a Forest Park Single Track Advisory Committee which is evaluating the potential for creating additional opportunities for this recreational desire. The recommendations that arise from this committee must improve both the cycling experience and the ecological health of Forest Park and will be evaluated by Portland Parks & Recreation.

The history of recreation in Forest Park illustrates that recreational demands will evolve over time as the popularity of particular leisure activities waxes and wanes. The ecological integrity of Forest Park must always be assessed and considered first when evaluating the accommodation of expanded recreation. Forest Park is a finite natural resource, managed as a natural area, and recreational demands and their impacts are potentially infinite. The 1995 Forest Park Natural Resource Management Plan, identifies broad recreational types for each of the three management units. To inform future park management the development of recreation guidelines and thresholds for each management unit is essential. For example, as the North Management Unit has been identified as having the highest resource qualities and lowest levels of use (City of Portland, 1995) a recommended guideline would be that future trail development be limited to regional trail expansion for pedestrian use only.

REFERENCES

Munger, Thorton. 1960. History of Portland's Forest-Park – Special 1998 50th Anniversary Edition. Friends of Forest Park and Portland Parks & Recreation.

City of Portland. Portland Parks & Recreation and Bureau of Planning. 1995. Forest Park Natural Resource Management Plan. Nancy Gronowski, Jim Sjulin, Tim Brooks, and Fred Nilsen. Ordinance no. 168509. Portland, Oregon.

City of Portland. Portland Parks & Recreation. 2009. Trail Design Guidelines for Portland's Park System.

APPENDIX IV

GIS Methodology for DFC

GIS analysis was utilized to determine the geographic distribution of the desired future conditions for Forest Park. Areas of the Park were categorized into one of 7 types:

1. Douglas-fir-Bigleaf Maple Forest (PSME-ACMA)
2. Douglas-fir-Western Hemlock Forest (PSME-TSHE)
3. Bigleaf Maple Forest (ACMA)
4. Bigleaf Maple Seasonally Flooded Forest (ACMA SFF)
5. Shrubland Corridor (SC)
6. Douglas-fir-Giant Forest (PSME GF)
7. Oregon White Oak Forest (QUGA)

Data regarding identified fire safety concerns from the Wildfire Risk Reduction Final Report (Trout Mountain Forestry 2008) was utilized to develop buffers of mixed forest composed of Douglas fir interspersed with bigleaf maple along the eastern and western edges of the park. Those buffers were defined as follows:

- Proximity to Skyline Road <500 ft, then DFC = PSME-ACMA
- Proximity to Thompson Road <500 ft, then DFC = PSME-ACMA
- Urban-interface, east boundary (Trout Mountain Forestry 2008), then DFC = PSME-ACMA*

** Existing vegetation inventories (City of Portland, 2004) and aerial analysis were utilized to identify significant areas of Oregon White Oak Forest (QUGA) within the urban-interface boundary. In areas of overlap, Oregon White Oak Forest (QUGA) is the desired future condition.*

LIDAR data was utilized to determine the percent conifer distribution and tree height classification throughout the park boundary. LIDAR data was collected in 2004 during leaf-off conditions utilizing a 1-meter footprint. The resulting first return data points represent conifer height very well, but effectively ignore deciduous structure, which enabled an estimation of overall conifer coverage and the identification of locations of coniferous structure that met specific height parameters.

Vegetation inventories (City of Portland, 2004) were utilized to confirm alliance types. The following rules were applied based upon species structural composition:

- If <25% conifer cover (LIDAR) and, bigleaf maple >25% with conifer presence>25% (Inventory), or If <25% conifer cover (LIDAR) and bigleaf maple 20-50%, and Douglas fir 10-20% (Inventory), then DFC = PSME-ACMA
- If >25% conifer cover, trees >200ft tall (LIDAR), and >60% cover conifer composition (Douglas fir >20%, western hemlock 1-10%, and western red cedar and/or grand fir 1-10%), dbh >30" present and Douglas-fir-Western Hemlock (Inventory), then DFC = PSME-TSHE
- If <25% conifer cover (LIDAR) and bigleaf maple >50% and < 25% conifer cover (Inventory), then DFC = ACMA
- If <25% conifer cover (LIDAR) and bigleaf maple >50% and located within 100 foot stream buffer, then DFC = ACMA SFF
- If >trace Oregon white oak present (Inventory) or trace located adjacent to vegetation unit >trace, then DFC = QUGA

All powerline corridors were designated as Shrubland Corridor Alliance which includes a desired future condition of a mosaic of shrubs, open meadows, and the retention of trees where they do not interfere with line transmission.

Appendices

Douglas-fir Giant Forest area was designated based knowledge of site conditions, topographical analysis, and field data collected during mapping of old growth trees within Forest Park.

REFERENCES

Trout Mountain Forestry. 2008. City of Portland – Forest Park. Wildfire Risk Reduction Final Report.

City of Portland. Portland Parks & Recreation (PP&R). 2004. Natural Area Vegetation Inventory.

APPENDIX V

DFC Projects

The following projects have been identified as important to meeting the Desired Future Condition for Forest Park. Each of these projects includes a target year for completion. It should be noted that many projects are ongoing or require maintenance which will precede or exceed the date of completion listed below. Ongoing projects or programs have been denoted.

SHRUBLAND/GRASSLAND ALLIANCE	
Project Description	**Target Year for Completion**
Establish management/maintenance plans with utility companies.	2015
Work closely with utility companies to retain trees throughout corridors. When removal is required, identify opportunities for snag preservation and creation. Provide snag and downed wood creation guidelines.	2015
Develop roadside mowing program that reduces frequency and informs timing of roadside mowing to encourage native species colonization and reduce the spread of invasives.	2015
Identify target wildlife species for management.	2015
Survey and map unique plants.	2015
Secure funding for long-term corridor management.	2020
Develop revegetation plans for utility corridors to provide shrub, forb, and grass diversity.	2020
Engage in active management of all Wildfire Fuel Reduction priority projects to reduce fuel load and invasive species along utility corridors.	2020
Develop revegetation plans for open meadows and roadsides to provide shrub, forb, and grass diversity.	2025
BIGLEAF MAPLE FOREST ALLIANCE	
Project Description	**Target Year for Completion**
Monitor alliance to determine wildlife utilization.	2015
Survey and map unique plants.	2015
Evaluate natural regeneration.	2015
Develop stand management plan.	2020
DOUGLAS FIR-BIGLEAF MAPLE FOREST ALLIANCE	
Project Description	**Target Year for Completion**
Identify target wildlife species for management.	2015
Evaluate natural regeneration.	2015
Survey and map unique plants.	2015
Minimize wildfire risk through the removal of flammable weeds and ladder fuels.	2020
Maintain a buffer of mixed conifer-deciduous forest composed of Douglas fir interspersed with bigleaf maple along the eastern and western edges of the park.	2020
Develop stand management plan.	2020

DOUGLAS FIR-WESTERN HEMLOCK ALLIANCE	
Project Description	**Target Year for Completion**
Identify target wildlife species for management.	2015
Evaluate natural regeneration.	2015
Survey and map unique plants.	2015
Develop stand management plan.	2020
DOUGLAS FIR GIANT FOREST ALLIANCE	
Project Description	**Target Year for Completion**
Identify target wildlife species for management.	2015
Survey and map unique plants.	2015
Map all old growth trees within this alliance.	2015
Core a sample of old growth trees to determine stand age.	2015
BIGLEAF MAPLE SEASONALLY FLOODED FOREST ALLIANCE	
Project Description	**Target Year for Completion**
Identify target wildlife species for management.	2015
Evaluate natural regeneration.	2015
Survey and map unique plants.	2015
OAK WOODLANDS ALLIANCE	
Project Description	**Target Year for Completion**
Identify target wildlife species for management.	2015
Survey and map unique plants.	2015
Assess all Oregon oak populations along eastern Park boundary. Identify stem density, conifer encroachment and understory associations. Utilize this data to determine priority oak management areas.	2015
Implement selective removal of encroaching conifers in identified priority areas.	2020
Identify opportunities for the restoration of this habitat type in the presence of natural disturbance such as climate change, disease, landslide or fire.	ongoing
Pursue acquisition of properties that contain significant remnant oak populations or provide a restoration opportunity of this alliance along the eastern boundary of Forest Park.	ongoing
RIPARIAN CORRIDORS AND AQUATIC HABITAT	
Project Description	**Target Year for Completion**
Inventory infrastructure such as roads, trails, culverts, bridges and water storage structures to establish priorities for improvement, replacement or removal.	2015 (Leif Erikson) 2020 (all other access roads) 2020 (fish bearing streams) 2035 (all other)
Work with the Bureau of Environmental Services to establish project priorities for subwatershed planning.	2015
Assess PP&R stream surveys of Balch and Miller Creek to inform priority areas for stream enhancement.	2015
Maintain and improve water quality to meet or exceed the Department of Environmental Quality's standards for tributaries to the Willamette River.	ongoing
Improve channel complexity and fish habitat in Balch and Miller Creeks.	2035

WILDLIFE HABITAT	
Project Description	**Target Year for Completion**
Removal of tree ivy which threatens the integrity of the forest canopy. Long-term maintenance and identified funding sources to maintain this work on a cycle of 5 years following initial treatment.	2015
Control invasive plant species listed on the City of Portland's Early Detection Rapid Response (EDRR) List.	ongoing
Complete initial treatment of invasive species in the most ecologically healthy units of the Park through the Protect the Best program.	2015
A long-term plan to reduce invasive species cover in less ecologically healthy areas which includes addressing funding required for long-term maintenance and restoration, measures of success and a monitoring strategy.	2015
Conduct wildlife studies to determine presence/absence, distribution and population of target species.	2015
Assessment of wildlife habitat features such as snags and large downed wood throughout alliances. Recommendations for creation/protection of these features.	2015
Identification of opportunities for urban habitat features such as but not limited to bird and bat boxes.	2015
Map existing wetlands throughout Park and develop protection/ enhancement strategies for these sites.	2015
Engage in regional planning efforts to protect wildlife corridor connection to the Coast Range.	2020
Implement protection/enhancement strategies for wetlands.	2020
Create a list of EDRR animal species for Forest Park and develop management response to detection.	2020
Work in partnership with outside agencies to monitor and control introduced insect pests.	ongoing
During the upgrade of buildings or installation of new structures include avian friendly designs and evaluate opportunities for urban habitat such as ecoroofs.	ongoing
Minimize impacts to wildlife from land management actions by utilizing the Migratory Bird Treaty Act TEES Guidelines.	ongoing

APPENDIX VI

Special Status Bird Species Association with NVCS Alliance

All Data resourced from Houle, 1982 unless noted otherwise: a) Johnson and O'Neil, 2001; b) Kotliar, 2007; c) Purple Martin Conservation Association, 2010; d) Broshot, 2010.

Bird Name	**Observed in Forest Park**	**Home Range**	**Associated Alliances**		
			Douglas Fir Giant Forest	Mixed Conifer Forest (includes all other forest types listed in DFC)	Disturbance corridor shrublands
American kestrel	Yes	270 acres	Breeding[1] Feeding[1]		Feeding[2]
Bald eagle	Yes	4 mile radius	Breeding[1] Feeding[2]		Feeding[2]
Band-tailed pigeon	Yes	0.1-0.5 mile radius	Feeding[2]	Breeding[1] Feeding[2]	Feeding[2]
Black Throated Gray Warbler	Yes	Unknown	Breeding[2] Feeding[1]	Breeding[2] Feeding[1]	Breeding[2] Feeding[2]
Brown creeper	Yes	Unknown	Breeding[1] Feeding[1]	Breeding[2] Feeding[2]	
Bullock's oriole	No	Unknown		Close Association	
Bushtit	Yes	Unknown	Breeding[2] Feeding[2]	Breeding[2] Feeding[2]	Breeding[1] Feeding[1]
Chipping sparrow	No	0.5-1.5 acres	Breeding[2] Feeding[2]	Breeding[2] Feeding[2]	Breeding[1] Feeding[1]
Common nighthawk	No	0.5 mile diameter	Breeding[2]	Breeding[2]	Breeding[2]
Downy woodpecker	Yes	5-8 acres		Breeding[2] Feeding[2]	
Great blue heron	Yes	10 mile radius	Breeding[2]	Breeding[1]	
Hermit warbler	No	Unknown	Breeding[1] Feeding[1]		
House wren	Yes	1.1-4.4 acres			Feeding[1]
Hutton's vireo	Yes	Unknown		Breeding[2] Feeding[2]	Breeding[2] Feeding[2]
Merlin	No	Unknown	Breeding[2] Feeding[2]		Feeding[2]
Nashville warbler	No	Unknown	Breeding[2] Feeding[2]	Breeding[2] Feeding[2]	Breeding[1] Feeding[1]
Olive-sided flycatcher	Yes	24-64 acres	Breeding[1] Feeding[1]	Feeding[2]	Feeding[1]
Orange-crowned warbler	Yes	5 acres		Breeding[2] Feeding[2]	Breeding[1] Feeding[1]

Pacific slope flycatcher	Yes	Unknown	Close Association	General Association	
Peregrine falcon	No	6.5 to 15.5 square miles	General association	General association	Feeding[1]
Pileated woodpecker	Yes	320-600 acres	Breeding[1] Feeding[1]	Feeding[2]	
Purple finch	Yes	Unknown	Breeding[1] Feeding[1]	Breeding[2] Feeding[2]	Breeding[2] Feeding[2]
Purple martin	No	5-10 square miles	Breeding[2]		Breeding[2] Feeding[2]
Red crossbill	Yes	Unknown	Breeding[1] Feeding[1]	Feeding[2]	
Red-eyed Vireo	Yes	Unknown			Breeding[2] Feeding[1]
Rufous hummingbird	Yes	Unknown	Breeding[2] Feeding[1]	Breeding[1]	Breeding[1] Feeding[1]
Swainson's thrush	Yes	Unknown	Breeding[2] Feeding[2]	Breeding[2] Feeding[2]	Breeding[2] Feeding[2]
Varied thrush	Yes	Unknown	Breeding[1] Feeding[1]	Breeding[2] Feeding[2]	Feeding[2]
Vaux's swift	Yes	Unknown	Feeding[1] Feeding[2]		Feeding[1]
Western wood-pewee	Yes	3-4 acres	Breeding[1] Feeding[1]	Breeding[2] Feeding[2]	Feeding[1]
White-breasted nuthatch	Yes	37 acres per pair	Breeding[2] Feeding[2]		
Willow flycatcher	Yes	0.8-2.9 acres			Breeding[1] Feeding[1]
Wilson's warbler	Yes	0.5-3.2 acres	Breeding[2] Feeding[2]	Breeding[1] Feeding[2]	Breeding[2] Feeding[2]
Winter wren	Yes	0.1-1.3 acres	Breeding[1] Feeding[1]	Breeding[2] Feeding[2]	
Yellow breasted chat	No	0.15-0.75 acres			Breeding[2] Feeding[2]
Yellow warbler	Yes	0.2-0.9 acres	Feeding[2]	Breeding[2] Feeding[2]	Breeding[1] Feeding[1]

[1] Preferred Habitat thought to support a higher population

[2] Habitat used by a species but thought to support a lower population

REFERENCES

Broshot, Nancy. 2010. Linfield College, Department of Biology. Personal Communication 3/21/2010

Houle, Marcy. One City's Wilderness: Its Wildlife and Habitat Interrelationships. 1982. Special Report for The Oregon Parks Foundation.

Johnson and O'Neil. 2001. Wildlife-Habitat Relationships in Oregon and Washington. Oregon State University Press.

Kotliar, Nancy. 2007. Olive-sided Flycatcher (Contopus cooperi): A Technical Conservation Assessment. Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project.

The Purple Martin Conservation Association. Erie, Pennsylvania *http://purplemartin.org/main/* Terminology accessed 3/20/2010

APPENDIX VII

Special Status Amphibian/Mammal Species Association with NVCS Alliance

All Data resourced from Houle, 1982 unless noted otherwise referenced: a) City of Portland, 1995; b) Johnson and O'Neil 2001.

Species name	Observed in Forest Park	Alliance Associations		
		Douglas Fir Giant Forest	Mixed Conifer Forest (Includes all other forest types listed in DFC)	Disturbance corridor shrublands
American beaver	Yes		Breeding[2] Feeding[2]	Breeding[1] Feeding[1]
California myotis	No data			Breeding[1] Feeding[1]
Hoary bat	No data	Breeding[2]		
Long-legged myotis	No data	Breeding[2] Feeding[2]	Breeding[2] Feeding[2]	Feeding[2]
Northern red-legged frog	Yes	Close Association	General Association	
Red tree vole	No data	Breeding[2] Feeding[2]		
Silver-haired bat	No data	Breeding[2]	Feeding[2]	Feeding[1]
Western gray squirrel	No data	Breeding[2] Feeding[2]	Breeding[1] Feeding[1]	Feeding[2]
White-footed vole	No data	Breeding[1] Feeding[1]	Breeding[1] Feeding[1]	Breeding[2] Feeding[2]
Yuma myotis	No data	Breeding[1]	Breeding[2]	Breeding[2] Feeding[2]

[1] Preferred Habitat thought to support a higher population

[2] Habitat used by a species but thought to support a lower population

REFERENCES

Houle, Marcy. One City's Wilderness: Its Wildlife and Habitat Interrelationships. 1982. Special Report for The Oregon Parks Foundation.

Johnson and O'Neil. 2001. Wildlife-Habitat Relationships in Oregon and Washington. Oregon State University Press.

Exhibit 7

Burlington Bottoms Wildlife Mitigation Site

Habitat Management Plan

Technical Report
2001

DOE/BP-00004888-1

September 2001

This Document should be cited as follows:

Bielke, Susan, "Burlington Bottoms Wildlife Mitigation Site", Project No. 1991-078-00, 24 electronic pages, (BPA Report DOE/BP-00004888-1)

Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

BURLINGTON BOTTOMS WILDLIFE MITIGATION SITE
Project #91-078

FIVE-YEAR HABITAT MANAGEMENT PLAN
2001-2005

Prepared for:

Bonneville Power Administration
905 NE 11th Avenue
Portland, Oregon 97232

Prepared by:

Susan G. Beilke
Oregon Department of Fish and Wildlife
Sauvie Island Wildlife Area
18330 NW Sauvie Island Road
Portland, Oregon 97231

September 2001

TABLE OF CONTENTS

1.0 INTRODUCTION.. 1

2.0 BACKGROUND.. 1

3.0 GOALS AND OBJECTIVES....................................... 2
- 3.1 Goal Statement.. 2
- 3.2 General Goals.. 2
- 3.3 General Objectives.. 3
- 3.4 General Mitigation Principles.................................. 3

4.0 FIVE-YEAR HABITAT ENHANCEMENT PLAN............... 5
- 4.1 Enhancement Strategies and Methods.......................... 5
- 4.1.1 Water Management Plan...................................... 5
- 4.1.2 Future Needs.. 6
- 4.1.3 Permits/Surveys.. 7
- 4.1.4 Additional Enhancement Methods............................ 7
- 4.2 Description of Zones 1-4, Associated Objectives and Enhancement Actions.. 10
- 4.2.1 Zone 1.. 10
- 4.2.2 Zone 2.. 11
- 4.2.3 Zone 3.. 12
- 4.2.4 Zone 4.. 13
- 4.3 Five-Year Enhancement Schedule.............................. 16

5.0 MONITORING AND EVALUATION.............................. 18
- 5.1 Enhancement Monitoring.. 18
- 5.2 Evaluation.. 20

6.0 INFRASTRUCTURE NEEDS...................................... 22
- 6.1 Access Roads.. 22
- 6.2 Equipment, storage facilities, etc................................ 23
- 6.3 Fencing... 23

7.0 ADAPTIVE MANAGEMENT STRATEGY....................... 23

8.0 OPERATIONS AND MAINTENANCE............................ 23

9.0 RECOMMENDATIONS... 24

10.0 CONSISTENCY WITH OTHER PLANS, PROGRAMS, ETC.. 24

11.0 ACKNOWLEDGEMENTS.. 24

LIST OF FIGURES & APPENDICES

FIGURES:	**Page**
1. Location Map of Burlington Bottoms	4
2. Aerial Photograph of Proposed Water Control Location/Affected Habitats	9
3. Aerial Photograph of Site and Zones 1-4	14
4. HEP Habitat Types and Acreage	15

APPENDIX A: DESCRIPTON OF HABITAT TYPES AND CURRENT AND DESIRED HABITAT CONDITIONS

APPENDIX B: WILDLIFE MONITORING PROTOCOLS

APPENDIX C: FISH MONITORING PROTOCOL

1. INTRODUCTION

Historically the lower Columbia and Willamette River Basins were ecologically rich in both the habitat types and the species diversity they supported. This was due in part to the pattern of floods and periodic inundation of bottomlands that occurred, which was an important factor in creating and maintaining a complex system of wetland, meadow, and riparian habitats. This landscape has been greatly altered in the past 150 years, primarily due to human development and agricultural activities including cattle grazing, logging and the building of hydroelectric facilities for hydropower, navigation, flood control and irrigation in the Columbia and Willamette River Basins.

The Burlington Bottoms (BB) wetlands contains some of the last remaining bottomlands in the area, supporting a diverse array of native plant and wildlife species. Located approximately twelve miles northwest of Portland and situated between the Tualatin Mountains to the west and Multnomah Channel and Sauvie Island to the east (Figure 1), the current habitats are remnant of what was once common throughout the region. In order to preserve and enhance this important site, a five-year habitat management plan has been written that proposes a set of actions that will carry out the goals and objectives developed for the site, which includes protecting, maintaining and enhancing wildlife habitat for perpetuity.

2.0 BACKGROUND

In 1991, Burlington Bottoms was one of the first sites in Oregon to be purchased by the Bonneville Power Administration (BPA) under the Willamette and Columbia River Basins Fish and Wildlife Programs, to provide partial mitigation for the impacts associated with the construction of hydroelectric facilities. The Northwest Power Act of 1980 established and charged the Northwest Power Planning Council (NPPC or Council) with the task of developing a comprehensive fish and wildlife mitigation program to protect, mitigate, and enhance fish and wildlife habitat in the Columbia and Willamette River Basins (Power Act 1980, Section 4 (H)(1)(A), page 12; NPPC 1994, Section 2, page 2-1). This program, initially adopted in 1982, was amended in 1984, 1987, 1991-1993, and 1994. Consistent with Section 1003(7) of the Council's Fish and Wildlife Program, BPA is authorized to fund implementation of projects that will help reach the Council's wildlife mitigation goals and objectives.

The Oregon Department of Fish and Wildlife (ODFW) was contracted by BPA in 1993 to conduct interim management of the BB site, which included completion of a habitat assessment or habitat evaluation procedure (HEP). The HEP, a process developed by the U.S. Fish and Wildlife Service (USFWS), utilizes a species/habitat approach to quantify relative habitat values for mitigation crediting (see the separate report titled *Burlington Bottoms Habitat Evaluation, August 1993,* for further information).

In addition to the HEP work, a hydrology and hydraulics assessment was completed in 1993. Results of the habitat and hydrology assessments were then incorporated into the writing of the Environmental Assessment/Management Plan in 1994. Implementation of the Management Plan began in 1995, which has included to date custodial oversight, removal of non-native invasive plant species and planting of native plants to increase the biological diversity on the site.

An assessment of both the current and desired future habitat conditions at BB was completed in November 1998, and was documented in the report titled *Current and Desired Future Habitat Conditions and Related Habitat Units at Burlington Bottoms, November 1998.* This report also identified maintenance and enhancement opportunities and associated costs that would benefit wildlife by 1) maintaining current habitat conditions (baseline habitat units), and 2) creating additional future habitat units (AAHUs).

The Five-Year Habitat Management Plan for BB incorporates information from all of the documents listed above. In addition, proposed enhancement actions and methodologies are based in part on a review of local and regional habitat management issues, current enhancement methods being used on projects on other sites (e.g., USFWS's Ridgefield Wildlife Refuge, USFW's Sandy River Delta), other BPA wildlife projects (e.g., Willamette Basin projects, Metro Parks and Greenspaces lands north of BB), ODFW's Sauvie Island Wildlife Area, and discussions with wildlife habitat managers and plant ecologists regarding the most effective and efficient methods for controlling/removing non-native plant species and enhancing native plant communities.

3.0 GOALS AND OBJECTIVES

The following project goal statement and general project objectives are consistent with the principles of the Council's Fish and Wildlife Program, and the Columbia Basin Fish and Wildlife Authority (CBFWA) Wildlife Caucus' Draft Guidelines for Enhancement, Operation, and Maintenance Activities for Wildlife Mitigation Projects (CBFWA 1998). Specific objectives designed to achieve the habitat enhancement goals are listed and described in Section 4.2.

3.1 Goal Statement

The overall goal of the Five-Year Habitat Management Plan is to protect, maintain and enhance fish and wildlife habitat at Burlington Bottoms. This will in turn satisfy a portion of the mitigation requirements of the Northwest Power Act of 1980, as amended. The project area will be maintained primarily as wetland and upland habitats typical of those found historically along the lower Willamette and Columbia River Basins. Any proposed future recreational, research, or other activity other than habitat maintenance and enhancement must be compatible with the goals and objectives of this Plan. Implementation of the 5-Year Habitat Management Plan will help achieve the project's overall goal to provide mitigation for the impacts associated with the hydropower system.

3.2 General Goals:

The general goals of the 5-Year Habitat Management Plan are to:

- Protect, maintain and enhance the biological diversity of the site.
- Maintain and enhance the six habitat types found on the site so that they more closely resemble bottomland habitats historically found in this area.
- Maintain consistency with the Council's Fish and Wildlife Program and Phase IV Resident Fish and Wildlife Program Amendments.

- Assist BPA in meeting their wildlife mitigation obligations in a cost-efficient manner.
- Assist BPA in finding a land management agency to assume ownership of the site.

3.3 General Objectives:

The general objectives of the BB wildlife mitigation project area are to:

- Protect and maintain 1,319 Habitat Units (HUs) for eight target and associated wildlife species through maintenance and enhancement of wildlife habitats (see 1993 BB HEP report).
- Provide an additional 105 or more future habitat units (AAHUs) by the year 2005, through enhancement of wildlife habitats (see 1993 BB HEP report). Determination of future AAHUs would be made by conducting a modified HEP after enhancement objectives have been met.

3.4 General Mitigation Principles:

This plan is based on and consistent with the following mitigation principles identified in the Council's Program (NPPC 1994) to help ensure that wildlife mitigation goals and objectives are met.

- Use the most cost efficient methods to achieve biological objectives.
- Have measurable benefits, such as the restoration of a given number of habitat units.
- Help protect or enhance natural ecosystems and species diversity over the long-term.
- Encourage the formation of partnerships with other persons or entities to reduce project costs, increase benefits, and/or eliminate duplicative activities.
- Do not impose on BPA the funding responsibilities of others, as prohibited by Section 4(h)(10)(A) of the Northwest Power Act.


north
Figure 1
SAUVIE
ISLAND
COLUMBIA RIVER
WASHINGTON
OREGON
PEARCY
ISLAND
WILLAMETTE RIVER
MULTNOMAH
CHANNEL
BURLINGTON
97231
97203
RAMSEY LAKE
MILLER
HARBORTON
FOREST PARK
WILLAMETTE

4.0 5-YEAR HABITAT ENHANCEMENT PLAN

In order to achieve the goals and objectives identified for the site, a combination of management strategies would be utilized over the five-year period. Enhancement methods would include manipulation of water levels, mechanical and hand removal of non-native vegetation and planting of native plants to increase diversity on the site.

Because the hydrology of the site is one of the major factors influencing both the character of the habitats and the wildlife species using those habitats, a water management plan has been developed that allows for control of the duration, amount, and timing of water in various areas. Water management is necessary on the site in order to mimic to the extent possible historic water conditions, which in turn allowed for native plant communities to flourish. Currently, control of water levels is one of the most widely accepted and successful methods of eliminating exotic plant species such as reed canary grass from wetlands. The water management plan is described in Section 4.1 along with other enhancement methods proposed for the site. Figure 2 depicts the areas (by elevation) that may be affected by water management activities.

Section 4.2 describes the four Zones (Figure 3) within BB, and the habitat types (Figure 4), enhancement actions and objectives specific to each zone. The four zones are essentially four sub-areas within the site which have been delineated for ease of planning and to more effectively monitor and evaluate enhancement actions over the long-term.

A five-year schedule of the enhancement actions is detailed in section 4.3. Other management actions such as maintaining/improving the infrastructure (e.g., improve existing roads) in order to access an area, are addressed in Section 6.0 under Infrastructure Needs.

4.1 Enhancement Strategies and Methods

The alteration of the water regimes and effects of long term cattle grazing at Burlington Bottoms in the past 50 years has had a substantial impact on native plant communities and wildlife species, allowing for an invasion of exotic plant and wildlife species over time and the overall loss of biological diversity in some areas on the site. Because of the complexity of the site and the difficulty in removing and/or controlling invasive plant species, a combination of methods, including water management, mechanical and hand removal, and native planting, would be utilized over the five-year period in order to restore native plant communities and species diversity in certain areas.

4.1.1 Water Management Plan

The installation and operation of a water control structure would be the primary method used to restore native plant communities on the site, by controlling the amount, timing and duration of water in various areas. The first phase of the water management strategy would include the following:

- Water levels would be manipulated through the installation of a water control structure on the outlet slough connecting Horseshoe Lake to Multnomah Channel (see Figure 2 for location), allowing for water availability and control in order to mimic natural hydrologic processes.

The water control structure will allow impoundment of an additional estimated 10-12 feet of water within the outlet slough; this is expected to overflow into the open water, emergent wetlands, wet meadow and forested wetland habitats. It is anticipated that the water control structure should flood approximately 125.0 acres (this will be determined after surveys are completed) in all four zones, in the following habitat types:

- Open water - approximately 60 acres; Emergent wetland - approximately 35 acres; Wet meadow - approximately 20 acres; and Forested wetland - approximately 10 acres.

These estimates are based on topographic features on the site and the anticipation that the water control structure may not affect any acreage at an elevation higher than 12 feet.

- Moist soil management techniques would be utilized to maintain and increase where possible the native plant diversity and to remove/control exotic plant species such as reed canary grass.
- The use of a high capacity pump to increase water flow (from the Multnomah Channel) into the southern portion of the site may be necessary, in order to augment existing water levels during a given year in order to control reed canary grass and other exotics. This technique may be necessary in years when water levels are low due to drought conditions and other unforeseen events, and there is insufficient water on the site to allow for proper water management.
- Habitat manipulations, including mowing, spraying, and disking may be used in conjunction with the water control structure, depending on conditions specific to a given area on the site.

Through the proper use of moist soil management techniques, it is expected that control/removal of exotic species including reed canary grass will be achieved in various habitats, allowing for the re-establishment of native plant species. Based on the habitat types and total acres that may be affected by water manipulation, it is estimated that:

- Approximately 125 acres of reed canary grass could be removed/controlled on the site, enhancing open water, emergent wetland, forested wetland and wet meadow habitats.
- In addition, other exotics such as Himalayan blackberry may also be affected, resulting in reduced number and vigor.
- Native plant communities would be restored in the wet meadow habitat and could provide an additional 105 or more future habitat units (AAHUs), to be measured by a future HEP.
- Existing native plant communities would be maintained in the affected habitats, protecting the baseline habitat units (HUs).

4.1.2 Future Needs

At a certain point in time, (e.g., after manipulation of water levels for 2 years), consideration of whether additional methods or structures are needed would be made. This could include:

- Installation of additional water control structure(s) on the site; possible future locations include: 1) the slough connecting Horseshoe Lake and South Pond; the wetlands south of the slough may not be affected by the first phase of the water management plan, hence the possible need for additional structures which could affect this area; and 2) installation of a water control structure on McCarthy Creek (see below).
- The use of a high capacity pump to increase water flow (from the Multnomah Channel) into the southern portion of the site, in order to augment existing water levels during a given year in order to control exotics. It is anticipated that pumping would not occur on a regular basis, but instead would occur on an as needed basis, depending on rainfall, etc.

- Obtain a water right for McCarthy Creek, a perennial stream located at the north end of the property and situated along the north access road. Analysis of historical aerial photos shows evidence that this creek once contributed flows to BB via various channels that were most likely cut off when the access road was built (date unknown). Given that currently there are no perennial streams contributing water to the site, the availability of water from this source would be highly beneficial for the enhancement of native plant communities.
- If a water right for McCarthy Creek is obtained, conduct a hydrologic assessment of the area to determine how to best use flows from the creek for enhancement purposes. This may entail construction of additional water control structure(s) on the north end, allowing for water availability on an as needed basis to control invasive non-native plant species.

4.1.3 Permits/Surveys

Prior to enhancement actions, permits would be needed for 1) water rights and 2) fill and removal from the Division of State Lands (DSL) and the Army Corp of Engineers. Various surveys (e.g., Threatened and Endangered (T&E) species, cultural resources) will be conducted prior to any ground-breaking or other significant management activity. For example, surveys for T&E fish species will be conducted prior to the design and installation of a water control structure. Consultation with the USFWS and the National Marine Fisheries Service (NMFS) would occur in regard to any T&E species present on the site. In addition, NEPA compliance will be achieved before any ground disturbance actions are taken.

4.1.4 Additional Enhancement Methods

In addition to the manipulation of water levels on the site, additional enhancement methods would be used to control exotic plant species and restore native plant communities on the site. Depending on the habitat type and zone-specific conditions (e.g, topography), enhancement methods used to achieve the enhancement actions would vary, depending in part on the degree of invasion by exotics and accessibility to a particular area. Since many areas that have exotic invasion occurring still contain native species, removal methods should be used that will preserve as much of the native plant communities as possible. In the long-term, this will preserve the diversity of a particular area and should help to reduce costs of planting and monitoring.

Additional methods used would include:

- <u>Mechanical methods:</u> Mechanical methods (disking, mowing, etc.) may be used in those areas that are accessible and where few or no native plant species are present; determination on where mechanical methods would be appropriate would be made on an area by area basis. For example, in wet meadow habitat dominated by exotics with less than 10% native species present, mechanical removal would be appropriate. Following removal, some areas may be spot sprayed with Rodeo or other herbicides to assist in the control of invasive plant species.
- <u>Herbicides:</u> Though herbicides have not been used on the site in the past, they should be considered where it is deemed appropriate (herbicides used would be USFWS approved products). Any application of herbicides must take into consideration impacts to wildlife species present in a particular area, including amphibian species such as the red-legged frog and Pacific chorus frog, which are particularly sensitive to herbicides.

- Hand control methods: Hand control methods, using local field crews such as Ameri-Corp, would be utilized in some areas, including dense riparian forest where English ivy is present. Hand control methods are currently used in areas such as Forest Park, where ivy has been removed from hundreds of trees in the past 5 years. Hand removal of non-native plants is best utilized in areas where native vegetation is already established, creating the least disturbance to native plant communities, and/or for areas that are accessible only on foot. Hand removal methods can also reduce the costs of purchasing and planting native plants in the long-term.
- Native planting/seeding: Planting of native species would occur at some point after removal/control of non-natives, in order to establish native trees, shrubs and forbs that are fast growing and to create a canopy to shade out invasive non-native species. Native planting will also increase the available food, cover, and reproductive habitat available over time. Planting density would vary, depending on the presence and abundance of native species.

In areas where there is low native plant species abundance and/or diversity, or where native species are absent altogether, planting density could be as high as 650 plants per acre (e.g. disturbed upland converted to forest habitat), or as low as 100 plants per acre depending on the percentage of native species already present in an area. Spacing of plants would vary, depending on area-specific conditions. All plants would be from local native plant nurseries. For some areas, species planted would include fast growing native tree species which produce high leaf litter (black cottonwood, Oregon ash, willow) to create a canopy to shade out invasive shrub and forb species (blackberry, thistle, etc.). Seed collection on site should be done where appropriate in order to maintain the local genetic diversity and reduce costs of planting. Also, several local nurseries carry native seed mixes that may be appropriate for the site, such as the disturbed upland where native shrubs and trees are not easily established.


Habitat which may be affected
by water management
Under 10 feet Elevation
2.12 acres
Under 12 feet Elevation
123.37 acres
Proposed water control structure
Burlington Bottoms
Planimetric data developed by Spencer Gross Inc.
under contract with W&H Pacific Inc. 1993.
Image not orthorectified. Use for approximate
location reference only.
OREGON

Figure 2

4.2 Descriptions of Zones 1-4; Associated Objectives and Enhancement Actions

Described below are the four zones (see Figure 3, page 13), along with management objectives for each zone and the recommended enhancement actions, based on the habitat types that occur within each zone and the current and desired future habitat conditions (a brief description of each of the habitat types along with current and desired future habitat conditions is included in Appendix A). Figure 4 (page 14) illustrates the location of the habitat types. The boundaries of the zones are based on physical features of the site (natural or man made), such as a slough or road.

A five-year schedule (Section 4.3) has been developed whereby enhancement actions can be implemented in a manner that meets BPA's mitigation requirements, protecting and maintaining the current wildlife habitat values while also enhancing habitat over time and creating additional future habitat values (AAHUs). All acreage figures listed are approximate and will be more accurately determined using GIS at some point in the near future.

4.2.1 - Zone 1. This area (total of 128 acres) encompasses all of the open water habitat located in the south half of the site including Horseshoe Lake and the large ponds to the south, South Pond and Deep Pond. Currently water levels in the lake and ponds are controlled by at least six known beaver dams, two on the slough connecting South Pond to Horseshoe Lake and four on the outlet channel connecting Horseshoe Lake to Multnomah Channel. Intermixed along the margins of these bodies of water are narrow bands of riparian forests of mixed age, riparian shrub, forested wetland, wet meadow, and emergent wetland habitats.

In addition, approximately 14.0 acres of disturbed upland habitat exists along the southwest margin of South Pond and the northwest margin of Deep Pond. The disturbed upland includes areas of gravel fill, part of which is dominated by blackberry and exotic grasses, with some patches of native shrubs and trees (primarily black cottonwood, big-leaf maple, nootka rose and spiraea), and several unique vernal pools that contain a diverse array of native plant species. This open, sunny upland area is important habitat for several species of reptiles, raptors (red-tailed hawks, turkey vultures) and songbirds. Five patches of English ivy are located on the east and southwest sides of South Pond and the east and west sides of Deep Pond.

Enhancement actions for this zone are designed to protect and maintain the baseline HUs and to increase both the quality and quantity of available wildlife habitat. Over time, these actions should show an increase in HEP values (AAHUs) for some of the target species, including the red-tailed hawk and valley quail. It is estimated that enhancement actions could be accomplished within the five-year period. However, some actions such as blackberry removal will be ongoing and should be considered part of the long-term operations and maintenance (O&M) for the site.

The management objectives for Zone 1 are:

- Enhance approximately 40 acres of open water, emergent wetland, forested wetland and wet meadow habitats.
- Enhance approximately 15 acres of riparian shrub and forest habitats along the margins of South Pond and Deep Pond.
- Restore approximately 5 acres of disturbed upland to riparian shrub and forest habitats.
- Maintain the current baseline habitat units (HUs) for all target wildlife species.
- Provide additional habitat units (AAHUs) through enhancement actions.

The habitat enhancement actions for Zone 1 are:

- Management of water levels affecting open water, emergent wetland, forested wetland and wet meadow habitats; approximately 40 ac.
- Removal of English ivy from riparian forest habitat: approximately 5 acres.
- Removal of Himalayan blackberry and other exotics from the disturbed upland and portions of the riparian shrub and forest habitats; approximately 15 acres.
- Planting of native trees and shrubs in portions of the disturbed upland and riparian forest habitat; approximately 15 acres.
- Increase habitat diversity by creating additional vernal pools and rock piles in the open, grassy areas.
- Mow (on an annual basis) portions of the disturbed upland to control exotic grasses and other non-natives; approximately 3 acres.

4.2.2 - Zone 2. This area encompasses a total of approximately 108.0 acres and includes all of the habitats east of Horseshoe Lake and the slough connecting the lake to Multnomah Channel, which is the eastern boundary of this zone. Habitats within this zone include riparian forest (primarily mature stands of Oregon ash and black cottonwood), small, narrow bands of riparian shrub and approximately 22 acres of upland and wet meadow habitats (the latter includes a temporary pond and emergent wetland habitats heavily used by waterfowl and other species including amphibians in the winter and spring months). Past human use of this area has included a high degree of disturbance (commercial use and cattle grazing), with the result that over time a large percentage of the habitats in this zone have become heavily invaded by exotics, primarily reed canary grass and Himalayan blackberry.

Enhancement actions for this zone are designed to restore the understory of the riparian forest to native shrubs and forbs, and to eliminate the exotics in the upland and wet meadow habitats, restoring the native plant communities for increased diversity and wildlife values. This would be accomplished primarily through the installation of a water control structure at the western edge of this zone, on the outlet slough, which would allow for the manipulation of water levels to control or eliminate exotic plant species (see Section 4.1). In addition, mechanical, spraying and hand removal of exotics in some habitats would occur, followed by planting of native species, including shrubs and forbs such as willow, red-osier dogwood, spiraea and rushes and sedges.

With enhancement, it may be possible to some degree to restore habitats to what was historically found in the bottomlands in this region. Because of the high degree of disturbance in this zone, it is estimated that some of the enhancement actions may need to continue beyond the proposed 5-year schedule for this Plan. Additional water control measures (e.g., water pump, supplementary water control structures) may be needed in the future to effectively carry out enhancement objectives.

The management objectives for Zone 2 are:

- Enhance approximately 30 acres of open water, emergent wetland and wet meadow habitats.
- Enhance approximately 20 acres of riparian shrub and forest habitats.
- Maintain the current baseline habitat units (HUs) for all target wildlife species.
- Provide additional future AAHUs through enhancement actions.

The habitat enhancement actions for Zone 2 are:

- Management of water levels affecting open water, emergent wetland and wet meadow habitats; approximately 30 acres.
- Widen and deepen the small channel that connects the outlet slough to the wet meadow and riparian shrub habitats to enhance water flow to these areas.
- Removal of Himalayan blackberry and other exotics from the riparian forest and shrub habitats; approximately 20 acres.
- Removal of exotics in the wet meadow habitat through disking, etc., to prepare the area for planting of native plants; approximately 5 acres.
- Planting of native trees and shrubs in portions of the riparian shrub and forest habitats; approximately 20 acres.
- Plant native shrubs and forbs in the wet meadow habitat; approximately 5 acres.

4.2.3 - Zone 3. With a total of 100.0 acres, this zone includes the most diverse mix of all six habitats found on the site, including at least ten shallow, temporary bodies of water that provide habitat for a diverse array of fish and wildlife species, including the State Sensitive listed northern red-legged frog, and western painted and pond turtles. The northern boundary is the north road and legal boundary of the site, the Multnomah Channel is found along the east side of the site, and two sloughs make up the southeast, south, and west boundaries of Zone 3. The largest and most contiguous stand of mature riparian forest found on the site is located in the northeast and east portions of this zone, and as evidenced from wildlife survey and monitoring efforts, provides important habitat for many species, including migratory songbirds such as the Swainson's thrush and red-eyed vireo, and the State Sensitive listed red-legged frog. Much of the wet meadow habitat and portions of the understory of the riparian forest habitat (at lower elevations) is dominated by reed canary grass. The predominant historic use of this area was cattle grazing.

Enhancement actions for Zone 3 are designed to protect and maintain the existing diverse wildlife habitats and their associated HEP values. In addition, enhancement of the wet meadow, open water, and riparian forest habitats would create additional habitat units (AAHUs) for species such as the valley quail, red-tailed hawk and black-capped chickadee. Through the management of water levels (see Section 4.1), mechanical, spraying and hand removal of exotics and planting of native plants in some areas, an estimated 50-75% of the management objectives could be achieved within 5 years of implementation. Because of the difficulty in removing exotics such as reed canary grass, additional water control structures or other measures may be proposed in the future.

The management objectives for Zone 3 are:

- Enhance 35 acres of open water, emergent wetland and wet meadow habitats.
- Enhance approximately 20 acres of riparian shrub and forest habitats.
- Maintain the baseline habitat units (HUs) for all target wildlife species.
- Provide additional future habitat units (AAHUs) through enhancement actions.

The habitat enhancement actions for Zone 3 are:

- Management of water levels to control/remove exotics in the open water, emergent wetland and wet meadow habitats: approximately 35 acres.
- Removal of Himalayan blackberry and other exotics from the riparian forest and shrub habitats; approximately 20 acres.

- Removal of exotics in the wet meadow habitat in some areas by disking, etc., for site preparation for planting of native plants; approximately 10 acres.
- Planting of native trees and shrubs in portions of the riparian shrub and forest habitats; approximately 15 acres.
- Plant native shrubs and forbs in the wet meadow habitat; approximately 10 acres.

4.2.4 - Zone 4. Located in the northwest, west and central portions of the site, this zone encompasses all six habitats found on the site, for a total of 81.0 acres. A large portion of the area is wet meadow and riparian shrub habitats dominated by reed canary grass, with numerous swales and small, temporary ponds found on the west side of the slough that make up the eastern boundary of Zone 4. The southern and southeastern portions are predominantly mature riparian forest, primarily Oregon ash with several large white oak trees at the higher elevations. The understory in the riparian forest is diverse and relatively undisturbed, with blackberry and reed canary grass just beginning to invade this habitat. At the present time, two streams flow into this zone from the Tualatin Mountains; a third stream (McCarthy Creek) historically flowed into the site at the northern end, but has been diverted and now contributes relatively little flow due to a non-maintained culvert under the north access road.

Similar to Zones 1-3, enhancement actions for this zone are designed to protect the existing high quality habitat values, in addition to restoring native plant communities in highly disturbed areas. Manipulation of water levels would be a primary means to accomplishing management objectives (see Section 4.1), as well as removal of exotics and planting of native trees, shrub, and forbs in the wet meadow and riparian shrub habitats. An estimated 50-75% of the management objectives could be achieved within 5 years of implementation. Because of the degree of difficulty in removing exotics such as reed canary grass, additional water control structures or other measures may be necessary in the future.

The management objectives for Zone 4 are:

- Enhance approximately 20 acres of open water, emergent wetland and wet meadow habitats.
- Enhance approximately 20 acres of riparian shrub and forest habitats.
- Maintain the baseline habitat units (HUs) for all target wildlife species.
- Provide additional future habitat units (AAHUs) through enhancement actions.

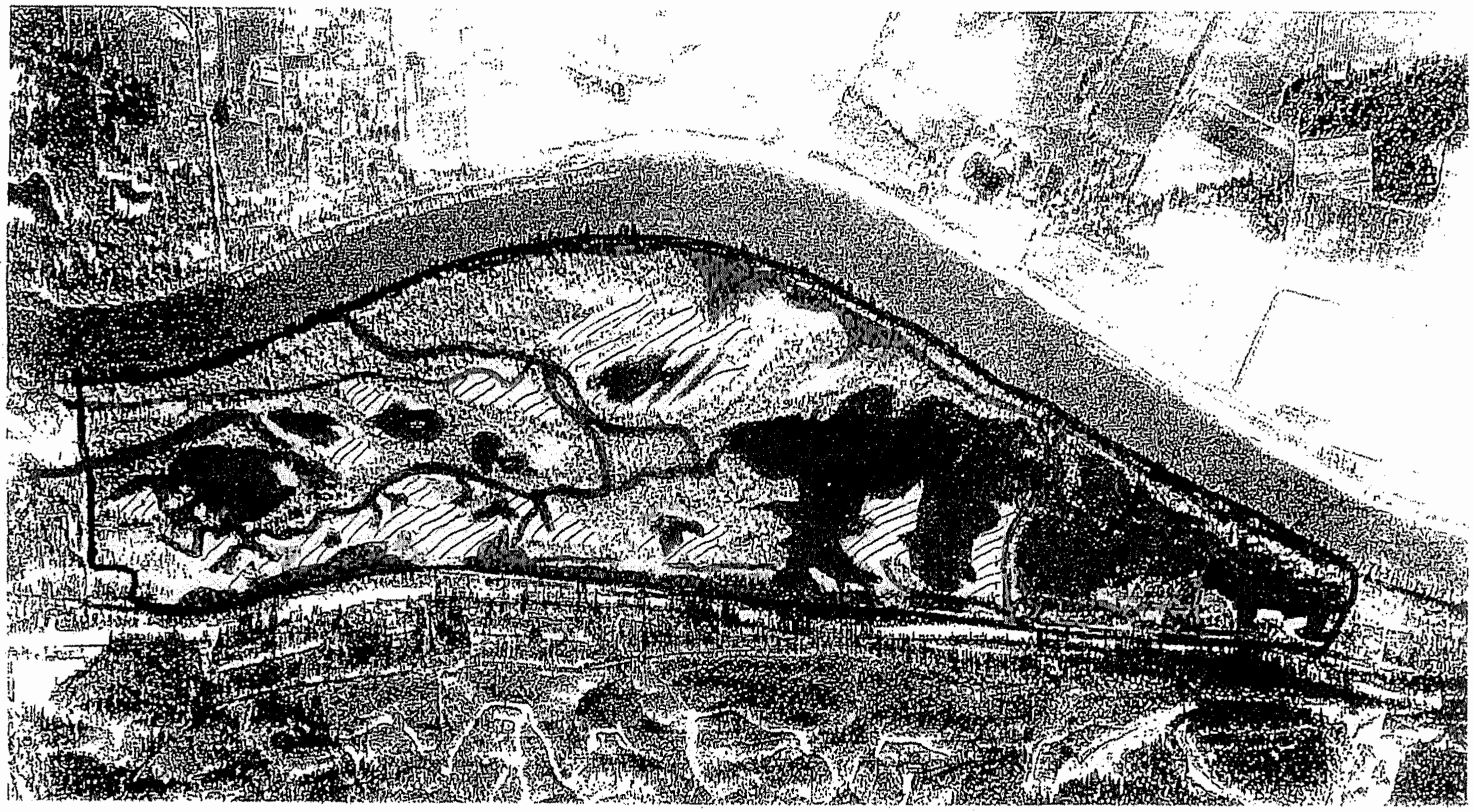
The habitat enhancement actions for Zone 4 are:

- Management of water levels to control/remove exotics in the open water, emergent wetland and wet meadow habitats: approximately 20 acres.
- Removal of Himalayan blackberry and other exotics from the riparian shrub and forest habitats; approximately 20 acres.
- Removal of exotics in the wet meadow habitat by disking, spraying, etc., for site preparation for planting of native plants; approximately 10 acres.
- Planting of native trees, shrubs and forbs in portions of the wet meadow, riparian shrub and forest habitats; approximately 15 acres.


3
2
4
1
Zones 1-4
Zone 1: 128 acres
Zone 2: 108 acres
Zone 3: 100 acres
Zone 4: 81 acres
Burlington Bottoms
Planimetric data developed by Spencer Gross Inc. under contract with W&H Pacific Inc. 1993.
Aerial Photography Flown 8-11-98
Image not orthorectified. Use for approximate location reference only.
OREGON
Fish & Wildlife

Figure 3

BURLINGTON BOTTOMS



Habitat Types

(215.32 ac) Riparian tree
(14.10 ac) Riparian shrub
(49.96 ac) Pasture (seasonally flooded)

Forested wetland (16.24 ac)
Emergent wetland (82.19 ac)
Disturbed areas (14.19 ac)
Open water (25.00 ac)

Figure 4

4.3 Five-Year Enhancement Schedule

The following multi-year enhancement schedule has been developed in order to carry out the proposed enhancement actions for BB in a manner that will afford the greatest habitat protection and mitigation benefits within a reasonable level of time and funding. Estimates of where enhancement will occur and acreage figures are tentative and may change based on available funding for a given year. Once funding has been finalized, a scope of work, budget, and detailed work plan would be developed on a yearly basis. Enhancement actions are described and organized by years 2001 through 2005, with a breakdown of number of acres, miles of road, etc. targeted for each of the four zones (see Table 1).

YEAR 2001:

1. Installation of water control structure: All Zones, (approximately 125.0 ac.); this action is ranked at the top since it may be the most effective method of controlling/removing reed canary grass and other exotics from the open water, forested wetland, emergent wetland and wet meadow habitats. Over time it would maintain the baseline wildlife values (HUs) and should also increase habitat units (AAHUs) in these habitats.
   - Schedule: construct in late summer, 2000, then maintain in following years (additional water control structures, pump, etc, may be needed in the future).
2. Removal of English ivy: Zone 1 (5ac.); Remove ivy from several areas in Zone 1.
   - Schedule: begin in year 2000 and complete by end of 2000 if possible.
3. Removal of exotic plant species: Zones 1 (5 ac.), 3 (5 ac.); Continue removal in several areas of riiparian shrub and forest habitats. Disturbed upland habitat (Zone 1, 2 ac.) will be mowed to
   control exotic grasses, etc.
   - Schedule: remove plants in fall, winter, grub/clip new sprouts in spring; spot spray with herbicide if needed.
4. Native planting: Zones 1 & 2 (7 ac.); Plant native species in riparian shrub and forest habitats.
   - Schedule: plant in late fall and winter.
5. M&E: Zones 1 & 3 (10 ac.); Monitor and evaluate exotic plant removal and planting projects from 1998-1999. Determine success/failure of activities, alter strategies where needed.
   - Schedule: late spring and summer.
6. M&E: Zones 1, 3, & 4; Begin establishment of additional transects, plots, etc. for future M&E activities related to water control structure, future plantings, etc.
   - Schedule: late spring, summer, fall.

YEAR 2002:

1. Maintain water control structure: Zones 1-4 (125 ac.); Continue to operate and maintain water levels as needed in order to control exotics.
   - Schedule: check water depths monthly; add or remove stop boards as needed. Routine maintenance on structure may be needed.
2. Removal of exotic plant species: Zones 1-3 (15 ac.); Riparian shrub and forest and open meadow habitats would be targeted. Continue to mow disturbed upland habitat (Zone 1).
   - Schedule: remove plants in fall, winter, grub/clip new sprouts in spring; spot spray with herbicide if needed; mow upland in summer.

3. Native planting: Zones 1-3 (15 ac.); Plant natives in riparian shrub, forest and open meadow habitats.
   - Schedule: plant in late fall/winter.
4. M&E: Zones 1-3; Monitor and evaluate previous exotic species removal and native planting from 1999-2001. Determine success/failure of enhancement activities, alter strategies where needed.
   - Schedule: late spring and summer.
   M&E: Zones 1-4; Continue establishment of additional transects, plots, etc. for future M&E activities related to water control structure, future plantings, etc.
   - Schedule: late spring, summer, fall.

YEAR 2003:

1. Maintain water control structure: Zones 1-4 (125 ac.); Continue to operate and maintain water levels as needed in order to control reed canary grass, etc.
   - Schedule: check water depths monthly; add or remove stop boards as needed. Routine maintenance on structure may be needed.
2. Removal of exotic plant species: Zones 1-3 (20 ac.); Continue removal of exotics in riparian shrub, forest and open meadow habitats. Mow uplands to control grasses.
   - Schedule: remove plants in fall, winter, grub/clip new sprouts in spring; spot spray with herbicide if needed; mow upland in summer.
3. Native planting: Zones 1-3 (10 ac.); Plant natives in open meadow, riparian shrub and forest habitats.
   - Schedule: plant in late fall/winter.
4. M&E: Zones 1-3; Monitor and evaluate previous exotic species removal and native planting from 2000-2002. Determine success/failure of activities, alter strategies where needed.
   - Schedule: late spring and summer.

YEAR 2004:

1. Maintain water control structure: Zones 1-4 (125 ac.); Continue to operate and maintain water levels as needed in order to control reed canary grass, etc.
   - Schedule: check water depths monthly; add or remove stop boards as needed. Routine maintenance on structure may be needed.
2. Removal of exotic plant species: Zones 1-4 (20 ac); Continue removal of blackberry and other exotics in open meadow, riparian shrub and forest habitats. Mow disturbed upland.
   - Schedule: remove plants in fall, winter, grub/clip new sprouts in spring; spot spray with herbicide if needed.
3. Native planting/seeding: Zones 1-4 (15 ac.); Plant natives in open meadow, riparian shrub and forest habitats.
   - Schedule: plant in late fall/winter.
4. M&E: Zones 1-4; Monitor and evaluate previous exotic species removal and native planting/ seeding from 2001-2003. Determine success/failure of enhancement activities, alter strategies where needed.
   - Schedule: late spring and summer.

YEAR 2005:

1. Maintain water control structure: Zones 1-4 (125 ac.); Continue to operate and maintain water levels as needed in order to control reed canary grass, etc.
   - Schedule: check water depths monthly; add or remove stop boards as needed. Routine maintenance on structure may be needed.
2. Removal of exotic plant species: Zones 1-4 (20 ac.); Continue removal of exotics in riparian shrub, forest and open meadow habitats. Mow uplands to control exotic grasses, etc.
   - Schedule: remove plants in fall, winter, grub/clip new sprouts in spring; spot spray with herbicide if needed; mow upland in summer.
3. Native planting/seeding: Zones 1-4 (15 ac.); Plant natives species in open meadow, riparian shrub and forest habitats. Seed native grass mix in wet meadow habitat.
   - Schedule: plant in late fall/winter.
4. M&E: Zones 1-4; Monitor and evaluate previous exotic species removal and native planting from 2002-2004. Determine success/failure of enhancement activities, alter strategies where needed.
   - Schedule: late spring and summer.

5.0 MONITORING AND EVALUATION

Monitoring and evaluation (M&E) of habitat management actions would occur in order to determine whether the stated goals and objectives for the habitat management plan have been met. Depending on the enhancement action in a particular habitat type, M&E may include the use of more than one monitoring method and success criteria, with monitoring occurring on a yearly basis (for each of the five years) and for the long-term life of the project as part of operations and maintenance (O&M). Wildlife surveys are expected to last five years with the opportunity for additional years if data analysis can justify such action. Fish surveys are required by the National Marine Fisheries Service (NMFS) to determine the effects on anadromous fish of constructing and operating a water control facility at BB. M&E will also include conducting a modified HEP upon completion of the five-year habitat management plan, in order to analyze the changes in habitat types (from baseline conditions) and related habitat units in response to enhancement actions.

5.1 Enhancement Monitoring:

- Upon installation of the water control structure, water depths will be recorded monthly (to meet water resources requirements). Storage in acre feet would be calculated and the extent of inundation on the ground would be delineated using staff gauges and topographic maps; all of this information would be recorded and mapped. It is anticipated that monitoring will occur on a weekly or monthly basis depending on the time of year and flow regime. Long-term monitoring will include water level manipulation as part of moist soil management techniques and a water rights form filed annually.
- Aerial photography (BPA provided aerial equipment, e.g., BPA helicopter) may also be used to document extent of inundation, vegetation changes etc.; this information would then be scanned into computer format and managed as part of the GIS database component.

- Water quality would be monitored (turbidity, temperature, pH levels, etc.) on a seasonal basis throughout the life of the project.
- Vegetation surveys would be conducted in all habitat types to determine general vegetation and habitat response to enhancement activities. In addition to the HEP transects established and marked in 1993, plots and transects would be established in 2001-2002 in areas not adequately addressed by the HEP surveys. 2001-2002 surveys would be conducted in order to establish baseline data, collecting information on species of trees, shrubs, forbs and grasses present, height, density and distribution of these species, percent canopy cover, etc. For areas where reed canary grass is present (e.g., wet meadow) stem counts would also be conducted. Control sites would be established to evaluate untreated areas and in some areas to serve as indicators of what the desired future habitat conditions should be, based on presence of native and non-native plant species. Location and placement of transects and plots will be based on the size (acreage) of a given area/habitat type and topographic features (e.g., elevation). All transects, etc. would be permanently marked. Monitoring would be conducted at least once per year (late summer/early fall) beginning in 2001 and continuing through 2005, and thereafter conducted as needed or as part of O&M.
- Determine annual planting success and causes of planting failure (poor stock, poor planting methods). Alter site preparation and/or planting methods as monitoring indicates. Document in annual report.
- Measure seeding survival twice per year and assess causes of seeding failure (e.g., poor conditions, poor seed source). Alter site preparation and/or planting methods as monitoring indicates. Document in annual report.
  - Photo monitoring points would be established to document significant changes in plant species composition/habitat changes over time, in particular in areas where exotics dominate the landscape prior to enhancement activities (e.g., where disturbed upland is converted to riparian forest habitat; where wet meadow is converted from reed canary grass dominated area to native forbs). Photos would be taken yearly at designated points to document changes at 1) the landscape level and 2) at the transect/plot level, documenting changes in species composition, height, etc. over time. It is expected that changes should be noted after one year of management activity(s). Photo points would be established at least one point per 10-20 acre (dependent on site conditions) in each direction. Analysis of photo points would coincide with analysis of data from vegetation surveys, by noting visual changes in the landscape due to enhancement activities. Photo point data will also be useful for presentations to agencies, etc. when presenting results of project activities.
  - Monitoring for salmonid use and maintain fish passage would occur using the protocol, success criteria and time line established by ODFW, National Marine Fisheries Service and Ducks Unlimited (DU), for the nearby sites, Sauvie Island and Multnomah Channel (see Appendix C). Data collected would include collecting detailed information on fish passage (species and numbers of fish, etc.) and surrounding habitat (dominant vegetation, water depth, turbidity, temperature, etc.). Photographs would be taken of a typical shoreline representative of each stratum at each season. Existing information on fish species present on the site includes fish surveys conducted by ODFW in 1994 and 1995.
- Using GIS technology, much of the data collected would become part of a database that would allow for producing accurate and timely maps of the results of enhancement activities and subsequent M&E.

- Surveys and monitoring of wildlife would include pond-breeding amphibians and neotropical migratory landbirds (NTMB). Surveys for both guilds are habitat based, and will provide a measure of the floristic and structural diversity of the associated habitats (see Appendix B). Data collected will include:

  Amphibians: surveys would be conducted from late January through early April, noting species and number of egg masses for each, type of attachment brace, water depth, distance to shoreline, overall vegetation species and composition in each pond and other pertinent information.

  NTMB: surveys would be conducted during the breeding season, typically mid-May through the end of June. Data collected would include noting all species and total number of detections at each point count, weather, vegetation type, % canopy cover, structural diversity and overall vegetation species and composition at each point count station, and other pertinent information.

  Surveys and monitoring for both amphibians and NTMB would be conducted using established regional protocols, with results and information applicable and available to other agencies and entities managing for similar species and habitat. Results would be compared to other local sites such as Ridgefield National Wildlife Refuge and Sandy River Delta where similar enhancement projects are being conducted.
- Results of wetland enhancement monitoring would be documented in the quarterly and annual reports.

5.2 Evaluation: The success of enhancement actions would be measured primarily by 1) conducting a modified HEP at some point in time after completion of the five-year plan, and 2) evaluating changes in habitats over time that would not be measured by the HEP. If a particular area or habitat type showed only a modest or no increase in native species, enhancement actions would need to be altered to achieve the desired objectives. In addition, fish and wildlife presence (HEP and T&E species, salmonids) and their use of various habitats will also be considered and evaluated. All acreage figures given are approximate and would be finalized once funding has been determined.

- ***Open water, emergent wetland, forest wetland and wet meadow habitats:*** following yearly vegetation surveys, evaluate enhancement activities (water management techniques, disking, planting) by using the following performance criteria:
  - Flood approximately 125 acres through June (based on precipitation and runoff).
  - Plant surveys should show an increase in native species presence and abundance and a decrease in non-natives (e.g., reduction of reed canary grass in number and vigor), particularly in those areas that were dominated by exotics prior to enhancement. Specific changes would be area specific depending on elevation, extent of inundation, etc. If a particular area or habitat type showed only a modest, no increase or decrease in native species, enhancement actions would need to be altered to achieve the desired objectives.
  - Approximately 25 acres of exotics would be treated (mechanically cleared, then sprayed with acceptable herbicide) by the end of the five-year plan.

- Approximately 25 acres of wet meadow habitat would be planted with native shrubs, forbs and grasses at a density of 650 plants per acre, depending on site conditions, by the end of the five-year plan.
- 70-80% seeding success the first year, 50-60% success by the third year in the wet meadow habitat.
- Transects and photo points from the 1993 HEP, as well as additional transects and photo points established in 2000-2001, would be evaluated on a yearly basis, noting visual changes at both the landscape and transect/plot levels. Photos should visually record and show significant changes in vegetation (e.g., species composition, height) at all points, and in addition should reflect plant and habitat changes at the landscape level. If after three years of photo point monitoring results are insignificant and do not visually record changes, this method would be evaluated and possibly dropped as part of the M&E efforts.
- Pond-breeding amphibians: the use of aquatic habitat by four species of amphibians will be documented by observation of egg masses during the breeding season for each year of the five-year monitoring period. Results of surveys (total number of egg masses, water depth, attachment brace (native vs non-native), distance to shoreline etc.) will be compared to previous years' data, and will be correlated with changes in the aquatic habitat, due to natural environmental variation and management action. Management activities that alter the aquatic vegetative communities, as well as altering the hydrologic regime, may have a significant effect on amphibian populations, and this should be evident in survey results. Water management should improve both the quality and quantity of habitat for pond-breeding amphibians over time.

  Performance criteria: The following criteria are based on the assumption that the effects of management actions (e.g., change in number of egg masses) can be differentiated from the effects of environmental variation and that the changes in number of egg masses can be correlated to the increase in number of areas inundated by water at critical times of the year.
  - The increase in the number of amphibian egg masses at the end of five years of data collection will be proportional to the total increase in number of acres inundated by water at critical times of the year.
  - The increase in the number of amphibian egg masses at the end of five years of data collection and management plan implementation will also be proportional to the increase in native vegetation in ponds at the site.

Riparian shrub, forest and disturbed upland habitats: following yearly vegetation surveys, evaluate enhancement activities (mechanical and hand removal, spraying, planting) by using the following performance criteria:

- Removal of 5 acres of English ivy in riparian forest habitat.
- Plant surveys should show an increase in native species presence and abundance, and a reduction in number and vigor of non-natives (e.g., Himalayan blackberry), particularly in those areas that were dominated by exotics prior to enhancement.
- Approximately 50 acres of exotics would be treated (mechanical and hand removal, herbicide spraying if appropriate) by the end of the five-year plan.
- Approximately 55 acres would be planted in the riparian shrub, forest, open meadow and disturbed upland habitats by the end of the five-year plan, with an expected 60-70% survival of trees and shrubs.

- Conduct a modified HEP at the completion of the five-year plan. It is expected that habitat values for some wildlife species would increase after enhancement actions have occurred, with a resulting increase in future habitat units (AAHUs) for some of the HEP wildlife species (see 1993 HEP report for Burlington Bottoms). Success/measurable criteria are built into the HEP models and will not be addressed in this document.
- Transects and photo points from the 1993 HEP, as well as additional transects and photo points established in 2001-2002, would be evaluated on a yearly basis, noting visual changes at both the landscape and transect/plot levels. Photos should visually record and show significant changes in vegetation (e.g., species composition, height) at all points, and in addition should reflect plant and habitat changes at the landscape level. If after three years of photo point monitoring results are insignificant and do not visually record changes, this method would be evaluated and possibly dropped as part of the M&E efforts.
- Neotropical migratory landbirds: the use of the riparian forest habitat will be documented for each year of the five-year plan, by estimating species abundance and diversity, including for HEP species black-capped chickadee and yellow warbler. At the end of the five-year plan, observations will be made on trends in abundance that may be evident from five years of data. Results will be correlated with changes in habitat due to management activities, including non-native plant removal and native planting.

  Performance Criteria: The following criteria are based on the assumption that the effects of management actions (e.g., increase in the number and diversity of NTMB) can be differentiated from the effects of environmental variation and that the increase in number and diversity of NTMB can be correlated to the increase and diversity of native plant species in the riparian forest habitat.
  - The increase in NTMB species diversity and abundance will be proportional to the increase and diversity of native plant species in the riparian forest habitat over the five-year period.

An adaptive management approach would be utilized in order to effectively respond to the success or failure of enhancement actions. If the performance criteria are not met, then the current management actions would need to be re-evaluated and modified in order to provide high quality habitat for both amphibians and NTMB. In addition, a consideration would need to be made whether other factors (e.g., drought) could be affecting habitat quality, and these would need to be addressed. An analysis of the M&E results could indicate that the assumptions upon which the performance criteria are based are not appropriate. An M&E report following the five years of data collection and analysis will address these factors.

6.0 INFRASTRUCTURE NEEDS

6.1 Access roads

In order to achieve the habitat enhancement goals and objectives for the site, access will be needed into all habitats where management actions are prescribed. Currently, there are four roads and several trails on the property which allow access to many but not all areas of the site. Yearly maintenance of the existing roads/trails would include removal of vegetation where appropriate to ensure access for management activities.

Several former primitive roads/trails that were open in 1993 have not been maintained, and have since been overtaken by non-native plants such as Himalayan blackberry. It is recommended that the former roads/trails be reopened and improved to allow for access into some areas in order to carry out enhancement activities including removal of invasive plant species.

Other than those listed above, it is not recommended that additional roads be built at this time. It is believed that through a combination of using the existing roads, improving the former primitive roads/trails, and with the installation and operation of a water control structure, all areas that require maintenance and enhancement will be accessible. Costs for additional roads would be prohibitive and it is unlikely that funding would be available in the future.

6.2 Equipment, storage facilities, etc.

Beginning in 1999, a tractor, mower and other equipment will be available for use at BB. A weed trimmer was purchased in 1997; hand tools and other supplies needed are available. All supplies and equipment will be stored at the ODFW/Sauvie Island Wildlife Area office on Sauvie Island.

6.3 Fencing

Fencing is recommended to protect the area from stray cattle wandering onto the site, and to reduce trespassing, both of which have been problems at BB in the past five years. Fencing was present along the north boundary until 1991 but was removed by BPA after purchase of the site. Fencing is recommended along the north boundary, along with relocating the existing gate on the north trail so that it is parallel to the fence line. The boundary corners of BPA property on the north end should be marked with steel angle iron.

7.0 ADAPTIVE MANAGEMENT STRATEGY

An adaptive management approach for Burlington Bottoms would afford the opportunity to alter management activities over time, in response to the success or failure of enhancement actions. Due to the high degree of disturbance resulting from past altered hydrologic conditions and the invasion by exotic plant species in many of the native plant communities, both proven and experimental techniques may be utilized for enhancement activities. As the plan proceeds, enhancement techniques may be altered based on results of M&E and determination of success or failure of particular method(s) used in particular habitat(s). Various local and regional efforts are underway at other sites, and information from these activities should be incorporated into management strategies for BB in the future if applicable.

8.0 OPERATIONS AND MAINTENANCE

Operations and maintenance activities would include the following: O&M of any water control structure(s), pumps, etc.; O&M of all roads and trails to ensure management access; fence maintenance (if applicable); debris removal; and control of exotics plant species such as Himalayan blackberry. It is assumed that in most cases, O&M would be required for the lifetime of the project.

9.0 RECOMMENDATIONS

The following recommendations have been made in order to improve implementation of the habitat plan, or to add value to the existing wetland habitats through consideration of purchase of several adjacent wetland habitats.

- Using GIS technology, redo all maps relating to habitat types and boundaries, location of exotic plant species, locations of past enhancement actions, and specific acreage figures.
- Replace the existing culvert in the slough under the north access road in order to restore flows from McCarthy Creek into BB. From observations of this culvert and of water flow in the past two years it appears that the culvert has collapsed and thus impedes water flow into the slough on the BB side. The increase in water flow should be helpful in habitat restoration efforts. This slough provides important habitat for many species of wildlife, including red-legged frogs, great blue herons, wood ducks and hooded mergansers.
- Consider purchase of the wetlands just beyond the southern property boundary and north of the commercial buildings (wrecking yard) and houseboat moorage facilities. Total acreage is estimated at 10.0 acres of wetland habitats; approximately 2.0 acres of emergent wetland and approximately 8.0 acres of a mature and diverse ash/cottonwood forest. The addition of these wetlands would: 1) complement and enhance the existing wetlands on the southern edge of BB since they are all part of the same wetland complex; and 2) move the southern property boundary to the north edge of the commercial buildings/moorage facilities, making a clear distinction between the wetlands and these developed lands.
- Continue discussions with the landowner directly north of BB, regarding the purchase or trade of the section of property they own that lies between the railroad tracks and BB's northwest boundary.

10.0 CONSISTENCY WITH OTHER PLANS, PROGRAMS, ETC.

This habitat enhancement plan is designed to be consistent with the following plans and programs:
- The Northwest Power Planning Council's Fish and Wildlife Program
- Willamette Basin Mitigation Program (Project No. 9206800)
- The Oregon Trust Agreement Planning Project (92-84)
- Assessing Oregon Trust Agreement Using GAP Analysis (95-65)
- Securing Wildlife Mitigation Sites-Oregon (Project No. 9705900).

11.0 ACKNOWLEDGEMENTS

The author of this plan (Susan Beilke) wishes to thank the following for their valuable insight and recommendations during the writing of this plan; Susan Barnes, John Beck, Mark Nebeker, and Greg Sieglitz, ODFW; and Tom Morse, BPA.

APPENDICES

APPENDIX A

DESCRIPTION OF HABITAT TYPES AND CURRENT AND DESIRED FUTURE HABITAT CONDITIONS

November, 1998

- **Riparian Forest Habitat** (215 acres; Present in Zones 1-4)

The riparian forest habitat is comprised of mature and mixed aged stands of Oregon ash and black cottonwood, with a well-developed shrub layer in most areas, and a ground cover of shade-tolerant forbs. This habitat type (Figure 3) is found throughout the site and is concentrated in long, narrow, bands interspersed among the numerous ponds and sloughs. Due in part to natural plant succession and a change in the historic water regimes of the Willamette and Columbia Rivers, which in turn has produced somewhat drier on-site conditions in the past 50 years, this habitat type is expanding into the upland meadow (pasture) habitat.

Encroachment of non-native plant species such as Himalayan blackberry, reed canary grass, and English ivy is occurring, with an estimated 150 acres of this habitat type throughout the site showing varying degrees of invasion by exotics. The three known patches of English ivy are concentrated in the southern portion of the site in Zone 1. Previous management actions in this habitat type in the past three years have included removal of Himalayan blackberry, Scot's broom, and English ivy on approximately 15-20 acres.

- **Forested Wetland Habitat** (16 acres; present in Zone 1)

The forested wetland provides important habitat for many wildlife species, including the three HEP species sampled for, wood duck, great blue heron, and beaver. It is dominated by Oregon ash and Pacific willow, with creek dogwood, red elderberry and Sitka willow common in the shrub layer. Native forbs include slough sedge and juncus spp. Historically, this habitat was inundated seasonally but flood control and other activities in the region have changed the water regime over time. Because of drier on site conditions, exotics such as reed canary grass have invaded the herbaceous layer; this was evident in all areas sampled during plant surveys in 1993 and 1995. Overall, there is probably less forested wetland habitat now as compared to historic levels, again due to diking, flood control, etc. No previous management activities have occurred in this habitat type.

- **Riparian Shrub Habitat** (14 acres; present in Zones 1-4)

This habitat type is well dispersed throughout the site and can be found along the edges of the numerous ponds and sloughs. Dense stands of willow, red-osier dogwood and other native shrub species provide habitat for many species of wildlife, including yellow warbler and beaver, both target HEP species analyzed in this habitat type. Cavities in the older Pacific willow trees along Horseshoe Lake provide important nesting habitat for swallows and other migratory songbirds.

Historically this habitat type was well adapted to frequent flooding, but to due to diking, flood control, and other human activities, conditions have dramatically changed, resulting in degraded conditions and in some cases a loss of this habitat type all together. During plant surveys conducted in 1993 and 1995, almost all areas sampled contained reed canary grass and/or other exotics such as Himalayan blackberry. In the past two years, management activities have included removal of blackberry and Scot's broom. Planting of native plants including willow, nootka rose, red-osier dogwood and Douglas spiraea, has occurred along pond and creek margins, on approximately 4 acres.

- **Wet Meadow (formerly pasture) Habitat** (50 acres; present in Zones 1-4)

Many species of wildlife, including songbirds, raptors, small and large mammals, amphibians and reptiles use this habitat type. Historically, much of this habitat would have been dominated by native grasses and sedges, including Columbia sedge and sweet vernal grass, with scattered patches of shrubs such as Douglas spiraea and nootka rose.

Up until 1991, most of the wet meadow habitat at BB was heavily grazed, with several areas having been seeded with reed canary grass in the past to provide a wetland forage species palatable only to cattle and a few wildlife species such as Canada geese. This grass has since spread and now dominates most of the wet meadow habitat on the site. Growing up to 8 feet in height in some areas, it has adapted well and forms a dense monoculture with low wildlife habitat value.

Habitat values for several of the HEP wildlife species (great blue heron, red-tailed hawk, valley quail, and spotted sandpiper) analyzed in the wet meadow were below optimal due to the dense stands of reed canary grass, which reduces prey availability for raptors, impedes movement for some species such as valley quail, and eliminates nesting habitat for turtles and other wildlife species. Other non-native plant species present include bull thistle and Himalayan blackberry. Management activities that have occurred in the past 4 years include hand removal of blackberry and mowing of reed canary grass during the late summer and fall, on approximately 4 acres.

- **Emergent Wetland Habitat** (82 acres; present in Zones 1-4)

Native plant species in the emergent wetland habitat include wapato, smartweed, and bur-reed, which provide important food, cover, and reproductive habitat for many species of waterfowl, wading birds, turtles, small and large mammals, and amphibians. HEP wildlife species analyzed in this habitat type include wood duck, great blue heron, beaver, and spotted sandpiper.

Most of the areas sampled in the emergent wetland habitat in 1993 and in subsequent surveys show varying levels of invasion by reed canary grass, depending on water depth and length of seasonal inundation. Some areas that were predominantly reed canary grass in the 1993 surveys had changed dramatically after the 1996 flood and the 1997 spring freshets; reed canary grass was absent or had died back considerably, with a notable increase in native plant diversity. No management activities have occurred in this habitat type to date.

- **Open Water Habitat** (25 acres; present in Zones 1-4)

Numerous ponds and sloughs are scattered throughout BB, with the largest body of water, Horseshoe Lake, located in the central portion of the site. Water levels are affected by runoff from the surrounding hillsides and U.S. Highway 30, nearby river levels, tidal changes, and beaver activity. Three beaver dams on the slough connecting Horseshoe Lake to Multnomah Channel currently serve as the principal water control structures on the site.
This habitat type supports a vast array of wildlife species, including the HEP wildlife species, wood duck, great blue heron, beaver, and spotted sandpiper. In addition, several State Sensitive listed species utilize this habitat, including the northern red-legged frog and both the western painted and pond turtles.

A comparison of aerial photos dating from the 1940's to the present indicates a significant loss of open water habitat in the past 50 years. This loss is a result of both on and off site human activities including diking, draining, and flood control. The continuous encroachment of reed canary grass at the edges of ponds and sloughs and the deposition of silts into these areas, may ultimately cause their transition to a wet marsh, with the resulting loss of additional open water habitat. No management activity has occurred in this habitat type to date.

- **Disturbed Areas** (14 acres; present in Zones 1-4)

The disturbed areas currently consist of several trails, roads and a gravel filled upland area located on the southwest portion of the site. Roads and trails would be maintained for access, and the upland fill area would be managed to provide a mosaic of habitats over time. In portions of the upland fill, vegetation consists primarily of non-native shrubs and grasses including Scot's broom, Himalayan blackberry, reed canary grass, and meadow foxtail. Native species have become established in recent years, and includes young stands (< 30 years old) of black cottonwood and other species of trees and shrubs. Because this area is relatively open and dry, it provides excellent habitat for many species of reptiles, including the common (red-spotted) garter snake (*Thamnophis sirtalis concinnus*), northern alligator lizard (*Elgaria coerulea*), and western painted turtle (*Chrysemys picta bellii*).

Management activities since 1995 have included the removal of exotics from approximately 10 acres of the disturbed areas. Scot's broom has been removed from all of the road edges and the upland fill site; blackberry has been removed along the roads and trails by several methods but continues to be a problem. Mowing of the open areas has occurred for the past two years to control non-native grasses that have become established since the flood of 1996. Several areas have been planted with native shrubs and trees with the intent to eventually shade out some of the non-native plant species, and to increase the quality and quantity of available wildlife habitat in this area.

APPENDIX B

WILDLIFE MONITORING PROTOCOLS

PROTOCOL FOR SURVEY AND MONITORING OF NEOTROPICAL MIGRATORY LANDBIRDS

SURVEY METHODS

Bird Populations: The point count method will be used for sampling bird populations. This method is the most commonly used, most cost effective, and provides a way in which to study the abundance patterns of species and the yearly changes of bird populations at fixed points (Ralph et al. 1993).

Point count stations will be established in the ash/cottonwood habitat. Stations will be spaced a minimum of 150 meters apart, with a fixed radius of 50 meters within a forested area. The stations will be chosen and located to minimize openings and the effect of edge. However, due to the configuration of the various habitat types (at Burlington Bottoms, forested habitat tends to occur in narrow, linear bands interspersed with open meadow and backwater slough habitats), most stations may have one or two openings, and it is possible that a station may have little or no forest beyond the 50 meter radius of the circle, therefore edge effect will be unavoidable for some of the stations.

Censusing will occur during the breeding season only, with one census at each point count station every 10 days. The 10-day census periods will begin in mid-late May and will continue through the month of June.

Surveys will occur between official sunrise and the following 3-5 hours as recommended by Ralph et al. (1993). The time of censusing will vary for each point count during the 10-day periods to avoid potential time-of-morning effects, and surveys will not be conducted after 10:30 a.m.

Observer(s) will approach each point count station making as little noise as possible, and upon arriving at the station will begin the 5-minute census. After the census is completed, observer(s) will continue on to the next point count station until all are completed.

Surveys will only occur if weather conditions are considered favorable (i.e. no rain or heavy wind). If a train passes or a plane flies over, censusing will stop until it has passed and will resume when it is gone. Each station will be surveyed for a total of 5 minutes for each of the four counts during the breeding season.

Data collected at each point count station will include date, start and end times, observers, weather conditions, station number, habitat type, all birds detected (seen and/or heard) both within the 50 meter radius and outside, and total numbers of birds per species.

PROTOCOL FOR SURVEY AND MONITORING OF POND-BREEDING AMPHIBIANS

SURVEY METHODS

Surveys and monitoring of pond-breeding amphibians will occur from January through early April to cover the breeding season for the following species: the Northern red-legged frog (*Rana aurora aurora*), Northwestern salamander (*Ambystoma gracile*), Long-toed salamander (*Ambystoma macrodactylum*), and Pacific chorus frog (*Pseudaris regilla*). Surveys will be conducted on a weekly basis through the breeding season in order to track onset and cessation of the breeding season, with red-legged frogs as the main focus species due to their current Sensitive species listing by the State of Oregon.

Areas to be surveyed include seven temporary ponds on the site, some of which have been surveyed and monitored since 1997 on a yearly basis by volunteers; these ponds were originally chosen because of their variability (percent native and non-native) in emergent vegetation (used by amphibians for ovipositing), and other factors. All ponds included in the study will be surveyed at least four times (to be spread out during the survey period) during the breeding season in order to ensure that all egg masses have been counted. If time and funding allows, additional ponds will be surveyed.

In order to adequately survey each pond each census time, a minimum of three people will be needed to cover the entire pond area. A spacing of approximately five feet will occur between each surveyor (arms length) as the surveyors slowly walk across each pond, counting and then assigning a number to each egg mass found. Upon encountering an egg mass, the following data will be recorded:

- species
- number
- attachment brace (vegetation species)
- water depth
- position in the water column (or distance below the water surface)
- distance to shoreline
- distance to cover (e.g., forest habitat)
- development stage (if possible)
- air and water temperatures
- note location of each egg mass on map to show approximate location in pond (locations will later be entered using GPS)

Only the red-legged frog and northwestern salamander egg masses will have the above data recorded. If present, egg masses of the long-toed salamander and Pacific chorus frog will be noted but the above data will not be taken for each since they are typically too numerous to count and are not currently considered a species of concern.

Additional information that will be recorded includes any beaver activity, changes in the pond or surrounding area (fallen trees, blocked stream due to beaver activity) and other pertinent activity. Photo documentation of the ponds and surrounding habitat will also occur at set photo points that were established in 2000.

APPENDIX C

FISH MONITORING PROTOCOL

PROTOCOL FOR MONITORING ANADROMOUS FISH

The Lower Columbia River ecoregion has experienced severe floodplain and estuarine habitat alteration and degradation as evidenced by declining salmon stocks and degraded water quality. Channelization activities and subsequent development of the area for timber, agriculture and commercial development have reduced the amount of wetland and estuarine habitat and compromised the quality of the remaining habitat. The rapid growth of urban areas in the northwest adds to the plight of wetlands and emphasizes the urgent need for a focused and coordinated conservation effort.

The evaluation of fish use and passage from restored wetlands is critical to understanding and implementing a holistic wetland conservation strategy. Monitoring of wetlands would occur to assess their importance to anadromous fish, and to evaluate the effectiveness of fish passage strategies. Sampling will consist of seasonal (early winter, late winter, and spring) surveys to document fish distribution and abundance within wetlands, and regular trapping of both sides of fishway structures to evaluate fish immigration/emigration patterns.

Survey Methods

Season-specific, intensive sampling is necessary to maximize the detectability of all fish species, and provide sufficiently low sampling variance to detect differences in Catch per unit effort (CPUE = a gear-specific index of abundance density) among treatments, and across systems, by season. A "Regular Fish Monitoring Program" (RFMP) is described in Appendix A to achieve this.

Temperate floodplains are characterized by frequent water level changes, especially during the winter and spring, and movements of fish may occur between RFMP samples. Also, understanding fish movements, especially of migratory, anadromous fishes, is important in interpreting seasonal habitat use. To this end, 2-way traps (based on a vertical slot design that is operational over a range of water levels (Bayley and Baker 2000)) will be employed at each of the three units. Apart from continuous monitoring at a strategic position at each site, traps will also be employed periodically upstream and downstream to control structures to test their effectiveness in permitting free passage of marked fish.

Continuous monitoring will not be possible at all water levels at all sites, because at high levels many access points are available and fish are more dispersed. However, strategic gill net sets have been very successful at sampling fish at very high water levels (Bayley and Baker 2000), and standard fleets used in the RFMP will also be employed in this manner.

All fish captured will be identified and measured to fork length. Selected specimens will be weighed to augment existing length-weight data sets. External anomolies, including parasites, will be recorded, as well as external or internal (pit) tags, and fin clips to denote hatchery fish. Scales will be sampled from salmonids for age determination. Samples of fishes will be sacrificed for age verification using otoliths and for diet analysis. When a standard pre-selected area for sampling is encountered dry, it will be recorded as a zero sample.

Habitat monitoring

Dominant vegetation, water depth, transparency (Secchi and/or tubidity meter) temperature, and electrical conductivity will be recorded at each site corresponding to each fish sample. A photograph will be taken of a typical shoreline representative of each stratum at each site and season, and the GPS position and direction of each photograph recorded. Temperature will also be continuously recorded using Hobo Temperature Probes (Onset Corp.) set to take readings every 1.6 hours. Probes will placed just below the surface and just above the bottom of lakes in each unit. Probes will also be placed in connecting rivers or sloughs.

APPENDIX A

Regular fish monitoring program (RFMP) - An affordable, consistent monitoring system is essential for estimating changes in fish populations during different seasons and among floodplain units. A protocol, RFMP, has been successfully implemented for floodplain restoration monitoring in aggregate-mined areas (Bayley and Baker 2000) and is recommended for the restoration units in this project. The methods include: 1. Boat electrofishing unit, 2. Standard gill net fleet, 3. Hoop net, and 4. Gee minnow trap, that are described in detail below.

1. Boat electrofishing unit.- (not applicable for Burlington Bottoms) Oregon Department of Fish and Wildlife (ODFW) will provide the electrofishing boat and personnel. Consistency in protocol, and the likelihood of maintaining it into the future, is more important than maximizing catch during particular sampling trips. The unit uses a Smith-Root GPP5 model powered by a 5000-W generator. All strata in all units will be sampled by a single pass per season. Although times of runs are recorded, effort is most appropriately measured as the distance of shoreline sampled; CPUE is here expressed as catch in numbers per 100-m of shoreline.

2. Standard gill net fleet.- (not applicable to BB) The remaining methods, 2, 3, and 4, use passive (set) gear, and therefore sets will be positioned randomly within each stratum (shore section) prior to each trip. The order in which the sections will be fished will also be randomized.

Each gill net fleet will be 6-ft deep and 125-ft-long with 5 panels (25-ft each) of 3/4, 1, 1.5, 2, 2.5-in square mesh sizes of multifilament nylon. It will have a polycore floatline and leadcore line weighted for fishing on the bottom. Fleets will be set roughly perpendicular to the shoreline with the finest mesh adjacent to shore. The mesh size in which each fish was entangled will be recorded.

3. Hoop net.- Each hoop net will be 2.5-ft diameter and 1" square mesh with a short 1" square mesh lead net attached to the middle of the opening for guiding fish in from either direction. Each set (one unit per stratum) will be arranged with the lead net towards the shore.

4. Gee minnow trap.- Three Gee minnow traps (1/4 inch mesh) will be randomly set each season in each stratum in shallow water, covered with macrophytes. Methods are to some extent complementary with respect to their ability to catch different species or sizes of fish from the common members of the community, and the joint sampling effort (in addition to vertical slot traps and strategic gill nets described above) will maximize the chance of encountering rarer species.

Each gear has a characteristic catchability range depending on species, size, and environment, that relates actual abundance or biomass density to catch-per-unit-effort (CPUE) with catch as numbers or weight of fish, respectively. A consistent protocol does not guarantee constant catchability, but makes it minimally variable in given habitats across floodplain units. Maintaining protocols will also permit the future application of catchabilities estimated from efficiency calibrations on-site, or with similar gear, species, and habitats elsewhere. This would transform CPUE data to actual abundance or biomass estimates. Where smaller water bodies exist, standardized protocols using backpack electrofisher or electric seine will be employed and maintained at those sites and seasons.

Exh. 8

August 27, 1993

FINAL REPORT

Burlington Bottoms
Hydrology and Hydraulics Assessment

Prepared for

The Oregon Department of
Fish and Wildlife

By

W&H Pacific
Portland, Oregon

REGISTERED PROFESSIONAL
ENGINEER
15,770
OREGON
JAMES H. LENHART JR.

ERRATA SHEET FOR BURLINGTON BOTTOMS
HYDROLOGY AND HYDRAULICS ASSESSMENT
DATE: October 25, 1993

Please note the following corrections to the above mentioned report:

On page 7, in Table 1 and in the last two paragraphs, Stream A and Stream B are incorrectly identified as conveying perennial flows. Both Streams A and B are classified by the U.S.G.S. as ephemeral.

Applied Ecosystem Services

2404 SW 22nd Street
CompuServe: 73557,2367

Troutdale, OR 97060-1247

(503) 669-6672
Internet: 73577.2367@compuserve.com

October 11, 1993

Sue Beilke
Columbia Region
Oregon Department of Fish and Wildlife
17330 SE Evelyn Street
Clackamas, OR 97015

Subject: Burlington Bottoms Hydrology and Hydraulics Assessment, Final Report

Dear Sue:

With regard to the above referenced report by W-H/Pacific dated August 27, 1993, I would like to bring to your attention a potentially mis-leading designation of one of the off-site stream channels.

Page 7 describes stream B as conveying perennial flows from a drainage which includes a portion of the northern area of the Angell Brothers property. On page 1 (section 1.1, paragraph 2), the report notes that data were collected from April through July of 1993. This four month period was quite wet, particularly in comparison with the drought conditions of the past few years. The most ressonable conclusion is that stream B was flowing because of the precipitation over this time period.

A perennial stream has a base flow during the entire year. In mid-August of this year, I did not observe any flow in this channel. Skip Anderson (President of Angell Brothers, Inc.) has been at this site for about 15 years and has found it to be dry for most months in each of those years. This channel may be better characterized as ephemeral; that is, flowing only during (and shortly after) precipitation events.

It would be a disservice if this portion of the report was taken out of context and used inappropriately. All of us work under time and budget constraints which limit how much data we can collect on any given project. We have a responsibility as scientists to not extrapolate conclusions beyond what the data will actually support.

I recognize that this is a peripheral issue to the focus of the report; however, it may be blown out of proportion. Therefore, I would encourage you to recognize the time limitation of the observations when using this report to establish the best management policies for the Bottoms themselves. As the report makes clear, this wetland's hydrology is influenced more by the adjacent rivers than by drainage from the West Hills.

Sincerely,

Rich Shepard

Richard B. Shepard, Ph.D.
Principal

Table of Contents

1 Introduction and Background 1
  1.1 General Site Description 1
  1.2 Site History 1
    1.2.1 Burlington Northern Rail Line 4
    1.2.2 Main Rail Fill Embankment 4
    1.2.3 Maintenance Area 4
    1.2.4 Access Roads 4
    1.2.5 Trestles 5
    1.2.6 Agricultural Uses 5

2 Off-site Hydrology 5
  2.1 Contributing Watersheds 5
  2.2 Inflow Modeling 8
  2.3 Soils, Erosion and Sediment Transport 13

3 On-site Hydrology 16
  3.1 Inlet Hydraulics 16
    3.1.1 Inflows Inventory 16
    3.1.2 Buffer Zones 17
  3.2 Description of Hydrologic Features 18
    3.2.1 Lake Geography 18
    3.2.2 Deep Lake and Upper Lake 20
    3.2.3 Horseshoe Lake 20
    3.2.4 North Lake 24
    3.2.5 Kidney Lake 24
    3.2.6 Scar Lake 24
    3.2.7 Outlet Channel 24
      3.2.7.1 Beaver Dam on the Outlet Channel 26
    3.2.8 Slough Characteristics 26
  3.3 Descriptions of Soils 26
  3.4 Seasonal Characteristics 26
  3.5 Influence of the Columbia River 27
  3.6 Data Collection 31
    3.6.1 Lake Stage and Precipitation Data 31
    3.6.2 Temperature Data 33
    3.6.3 Evaporation Data 33

4 Groundwater 34

5 Water Quality 35
  5.1 TSS 36
  5.2 Phosphorus 37
  5.3 Metals 37
  5.4 Nitrogenous Compounds 38
  5.5 Oil and Grease 38
  5.6 pH 38

6 Geographic Information System - Reed Canary Grass 39
6.1 Fate of the Burlington Bottoms Lake System 39

7 River Bank Assessment of the Multnomah Channel 43

8 Conclusion 43

Table of Figures

Burlington Bottoms Vicinity Map 2
Burlington Bottoms Site Map 3
Off-site Watershed and Sub-basins 6
2 Year Inflow Hydrograph 9
5 Year Inflow Hydrograph 10
10 Year Inflow Hydrograph 11
100 Year Inflow Hydrograph 12
SCS Soils Map for Burlington Bottoms 14
Areas of Local Erosion 15
Locations of Culvert Crossings 19
Approximate Location of Lake Sections 21
Cross Section of Upper Lake 22
Cross Section of Horseshoe Lake 23
Outlet Channel Cross Section 25
Daily Maximum River Stage (Vancouver, 1989) 27
Daily Maximum River Stage (Vancouver, 1984-1989) 28
Hourly River Stage (Vancouver, 1993) 29
Cumulative Frequency Distribution (Vancouver, 1984-1993) 30
Area vs. Elevation Histogram for Reed Canary Grass 40
Accumulated Area vs. Elevation for Reed Canary Grass 41
Reed Canary Grass as a Percentage of Total Area Analyzed 42

Table of Tables

Areas of Contributing Watersheds 7
Calculated Peak Offsite Flows 8
Lake Area and Elevation Data 18
Lake Stage and Precipitation Data 32
Temperature and Relative Humidity Data 33
Pan Evaporation Data 34
Water Quality Sample Descriptions 36
Summary of Phosphorus Data 37
pH Readings 38

Burlington Bottoms
Hydrology and Hydraulics Assessment

August 27, 1993

1 Introduction and Background

Burlington Bottoms is being evaluated for habitat value using the Habitat Evaluation Process (HEP). This report is a supplement to the HEP being prepared by the Oregon Department of Fish and Wildlife.

1.1 General Site Description

Burlington Bottoms is a 417 acre wildlife habitat mitigation site located 15 miles northwest of Portland, Oregon. The site is situated directly across from the southwestern end of Sauvie Island between U.S. Highway 30 and the Multnomah Channel. Figure 1 is a general vicinity map showing the location of the project.

The purpose of this report is to provide a groundwork in understanding the hydrology of this wetlands area. This report is based primarily upon data and observations collected over a four month period from April through July of 1993.

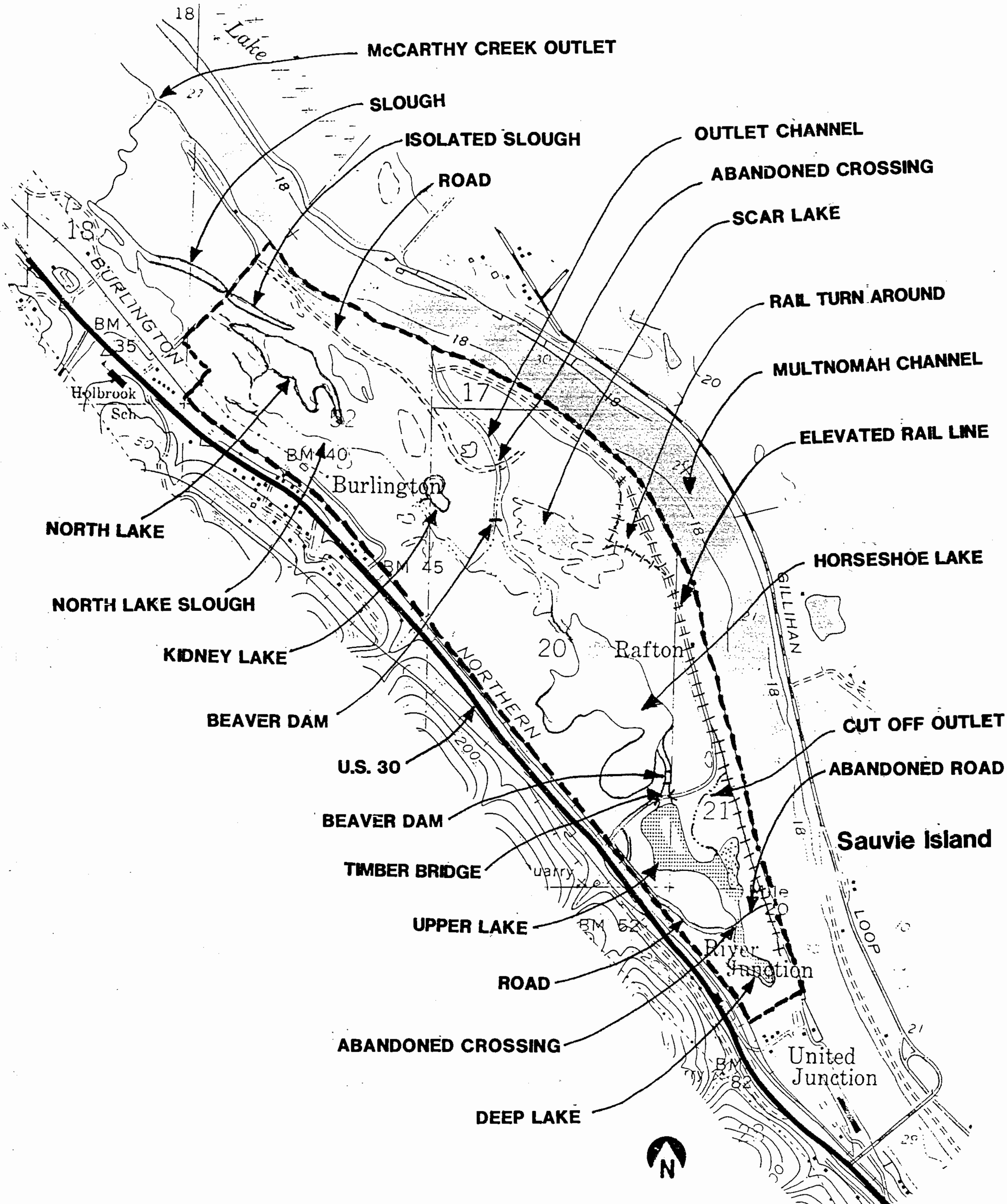
The hydrology of Burlington Bottoms is a very dynamic and complex system that is influenced by many factors, both man-made as well as natural. The wetlands area is composed of a series of interconnected lakes, marshes, and backwater channels. Portions of the area are inundated by the annual spring freshet of the Columbia and Willamette Rivers. Runoff from the surrounding hillsides and from U.S. Highway 30 also contributes flows to Burlington Bottoms through a series of culverts.

The hydrologic boundaries of the site are roads bordering the southeast (NW Johnson Mill Road) and northwest ends of the property, the Multnomah Channel, and the Burlington Northern Railroad (north of US 30). Figure 2 is a site map showing the major hydrologic features.

Whereas the off-site hydrology is largely influenced by human activities, the on-site hydrology is presently affected by natural factors with indications that, historically, there has been a strong human influence. The factors that ultimately have the greatest hydrologic impact on-site are the freshwater inflows from across U.S. 30, the tidal influence of the Columbia River, and the effect of beaver dams.

1.2 Site History

The project site has historically been influenced by human activity. Historical photographs indicate that beginning around 1936, this area had considerable industrial activity, principally revolving around the maintenance of railroad equipment. At later dates the property was utilized for grazing of livestock and shanty town housing along the bank of the Multnomah Channel.



Site Map

W&H PACIFIC

Figure 2

Old photographs indicate that a considerable amount of excavation and fill significantly altered the topography and water features to their present state. Below are listed some of the major activities which have permanently influenced the site hydrology. In Appendix 1 are photocopies of most of the older aerial photographs of the site.

1.2.1 Burlington Northern Rail Line

This existing BN rail line is an elevated topographic boundary to runoff from the off-site watershed. The construction of this line caused the redirection and channelization of off-site flows into the Burlington Bottoms watershed. Rechannelization has been principally with ditches and culverts. U.S. Highway 30, running parallel to the BN Railroad has a similar influence.

1.2.2 Main Rail Fill Embankment

For equipment access to the now abandoned maintenance facility a fill embankment was constructed from what appears to be locally excavated material or dredge fill. This embankment runs almost the length of the project site along the bank of the Multnomah Channel. This embankment is at an approximate elevation of 25 feet. The construction of this embankment occluded what appears to be the outlet for the upper lake(s). This embankment has had significant impact on the hydrologic operations of the bottoms.

1.2.3 Maintenance Area

The maintenance area is where locomotives were maintained. To facilitate the turning of the locomotives a large triangular pad was constructed. This pad appears to have been constructed by excavating a large volume of the Burlington Bottoms lowland just adjacent to the pad. The excavated area is now a seasonal pond refered to as Scar Lake on the site map. From aerial photographs this excavated area appears as a heavily scarafied area.

1.2.4 Access Roads

The are at least four roads which were constructed to access the maintenance facility. The first road divides the upper and lower lakes. The source of fill of this road is unknown. Perhaps it was constructed from dredge fill or locally excavated materials. A timber bridge was constructed to allow flows from the upper lakes to lower lakes and ultimately the outlet channel. This road still exists and is the only access to the maintenance area. The timber bridge, however, is in a state of disrepair and not considered safe to cross.

A second road defines the boundary of the project sites north side. It is likely that was constructed over a backwater of McCarthy Creek. The road fill has isolated a portion of the slough from the normal connection with McCarthy Creek. However, there remains a slight hydraulic connection between the isolated slough and the main slough via the gravel fill of the roadway.

A third roadway which crosses the outlet channel does not appear to involve large quantities of fill material. It is believed that this roadway was used for the transport of livestock in more recent times. The main hydrologic impact is that the outlet channel was filled with timber and soil to facilitate crossing. Since no culvert was installed, this dam has for all practical purposes been eroded away.

The fourth roadway crosses the project toward the south end. Today portions of the road still remain around the western periphery of the project site. The remnants of this road divide Upper lake from Deep lake to the south. It does appear, however, that at some time portions of the road were excavated between the two lakes. This may have been done to drain Deep Lake, which has no other outlet or to prevent access to the maintenance site.

There are other small jeep trails on the site, most originating along the BN Railroad. These trails are probably from recreational vehicles.

1.2.5 Trestles

On the southern end of the project there are some old abandoned trestle piles. Old photographs clearly show that a substantial trestle was constructed to allow rail transport to the maintenance facility. There is little evidence that there was a significant impact on the water courses from this structure.

1.2.6 Agricultural Uses

There has been some use of the land for agricultural purposes. It appears that there was no cultivation of the soil, rather the main use was for range forage purposes. Presumably cattle and swine were allowed to forage the north end of the properties. There are remnants of barbed wire and wooden fences within the area.

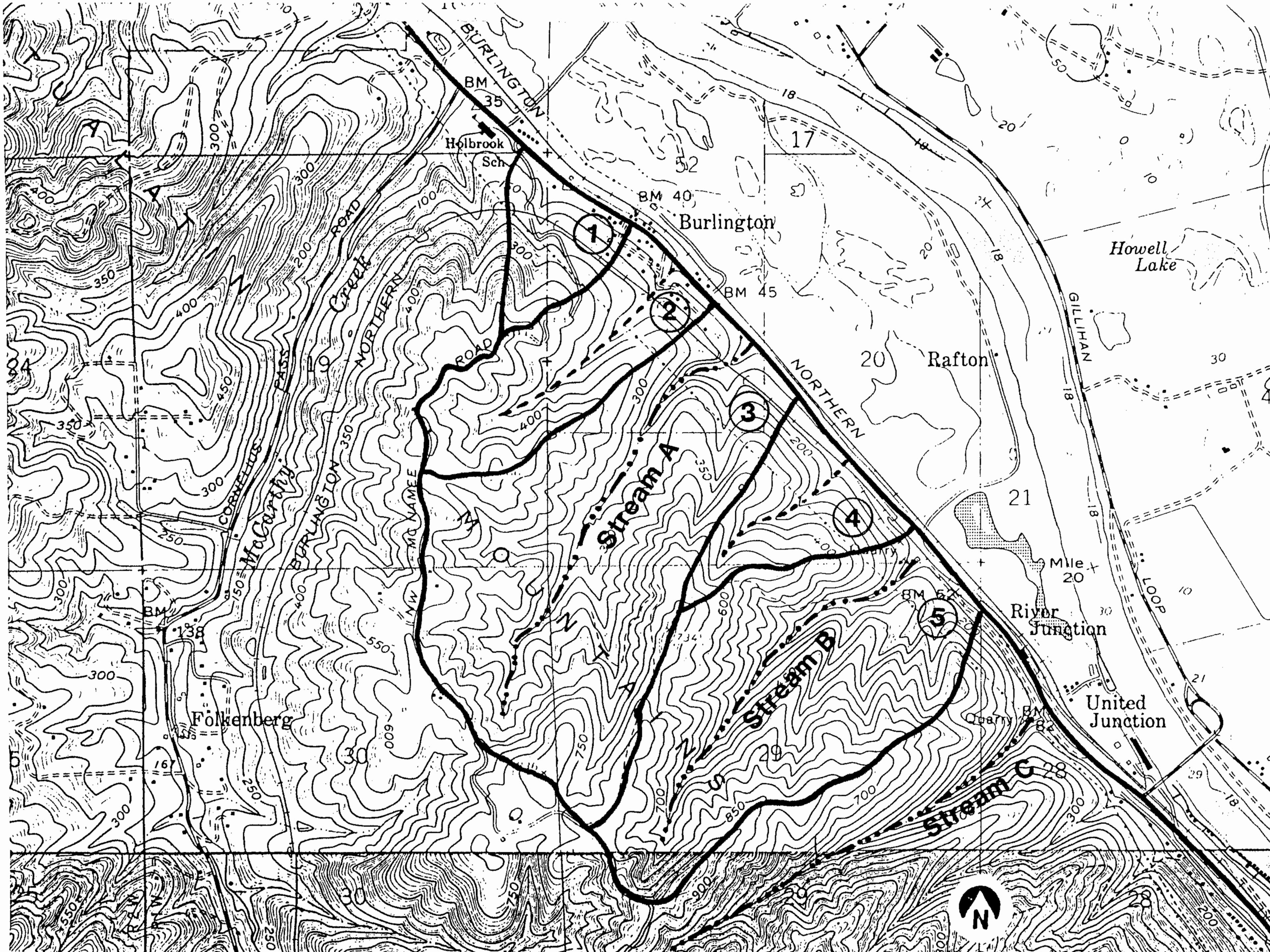
2 Off-site Hydrology

It is important to understand the nature of the off-site contributing watershed. In the future, runoff from the off-site watershed will have an increasing influence on both peak inflows and water quality of Burlington Bottoms.

2.1 Contributing Watersheds

The contributing off-site watershed for Burlington Bottoms is approximately 900 acres of predominantly forested hillsides in the Tualatin Mountains. The area is used for timber production, quarry mining, wildlife habitat, and scattered residential homes. Although the majority of the land remains forested, there are many areas that exhibit changes to the landscape due to human activities such as construction, timber harvesting, and mining. Figure 3 shows the off-site watershed delineated on a USGS topographic map.

Slopes are varied but are generally steep and can be found in excess of 50 percent. The highest point in the off-site watershed occurs at an elevation of 940 feet NGVD. North West McNamee Road runs along a ridge that defines most of the watersheds upper reaches. The Burlington Northern Railroad north of U.S. 30, considered the watershed's downstream boundary, has an average elevation of about 34 feet, NGVD.



Contributing Sub-Basin Map

W&H PACIFIC

Figure 3

To get an understanding of this 900 acre watershed it was divided into five sub-basins as shown Figure 3. Data are presented in Table 1.

Table 1

Calculated Areas of Watersheds Contributing to Burlington Bottoms

Sub-Basin	Drainageway Name	Area (AC)
1	Ephemeral Stream 1	40
2	Ephemeral Stream 2	141
3	Stream A	351
4	Ephemeral Stream 4	95
5	Stream B	270
Total		897

Sub-Basins 1, 2 and 4 contribute a small amount of flow via culvert crossings to the project site during rainstorm events only.

From field investigations, it was determined that both McCarthy Creek and Stream C do not contribute flows to the Burlington Bottom area. McCarthy Creek flows directly to the Multnomah Channel, however during periods of high stage in the Multnomah Channel there is a hydraulic connection between the McCarthy Creek Slough and the isolated slough. The direction of flow is dependent on the relative surface elevations of the sloughs.

Stream C may have, at one time, contributed flows to the project area. However, constructed drainage ways of U.S. 30 and the BN railroad have diverted the drainage south through United Junction. Stream C is the principal drainage way of the existing Angell Brothers Quarry. Since it does not discharge to Burlington Bottoms it appears that there are no direct water quality impacts.

Stream A conveys perennial flows from sub-basin 3. It drains an area of approximately 350 acres and enters the lower lakes of Burlington Bottoms through two 48" corrugated metal pipes passing beneath the railroad. Stream A has a reach of about 6,200 feet with an average stream gradient of 8.1 percent.

Stream B conveys perennial flows from an area of 270 acres and enters the upper lakes of Burlington Bottoms through a 30" concrete pipe. The northwestern end of the Angell Brothers quarry is a part of the watershed that drains through stream B. A site investigation showed that an access road belonging to the Angell Brothers Quarry is within this watershed. At the time of the site visits it was difficult to establish if the roadway is contributing sediment to the stream reach. Stream B's reach is about 5,400 feet in length with an average stream gradient of 14.0 percent.

2.2 Inflow Modeling

Inflow hydrographs were developed for the contributing watersheds for the 2, 5, 10, and 100 year storm events (Figures 4, 5, 6, and 7). These hydrographs were produced using the Haestad Method program QTR55 which is based on the USDA-SCS Technical Release 55: Urban Hydrology for Small Watersheds.

The chief factors used by QTR55 to develop the hydrographs are: land use, hydrologic soil group, slope and length of waterway, rainfall intensity, and watershed area.

Cumulative results for peak discharge of the 5 sub-basins for the contributing watershed are listed in Table 2.

Table 2

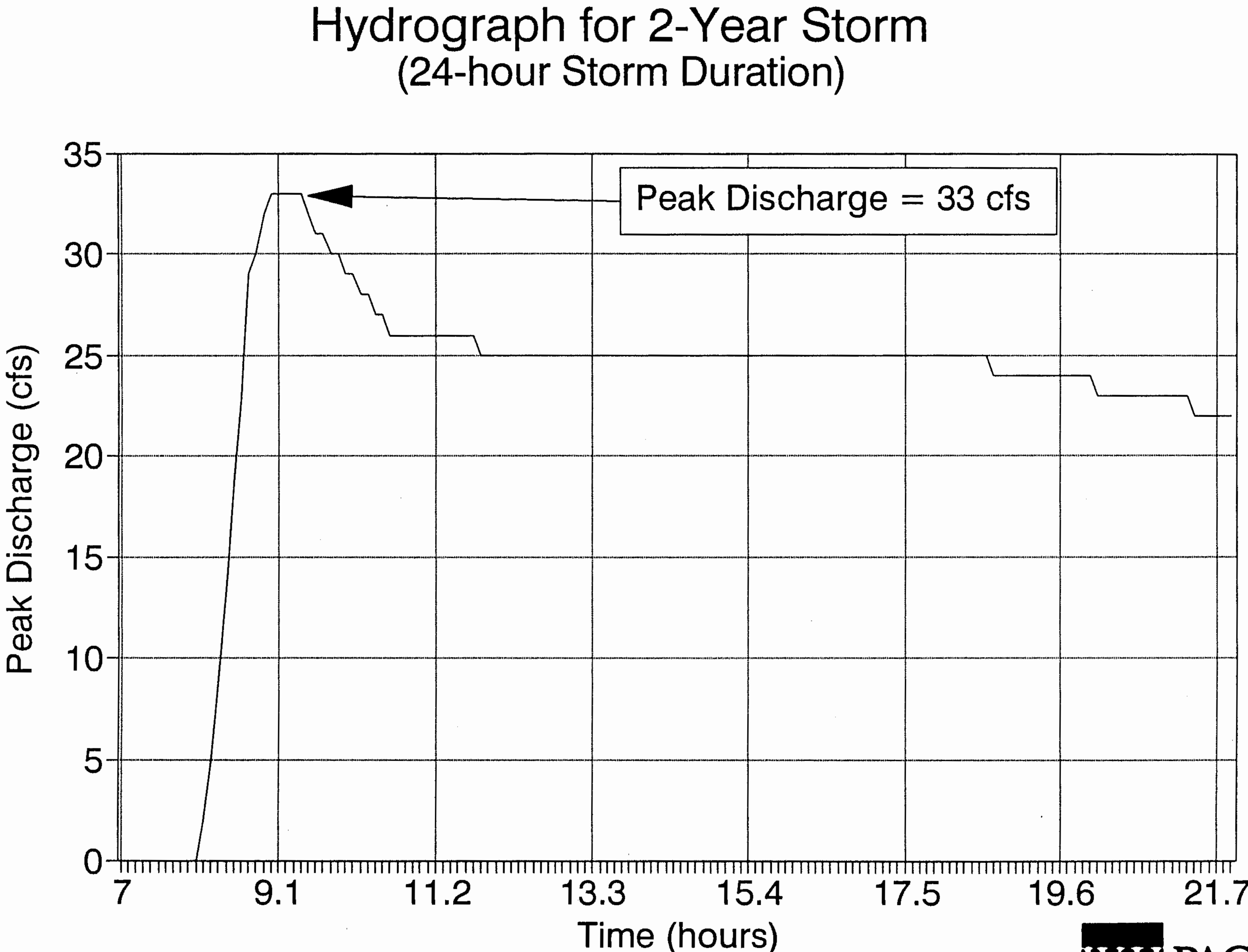
Flood Flow Results
Contributing Watershed Burlington Bottoms

Return Period of 24-hour Storm Event (yrs)	Peak Discharge (cfs)	Time to Peak Discharge (hrs)
2	33	9.0
5	53	9.0
10	81	9.2
100	319	8.7

A typical two-year, 24-hour storm would expect to have a peak discharge of 33 cfs. Input and output data for the model can be found in Appendix 2.

Though not demonstrated with a hydraulic model, it is believed that even the 100 year storm would not cause a rapid rise in the lake levels. The ratio of the lakes area with respect to the contributing watershed is high. Therefore inflow hydrographs will peak quickly. The large surface area of the lakes will attenuate the off-site flows and rise very little. Assuming 71 acres of lake surface area, a total of 309,000 cubic feet of water would be required to raise the lakes elevation by 0.1 feet.

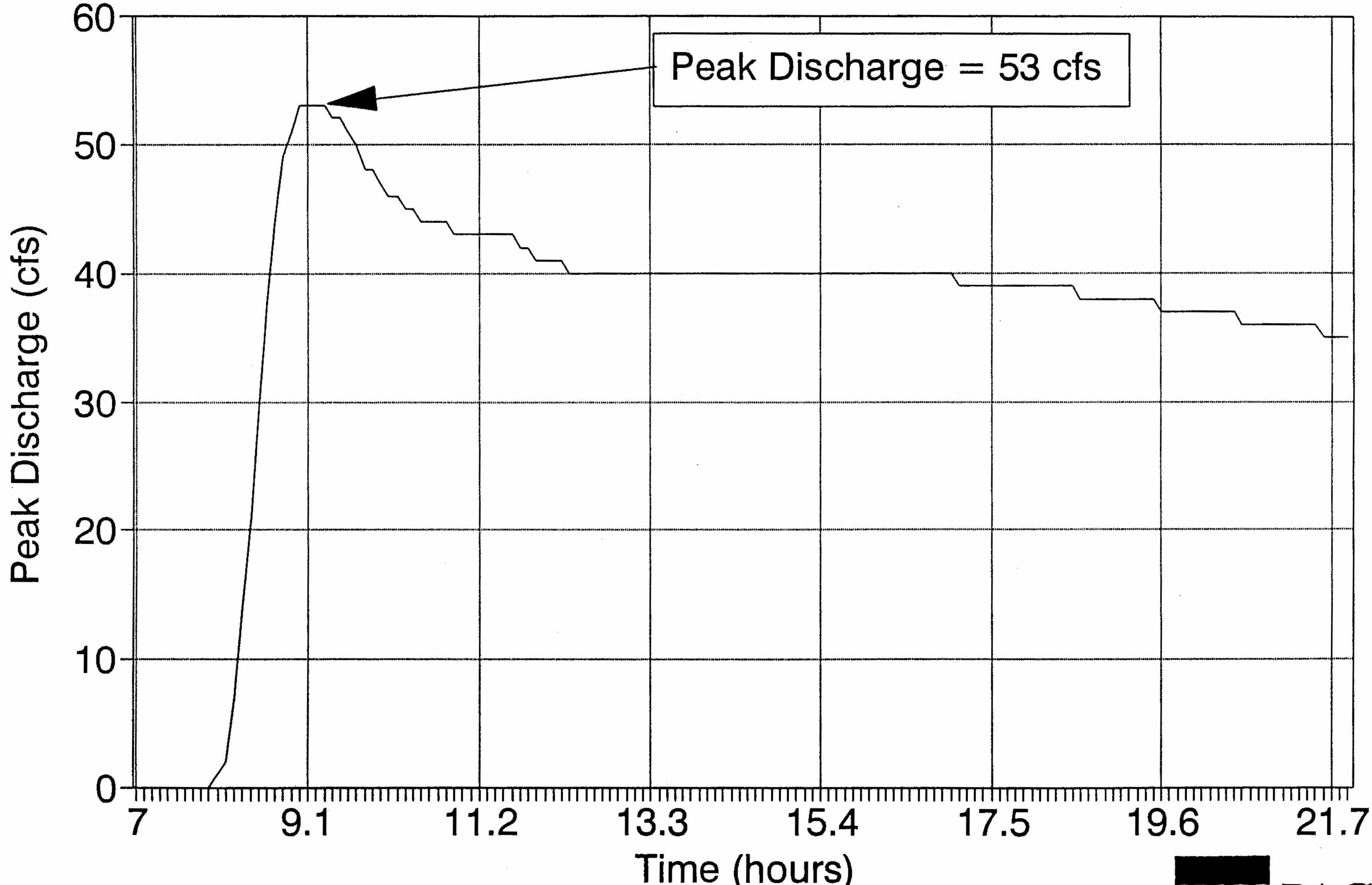
The 10 year storm would generate about 2.8 million cubic feet of water in about 17 hours. Assuming no outflows from the lakes the net rise of the water surface elevation would be about 0.9 feet.



W&H PACIFIC

Figure 4

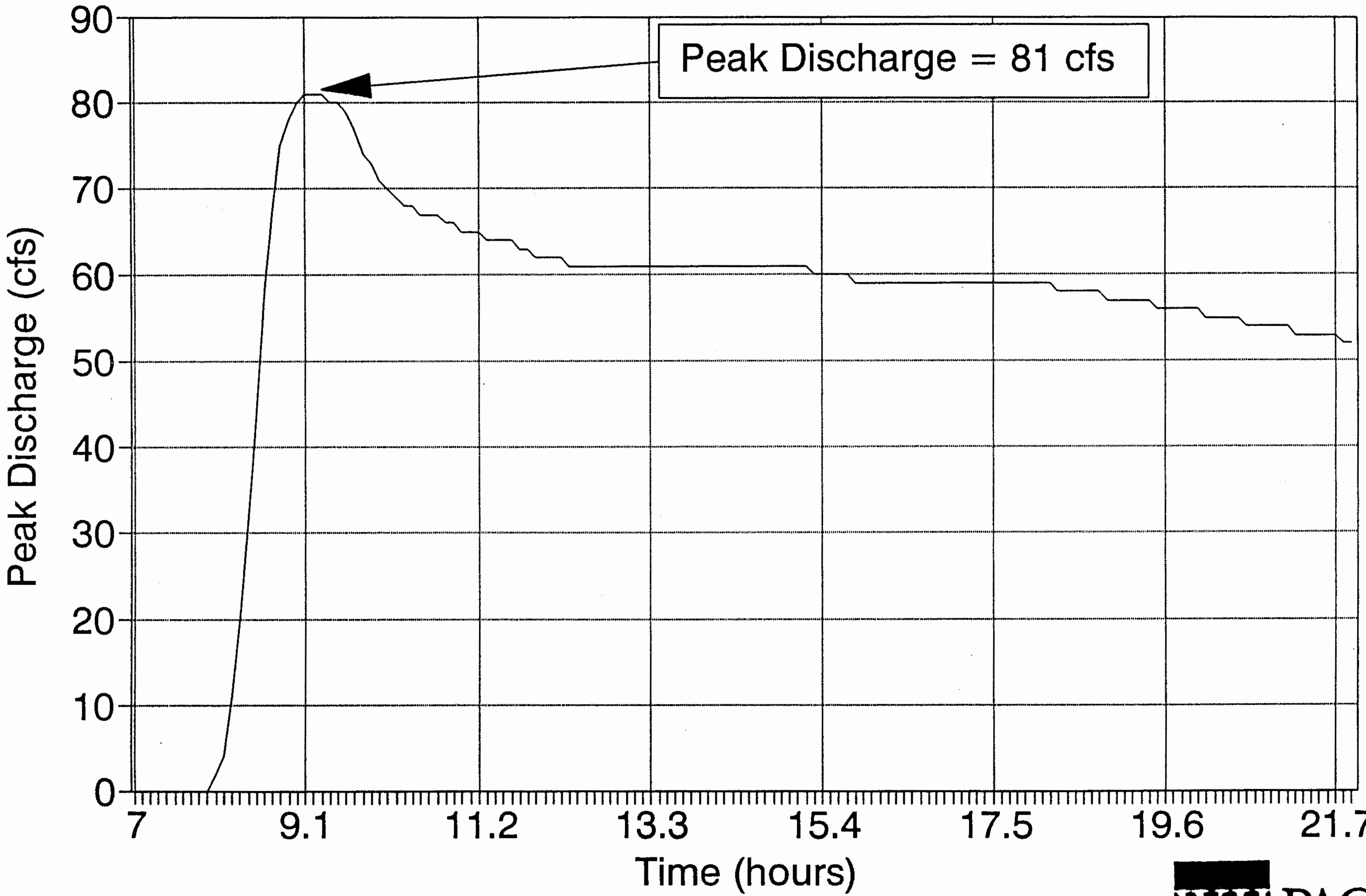
Hydrograph for 5-Year Storm
(24-hour Storm Duration)



W&H PACIFIC

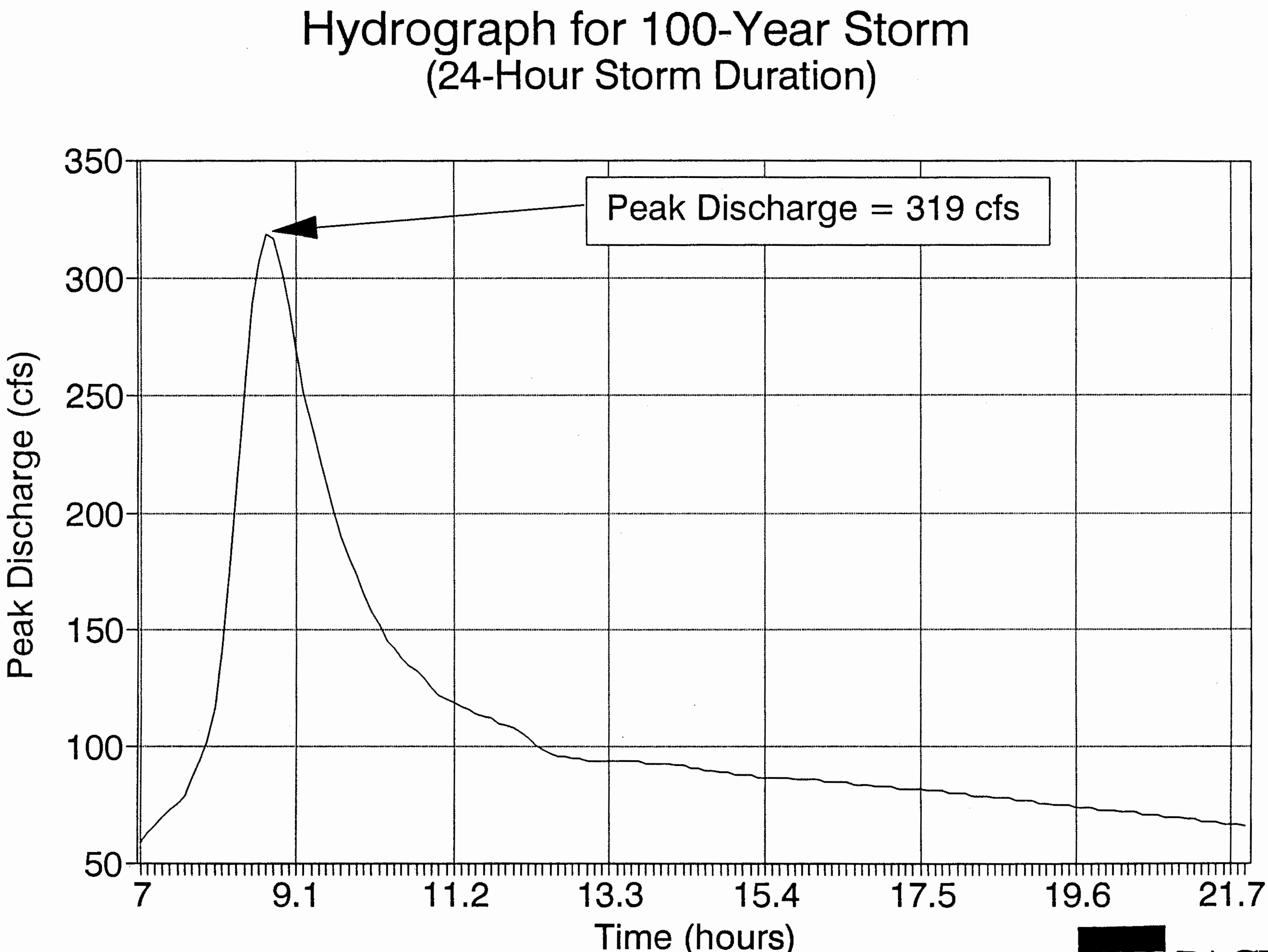
Figure 5

Hydrograph for 10-Year Storm
(24-Hour Storm Duration)



W&H PACIFIC

Figure 6



W&H PACIFIC

Figure 7

The lower lakes elevations are controlled by a beaver dam located down stream in the outlet channel. The hydraulic length of the beaver dam is about 30 feet. Modeling the dam as a broad crested weir (C = 2.62), the head on the weir, which matches the 1/2 of average 10 year inflow to account for peak flow attenuation of 27 CFS, is 0.5 feet. Since the average outflow is half the average inflow the rise in the water surface elevation would be about 0.5 feet for the 10 year storm. This rise would occur over a period of about 10 hours.

It is our opinion that the only serious flood threat to Burlington Bottoms if from the Columbia and/or Willamette Rivers as evidenced by the historical Danport Flood photographs in Appendix 2.

2.3 Soils, Erosion and Sediment Transport

Goble Silt Loams cover approximately 96 percent of the contributing watershed and Wauld Very Gravelly Loam covers about 4 percent. The remaining 6 percent is composed of Burlington Fine Sandy Loam, Quatama Loam, Haploxerolls and Cascade Silt Loams. The lower reaches of Streams B and C pass directly through the Wauld Gravelly Loam soil series. Figure 8 is a copy of the SCS soils map for this area. Appendix 3 includes photocopies of pertinent soils information for the SCS Soil Survey for Multnomah County.

The USDA-SCS classifies soils into hydrologic soil groups which estimate the runoff potential of precipitation. Soils in group A would be expected to have the lowest amount of runoff while soils classified as group D would have the highest. Goble silt loams and Wauld very gravelly loam are in hydrologic soil groups C and B, respectively. Due the steep slopes and only moderate permeability, the erosion potential for the Goble silt loam is considered high.

From aerial photographs it is clear that a large fraction of the contributing watershed has recently been subjected to clear cut logging. Field observations of the culverts which convey flow from these areas do not yet show sediment deposits associated with the high erosion potential of clear cut logging.

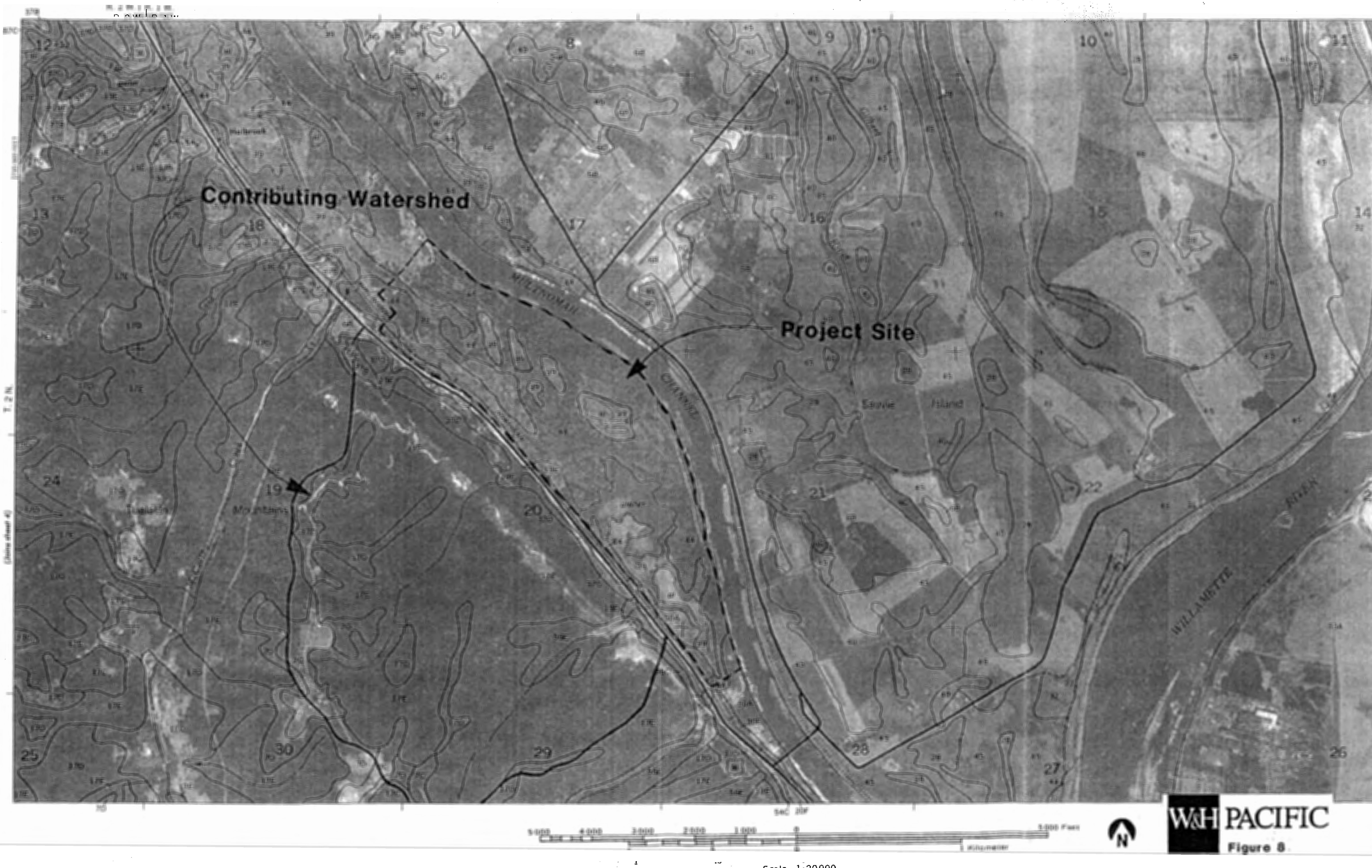
Runoff resulting from a high intensity storm has not been observed. It is possible that during high flow events that heavier sediments are deposited when they reach U.S. 30 and do not reach the project site. Lighter suspended sediments are transported to the vegetative buffer areas or directly into the lakes.

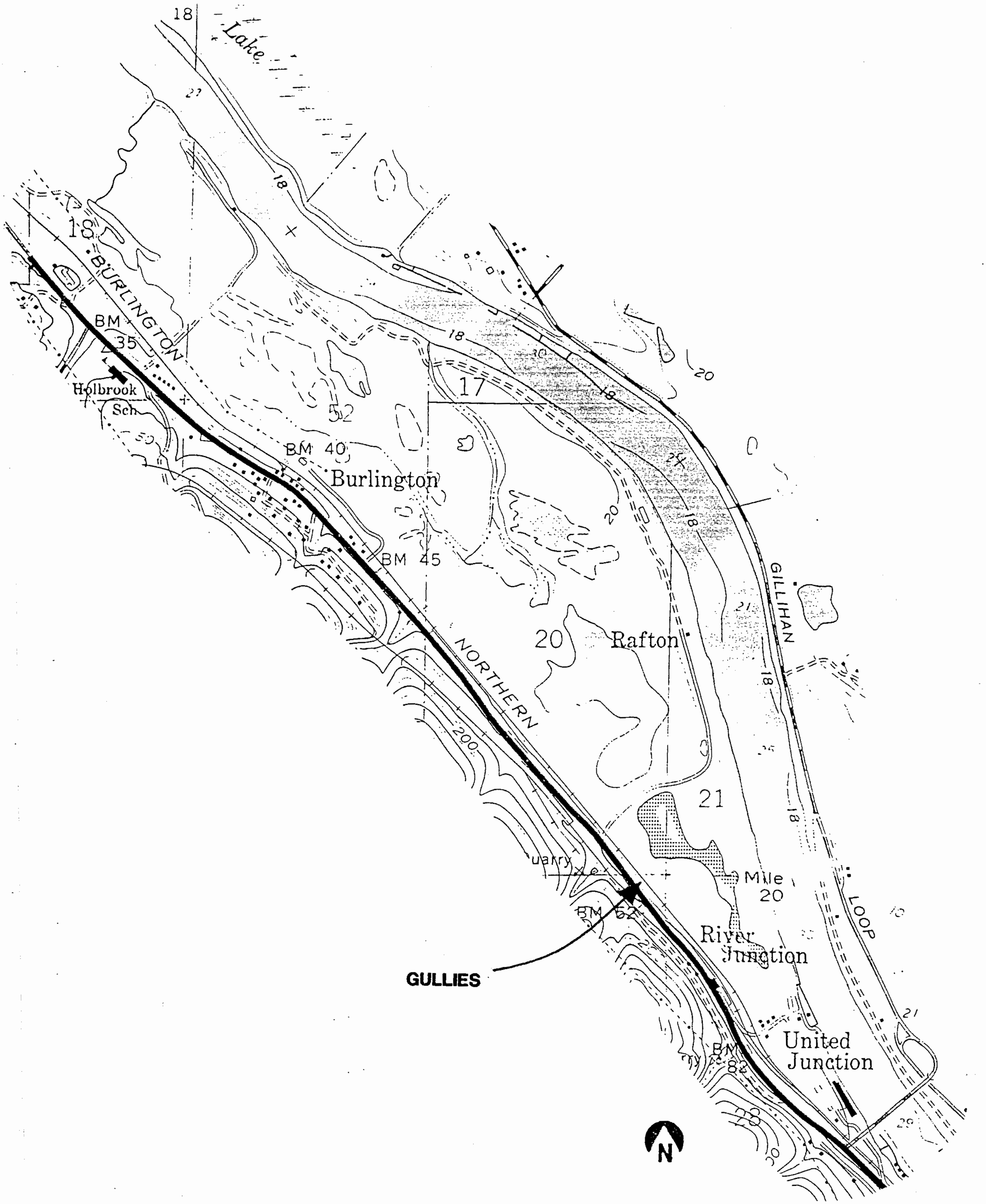
There is one area of local accelerated erosion caused from local highway runoff. Two gullies have developed alongside U.S. 30 just southeast of NW Rafton Road, the middle access road to the site. See Figure 9 for the approximate location.

In general, heavy sediment loading from off-site does not appear to be a problem. There are a number of man-made and natural filters which probably help to alleviate sediment transport to the lakes. The first filter is the railroad ballast. Areas of local erosion associated with shallow concentrated flow deposit sediments on the upstream side of the ballast rock. As the runoff filters though the rock it is cleaned up fairly well.

Most of the culvert outlets to the lakes do not discharge to the lakes directly. Usually the culvert outlets will simply discharge to low lying areas which are typically well vegetated with wetlands species. The runoff then seeps and meanders through the vegetative mass to the lakes. This process removes most of the suspended sediments, particularly during low flow events.

SOIL SURVEY OF MULTNOMAH COUNTY, OREGON — SHEET NUMBER 5





Areas of Erosion

W&H PACIFIC

Figure 9

3 On-site Hydrology

The on-site hydrology is characterized by a series of interconnected lakes. These lakes exist at two primary elevations. To the south are the upper lakes which are at an elevation higher the lower lakes to the north.

3.1 Inlet Hydraulics

The inlets to Burlington Bottoms are primarily culverts which convey flows from the off-site watershed underneath U.S. Highway 30 and the BN Railroad.

3.1.1 Inflows Inventory

The major source of off-site freshwater inflows comes through numerous culverts on the west side of Burlington Bottoms that range in size from twelve to forty-eight inches in diameter. Over a dozen culverts were found that passed under the railroad discharging to the project site. Figure 10 shows the location of the inflow sources.

The following is an inventory and brief description of all the found inflow sources. Note that the numbers of this inventory correspond to numbers on Figure 10 and the Site Analysis Plan prepared for the Recreational Use Plan.

1. Hydraulic Connection - A backwater area of McCarthy Creek is connected to Burlington Bottoms underneath the road bordering the NW end of the property. Field observations indicate that when the water surface elevation of the McCarthy Creek backwater exceed the backwater on the Burlington Bottoms side that a substantial flow of water pipes underneath the gravel fill roadway separating the bodies of water.

   Assuming that the back water of McCarthy creek is under tidal influence it is likely that the flow direction will reverse when low tides and river stage cause the backwater water surface elevation to drop below the backwater on the Burlington Bottoms side.

2. McCarthy Creek - Major creek in the area drains along NW side of Burlington Bottoms. Only direct connection is through No.1 above.
3. 18" CSP Culvert - Culvert drains under railroad. Flows appear to be ephemeral. Flow drains into vegetative area.
4. Covered Culvert - Culvert passes beneath railroad but was covered by the ballast that the railroad is built upon. Slow but steady flow through a distinct draw toward marshy area.
5. 12" CMP Culvert - Culvert is located between U.S. 30 and railroad. Culvert runs parallel to railroad and drains to the southeast. No flow was present.
6. 12" CMP Culvert - Partially crushed culvert under railroad. An 18" CMP culvert under U.S. 30 is located nearby. No flow was present in either culvert.
7. 36" CMP Culvert - Culvert passes under U.S. 30. Culvert was half full with a low velocity flow. Stream 'A' flows into this culvert.
8. Twin 48" CMP Culverts - Culverts drain flow from No.7 (Stream 'A') under railroad. Higher velocity flows about four inches in depth. A water quality sample was taken from this location.

9. 12" CSP Culvert - Culvert drains under U.S. 30 and flows toward No.10. Very low flow. Area is poorly sloped to drain toward No.10 and water frequently inundates the railroad tracks.
10. 18" CMP Culvert - Culvert runs under railroad. Inlet of culvert is half covered with rocks.
11. Covered Culvert - Culvert is drains under railroad and into a draw.
12. 32"x18" Catch Basin - Catch basin has an 18" pipe coming in and 12" pipe going out. 18" pipe was flowing 8" deep. The location of the outlet for the 12" pipe was not found but is believed to discharge under the railroad into a heavily overgrown area. Water source is from watershed No.4 and U.S. 30 runoff.
13. 12" CMP Culvert - Culvert drains beneath railroad.
14. 30" CSP Culvert - Culvert runs under railroad and is fed from Stream 'B' and runoff from U.S. 30 through a manhole. Culvert was half submerged with water. Low velocity flow. A water quality sample was taken from this location.
15. 42" CMP Culvert - Culvert drains under railroad just south of No.14. Culvert is about five feet above No.14 and is designed to handle surface flows. No flow was ever seen in culvert.
16. 18" CMP Culvert - Culvert drains from U.S. 30 and was observed flowing one-third full. Flow splits over grassed area before collecting into ditch next to railroad.
17. 24" CMP Culvert - Culvert runs beneath railroad. Culvert was draining from both directions into wet meadow area.
18. 18" CMP Culvert - Culvert drains from U.S. 30. Very low flow detected.
19. 36"x36" Catch Basin - No overland flow into catch basin, but steady flow present from ground water. The location of the outlet from the catch basin was not found but is believed to discharge under the railroad into a heavily vegetated area.
20. 18" CMP Culvert - Culvert drains runoff from U.S. 30. Culvert was observed to be dry.
21. 48" CMP Culvert - Culvert drains Stream 'C' and runoff from U.S. 30 to an area southeast of the Burlington Bottoms property. The culvert was one-third full and water was flowing steadily from culvert.

The greatest volume of flows occurred in the culverts for Stream 'A' and B' (No. 8 and No. 14). The initial inventory of inflows was performed in April 1993. By July 1993 the flows in culverts No. 8 and No. 14 were greatly diminished. Flows were estimated at well under 0.5 cfs.

3.1.2 Buffer Zones

All culverts were found to discharge to Burlington Bottoms through heavily vegetated areas. There were no well defined channels discharging directly into the upper or lower lakes observed. These vegetated areas serve well to filter out sediment loadings before reaching the lake system. It is important that these buffer zones be preserved. Some of these buffer zones are monotypic stands of reed canary grass which in this case serve the lake very well from a water quality aspect.

3.2 Description of Hydrologic Features

Burlington Bottoms is a low lying wetlands area consisting of a series of interconnecting lakes and backwater channels with a single outlet to the Multnomah Channel. Figure 2 shows the locations of the major lakes, ponds, waterways and hydrologic control features. For the sake of this report these features were named.

3.2.1 Lake Geography

Table 3 gives some of the geographic features of the main lakes and ponds.

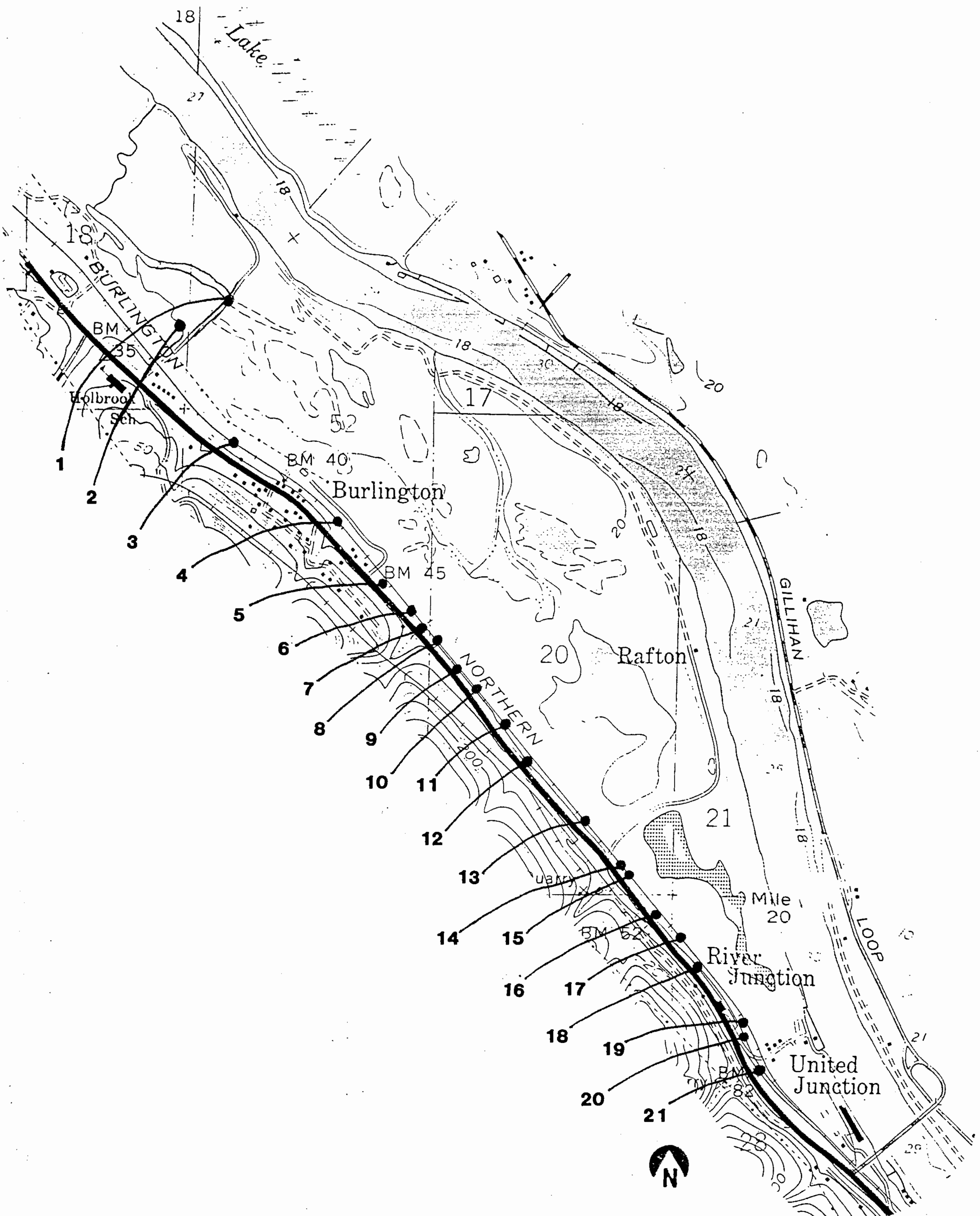
Table 3

Area and Elevation Data for Major Burlington Bottom Lakes

Lake	Area (AC)	Type	Elevation (March 1993)
Horseshoe	44	Permanent	11.9
Upper	10	Permanent	14.5
Deep	4	Permanent	14.5
North	6	Permanent	11.8
Scar	6	DRY	10.6
Kidney	1	DRY	11.9
TOTAL	71		

The Type in Table 3 refers to the summertime state of the lake assuming a "normal year" There are verbal accounts that in dry years all of the lake beds can be dry.

All of these lakes are shallow. It is not likely that the depth of the lakes exceed 5 feet assuming the normal water surface elevation is near to those given in Table 3. From random probing of the lake bottoms, Deep Lake is probably the deepest. The north end of the lake had depths measured up to 5 feet.



Inflows Inventory

W&H PACIFIC

Figure 10

To gain more precise data on the configurations of the lake bottoms both the Upper and Horseshoe lakes had sections surveyed. Figure 11 shows the approximate locations of where the survey sections were taken. Figures 12 and 13 show the survey results.

From the section survey and random probing, these lakes can be characterized as frying pan shaped. The mean depth of both lakes is from 3 to 4 feet depending the surface elevation. Depth is reached fairly quickly, especially on the banks which are actually fill slopes. Though not measured there are some areas of the lakes that have shallow benches as evidenced by the growth of Reed Canary Grass.

3.2.2 Deep Lake and Upper Lake

Both Deep Lake and Upper Lake are at higher elevations than Horseshoe Lake. They are hydraulically connected and appear to remain at the same elevation with each other. The principal hydraulic connection between the two lakes is through a narrow land bridge which separates the two.

The principal water surface control for these lakes is a beaver dam situated on the north side of the Timber Bridge. It is estimated that the beavers have raised the permanent pool elevation by at least 2 feet. Below this regulating beaver dam is another beaver dam at a lower elevation.

Field observations indicate the upper dam was constructed this year. Perhaps the lower beaver dam has been abandoned in favor of the new one.

Also located on the north east end of Upper Lake is the cutoff outlet. Observations indicate that prior to construction of the elevated rail line, what is now a backwater slough was actually the outlet for all of the upper lakes. The construction of the rail line occluded this outlet to the Multnomah Channel.

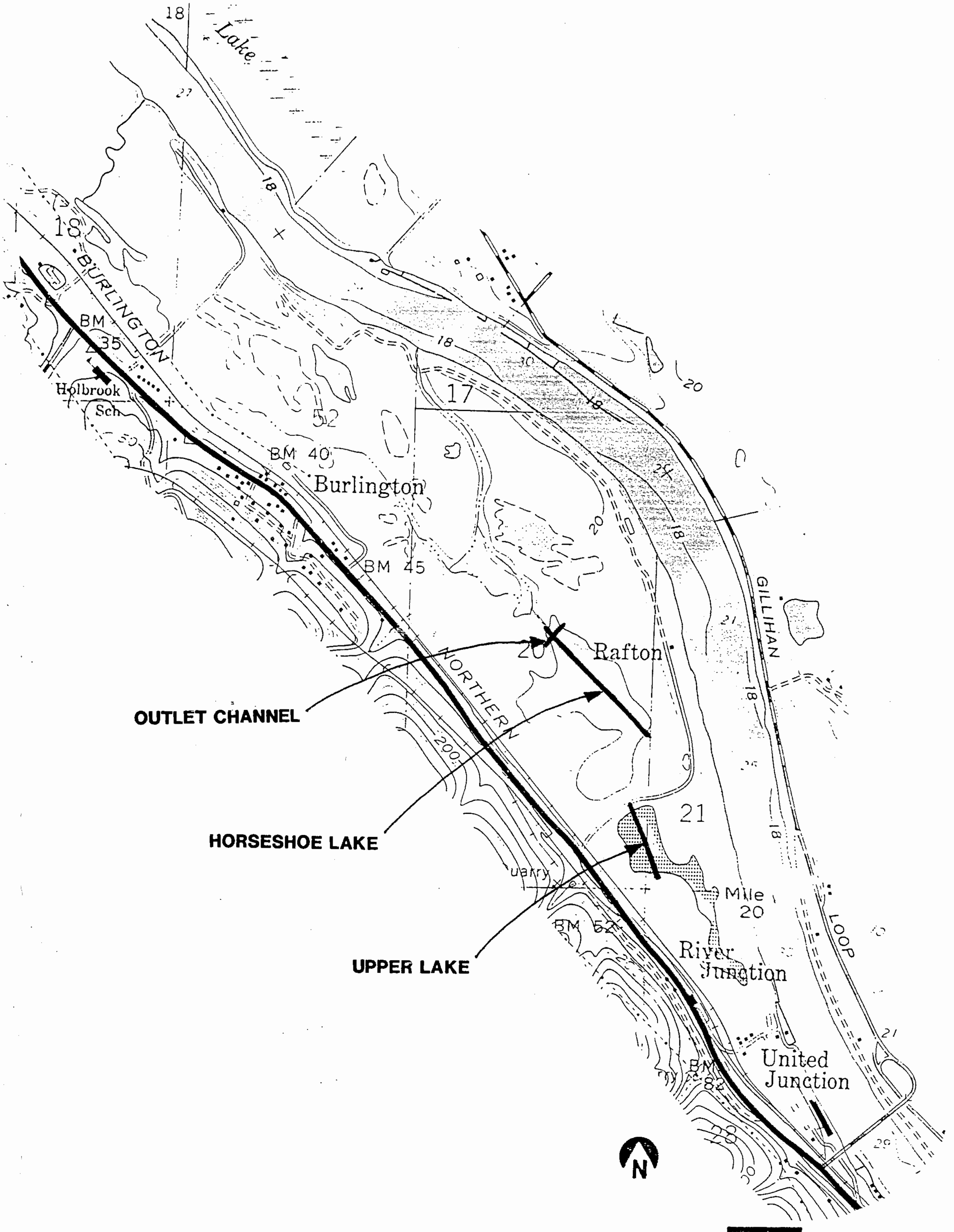
If part of the long term management plan involves the regulation of the upper lake system, the installation of a flow control structure in this slough would be an ideal location.

3.2.3 Horseshoe Lake

Horseshoe lake is the main aquatic feature of Burlington Bottoms. Its principal source of water is flow from the upper lakes, off-site flows and the spring freshet from the Columbia River.

The principal flow control for the entire lower lake system is a beaver dam located downstream of the confluence of the outlet channel and the North Lake Slough. This cleverly placed dam maintains an estimated water surface elevation of about 11 feet NGVD plus or minus. The beaver dam has an estimated length of 50 feet and is about 4 feet high. Should this dam fail it is likely that the entire lower lake system would drain in a few days. To maintain dam integrity and prevent vandalism, access to the dam should not be allowed.

Horseshoe lake is choked with aquatic vegetatation and supports a substantial population of Carp.

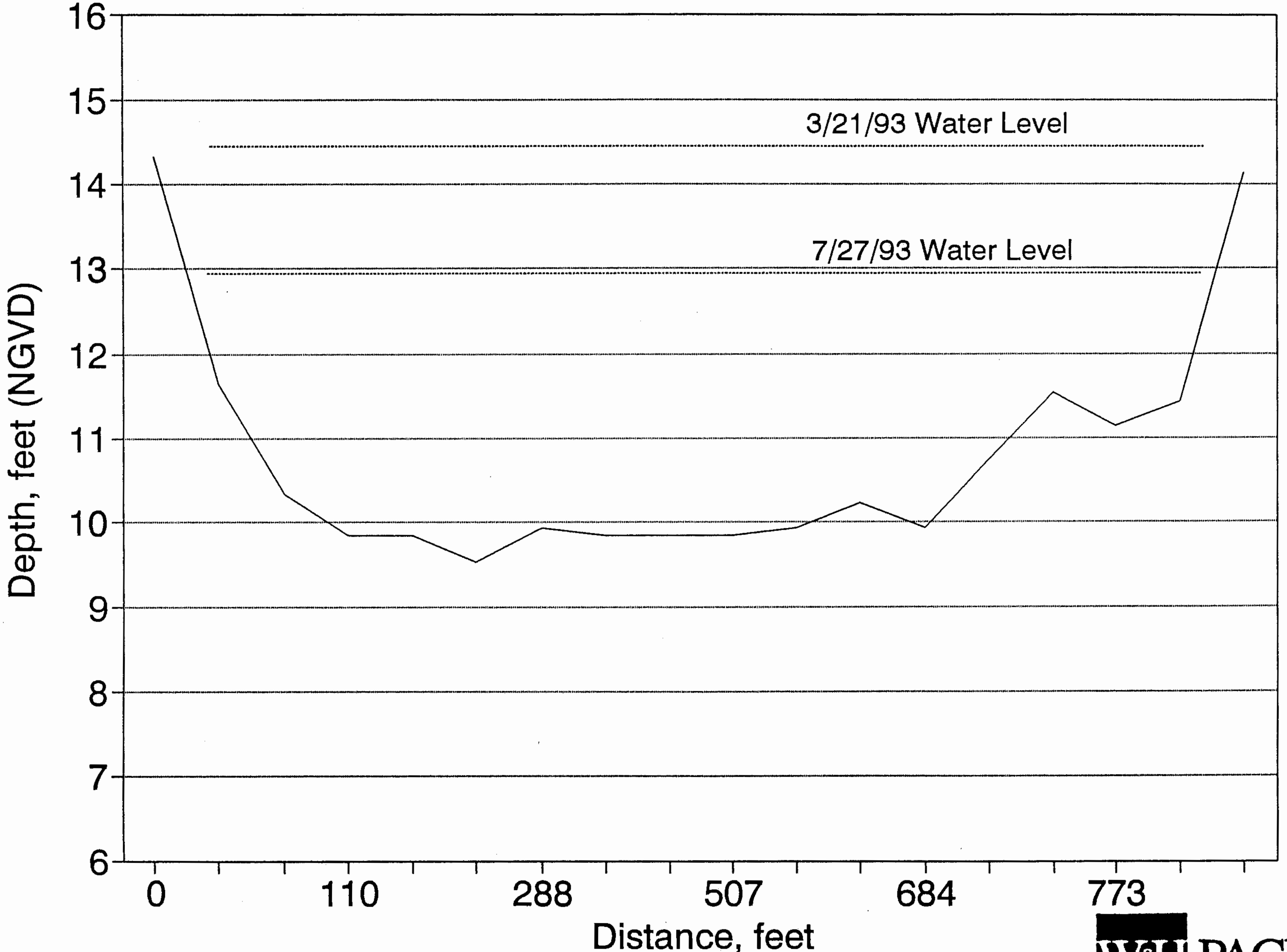


Lake Sections

W&H PACIFIC

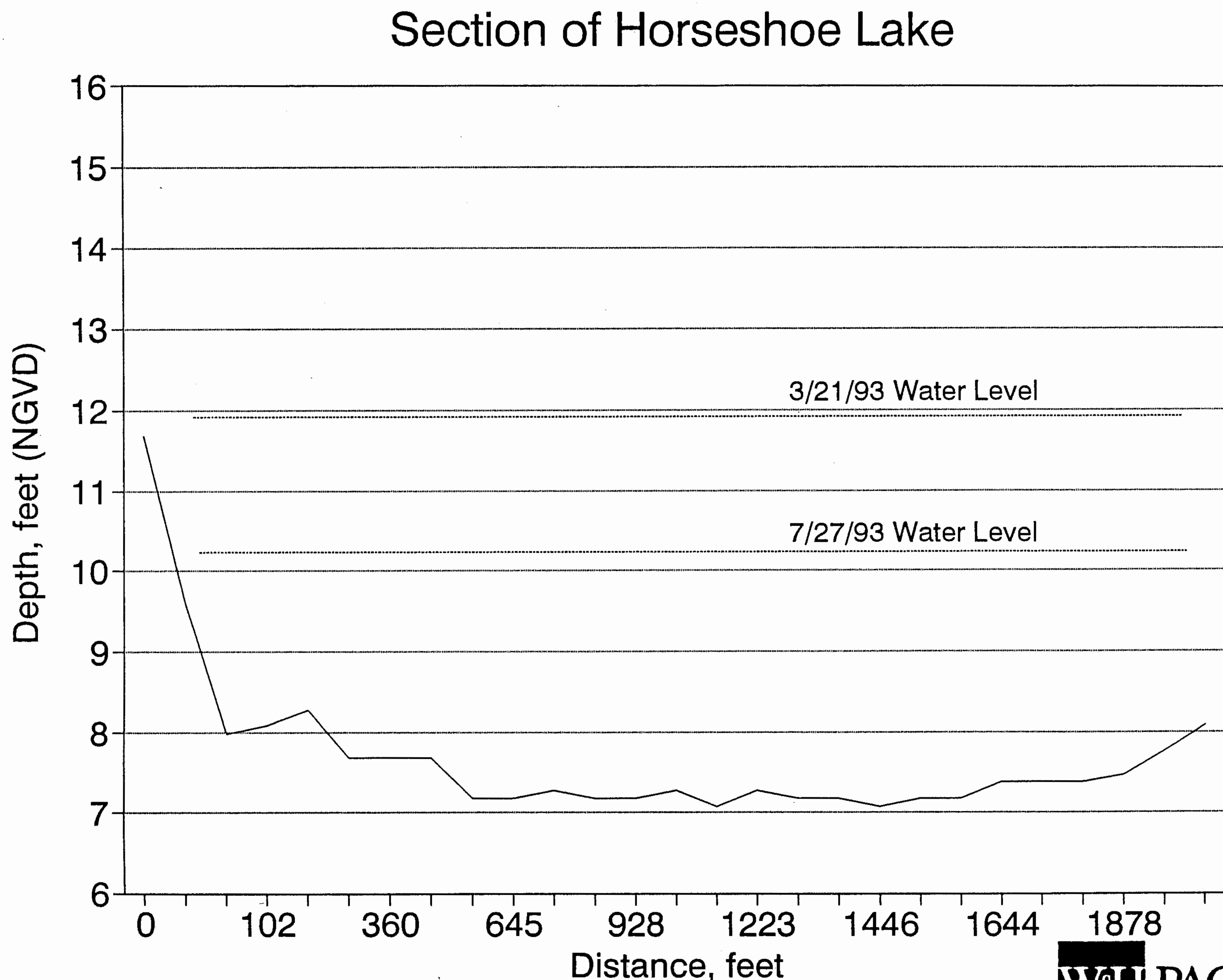
Figure 11

Section of Upper Lake



W&H PACIFIC

Figure 12



W&H PACIFIC

Figure 13

3.2.4 North Lake

North Lake is connected to the outflow channel via a marsh and the North Lake Slough. It appears that the North lake is simply a backwater of Horseshoe lake. North Lake is difficult to access possibly making it a good location for a restricted access habitat.

3.2.5 Kidney Lake

Kidney Lake is a small lake connected to the North Lake Slough. This lake is filled during the spring freshet. During low flow periods the hydraulic connection appears to become isolated from the rest of the lakes.

Field observations indicate that the connection is slowly becoming occluded due to the growth of reed canary grass and accumulation of bog like organic matter.

3.2.6 Scar Lake

Scar Lake is believed to be man-made. It was probably created when material was excavated to construct the rail turn around. Except in periods of high flow this lake is isolated from the lower lake system. During the dry months this lake is dry and could be classified as a wet meadow.

3.2.7 Outlet Channel

The Outlet Channel is the sole outlet of the Burlington Bottoms lake system. It is characterized as a wide parabolic channel with heavy riparian vegetation. Figure 14 is a survey cross section of the channel taken at the inlet (the outlet of Horseshoe Lake).

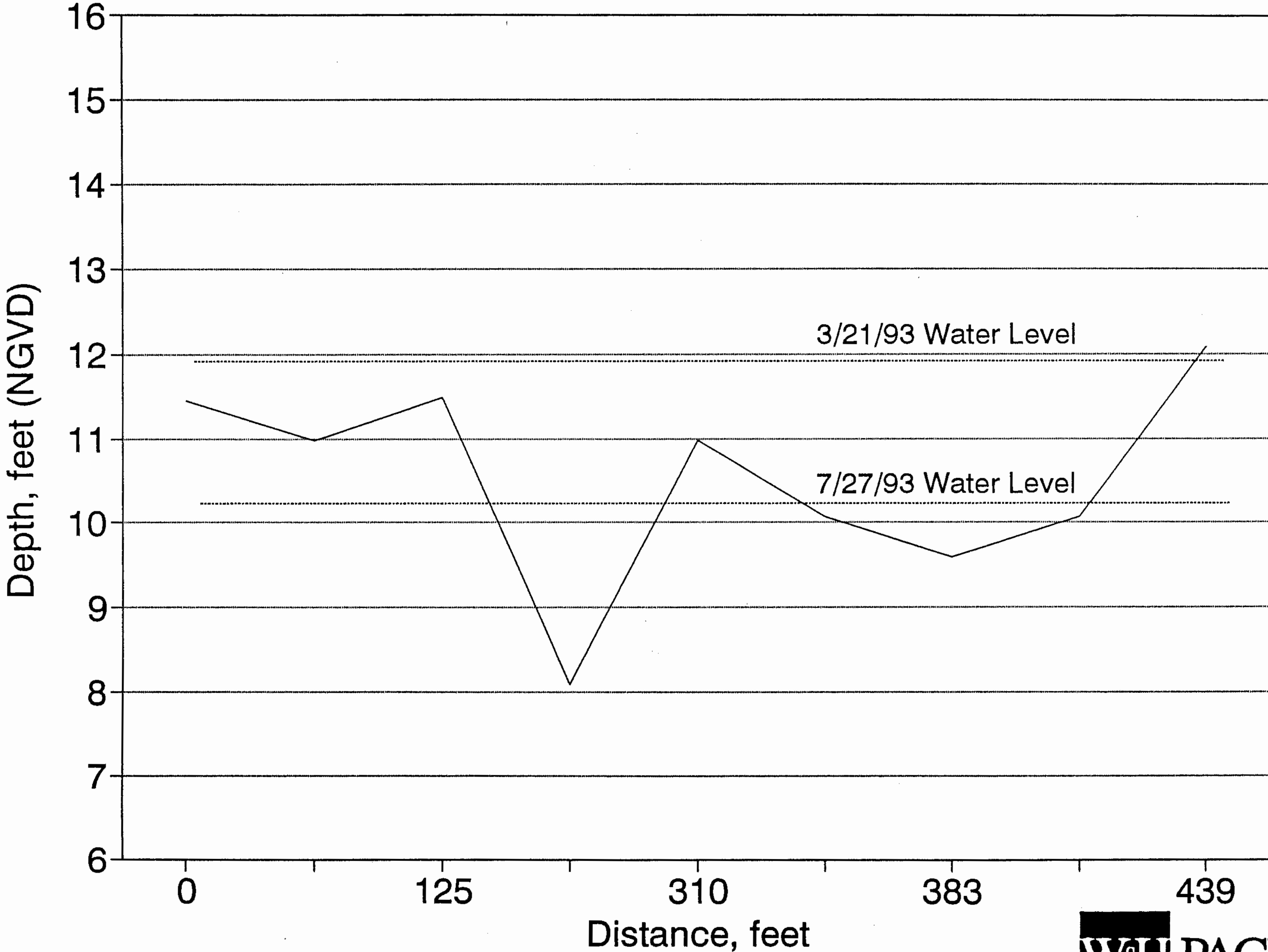
The portion of the channel which lies between the mouth at the Multnomah channel and the beaver dam upstream is sometimes full of water, acting as an inflow - outflow conduit between the Multnomah Channel and the lower lake system. This usually occurs during the late winter and early spring freshet. In the late spring, summer and fall the channel is dry since the channel invert is above the river stage and the beaver dam above prevents flow from the lower lake system.

It is not possible to place a simple staff gage on this channel to establish a flow rating curve. Due to river backwater and tidal action this channel is under shifting control, i.e. there is not direct relationship between stage and flow.

In fact flow direction in this channel can reverse in a matter of hours. During periods of high river stage and high tide, water will flow from the river to the lower lake system. As the tide falls the flow direction will reverse and water will flow from the lake system to the Multnomah Channel.

Though not yet observed it is likely that the downstream portions of the channel are subjected to tidal bores, which are waves that will propagate up the channel during a rising tide. In areas where the channel narrows the wave height and velocity will increase. This wave action will scour the banks and bottom of the channel. Some of the channel bank erosion areas observed in the field are indicative of scour by wave action. These areas are typically steep or vertical sides with exposed soils and plant roots.

Section of Outlet Channel



W&H PACIFIC

Figure 14

It is likely that, if there is a tidal bore, it will dissipate before it reaches the regulating beaver dam or any of the lakes.

3.2.7.1 Beaver Dam on the Outlet Channel

The beaver dam on the outlet channel is the most significant control feature of the lake system. The dam serves to maintain the lower lake system elevation about 3 to 4 feet above what it would be should the dam not be present.

The dam maintains a water surface elevation of about 11 feet NGVD plus or minus. It is not known how long this structure has been in place. It is well maintained by the beavers.

During the spring freshet the river stage rises above the top of the dam and water flows from the river to the lake system over the top. As the river stage declines the lake level will decline until the water surface elevation is again controlled by the dam.

Field observations indicate that when the river stage recedes and the dam is exposed the beaver(s) will effect repairs on any damage cause by the inundation. One concern is that during a period of inundation and river stage decline the dam may suffer a catastrophic failure. It is likely that until a substantial portion of the lake drained, the beavers would not be able to reconstruct it.

3.2.8 Slough Characteristics

Most of the major sloughs were traveled by canoe. The slough widths average from 20 to 30 feet. Both the North Lake Slough and the Cutoff Outlet slough have heavily vegetated banks. There are numerous snags from trees fallen by beaver and natural causes. Channel shapes appear to be parabolic with variable side slopes. In some areas, the encroachment of reed canary grass and other species has caused a high vegetative loading. However, no anoxic conditions were noticed to a marked degree during the field trips.

3.3 Descriptions of Soils

Soils in Burlington Bottoms are predominantly Rafton and Sauvie silt loams. Both of these soils are considered to be in the "C" hydrologic soil group when dry. Under damp conditions these soils are considered to be in the "D" hydrologic soil group. Both soils are considered poorly drained and are poorly suited for any uses other than wildlife habitat.

Also found on the Burlington Bottoms property are areas where gravel and or asphalt bases were placed. These were found toward the southern end of the property near the Burlington Northern Railroad. Initial attempts to install a ground water monitoring well in this area were abandoned due to a gravel base several feet thick.

All of the man-made fill embankments appear to be locally excavated material or dredge fill.

3.4 Seasonal Characteristics

The lower lake system is strongly influenced by fluctuations of the Columbia River. Lake levels generally reach a peak in early winter and late spring. Early winter releases are from winter rains in lower elevations whereas late spring releases, typically of higher magnitude, are from snow melt. Figure 15 demonstrates the typical seasonal river stage fluctuation.

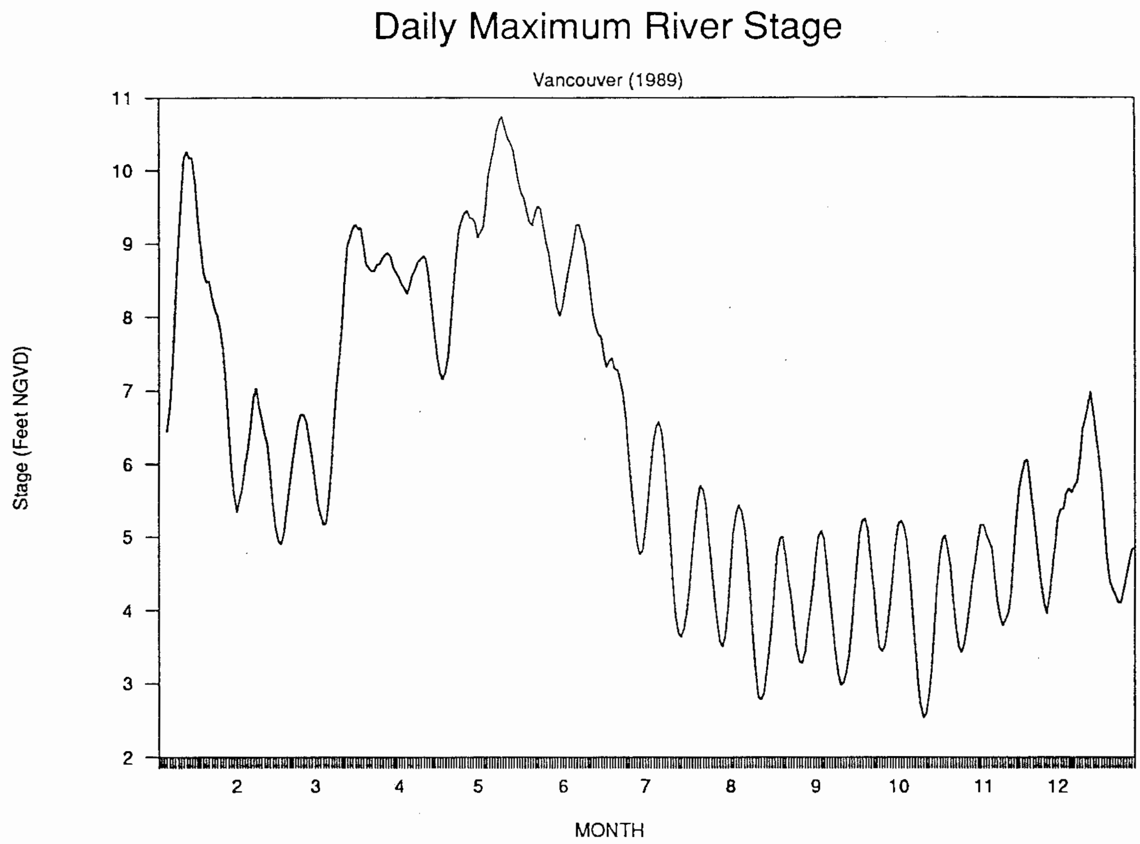


Figure 15

3.5 Influence of the Columbia River

Figure 16 shows the daily high river stage at Vancouver from 1984 to 1989. Note that for the river to flow over the beaver dam it must be at an elevation of at about 12 feet. Using Figure 16 it can be surmised that the lower lakes were only inundated by the river in 1984 and 1986 with perhaps one day in 1987. The maximum 10, 50 and 100 year river stages at River Mile 100.43 are 21.8, 25.2, and 26.5 respectively.

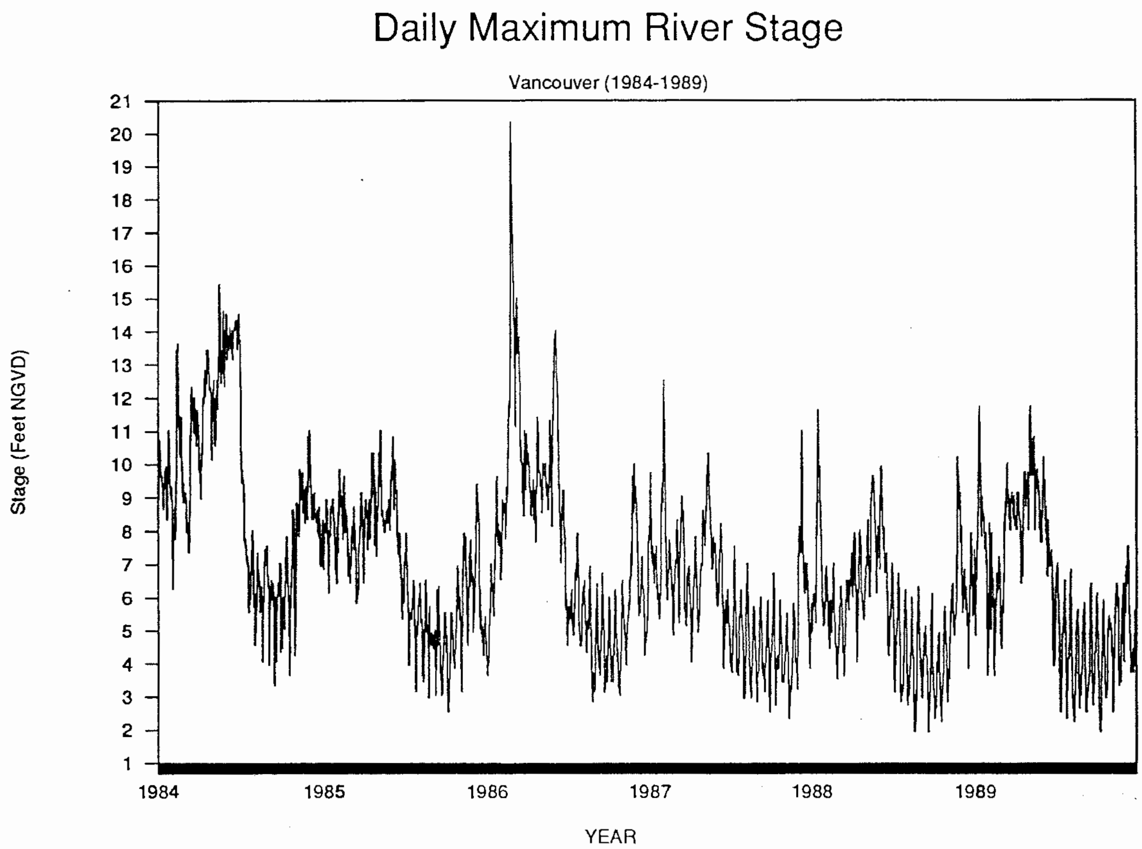


Figure 16

Figure 17 is a graph of the hourly stages at Vancouver from January through May 1993. The graph shows that the lower lakes were inundated in late March for a few days but during May the lower lakes were inundated for a period of almost 2 weeks. Note that during periods of high stage that the graph is less "fuzzy". The fuzz or white noise is the daily tidal fluctuations. The white noise will tend to dampen out as stage increases because the ocean has less of a backwater tidal influence during these periods. In other words when the river stage is higher it is more difficult for the ocean to "push" the water back upstream.

Note that for a short period of time the river reached a stage in excess of 14.5 feet. At that stage the upper lakes would also begin to be submerged by the river.

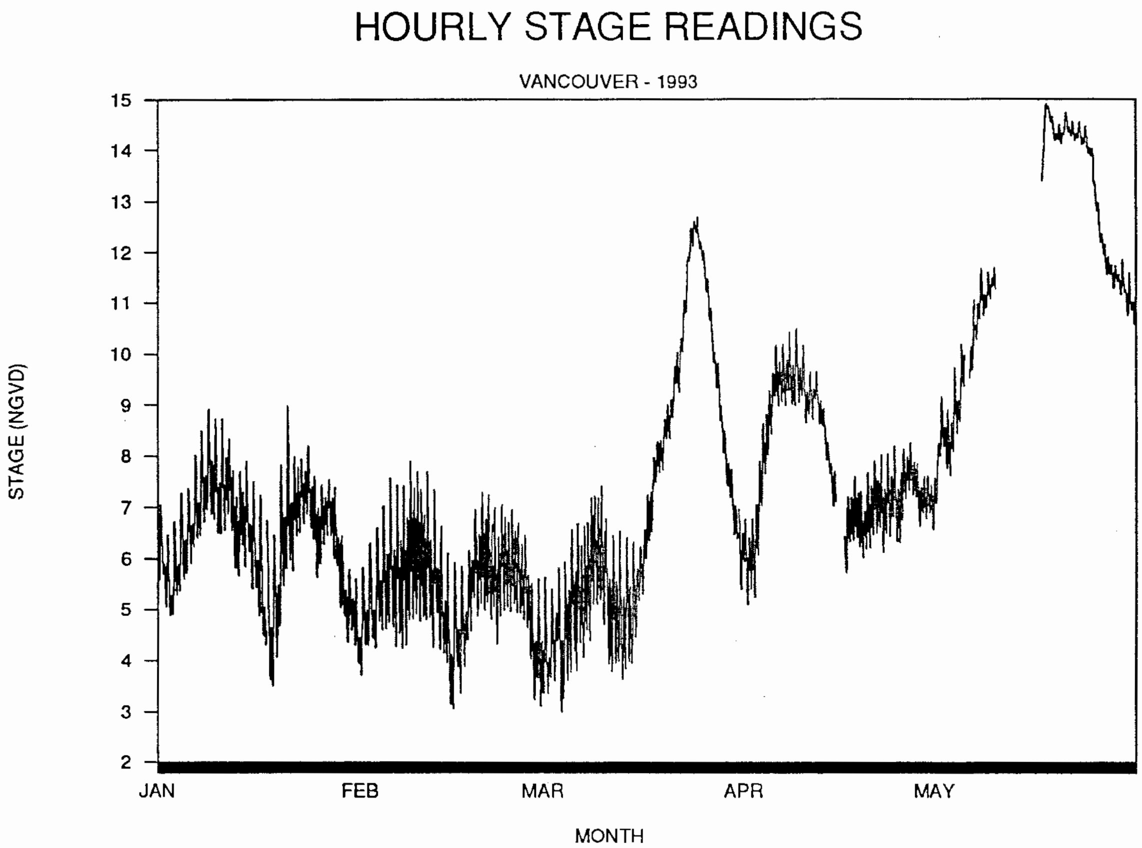
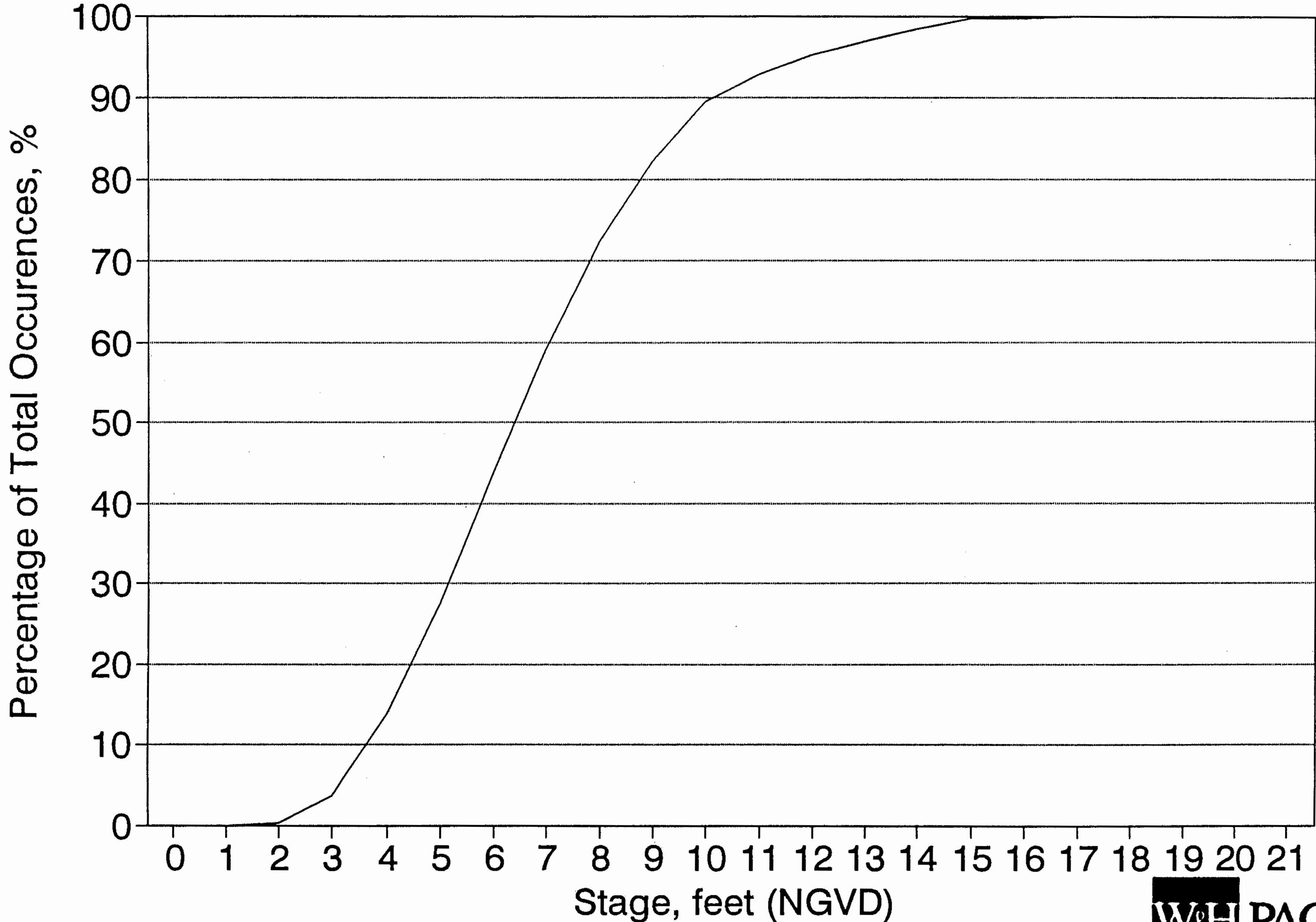


Figure 17

Figure 18 is a cumulative frequency distribution histogram for the Columbia River at Vancouver. From this graph, using 9 years of daily peak flows, it can be estimated that 5 percent of the time the river stage is high enough to influence the lower lake system. This translates to an average of 18 days per year. Since the data are daily peaks, they do not mean that the lake is inundated for the full 24 hour period. In fact the period of inundation can range from the full 24 hour periods (during extreme highs) or perhaps a period of one hour during a short tidal influence crest period.

Using the same graph it can be seen that water surface elevation of the upper lake system is reached about 1 percent of the time or about 3 days a year on the average. It is more likely that the period of inundation is relatively short since this elevation tends to be at the peak of a hydrograph crest.

CUMULATIVE FREQUENCY DISTRIBUTION AT VANCOUVER STATION (1/84-7/93)



W&H PACIFIC

3.6 Data Collection

Periodic readings were taken by staff from W&H Pacific and the ODFW. Data collected include precipitation, evaporation, lake stage, humidity, air and water temperature. Since the period of record is short it is difficult to extract substantive statistical information from the data.

A 6" rain gage and standard Class A evaporation pan were used to precipitation and evaporation measurements. Lake stage was recorded on Steven's staff gages.

3.6.1 Lake Stage and Precipitation Data

Lake levels were monitored with Steven's staff gages in the Lower and the Upper Lakes throughout the study period. The staff gage for the upper lake was located just above the beaver dam near the Timber Bridge. The second staff gage was placed at the south end of Horseshoe Lake. Data are presented below in Table 4.

Though not permanent, the staff gages will remain at the project site. To convert from the staff gage reading to elevation NGVD, 1929 use the following equations:

Upper Lake: NGVD = READING + 11.95

Horse Shoe Lake: NGVD = READING + 9.46

Table 4

Lake Stage and Precipitation Data
(Stage in Feet NGVD, 1929)

DATE	TIME	Horseshoe Lake	Upper Lake	PRECIP (IN)
04-07-93	1120	10.99	14.82	0
04-14-93	1400	10.75	14.84	2.81
04-22-93	1330	10.70	14.84	2.19
04-28-93	1330	10.66	14.80	0.98
04-30-93	1355	10.69	14.76	
05-05-93	1430	10.90	14.73	
05-08-93	1200	10.98	14.75	0.99
05-10-93	1710	10.94	14.73	
05-10-93	1840	10.93	14.73	
05-10-93	2000	10.92	14.73	
05-11-93	1100	10.93	14.72	
05-11-93	1200	10.94	14.72	
05-11-93	1300	10.95	14.72	
05-11-93	1350	10.96	14.72	
05-11-93	1430	10.96	14.72	
05-19-93	1000	13.78	14.24	1.19
05-21-93	1000	Nd	14.28	
06-24-93	920	10.55	14.07	4.54
06-30-93	1600	10.48	13.84	0.15
07-27-93	930	10.27	12.97	
08-04-93	1700	10.15	12.84	
TOTAL				12.85

A series of lake stage readings were taken during some of the most extreme high tides of May 1993 whaen the Columbia River fluctuated several feet between high and low tide. The lake stage readings showed an increase of 0.03 feet in the Lower Lake over a period of three hours. The difference in change can be attributed to the dampening effects of the beaver dam. Water from the Multnomah Channel was to a level where it was just above the top of the beaver dam. As the tide increased the water level on the down stream side of the dam flow reversed over the dam and discharged into Horseshoe Lake. Assuming a 60 acre water surface about 78,000 cubic feet of water would need to flow into the lakes. Over a 3 hour period the average flow into the lakes would be about 7.3 CFS. Modeling the dam as a weir the depth of water or the weir was about 0.2 feet.

Horseshoe Lake readings during the study period ranged from 10.15 to 13.8 feet. With the exception of the rise during the snow melt release, an overall slow, steady drop was observed.

For the 84 day period from April 7th to June 30th a total of 12.85 inches of rainfall were recorded for an average of 0.15 inches/day. Evaporation over the same period was found to be just over half of the precipitation at 6.65 inches total and 0.08 inches/day average.

3.6.2 Temperature Data

Temperature data were collected with a precision mercury thermometer. Water temperatures were taken one ffot below the surface. Humidity was determined using a sling psychrometer. Due to the shallow depth of the lakes, thermal stratification is not likely. Consequently the spring turnover in the lakes is likely. This helps to maintain the lakes oxygen levels and retards anoxic decomposition of organic sediments.

Table 5

Temperature and Humidity Data (Degrees F)

DATE	TIME	T-Horseshoe	T-UPPER	TAIR	RH (%)
04-14-93	1400	58.0	55.0	70.0	22
04-22-93	1330	57.5	57.5	68.0	82
04-28-93	1330	59.5	58.5	52.5	75
04-30-93	1355	55.0	56.5	56.0	53
05-21-93	1000	62.0	69.0	63.0	80

3.6.3 Evaporation Data

During the summer months evaporation causes a substantial loss of water from the lakes surface. Evaporation data were collected from a standard Class A pan. The pan was placed on the Timber Bridge between Upper and Horseshoe lake. This location is about 6 feet above the lake surface in a fairly well protected spot. The pan was not shaded from direct noon sunlight. Data are presented in Table 6. It should be noted that the spring and early summer of 1993 had above normal rainfall with cooler temperatures and less direct solar radiation.

Table 6

Pan Evaporation Data

DATE	EVAP (IN)
04-07-93	START
04-14-93	0.417
04-22-93	0.579
04-28-93	0.322
05-08-93	0.123
05-21-93	0.669
06-24-93	3.724
06-30-93	0.82
TOTAL	6.654

For the 84 day period of record the total evaporation was 6.65 inches for a mean evaporative loss of 0.08 inches per day. Assuming a pan coefficient of 0.7 the net evaporative losses from the lakes during the period of record is 4.65 inches. Regional estimates by the National Weather Service estimate the average annual evaporation at 26 inches per year. Of course, the majority of the evaporative losses are during the summer dry season.

Aside from evaporation the only other losses from the lake are surface water outflows through the beaver dam and seepage through the groundwater system. Seepage can be positive or negative depending on the relative elevations of the groundwater pieziometric surface and the water surface elevation of the lake. It is likely that seepage occurs from the upper lakes to the lower lakes and from both lake systems toward the Multnomah Channel. This will occur particularly when the water surface of the Multnomah Channel is very low relative to the lakes.

4 Groundwater

Geotechnical Resources, Inc. (GRI) was subcontracted to establish a monitoring well and evaluate the ground water hydrology of the site. Their report can be found Appendix 4.

A two inch diameter PVC ground water monitoring well was placed approximately 200 feet northwest of where NW Rafton Road enters the site. The well is 25 feet deep with the lower 15 feet screened with 0.01 inch slotted PVC pipe. The soil boring log indicated that silt loam soil was present to a depth of 13 feet. From a depth of 13 to 26.5 feet the soil was found to be increasingly more sandy. The top of the PVC pipe is at an elevation of 17.52 NGVD, 1929.

In late July the ground water level was found to be approximately five feet below the ground surface at an elevation of 12.3 feet. At the same time the Upper and Horseshoe Lake elevations were found to be 12.97 and 10.27 feet, respectively.

The high ground water table is believed to be hydraulically connected to the Multnomah Channel and follows its seasonal fluctuations. The general ground water flow direction is considered to be toward the channel. During rapid rises of river levels however, the flow direction may reverse.

5 Water Quality

The inflows to Burlington Bottoms have a potential adverse impact on the water quality of the lake system. Possible sources of these impacts include runoff from U.S. 30, and sediment loadings from construction, logging, and mining activities in the contributing watersheds.

Another source of pollutants is groundwater contamination. Potential sources are plumes from off-site or locally. There are concerns that some local contamination may be present particularly within the vicinity of the old railroad maintenance facility. At this time there is no access to this area to drill a monitoring well. If there are any contaminants on this site, it is likely that the plumes will migrate toward the Multnomah Channel.

The last significant source of pollutants is the Multnomah Channel itself. During period of high flows water from the Multnomah Channel will enter the lake system. Of primary concern are nutrients which can affect the lakes ecosystem.

Eight water quality samples were taken, six from surface waters and two from the ground water monitoring well. The locations and Sample Type are listed in Table 7. All samples were analyzed by AMTEST, an independent testing laboratory. Photocopies of the original data sheets provided by AMTEST are included as Appendix 5. Note that groundwater well sample number 2 was taken immediately following sample 1. Due to the disturbance of sediments caused by the rapid influx of groundwater the data from sample number 2 should be discarded due to improper sampling technique.

Table 7

Water Quality Sample Descriptions

SAMPLE LOCATION	SAMPLE TYPE	DATE	METHOD
Culvert 8	Oil and Grease, ICP Metals, TSS ,Nitrate, TP, Ortho P, pH	06-25-93	Surface Running Water
Culvert 14	Oil and Grease, ICP Metals, TSS ,Nitrate, TP, Ortho P, pH	06-25-93	Surface Running Water
Upper Lake 1	Oil and Grease, ICP Metals, TSS ,Nitrate, TP, Ortho P, pH	06-25-93	Skim Quiescent Surface Water
Upper Lake 2	Oil and Grease, ICP Metals, TSS ,Nitrate, TP, Ortho P, pH	07-27-93	Skim Quiescent Surface Water
Lower Lake or Horseshoe Lake 1	Oil and Grease, ICP Metals, TSS ,Nitrate, TP, Ortho P, pH	06-25-93	Skim Quiescent Surface Water
Lower Lake or Horseshoe Lake 2	Oil and Grease, ICP Metals, TSS ,Nitrate, TP, Ortho P, pH	07-27-93	Skim Quiescent Surface Water
Groundwater Monitoring Well 1	Oil and Grease, ICP Metals, TSS ,Nitrate, TP, Ortho P, pH	07-27-93	Polyethylene Bailer
Groundwater Monitoring Well 2	Oil and Grease, ICP Metals, TSS ,Nitrate, TP, Ortho P, pH	07-27-93	Polyethylene Bailer Immediately After 1

5.1 TSS

TSS or Total Suspended Solids is a measure of the amount of fine sediments that are entering or have entered the lakes. For both inlet culverts and the upper lake (All samples) TSS was undetectable. Note that the culvert samples were not taken during a period of high flows, when the concentration of TSS would be expected to increase.

The Horseshoe Lake had TSS values of 21 and 34 mg/L. This is probably due to the high density of aquatic vegetation present and not due to the presence of soil erodents.

The groundwater well sample had a TSS of 28 mg/L. Much of this is probably silica containing materials which has an ICP metals value of 26 mg/liter. The action of the bailer when the sample is taken tends to disturb sediments which have adhered to the side of the well case.

5.2 Phosphorus

Phosphorus is an important nutrient in lake systems. Phosphorus is usually a limiting nutrient to aquatic plant life. The addition of Phosphorus can stimulate algae blooms which can be deleterious to the lake ecosystem.

Table 8

Summary of Phosphorus Data

Location	Dissolved	Ortho	Total
Culvert 8	ND	.05	0.05
Culvert 14	ND	ND	0.04
Upper Lake 1	BAD	ND	0.05
Upper Lake 2	0.01	0.01	0.05
Horseshoe Lake 1	0.04	ND	0.39
Horseshoe Lake 2	0.02	0.03	0.15
Gwell 1	0.09	0.12	0.16

For lakes, in general, biochemically active Phosphorus with a mean loading of 84.4 mg/cubic meter classifies the lake as eutrophic. The loading for Horseshoe Lake is 150 mg/M^3 and is therefore classified to be in a eutrophic state. This is evidenced by the dense aquatic vegetation throughout the lake. Though not demonstrated, it is believed that the high phosphorus loading comes from overflows by the Multnomah Channel.

The upper lakes are probably classified as mesotrophic with the lower levels of Phosphorus.

5.3 Metals

It is beyond the scope of this report to discuss all of the metals data. A cursory inspection of the data does not reveal any alarming concentrations of metals. Zinc, Iron and Aluminum are somewhat on the high side. The source of these pollutants is probably the railroad tracks and US Highway 30. Iron from rusting rail is leached from the rail ballast. Direct runoff from the highway and decomposition of zinc plated and aluminized culverts are sources of zinc and aluminum.

5.4 Nitrogenous Compounds

For eutrophic classification the mean total nitrogen content is 753 mg/M^3 or 0.7 ppm. The presence of nitrates indicate the Horseshoe Lake is again eutrophic. Due to the trophic nature it is likely that much of the nitrogen is being fixed by species of algae and bacteria.

The culverts also have significant levels of nitrate and nitrite. More than likely these nutrients have been leached from the soils of the contributing watershed. Nitrates and Nitrites are also present in the ground water indicating that background levels are high.

5.5 Oil and Grease

Oil and Grease was non detectable in all samples except in Horseshoe Lake 1. It is likely that some oil film was transported from the Multnomah Channel which carries recreational boat traffic. Industrial discharges from the Port of Portland may also contribute petroleum hydrocarbons from industrial runoff.

There are no records of anyone observing oil sheens on the lakes or lake inflows from the upper watershed.

5.6 pH

Table 9 gives the pH values for all of the samples taken. pH was taken at the laboratory immediately upon receipt of the samples. The age of the first sample set did not exceed 6 hours and the second sample set 1 hour.

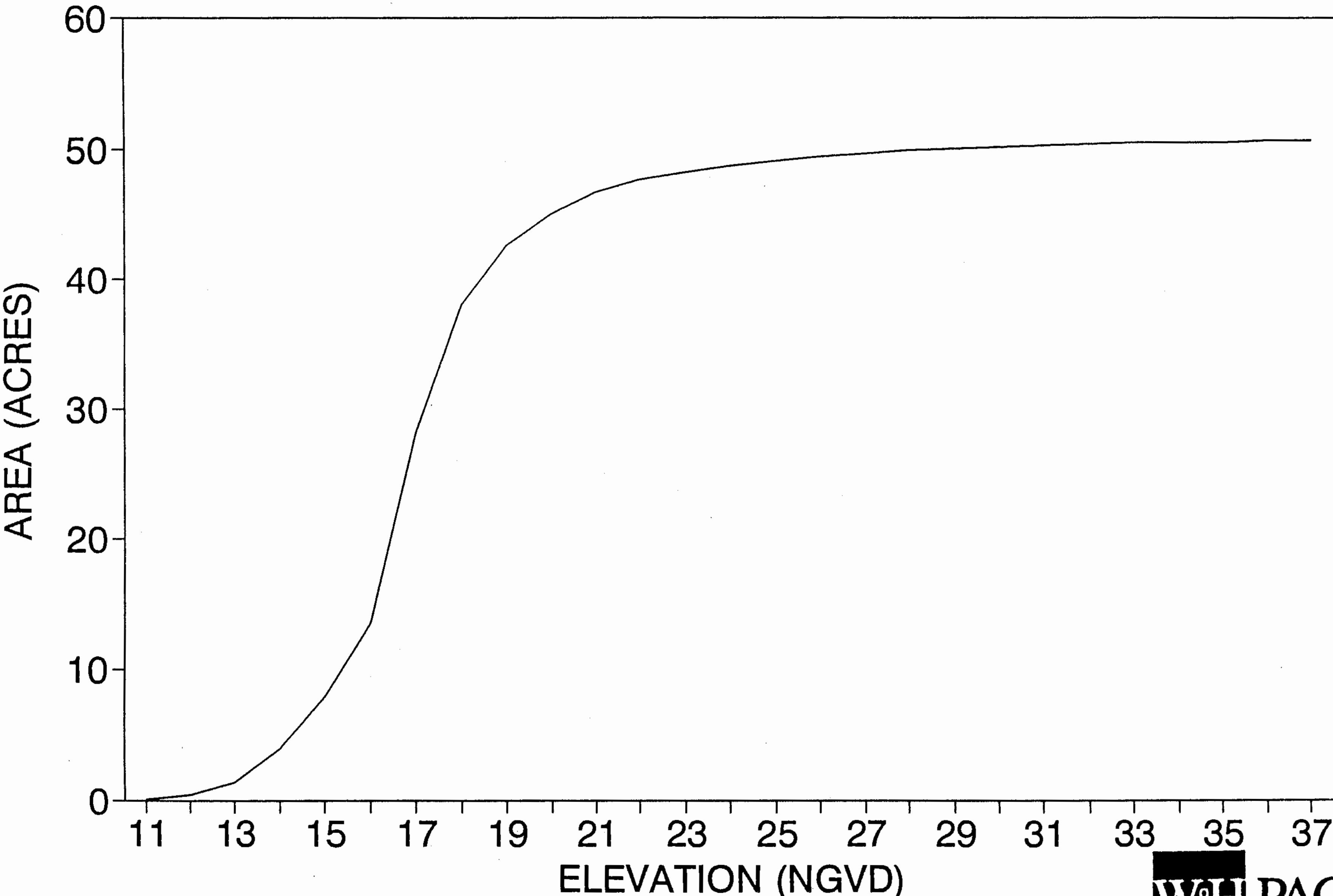
Table 9

Ph Readings

Location	pH
Culvert 8	8.2
Culvert 14	7.1
Upper Lake 1	7.2
Upper Lake 2	8.5
Horseshoe Lake 1	10.4
Horseshoe Lake 2	10.2
Gwell 1	6.6

The pH of the influent waters and upper lakes is within an acceptable range, Horseshoe Lake however is of concern. The pH of 10.4 is strongly basic. The alkalinity of waters refers to the quantity and kinds of compounds present which collectively shift the pH to the alkaline side of neutrality. The property of alkalinity is usually imparted by the presence of bicarbonates, carbonates, and hydroxides. Sometimes in inland waters borate, silicate, and phosphates will raise the pH.

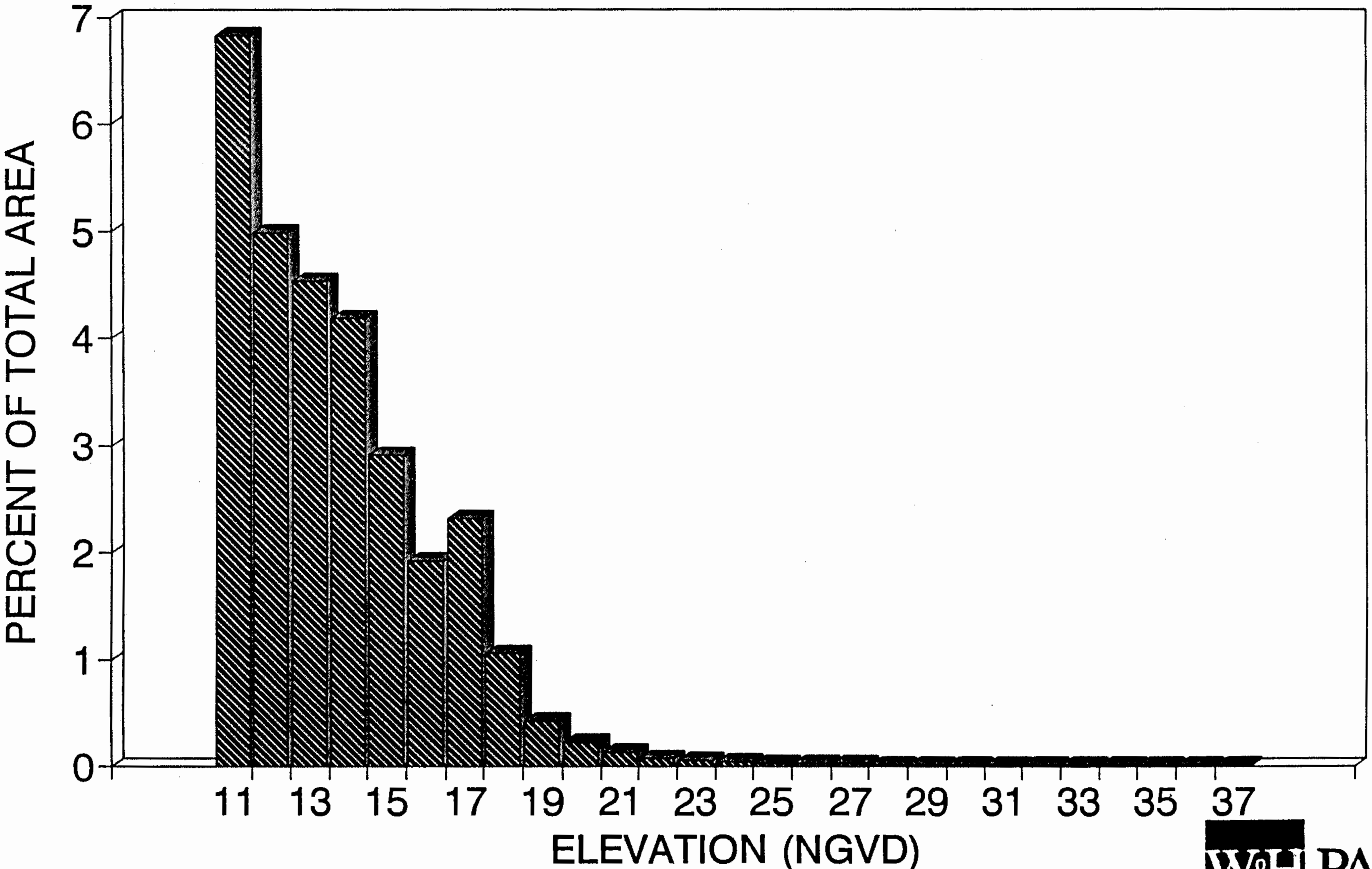
ACCUMULATED AREA VS. ELEVATION
REED CANARY GRASS - BURLINGTON BOTTOMS



W&H PACIFIC

Figure 20

PERCENTAGE OF TOTAL AREA ANALYZED
REED CANARY GRASS - BURLINGTON BOTTOMS



W&H PACIFIC

Figure 2.1

7 River Bank Assessment of the Multnomah Channel

The project site has about 10,700 feet of bankline along Multnomah Channel. The banks are generally characterized as steep with varied levels of riparian vegetation. In general the bank rises 15 feet from the normal water surface elevation of the Multnomah Channel to the top of the bank. The top of bank is now the access road which used to be the tracke line to the railroad maintenance yard.

Along the entire length of the bank are timber piles which are remnants of old docks and shanty town structures. Some of these structures now serve to protect the banks from erosion. There are some significant piles of scrap metal, cabling and steel banding along the bank. There are also a few abandoned sheds and ramps which are probably hazardous to curiosity seekers. Though not confirmed it may be the case that significant oil spills or years of oil accumulation have contaminated soils along the bank. This is particularly true within the vicinity of the old maintenance yard.

Bank loss from erosion is considered high. Varying water levels from hydroelectric dam release, tidal action and wave action from winds and boat wakes are clearly causing severe erosion in some areas. It is estimated that from 30 to 50 percent of the bankline exhibit some degree of erosion or sloughing. In some places bank sloughing and erosion has caused the undercutting of substantial trees which have fallen into the channel.

The beneficial use of riprap was clearly exhibited along portions of the bank. Where the riprap was absent, the bank was found to be heavily scoured. The removal of wood piles or crib walls should be carefully considered. Though not estheticaly pleasing many of these structures have become integrated into the natural system and act to reduce or prevent erosion. However, dependent on the final Burlington Bottoms management plan, the removal of some of these features may be advantageous to prevent human access to the project site. Removal of selected structures may also be warranted in the interest of public safety.

8 Conclusion

From research and field investigations it has been determined the Burlington Bottoms hydrologic characteristics are complex. Largely due to the influence of the Columbia River the characteristics of the upper and lower lakes are significantly different.

Historically, this area has been strongly influenced by man. The construction of road embankments and a railroad utility yard have significantly altered the hydrologic operation of the system over the past 60 years. Presently the most significant controls are beaver dams on the upper and lower lakes.

Water quality of the lakes varies. Due to spring freshets of the Columbia the lower lakes are in a higher trophic state than the upper lakes. There is no strong evidence that sediment transported from the upper watershed is presently a problem. However, due to logging activities and potential mining of the watershed, sediment control should be a major component of the long term management plan. There are significant buffer strips between the lakes and the cross highway and railroad culverts. These buffer strips should be maintained or even enhanced to maintain water quality.

Encroachment of Reed Canary Grass is a problem and will probably continue to increase in its domination of lowlying areas.

The banks of the Multnomah Channel are in poor condition. In some areas erosion and bank sloughing are excessive. It is possible that continued erosion and bank sloughing combined with occasional high water events may lead to a failure of the embankments.

1945

June 23, 1948 (1/3)

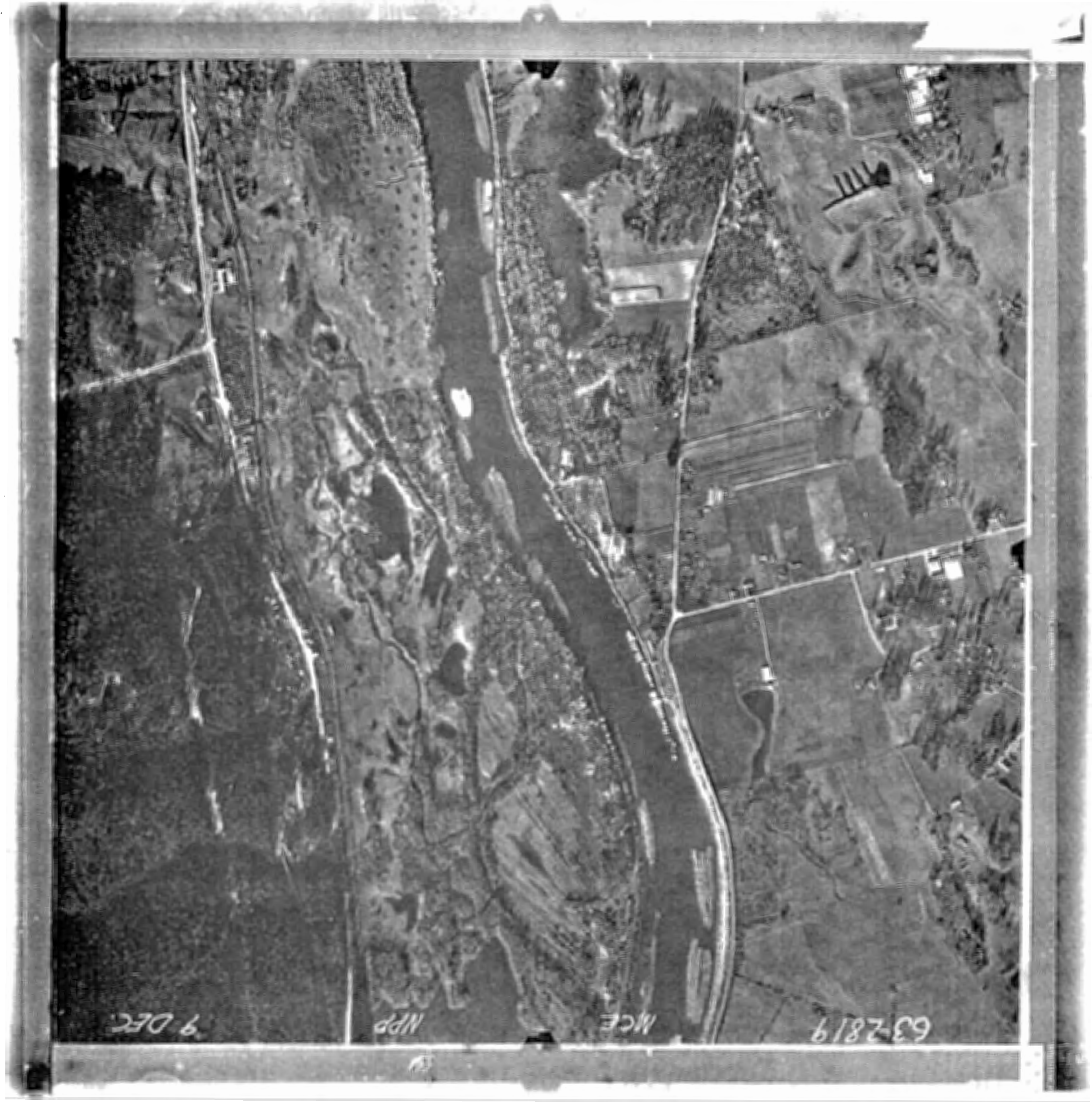
June 23, 1948 (2/3)


1897 VV-DAS M PD 23 JUNE 48 COL. R FLOOD

November 19, 1956

December 9, 1963 (1/2)

December 9, 1963 (2/2)



April 2, 1967

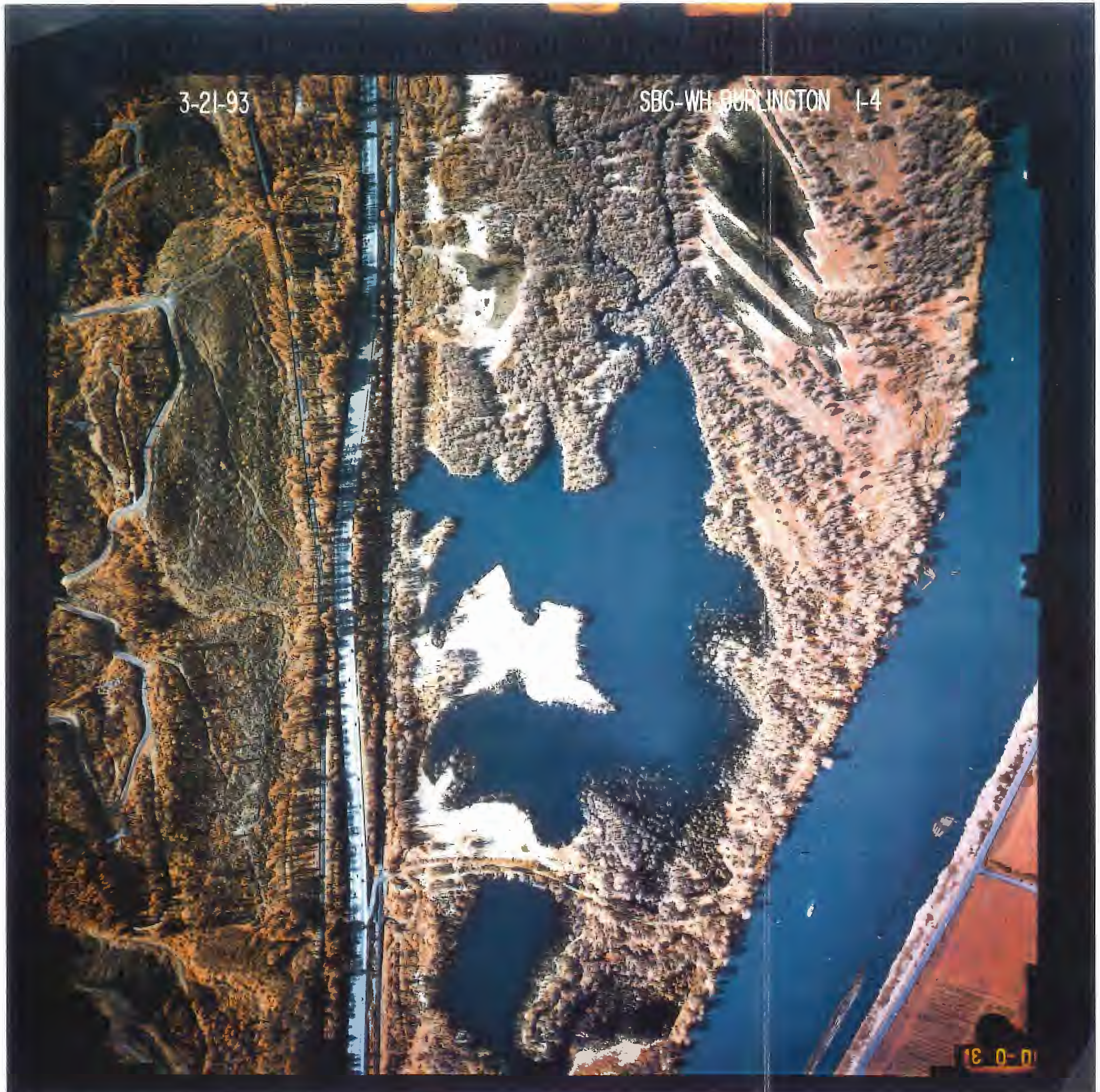
November 11, 1972

January 30, 1980 (1/2)

January 30, 1980 (2/2)

March 21, 1993

March 23, 1993 (1/4)



March 23, 1993 (2/4)

March 23, 1993 (3/4)

March 23, 1993 (4/4)

Appendix 2

QTR55 Data

Burlington Bottoms - SCS Curve Number

RUNOFF CURVE NUMBER SUMMARY

Subarea Description	Area (acres)	CN (weighted)
1	39.70	73
2	140.90	73
3	350.80	73
4	94.50	73
5	270.30	71

Quick TR-55 Ver.5.44 S/N:1315460004 Executed: 16:38:04 08-06-1993

Burlington Bottoms - SCS Curve Number

RUNOFF CURVE NUMBER DATA

::

Composite Area: 1

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	39.70	73	
COMPOSITE AREA --->	39.70	73.0	(73)

:::

Composite Area: 2

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	140.90	73	
COMPOSITE AREA --->	140.90	73.0	(73)

:::

Composite Area: 3

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	350.80	73	
COMPOSITE AREA --->	350.80	73.0	(73)

:::

Quick TR-55 Ver.5.44   S/N:1315460004   Executed: 16:38:04   08-06-1993

Composite Area: 4

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	94.50	73	
COMPOSITE AREA --->	94.50	73.0	(73)

::

Composite Area: 5

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	234.90	73	
Woods, Fair, HSG-B	35.40	60	
COMPOSITE AREA --->	270.30	71.3	(71)

::

```
Quick TR-55 Ver.5.44   S/N:1315460004   Executed: 17:25:02   07-12-1993

              Burlington Bottoms - Time of Concentration

                     Tc COMPUTATIONS FOR: 1

 SHEET FLOW (Applicable to Tc only)
     Segment ID
     Surface description
     Manning's roughness coeff., n                0.6000
     Flow length, L (total < or = 300)    ft      300.0
     Two-yr 24-hr rainfall, P2            in      2.300
     Land slope, s                       ft/ft    0.1000
                        0.8
          .007 * (n*L)
     T =  --------------                  hrs      0.74            =  0.74
             0.5     0.4
           P2    *  s

 SHALLOW CONCENTRATED FLOW
     Segment ID
     Surface (paved or unpaved)?                 Unpaved
     Flow length, L                       ft     2099.0
     Watercourse slope, s                ft/ft   0.1910

                          0.5
     Avg.V =  Csf *  (s)                  ft/s   7.0513
     where:   Unpaved Csf = 16.1345
              Paved   Csf = 20.3282

     T = L / (3600*V)                     hrs      0.08            =  0.08


 CHANNEL FLOW
     Segment ID
     Cross Sectional Flow Area, a        sq.ft     0.00
     Wetted perimeter, Pw                 ft       0.00
     Hydraulic radius, r = a/Pw           ft      0.000
     Channel slope, s                    ft/ft    0.0000
     Manning's roughness coeff., n                0.0000

                      2/3     1/2
          1.49   *   r    *   s
     V =  --------------------            ft/s    0.0000
                    n

     Flow length, L                       ft          0

     T = L / (3600*V)                     hrs      0.00            =  0.00

     ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                                             TOTAL TIME (hrs)        0.82
```

Quick TR-55 Ver.5.44 S/N:1315460004 Executed: 16:38:04 08-06-1993

Burlington Bottoms - SCS Curve Number

RUNOFF CURVE NUMBER DATA

::

Composite Area: 1

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	39.70	73	
COMPOSITE AREA --->	39.70	73.0	(73)

:::

Composite Area: 2

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	140.90	73	
COMPOSITE AREA --->	140.90	73.0	(73)

:::

Composite Area: 3

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	350.80	73	
COMPOSITE AREA --->	350.80	73.0	(73)

:::

Quick TR-55 Ver.5.44 S/N:1315460004 Executed: 16:38:04 08-06-1993

Composite Area: 4

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	94.50	73	
COMPOSITE AREA --->	94.50	73.0	(73)

Composite Area: 5

SURFACE DESCRIPTION	AREA (acres)	CN	
Woods, Fair, HSG-C	234.90	73	
Woods, Fair, HSG-B	35.40	60	
COMPOSITE AREA --->	270.30	71.3	(71)

```
Quick TR-55 Ver.5.44   S/N:1315460004   Executed: 17:25:02   07-12-1993

                Burlington Bottoms - Time of Concentration

                     Tc COMPUTATIONS FOR: 1

 SHEET FLOW (Applicable to Tc only)
     Segment ID
     Surface description
     Manning's roughness coeff., n                  0.6000
     Flow length, L (total < or = 300)    ft      300.0
     Two-yr 24-hr rainfall, P2            in      2.300
     Land slope, s                        ft/ft   0.1000
                           0.8
          .007 * (n*L)
     T =  --------------                  hrs      0.74            =  0.74
             0.5    0.4
           P2    *   s

 SHALLOW CONCENTRATED FLOW
     Segment ID
     Surface (paved or unpaved)?                 Unpaved
     Flow length, L                       ft     2099.0
     Watercourse slope, s                 ft/ft   0.1910

                             0.5
     Avg.V =  Csf *  (s)                  ft/s   7.0513
     where:   Unpaved Csf = 16.1345
              Paved   Csf = 20.3282

     T = L / (3600*V)                     hrs      0.08            =  0.08


 CHANNEL FLOW
     Segment ID
     Cross Sectional Flow Area, a         sq.ft    0.00
     Wetted perimeter, Pw                 ft       0.00
     Hydraulic radius, r = a/Pw           ft       0.000
     Channel slope, s                     ft/ft   0.0000
     Manning's roughness coeff., n                0.0000

                        2/3    1/2
          1.49   *  r    *  s
     V =  --------------------            ft/s   0.0000
                    n

     Flow length, L                       ft          0

     T = L / (3600*V)                     hrs      0.00            =  0.00

   ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                                              TOTAL TIME (hrs)        0.82
```

```
Quick TR-55 Ver.5.44   S/N:1315460004   Executed: 17:25:02   07-12-1993

                Burlington Bottoms - Time of Concentration

                     Tc COMPUTATIONS FOR: 2

 SHEET FLOW (Applicable to Tc only)
     Segment ID
     Surface description
     Manning's roughness coeff., n                    0.6000
     Flow length, L (total < or = 300)     ft         300.0
     Two-yr 24-hr rainfall, P2             in         2.300
     Land slope, s                         ft/ft      0.1000
                        0.8
           .007 * (n*L)
     T =  --------------                   hrs        0.74              =  0.74
              0.5      0.4
            P2    *  s

 SHALLOW CONCENTRATED FLOW
     Segment ID
     Surface (paved or unpaved)?                      Unpaved
     Flow length, L                        ft         3674.0
     Watercourse slope, s                  ft/ft      0.1220

                          0.5
     Avg.V =   Csf *  (s)                  ft/s       5.6355
     where:    Unpaved Csf = 16.1345
               Paved   Csf = 20.3282

     T = L / (3600*V)                      hrs        0.18              =  0.18


 CHANNEL FLOW
     Segment ID
     Cross Sectional Flow Area, a          sq.ft      0.00
     Wetted perimeter, Pw                  ft         0.00
     Hydraulic radius, r = a/Pw            ft         0.000
     Channel slope, s                      ft/ft      0.0000
     Manning's roughness coeff., n                    0.0000

                     2/3     1/2
           1.49   *  r    *  s
     V =  --------------------             ft/s       0.0000
                    n

     Flow length, L                        ft         0

     T = L / (3600*V)                      hrs        0.00              =  0.00

   ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                                                TOTAL TIME (hrs)        0.92
```

```
Quick TR-55 Ver.5.44   S/N:1315460004   Executed: 17:25:02   07-12-1993

                Burlington Bottoms - Time of Concentration

                     Tc COMPUTATIONS FOR: 3

 SHEET FLOW (Applicable to Tc only)
     Segment ID
     Surface description
     Manning's roughness coeff., n               0.6000
     Flow length, L (total < or = 300)    ft      300.0
     Two-yr 24-hr rainfall, P2            in      2.300
     Land slope, s                        ft/ft  0.1670
                          0.8
          .007 * (n*L)
     T = --------------                   hrs      0.60                =  0.60
             0.5     0.4
           P2    *   s

 SHALLOW CONCENTRATED FLOW
     Segment ID
     Surface (paved or unpaved)?                Unpaved
     Flow length, L                       ft      600.0
     Watercourse slope, s                 ft/ft  0.4170

                            0.5
     Avg.V =   Csf *  (s)                 ft/s   %10.4189
     where:    Unpaved Csf = 16.1345
               Paved   Csf = 20.3282

     T = L / (3600*V)                     hrs      0.02                =  0.02


 CHANNEL FLOW
     Segment ID
     Cross Sectional Flow Area, a         sq.ft    0.50       1.13
     Wetted perimeter, Pw                 ft       2.24       3.35
     Hydraulic radius, r = a/Pw           ft      0.223      0.336
     Channel slope, s                     ft/ft  0.0850     0.0780
     Manning's roughness coeff., n               0.0500     0.0500

                     2/3    1/2
          1.49   *  r    *  s
     V = --------------------             ft/s   3.1970     4.0210
                    n

     Flow length, L                       ft       2949       3204

     T = L / (3600*V)                     hrs      0.26   +   0.22     =  0.48

   ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                                                 TOTAL TIME (hrs)         1.10
```

```
Quick TR-55 Ver.5.44   S/N:1315460004   Executed: 17:25:02   07-12-1993

                Burlington Bottoms - Time of Concentration

                        Tc COMPUTATIONS FOR: 4

 SHEET FLOW (Applicable to Tc only)
     Segment ID
     Surface description
     Manning's roughness coeff., n                  0.6000
     Flow length, L (total < or = 300)     ft       300.0
     Two-yr 24-hr rainfall, P2             in       2.300
     Land slope, s                         ft/ft    0.1330
                          0.8
          .007 * (n*L)
     T = ---------------                   hrs      0.66              =  0.66
             0.5     0.4
          P2     *  s

 SHALLOW CONCENTRATED FLOW
     Segment ID
     Surface (paved or unpaved)?                   Unpaved
     Flow length, L                        ft       2773.0
     Watercourse slope, s                  ft/ft    0.1800

                            0.5
     Avg.V =   Csf *   (s)                 ft/s     6.8453
     where:    Unpaved Csf = 16.1345
               Paved   Csf = 20.3282

     T = L / (3600*V)                      hrs      0.11              =  0.11


 CHANNEL FLOW
     Segment ID
     Cross Sectional Flow Area, a          sq.ft    0.00
     Wetted perimeter, Pw                  ft       0.00
     Hydraulic radius, r = a/Pw            ft       0.000
     Channel slope, s                      ft/ft    0.0000
     Manning's roughness coeff., n                  0.0000

                         2/3    1/2
          1.49   *   r    *   s
     V = --------------------              ft/s     0.0000
                     n

     Flow length, L                        ft       0

     T = L / (3600*V)                      hrs      0.00              =  0.00

   ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                                            TOTAL TIME (hrs)         0.77
```

```
Quick TR-55 Ver.5.44   S/N:1315460004   Executed: 17:25:02   07-12-1993

               Burlington Bottoms - Time of Concentration

                    Tc COMPUTATIONS FOR: 5

 SHEET FLOW (Applicable to Tc only)
     Segment ID
     Surface description
     Manning's roughness coeff., n                 0.6000
     Flow length, L (total < or = 300)    ft       300.0
     Two-yr 24-hr rainfall, P2            in       2.300
     Land slope, s                        ft/ft    0.3330
                         0.8
           .007 * (n*L)
     T =   --------------                 hrs       0.46               =  0.46
              0.5     0.4
            P2    *  s

 SHALLOW CONCENTRATED FLOW
     Segment ID
     Surface (paved or unpaved)?                  Unpaved
     Flow length, L                        ft      300.0
     Watercourse slope, s                  ft/ft   0.5000

                           0.5
     Avg.V =  Csf *  (s)                   ft/s   %11.4088
     where:   Unpaved Csf = 16.1345
              Paved   Csf = 20.3282

     T = L / (3600*V)                      hrs      0.01               =  0.01


 CHANNEL FLOW
     Segment ID
     Cross Sectional Flow Area, a          sq.ft    0.50      1.13
     Wetted perimeter, Pw                  ft       2.24      3.35
     Hydraulic radius, r = a/Pw            ft      0.223     0.336
     Channel slope, s                      ft/ft   0.1580    0.1140
     Manning's roughness coeff., n                 0.0500    0.0500

                        2/3     1/2
           1.49   *   r    *   s
     V =   --------------------           ft/s    4.3587    4.8612
                      n

     Flow length, L                        ft       3155      2287

     T = L / (3600*V)                      hrs      0.20  +   0.13     =  0.33

    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
                                           TOTAL TIME (hrs)               0.80
```

SUMMARY SHEET FOR Tc or Tt COMPUTATIONS
(Solved for Time using TR-55 Methods)

Burlington Bottoms - Time of Concentration

Subarea descr.	Tc or Tt	Time (hrs)
1	Tc	0.82
2	Tc	0.92
3	Tc	1.10
4	Tc	0.77
5	Tc	0.80

Return Frequency: 2 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B2-HYD.HYD

>>>> Input Parameters Used to Compute Hydrograph <<<<

Subarea Description	AREA (acres)	CN	Tc (hrs)	* Tt (hrs)	Precip. (in)	Runoff (in)	Ia/p input	Ia/p used
1	39.70	73.0	0.75	0.00	2.30	0.46	.32	.30
2	140.90	73.0	1.00	0.00	2.30	0.46	.32	.30
3	350.80	73.0	1.00	0.00	2.30	0.46	.32	.30
4	94.50	73.0	0.75	0.00	2.30	0.46	.32	.30
5	270.30	71.0	0.75	0.00	2.30	0.40	.36	.30

* Travel time from subarea outfall to composite watershed outfall point.
Total area = 896.20 acres or 1.4003 sq.mi
Peak discharge = 33 cfs

>>>> Computer Modifications of Input Parameters <<<<<

Subarea Description	Input Values Tc (hr)	Input Values * Tt (hr)	Rounded Values Tc (hr)	Rounded Values * Tt (hr)	Ia/p Interpolated (Yes/No)	Ia/p Messages
1	0.82	0.00	0.75	0.00	No	--
2	0.92	0.00	1.00	0.00	No	--
3	0.92	0.00	1.00	0.00	No	--
4	0.77	0.00	0.75	0.00	No	--
5	0.67	0.00	0.75	0.00	No	--

* Travel time from subarea outfall to composite watershed outfall point.

Return Frequency: 2 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B2-HYD.HYD

>>>> Summary of Subarea Times to Peak <<<<

Subarea	Peak Discharge at Composite Outfall (cfs)	Time to Peak at Composite Outfall (hrs)
1	2	8.7
2	5	9.0
3	13	9.0
4	4	8.7
5	9	8.7
Composite Watershed	33	9.0

Return Frequency: 2 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B2-HYD.HYD

Composite Hydrograph Summary (cfs)

Subarea Description	7.0 hr	7.3 hr	7.6 hr	7.9 hr	8.0 hr	8.1 hr	8.2 hr	8.3 hr	8.4 hr
1	0	0	0	0	0	0	0	1	1
2	0	0	0	0	0	0	1	1	2
3	0	0	0	0	0	1	1	3	4
4	0	0	0	0	0	0	1	1	2
5	0	0	0	0	0	1	2	3	5
Total (cfs)	0	0	0	0	0	2	5	9	14

Subarea Description	8.5 hr	8.6 hr	8.7 hr	8.8 hr	9.0 hr	9.2 hr	9.4 hr	9.6 hr	9.8 hr
1	1	1	2	2	2	2	2	1	1
2	2	3	4	4	5	5	5	5	5
3	6	8	10	11	13	13	13	13	13
4	3	3	4	4	4	4	4	3	3
5	7	8	9	9	9	9	9	9	8
Total (cfs)	19	23	29	30	33	33	33	31	30

Quick TR-55 Version: 5.44 S/N: 1315460004 Page 4
Return Frequency: 2 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B2-HYD.HYD

Composite Hydrograph Summary (cfs)

Subarea Description	10.0 hr	10.3 hr	10.6 hr	11.0 hr	11.5 hr	12.0 hr	12.5 hr	13.0 hr	13.5 hr
1	1	1	1	1	1	1	1	1	1
2	5	5	4	4	4	4	4	4	4
3	12	12	11	11	11	10	10	10	10
4	3	3	3	3	3	3	3	3	3
5	8	7	7	7	7	7	7	7	7
Total (cfs)	29	28	26	26	26	25	25	25	25

Subarea Description	14.0 hr	15.0 hr	16.0 hr	18.0 hr	22.0 hr
1	1	1	1	1	1
2	4	4	4	4	4
3	10	10	10	10	9
4	3	3	3	3	2
5	7	7	7	7	6
Total (cfs)	25	25	25	25	22

Return Frequency: 2 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B2-HYD.HYD

Time (hrs)	Flow (cfs)	Time (hrs)	Flow (cfs)
7.0	0	10.8	26
7.1	0	10.9	26
7.2	0	11.0	26
7.3	0	11.1	26
7.4	0	11.2	26
7.5	0	11.3	26
7.6	0	11.4	26
7.7	0	11.5	26
7.8	0	11.6	26
7.9	0	11.7	26
8.0	0	11.8	25
8.1	2	11.9	25
8.2	5	12.0	25
8.3	9	12.1	25
8.4	14	12.2	25
8.5	19	12.3	25
8.6	23	12.4	25
8.7	29	12.5	25
8.8	30	12.6	25
8.9	32	12.7	25
9.0	33	12.8	25
9.1	33	12.9	25
9.2	33	13.0	25
9.3	33	13.1	25
9.4	33	13.2	25
9.5	32	13.3	25
9.6	31	13.4	25
9.7	31	13.5	25
9.8	30	13.6	25
9.9	30	13.7	25
10.0	29	13.8	25
10.1	29	13.9	25
10.2	28	14.0	25
10.3	28	14.1	25
10.4	27	14.2	25
10.5	27	14.3	25
10.6	26	14.4	25
10.7	26	14.5	25

Return Frequency: 2 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B2-HYD.HYD

Time (hrs)	Flow (cfs)	Time (hrs)	Flow (cfs)
14.6	25	18.4	25
14.7	25	18.5	25
14.8	25	18.6	25
14.9	25	18.7	24
15.0	25	18.8	24
15.1	25	18.9	24
15.2	25	19.0	24
15.3	25	19.1	24
15.4	25	19.2	24
15.5	25	19.3	24
15.6	25	19.4	24
15.7	25	19.5	24
15.8	25	19.6	24
15.9	25	19.7	24
16.0	25	19.8	24
16.1	25	19.9	24
16.2	25	20.0	24
16.3	25	20.1	23
16.4	25	20.2	23
16.5	25	20.3	23
16.6	25	20.4	23
16.7	25	20.5	23
16.8	25	20.6	23
16.9	25	20.7	23
17.0	25	20.8	23
17.1	25	20.9	23
17.2	25	21.0	23
17.3	25	21.1	23
17.4	25	21.2	23
17.5	25	21.3	23
17.6	25	21.4	22
17.7	25	21.5	22
17.8	25	21.6	22
17.9	25	21.7	22
18.0	25	21.8	22
18.1	25	21.9	22
18.2	25		
18.3	25		

Return Frequency: 5 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B5-HYD.HYD

>>>> Input Parameters Used to Compute Hydrograph <<<<

Subarea Description	AREA (acres)	CN	Tc (hrs)	* Tt (hrs)	Precip. (in)	Runoff (in)	Ia/p input	Ia/p used
1	39.70	73.0	0.75	0.00	2.80	0.74	.26	.30
2	140.90	73.0	1.00	0.00	2.80	0.74	.26	.30
3	350.80	73.0	1.00	0.00	2.80	0.74	.26	.30
4	94.50	73.0	0.75	0.00	2.80	0.74	.26	.30
5	270.30	71.0	0.75	0.00	2.80	0.65	.29	.30

* Travel time from subarea outfall to composite watershed outfall point.
Total area = 896.20 acres or 1.4003 sq.mi
Peak discharge = 53 cfs

>>>> Computer Modifications of Input Parameters <<<<<

Subarea Description	Input Values Tc (hr)	Input Values * Tt (hr)	Rounded Values Tc (hr)	Rounded Values * Tt (hr)	Ia/p Interpolated (Yes/No)	Ia/p Messages
1	0.82	0.00	0.75	0.00	No	--
2	0.92	0.00	1.00	0.00	No	--
3	0.92	0.00	1.00	0.00	No	--
4	0.77	0.00	0.75	0.00	No	--
5	0.67	0.00	0.75	0.00	No	--

* Travel time from subarea outfall to composite watershed outfall point.

Return Frequency: 5 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B5-HYD.HYD

>>>> Summary of Subarea Times to Peak <<<<

Subarea	Peak Discharge at Composite Outfall (cfs)	Time to Peak at Composite Outfall (hrs)
1	3	8.8
2	9	9.2
3	21	9.0
4	6	8.7
5	15	8.7
Composite Watershed	53	9.0

Return Frequency: 5 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B5-HYD.HYD

Composite Hydrograph Summary (cfs)

Subarea Description	7.0 hr	7.3 hr	7.6 hr	7.9 hr	8.0 hr	8.1 hr	8.2 hr	8.3 hr	8.4 hr
1	0	0	0	0	0	0	0	1	1
2	0	0	0	0	0	0	1	2	3
3	0	0	0	0	0	1	2	4	6
4	0	0	0	0	0	0	1	2	3
5	0	0	0	0	1	1	3	5	8
Total (cfs)	0	0	0	0	1	2	7	14	21

Subarea Description	8.5 hr	8.6 hr	8.7 hr	8.8 hr	9.0 hr	9.2 hr	9.4 hr	9.6 hr	9.8 hr
1	2	2	2	3	3	2	2	2	2
2	4	5	6	7	8	9	8	8	8
3	9	13	15	18	21	21	21	21	20
4	4	5	6	6	6	6	6	6	5
5	11	13	15	15	15	15	15	14	13
Total (cfs)	30	38	44	49	53	53	52	51	48

Return Frequency: 5 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B5-HYD.HYD

Composite Hydrograph Summary (cfs)

Subarea Description	10.0 hr	10.3 hr	10.6 hr	11.0 hr	11.5 hr	12.0 hr	12.5 hr	13.0 hr	13.5 hr
1	2	2	2	2	2	2	2	2	2
2	8	7	7	7	7	7	7	7	7
3	19	19	18	17	17	17	16	16	16
4	5	5	5	5	5	4	4	4	4
5	13	12	12	12	12	11	11	11	11
Total (cfs)	47	45	44	43	43	41	40	40	40

Subarea Description	14.0 hr	15.0 hr	16.0 hr	18.0 hr	22.0 hr
1	2	2	2	2	2
2	7	7	7	6	6
3	16	16	16	16	14
4	4	4	4	4	4
5	11	11	11	11	9
Total (cfs)	40	40	40	39	35

Return Frequency: 5 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B5-HYD.HYD

Time (hrs)	Flow (cfs)	Time (hrs)	Flow (cfs)
7.0	0	10.8	44
7.1	0	10.9	43
7.2	0	11.0	43
7.3	0	11.1	43
7.4	0	11.2	43
7.5	0	11.3	43
7.6	0	11.4	43
7.7	0	11.5	43
7.8	0	11.6	43
7.9	0	11.7	42
8.0	1	11.8	42
8.1	2	11.9	41
8.2	7	12.0	41
8.3	14	12.1	41
8.4	21	12.2	41
8.5	30	12.3	40
8.6	38	12.4	40
8.7	44	12.5	40
8.8	49	12.6	40
8.9	51	12.7	40
9.0	53	12.8	40
9.1	53	12.9	40
9.2	53	13.0	40
9.3	53	13.1	40
9.4	52	13.2	40
9.5	52	13.3	40
9.6	51	13.4	40
9.7	50	13.5	40
9.8	48	13.6	40
9.9	48	13.7	40
10.0	47	13.8	40
10.1	46	13.9	40
10.2	46	14.0	40
10.3	45	14.1	40
10.4	45	14.2	40
10.5	44	14.3	40
10.6	44	14.4	40
10.7	44	14.5	40

Return Frequency: 5 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B5-HYD.HYD

Time (hrs)	Flow (cfs)	Time (hrs)	Flow (cfs)
14.6	40	18.4	39
14.7	40	18.5	39
14.8	40	18.6	38
14.9	40	18.7	38
15.0	40	18.8	38
15.1	40	18.9	38
15.2	40	19.0	38
15.3	40	19.1	38
15.4	40	19.2	38
15.5	40	19.3	38
15.6	40	19.4	38
15.7	40	19.5	38
15.8	40	19.6	37
15.9	40	19.7	37
16.0	40	19.8	37
16.1	40	19.9	37
16.2	40	20.0	37
16.3	40	20.1	37
16.4	40	20.2	37
16.5	40	20.3	37
16.6	40	20.4	37
16.7	40	20.5	37
16.8	40	20.6	36
16.9	40	20.7	36
17.0	40	20.8	36
17.1	39	20.9	36
17.2	39	21.0	36
17.3	39	21.1	36
17.4	39	21.2	36
17.5	39	21.3	36
17.6	39	21.4	36
17.7	39	21.5	36
17.8	39	21.6	35
17.9	39	21.7	35
18.0	39	21.8	35
18.1	39	21.9	35
18.2	39		
18.3	39		

Return Frequency: 10 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B10-HYD.HYD

>>>> Input Parameters Used to Compute Hydrograph <<<<

Subarea Description	AREA (acres)	CN	Tc (hrs)	* Tt (hrs)	Precip. (in)	Runoff (in)	Ia/p input	Ia/p used
1	39.70	73.0	0.75	0.00	3.40	1.11	.22	.30
2	140.90	73.0	1.00	0.00	3.40	1.11	.22	.30
3	350.80	73.0	1.00	0.00	3.40	1.11	.22	.30
4	94.50	73.0	0.75	0.00	3.40	1.11	.22	.30
5	270.30	71.0	0.75	0.00	3.40	1.00	.24	.30

* Travel time from subarea outfall to composite watershed outfall point.
Total area = 896.20 acres or 1.4003 sq.mi
Peak discharge = 81 cfs

>>>> Computer Modifications of Input Parameters <<<<<

Subarea Description	Input Values Tc (hr)	Input Values * Tt (hr)	Rounded Values Tc (hr)	Rounded Values * Tt (hr)	Ia/p Interpolated (Yes/No)	Ia/p Messages
1	0.82	0.00	0.75	0.00	No	--
2	0.92	0.00	1.00	0.00	No	--
3	0.92	0.00	1.00	0.00	No	--
4	0.77	0.00	0.75	0.00	No	--
5	0.67	0.00	0.75	0.00	No	--

* Travel time from subarea outfall to composite watershed outfall point.

Return Frequency: 10 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B10-HYD.HYD

>>>> Summary of Subarea Times to Peak <<<<

Subarea	Peak Discharge at Composite Outfall (cfs)	Time to Peak at Composite Outfall (hrs)
1	4	8.7
2	13	9.2
3	32	9.2
4	9	8.7
5	24	8.8
Composite Watershed	81	9.2

Return Frequency: 10 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B10-HYD.HYD

Composite Hydrograph Summary (cfs)

Subarea Description	7.0 hr	7.3 hr	7.6 hr	7.9 hr	8.0 hr	8.1 hr	8.2 hr	8.3 hr	8.4 hr
1	0	0	0	0	0	0	1	1	2
2	0	0	0	0	0	0	1	2	4
3	0	0	0	0	1	1	3	6	10
4	0	0	0	0	0	1	2	3	5
5	0	0	0	0	1	2	4	8	12
Total (cfs)	0	0	0	0	2	4	11	20	33

Subarea Description	8.5 hr	8.6 hr	8.7 hr	8.8 hr	9.0 hr	9.2 hr	9.4 hr	9.6 hr	9.8 hr
1	3	3	4	4	4	4	4	4	3
2	6	8	9	11	12	13	13	13	12
3	14	19	23	27	31	32	32	32	30
4	6	8	9	9	9	9	9	8	8
5	16	20	22	24	24	23	22	22	21
Total (cfs)	45	58	67	75	80	81	80	79	74

Return Frequency: 10 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B10-HYD.HYD

Composite Hydrograph Summary (cfs)

Subarea Description	10.0 hr	10.3 hr	10.6 hr	11.0 hr	11.5 hr	12.0 hr	12.5 hr	13.0 hr	13.5 hr
1	3	3	3	3	3	3	3	3	3
2	12	11	11	11	10	10	10	10	10
3	29	28	27	26	26	25	24	24	24
4	8	7	7	7	7	7	7	7	7
5	19	19	19	18	18	17	17	17	17
Total (cfs)	71	68	67	65	64	62	61	61	61

Subarea Description	14.0 hr	15.0 hr	16.0 hr	18.0 hr	22.0 hr
1	3	3	3	3	2
2	10	10	10	10	9
3	24	24	24	24	21
4	7	7	6	6	6
5	17	17	16	16	14
Total (cfs)	61	61	59	59	52

Return Frequency: 10 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B10-HYD.HYD

Time (hrs)	Flow (cfs)	Time (hrs)	Flow (cfs)
7.0	0	10.8	66
7.1	0	10.9	66
7.2	0	11.0	65
7.3	0	11.1	65
7.4	0	11.2	65
7.5	0	11.3	64
7.6	0	11.4	64
7.7	0	11.5	64
7.8	0	11.6	64
7.9	0	11.7	63
8.0	2	11.8	63
8.1	4	11.9	62
8.2	11	12.0	62
8.3	20	12.1	62
8.4	33	12.2	62
8.5	45	12.3	61
8.6	58	12.4	61
8.7	67	12.5	61
8.8	75	12.6	61
8.9	78	12.7	61
9.0	80	12.8	61
9.1	81	12.9	61
9.2	81	13.0	61
9.3	81	13.1	61
9.4	80	13.2	61
9.5	80	13.3	61
9.6	79	13.4	61
9.7	77	13.5	61
9.8	74	13.6	61
9.9	73	13.7	61
10.0	71	13.8	61
10.1	70	13.9	61
10.2	69	14.0	61
10.3	68	14.1	61
10.4	68	14.2	61
10.5	67	14.3	61
10.6	67	14.4	61
10.7	67	14.5	61

Return Frequency: 10 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B10-HYD.HYD

Time (hrs)	Flow (cfs)	Time (hrs)	Flow (cfs)
14.6	61	18.4	58
14.7	61	18.5	58
14.8	61	18.6	58
14.9	61	18.7	58
15.0	61	18.8	58
15.1	61	18.9	57
15.2	61	19.0	57
15.3	60	19.1	57
15.4	60	19.2	57
15.5	60	19.3	57
15.6	60	19.4	57
15.7	60	19.5	56
15.8	59	19.6	56
15.9	59	19.7	56
16.0	59	19.8	56
16.1	59	19.9	56
16.2	59	20.0	56
16.3	59	20.1	55
16.4	59	20.2	55
16.5	59	20.3	55
16.6	59	20.4	55
16.7	59	20.5	55
16.8	59	20.6	54
16.9	59	20.7	54
17.0	59	20.8	54
17.1	59	20.9	54
17.2	59	21.0	54
17.3	59	21.1	54
17.4	59	21.2	53
17.5	59	21.3	53
17.6	59	21.4	53
17.7	59	21.5	53
17.8	59	21.6	53
17.9	59	21.7	53
18.0	59	21.8	52
18.1	59	21.9	52
18.2	59		
18.3	58		

Return Frequency: 100 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B100-HYD.HYD

>>>> Input Parameters Used to Compute Hydrograph <<<<

Subarea Description	AREA (acres)	CN	Tc (hrs)	* Tt (hrs)	Precip. (in)	Runoff (in)	Ia/p input	Ia/p used
1	39.70	73.0	0.75	0.00	4.80	2.12	.15	.10
2	140.90	73.0	1.00	0.00	4.80	2.12	.15	.10
3	350.80	73.0	1.00	0.00	4.80	2.12	.15	.10
4	94.50	73.0	0.75	0.00	4.80	2.12	.15	.10
5	270.30	71.0	0.75	0.00	4.80	1.97	.17	.10

* Travel time from subarea outfall to composite watershed outfall point.
Total area = 896.20 acres or 1.4003 sq.mi
Peak discharge = 319 cfs

>>>> Computer Modifications of Input Parameters <<<<<

Subarea Description	Input Values Tc (hr)	Input Values * Tt (hr)	Rounded Values Tc (hr)	Rounded Values * Tt (hr)	Ia/p Interpolated (Yes/No)	Ia/p Messages
1	0.82	0.00	0.75	0.00	No	--
2	0.92	0.00	1.00	0.00	No	--
3	0.92	0.00	1.00	0.00	No	--
4	0.77	0.00	0.75	0.00	No	--
5	0.67	0.00	0.75	0.00	No	--

* Travel time from subarea outfall to composite watershed outfall point.

Return Frequency: 100 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B100-HYD.HYD

>>>> Summary of Subarea Times to Peak <<<<

Subarea	Peak Discharge at Composite Outfall (cfs)	Time to Peak at Composite Outfall (hrs)
1	15	8.5
2	50	8.8
3	125	8.8
4	37	8.6
5	97	8.6
Composite Watershed	319	8.7

Return Frequency: 100 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B100-HYD.HYD

Composite Hydrograph Summary (cfs)

Subarea Description	7.0 hr	7.3 hr	7.6 hr	7.9 hr	8.0 hr	8.1 hr	8.2 hr	8.3 hr	8.4 hr
1	3	3	4	5	6	7	9	11	14
2	9	11	12	15	17	20	24	29	35
3	22	27	30	38	43	50	60	73	88
4	7	8	9	12	14	18	22	27	32
5	18	21	24	32	37	47	59	72	86
Total (cfs)	59	70	79	102	117	142	174	212	255

Subarea Description	8.5 hr	8.6 hr	8.7 hr	8.8 hr	9.0 hr	9.2 hr	9.4 hr	9.6 hr	9.8 hr
1	15	15	15	15	12	11	9	9	8
2	41	45	49	50	48	42	38	34	30
3	102	113	121	125	119	106	94	84	76
4	36	37	37	35	30	25	23	20	18
5	95	97	97	92	79	67	60	54	48
Total (cfs)	289	307	319	317	288	251	224	201	180

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B100-HYD.HYD

Composite Hydrograph Summary (cfs)

Subarea Description	10.0 hr	10.3 hr	10.6 hr	11.0 hr	11.5 hr	12.0 hr	12.5 hr	13.0 hr	13.5 hr
1	7	6	6	5	5	5	4	4	4
2	28	24	22	20	19	18	16	15	15
3	69	60	56	50	46	44	40	38	38
4	17	15	14	13	12	11	10	10	10
5	44	40	37	34	32	30	27	27	27
Total (cfs)	165	145	135	122	114	108	97	94	94

Subarea Description	14.0 hr	15.0 hr	16.0 hr	18.0 hr	22.0 hr
1	4	4	4	4	3
2	15	14	14	13	11
3	37	36	35	33	27
4	10	9	9	8	7
5	27	25	24	22	18
Total (cfs)	93	88	86	80	66

Return Frequency: 100 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B100-HYD.HYD

Time (hrs)	Flow (cfs)	Time (hrs)	Flow (cfs)
7.0	59	10.8	129
7.1	63	10.9	125
7.2	66	11.0	122
7.3	70	11.1	120
7.4	73	11.2	119
7.5	76	11.3	117
7.6	79	11.4	116
7.7	87	11.5	114
7.8	94	11.6	113
7.9	102	11.7	112
8.0	117	11.8	110
8.1	142	11.9	109
8.2	174	12.0	108
8.3	212	12.1	106
8.4	255	12.2	104
8.5	289	12.3	101
8.6	307	12.4	99
8.7	319	12.5	97
8.8	317	12.6	96
8.9	303	12.7	96
9.0	288	12.8	95
9.1	269	12.9	95
9.2	251	13.0	94
9.3	237	13.1	94
9.4	224	13.2	94
9.5	213	13.3	94
9.6	201	13.4	94
9.7	190	13.5	94
9.8	180	13.6	94
9.9	173	13.7	94
10.0	165	13.8	93
10.1	158	13.9	93
10.2	152	14.0	93
10.3	145	14.1	93
10.4	142	14.2	92
10.5	138	14.3	92
10.6	135	14.4	91
10.7	132	14.5	91

Return Frequency: 100 years

TR-55 TABULAR HYDROGRAPH METHOD
Type IA. Distribution
(24 hr. Duration Storm)

Executed: 07-14-1993 14:33:45
Watershed file: --> BB1 .MOP
Hydrograph file: --> B100-HYD.HYD

Time (hrs)	Flow (cfs)	Time (hrs)	Flow (cfs)
14.6	90	18.4	79
14.7	90	18.5	78
14.8	89	18.6	78
14.9	89	18.7	78
15.0	88	18.8	77
15.1	88	18.9	77
15.2	88	19.0	77
15.3	87	19.1	76
15.4	87	19.2	76
15.5	87	19.3	75
15.6	87	19.4	75
15.7	87	19.5	75
15.8	86	19.6	74
15.9	86	19.7	74
16.0	86	19.8	74
16.1	86	19.9	73
16.2	85	20.0	73
16.3	85	20.1	73
16.4	85	20.2	72
16.5	85	20.3	72
16.6	84	20.4	72
16.7	84	20.5	71
16.8	84	20.6	71
16.9	83	20.7	71
17.0	83	20.8	70
17.1	83	20.9	70
17.2	82	21.0	70
17.3	82	21.1	69
17.4	82	21.2	69
17.5	82	21.3	68
17.6	81	21.4	68
17.7	81	21.5	68
17.8	81	21.6	67
17.9	80	21.7	67
18.0	80	21.8	67
18.1	80	21.9	66
18.2	79		
18.3	79		

Appendix 3

Soil Survey Information

United States Department of Agriculture

Soil Conservation Service

In Cooperation with United States Department of Agriculture Forest Service and Oregon Agricultural Experiment Station

Soil Survey of Multnomah County, Oregon

TABLE 24.--SOIL AND WATER FEATURES

[The definitions of "flooding" and "water table" in the Glossary explain terms such as "rare," "brief," "apparent," and "perched." The symbol < means less than; > means more than. Absence of an entry indicates that the feature is not a concern]

Soil name and map symbol	Hydro-logic group	Flooding			High water table			Bedrock		Potential frost action	Risk of corrosion	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hardness		Uncoated steel	Concrete
					Ft			In				
1A, 1B Aloha	C	None	---	---	1.5-2.0	Perched	Dec-Apr	>60	---	---	High	Moderate.
2A*:												
Aloha	C	None	---	---	1.5-2.0	Perched	Dec-Apr	>60	---	---	High	Moderate.
Urban land.												
3D, 3E, 3F Aschoff	B	None	---	---	>6.0	---	---	>60	---	---	Moderate	Moderate.
4F*:												
Aschoff	B	None	---	---	>6.0	---	---	>60	---	---	Moderate	Moderate.
Rock outcrop.												
Wahkeena	B	None	---	---	>6.0	---	---	>60	---	---	Moderate	Low.
5B, 5C, 5D, 5E, 5F Bull Run	B	None	---	---	>6.0	---	---	>60	---	---	High	Moderate.
6B, 6C Burlington	A	None	---	---	>6.0	---	---	>60	---	---	Low	Low.
7B, 7C, 7D, 7E Cascade	C	None	---	---	1.5-2.5	Perched	Dec-Apr	>60	---	---	High	Moderate.
8B*, 8C*, 8D*:												
Cascade	C	None	---	---	1.5-2.5	Perched	Dec-Apr	>60	---	---	High	Moderate.
Urban land.												
9B, 9C, 9D, 9E Cazadero	C	None	---	---	>6.0	---	---	>60	---	---	High	Moderate.
10B, 10C, 10D Cornelius	C	None	---	---	2.5-4.0	Perched	Dec-Apr	>60	---	---	High	Moderate.
11B*, 11C*:												
Cornelius	C	None	---	---	2.5-4.0	Perched	Dec-Apr	>60	---	---	High	Moderate.
Urban land.												

See footnotes at end of table.

TABLE 24.--SOIL AND WATER FEATURES--Continued

Soil name and map symbol	Hydro-logic group	Flooding			High water table			Bedrock		Potential frost action	Risk of corrosion	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hardness		Uncoated steel	Concrete
					Ft			In				
12*. Cryofibrists nearly level												
13---------------- Dabney	A	None---------	---	---	>6.0	---	---	>60	---	---	Low-------	High.
14C**------------- Delena	D	None---------	---	---	+1-1.5	Perched	Dec-May	>60	---	---	High------	Moderate.
15---------------- Faloma	B/D	Frequent-----	Long-------	May-Jun	0-1.0	Apparent	Dec-Jun	>60	---	---	High------	Moderate.
16---------------- Faloma	B/D	Protected----	---	---	0-1.0	Apparent	Dec-Jun	>60	---	---	High------	Moderate.
17C, 17D, 17E----- Goble	C	None---------	---	---	2.5-4.0	Perched	Dec-Apr	>60	---	---	High------	High.
18C*, 18D*: Goble-------------	C	None---------	---	---	2.5-4.0	Perched	Dec-Apr	>60	---	---	High------	High.
Urban land.												
19E*. Haploxerolls												
20C*, 20F*. Haplumbrepts												
21B--------------- Helvetia	C	None---------	---	---	3.0-6.0	Perched	Dec-Mar	>60	---	---	High------	Moderate.
22D*, 22E*: Kinzel------------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High------	High.
Divers------------	B	None---------	---	---	>6.0	---	---	>60	---	Low-------	Moderate	Moderate.
Goodlow-----------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High------	High.
23F*: Kinzel------------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High------	High.
Lastance----------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High------	High.
Rubble land.												

See footnotes at end of table.

TABLE 24.--SOIL AND WATER FEATURES--Continued

Soil name and map symbol	Hydro-logic group	Flooding			High water table			Bedrock		Potential frost action	Risk of corrosion	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hardness		Uncoated steel	Concrete
					Ft			In				
36A, 36B, 36C------ Quafeno	C	None---------	---	---	2.0-3.0	Apparent	Dec-Apr	>60	---	---	Moderate	Low.
37A, 37B, 37C, 37D-------------- Quatama	C	None---------	---	---	2.0-3.0	Apparent	Dec-Apr	>60	---	---	Moderate	Moderate.
38A*:												
Quatama----------	C	None---------	---	---	2.0-3.0	Apparent	Dec-Apr	>60	---	---	Moderate	Moderate.
Urban land.												
39---------------- Rafton	C/D	Frequent----	Long------	Dec-Jun	0-1.0	Apparent	Dec-Jul	>60	---	---	High-----	Moderate.
40**-------------- Rafton	C/D	Protected---	---	---	+2-1.0	Apparent	Dec-Apr	>60	---	---	High-----	Moderate.
41*. Riverwash												
42F*:												
Rock outcrop.												
Rubble land.												
43C, 43E---------- Saum	C	None---------	---	---	>6.0	---	---	40-60	Hard	---	Moderate	Moderate.
44---------------- Sauvie	C/D	Frequent----	Long------	Dec-Jun	0-1.0	Apparent	May-Jun	>60	---	---	Moderate	Moderate.
45, 46------------ Sauvie	C/D	Protected---	---	---	>6.0	---	---	>60	---	---	High-----	Moderate.
47A*:												
Sauvie-----------	C/D	None---------	---	---	0-1.0	Apparent	May-Jun	>60	---	---	Moderate	Moderate.
Rafton-----------	C/D	None---------	---	---	0-1.0	Apparent	Dec-Jul	>60	---	---	High-----	Moderate.
Urban land.												
48---------------- Sifton	B	Occasional	Brief-----	Dec-Jun	>6.0	---	---	>60	---	---	---	---
49D*, 49E*:												
Talapus----------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High-----	High.

See footnotes at end of table.

TABLE 24.--SOIL AND WATER FEATURES--Continued

Soil name and map symbol	Hydro- logic group	Flooding			High water table			Bedrock		Potential frost action	Risk of corrosion	
		Frequency	Duration	Months	Depth	Kind	Months	Depth	Hardness		Uncoated steel	Concrete
					Ft			In				
49D*, 49E*:												
Lastance----------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High-----	High.
50A*, 50C*.												
Urban land												
51A*, 51B*, 51C*, 51D*:												
Urban land.												
Latourell--------	B	None---------	---	---	>6.0	---	---	>60	---	---	Moderate	Moderate.
52A*, 52B*, 52C*:												
Urban land.												
Multnomah---------	B	None---------	---	---	>6.0	---	---	>60	---	---	High-----	Moderate.
53A*, 53B*, 53C*:												
Urban land.												
Quafeno-----------	C	None---------	---	---	2.0-3.0	Apparent	Dec-Apr	>60	---	---	Moderate	Low.
54B*, 54C*:												
Urban land.												
Quatama-----------	C	None---------	---	---	2.0-3.0	Apparent	Dec-Apr	>60	---	---	Moderate	Moderate.
55----------------- Wapato	D	Frequent----	Brief-----	Dec-Apr	0-1.0	Apparent	Dec-Apr	>60	---	---	High-----	Moderate.
56E---------------- Wauld	B	None---------	---	---	>6.0	---	---	20-40	Hard	---	Moderate	Low.
57**--------------- Wollent	D	None---------	---	---	+1-1.0	Perched	Nov-May	>60	---	---	High-----	Moderate.
58D, 58E----------- Zygore	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High-----	Moderate.
59F*:												
Zygore------------	B	None---------	---	---	>6.0	---	---	>60	---	Moderate	High-----	Moderate.
Rock outcrop.												

* See description of the map unit for composition and behavior characteristics of the map unit.

** Plus sign under "High water table--Depth" indicates ponding.

of the potential for wildlife habitat depends on the management of existing plant communities.

This soil has severe limitations for homesites and other urban uses because of slopes of 60 to 80 percent. Slumping occurs in areas of cut and fill, and additional maintenance is required for banks, roads, and building foundations. Irrigation during summer is desirable for best results with lawn grasses, shade trees, ornamental trees, vines, and shrubs. Soil washing on disturbed areas can be controlled with cover crops. Mulching and fertilizing help establish plants in disturbed areas. Plants that tolerate droughty conditions should be selected if irrigation is not provided. Development is limited in some areas by the wet, cold climate during winter.

This soil is in capability subclass VIIe.

6B—Burlington fine sandy loam, 0 to 8 percent slopes. This somewhat excessively drained soil is on terraces along the lower Columbia River and its tributaries. This soil formed in alluvium that has been re-worked by wind to form rolling dunelike topography. Elevation is 20 to 50 feet. The average annual precipitation is 40 to 65 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is very dark grayish brown and dark brown fine sandy loam about 12 inches thick. The substratum is dark brown and dark yellowish brown loamy fine sand to a depth of 60 inches or more.

Included with this soil in mapping and making up as much as 5 percent of the map unit are areas of Sauvie, Quafeno, and Latourell soils. Also included and making up as much as 10 percent are areas that are mapped as Burlington soils, but they do not have a dark colored surface layer. These areas are in T. 1 N., R. 4 E., and on larger islands in the Columbia River.

Permeability is rapid. Effective rooting depth is 60 inches or more. Available water capacity is 7 to 8 inches. Water-supplying capacity is 17 to 20 inches. Runoff is slow, and the hazard of erosion is slight.

This soil is used for farming, nursery crops, urban development, and wildlife habitat.

The vegetation in areas not cultivated is Douglas-fir, Oregon white oak, western redcedar, bigleaf maple, western hazel, common snowberry, tall Oregon-grape, creambush oceanspray, roses, willow, trailing blackberry, brackenfern, forbs, and grasses.

This soil is well suited to farming. If this soil is irrigated, most climatically adapted crops do well. The major crops are nursery stock, vegetables, berries, hay, and pasture. Returning all crop residue to the soil and including grasses, legumes, or grass-legume mixtures in the cropping system help maintain fertility and tilth. If the soil is to be left bare over winter, it should be fertilized and planted to a cover crop in fall. Limiting tillage to seedbed preparation and weed control helps control blowing. A cloddy condition helps protect the soil from erosion during windy periods. Grain and grass crops respond to nitrogen. Legumes respond to phosphorus, potassium, sulfur, and lime and in places, to boron. Sprinkler irrigation helps increase crop production in dry periods in summer. Irrigation water needs to be applied carefully at rates low enough to prevent runoff.

A variety of grasses, vegetables, fruits, and nursery crops along with shrubs and trees is grown on this soil. This variety of plants furnish good food and cover for ring-necked pheasant, California quail, and mourning dove. Other common wildlife species are a few black-tailed deer, foxes, skunks, oppossum, rabbits, and mice. Birdlife includes hawks, owls, vultures, jays, crows, woodpeckers, flycatchers, shore birds, blackbirds, larks, starlings, and many kinds of small birds. Where this soil is adjacent to bodies of water, it provides food and habitat for numerous waterfowl. The potential for wildlife habitat is good. Planting desirable vegetation and protecting and managing existing vegetation improve the habitat.

This soil has no major limitations for urban development. Cut banks and other excavations are not stable and are subject to slumping. Soil blowing is a concern in disturbed areas in places but can be controlled by mulching. Septic tank absorption fields contaminate adjacent water sources in places because of the rapid permeability. Irrigation during summer is required for best results with lawn grasses, shrubs, vines, shade trees, and ornamental trees. Establishing plants in disturbed areas is difficult. Mulching, fertilizing, and irrigating help to establish plants.

This soil is in capability subclass IIe.

6C—Burlington fine sandy loam, 8 to 15 percent slopes. This somewhat excessively drained soil is on terraces along the lower Columbia River and its tributaries. This soil formed in alluvium. Elevation is 20 to 50 feet. The average annual precipitation is 40 to 65 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is very dark grayish brown and dark brown fine sandy loam about 12 inches thick. The substratum is dark brown and dark yellowish brown loamy fine sand to a depth of 60 inches or more.

Included with this soil in mapping and making up as much as 5 percent of the mapped areas are Sauvie, Quafeno, and Latourell soils. Also included and making up as much as 10 percent are areas of Burlington soils that have a surface layer of loamy fine sand which is not dark colored. These areas are in T. 1 N., R. 4 E., and on larger islands in the Columbia River.

Permability is rapid. Effective rooting depth is 60 inches or more. Available water capacity is 7 to 8 inches. Water-supplying capacity is 17 to 20 inches. Runoff is medium, and the hazard of erosion is moderate.

This soil is used for farming, nursery crops, urban development, and wildlife habitat.

This soil is well suited to farming. If this soil is irrigated, most climatically adapted crops do well. The major and the resultant perched water table from December through April. Some windthrow of trees is possible because of restricted rooting depth. When the soil is wet, the use of some conventional logging systems is limited. Roads and landings can be protected from erosion by constructing water bars and by seeding cuts and fills. All-season roads on this soil need a heavy base of rock.

This soil is along a fringe area that is transitional from valley to forested hills. Openland and woodland are almost equal in extent. A wide variety of grain and grasses along with shrubs and trees furnish good food and cover for wildlife. Resident and seasonal wildlife in areas of this soil include black-tailed deer, Roosevelt elk, black bear, coyote, bobcat, raccoon, skunks, foxes, opossum, rabbits, squirrels, mice, moles, and gophers. Common birds are hawks, owls, jays, ravens, crows, vultures, woodpeckers, insect eaters, mourning doves, band-tailed pigeon, ruffed grouse, blue grouse, mountain quail, California quail, ring-necked pheasant, and many kinds of small birds. Potential is good for building ponds for fish and wildlife on this soil. Ponds have been built, and fish production generally is good in these ponds. Most of the potential for wildlife habitat depends on the management of existing plant communities, but some potential depends on growing desirable vegetation.

Increased population growth has resulted in increased homesite construction on this soil. The main limitations for urban development are the seasonal water table, slow permeability, and a fragipan at a depth of 20 to 30 inches. Dwellings and roads must be designed to offset these limitations. Excavation during summer is difficult because of the strongly compacted fragipan. A seasonal water table is perched on top of the fragipan and requires drainage for best results with basements and crawl spaces. Septic tank absorption fields do not function properly during rainy periods because of wetness and slow permeability. Drainage is required for best results with lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables, and irrigation during summer is desirable. Recreational uses are limited by the seasonal high water table. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass IIIw.

7C—Cascade silt loam, 8 to 15 percent slopes. This somewhat poorly drained soil is on convex side slopes of broad, rolling ridgetops. This soil formed in silty materials. Elevation is 250 to 1,400 feet. The average annual precipitation is 50 to 60 inches, the average annual air temperature is 50 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark brown silt loam about 8 inches thick. The subsoil is dark brown silt loam about 19 inches thick. The substratum is a dark brown, mottled, silt loam fragipan to a depth of 60 inches or more.

Included with this soil in mapping are areas of Goble and Cornelius soils and other Cascade soils. The included soils make up as much as 10 percent of this unit. Also included in Tps. 1 N. and 1 S., R. 1 E., are areas of Cascade soils, but in places these soils have basalt bedrock at a depth of 40 to 60 inches.

Permeability is slow. Effective rooting depth is 20 to 30 inches. Available water capacity is 5 to 7.5 inches. Water-supplying capacity is 17 to 19 inches. Runoff is medium, and the hazard of erosion is moderate. A water table is at a depth of 18 to 30 inches from December through April.

This soil is used for farming, timber production, urban development, and wildlife habitat.

This soil is suited to farming. If this soil is drained, most climatically adapted crops do well. The major crops are grain, berries, vegetables, nursery stock, hay, and pasture. Irrigation during summer is required for maximum production of most crops. Returning all crop residue to the soil and including grasses, legumes, or grass-legume mixtures in the cropping system help maintain fertility and tilth. If the soil is to be left bare during winter, it should be fertilized and planted to a cover crop in fall. Grassed waterways help control erosion in drainageways. Limiting tillage to seedbed preparation and weed control helps to control runoff and erosion. A cloddy condition helps protect the soil from erosion during rainy periods.

Excessive cultivation can result in formation of a tillage pan in this soil. Subsoiling is required to break up this pan and is more successful if done when the soil is dry than when wet.

The soil has a perched water table in winter and early in spring. Tile systems are difficult to install because of shallow depth to the hardpan. Tile systems are installed across the slope to intercept ground water. Subsoiling should be across the tile lines. Sprinkler irrigation can be used to increase crop production in dry periods in summer. Water needs to be applied slowly to prevent runoff. Grain and grass crops respond to nitrogen. Legumes respond to phosphorus, potassium, sulfur, and lime and in places, to boron. Berries respond to nitrogen, phosphorus, potassium, and sulfur and in places, to boron.

The vegetation in areas not cultivated is Douglas-fir, western redcedar, red alder, grand fir, western hemlock, bigleaf maple, willow, Pacific dogwood, wild cherry, western hazel, thimbleberry, salal, vine maple, trailing blackberry, Cascade Oregon-grape, swordfern, common snowberry, roses, forbs, and grasses.

This soil is suited to Douglas-fir. The site index for Douglas-fir on this soil ranges from 150 to 165. Based on a site index of 157, this soil is capable of producing about 10,720 cubic feet from a fully stocked stand of 70-year old trees, or 63,280 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 80-year old trees. Brushy species, including salal, Cascade Oregon-grape, and common snowberry, restrict natural regeneration of Douglas-fir.

The main limitations to timber production are the slowly permeable fragipan at a depth of 20 to 30 inches and the resultant perched water table from December through April. Some windthrow of trees is possible because of restricted rooting depth. When the soil is wet, the use of some conventional logging methods is limited. Roads and landings can be protected from erosion by constructing water bars and by seeding cuts and fills. All-season roads on this soil need a heavy base of rock.

This soil is along a fringe area that is transitional from valley to forested hills. Openland and woodland are almost equal in extent. A wide variety of grain and grasses along with shrubs and trees furnish good food and cover for wildlife.

Resident and seasonal wildlife in areas of this soil include black-tailed deer, Roosevelt elk, black bear, coyote, bobcat, raccoon, skunks, foxes, oppossum, rabbits, squirrels, mice, moles, and gophers. Common birds are hawks, owls, jays, ravens, crows, vultures, woodpeckers, insect eaters, mourning dove, band-tailed pigeon, ruffed grouse, blue grouse, mountain quail, California quail, ring-necked pheasant, and many kinds of small birds. Potential is good for building ponds for fish and wildlife on this soil. Ponds have been built, and fish production is generally good in these ponds. Most of the potential for wildlife habitat depends on the management of existing plant communities, but some potential depends on growing desirable vegetation.

Increased population growth has resulted in increased homesite construction on this soil (fig. 6). The main limitations for urban development are the seasonal high water table, slow permeability, low strength, a fragipan at a depth of 20 to 30 inches, and slopes of 8 to 15 percent. Dwellings and roads need to be designed to offset these limitations. Excavating during summer is difficult because of the strongly compacted fragipan. A seasonal water table is perched on top of the fragipan and requires drainage for best results with basements and crawl spaces. Septic tank absorption fields do not function properly during rainy periods because of wetness and slow permeability. Drainage is required for best results with lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables, and irrigation during summer is desirable. Recreational uses are limited by slope and a seasonal high water table. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass IIIe.

7D—Cascade silt loam, 15 to 30 percent slopes. This somewhat poorly drained soil is on convex side slopes of broad, rolling ridgetops. This soil formed in silty materials. Elevation is 250 to 1,400 feet. The average annual precipitation is 50 to 60 inches, the average annual air temperature is 50 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark brown silt loam about 8 inches thick. The subsoil is dark brown silt loam about 19 inches thick. The substratum is a dark brown, mottled, silt loam fragipan to a depth of 60 inches or more.

Figure 6.—Homesites on Cascade silt loam.

Included with this soil in mapping are areas of Goble and Cornelius soils and other Cascade soils. The included soils make up as much as 15 percent of this map unit. Also included in Tps. 1 N. and 1 S., R. 1E., are areas of Cascade soils, but in places these soils have basalt bedrock at a depth of 40 to 60 inches.

Permeability is slow. Effective rooting depth is 20 to 30 inches. Available water capacity is 5 to 7.5 inches. Water-supplying capacity is 17 to 19 inches. Runoff is medium, and the hazard of erosion is high. A water table is at a depth of 18 to 30 inches from December through April.

This soil is used for farming, timber production, urban development, and wildlife habitat.

The native vegetation is Douglas-fir, western redcedar, red alder, grand fir, western hemlock, bigleaf maple, willow, Pacific dogwood, wild cherry, western hazel, thimbleberry, salal, vine maple, trailing blackberry, Cascade Oregon-grape, roses, swordfern, common snowberry, forbs, and grasses.

This soil is suited to Douglas-fir. The site index for Douglas-fir on this soil ranges from 150 to 165. Based on a site index of 157, this soil is capable of producing about 10,720 cubic feet from a fully stocked stand of 70-year old trees, or 63,280 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 80-year old trees. Brushy species, including salal, Cascade Oregon-grape, and common snowberry, restrict natural regeneration of Douglas-fir.

The main limitations for timber production are the slowly permeable fragipan at a depth of 20 to 30 inches and the resultant perched water table from December through April. Some windthrow of trees is possible because of the restricted rooting depth. When the soil is wet, the use of some conventional logging methods is limited. Roads and landings can be protected from erosion by constructing water bars and by seeding cuts and fills. All-season roads on this soil need a heavy base of rock.

This soil is poorly suited to farming. If this soil is drained, most climatically adapted crops do well. The major crops are grain, hay, and pasture. Irrigation during summer is required for maximum production of most crops. Returning all crop residue to the soil and including grasses, legumes, or grass-legume mixtures in the cropping system help maintain fertility and tilth. Tilling and planting across the slope help reduce runoff and erosion. If the soil is to be left bare over winter, it should be fertilized and planted to a cover crop in fall. Grassed waterways help control erosion in drainageways. Limiting tillage to seedbed preparation and weed control helps control runoff and erosion. A cloddy condition helps protect the soil from erosion during rainy periods.

Excessive cultivation can result in the formation of a tillage pan in this soil. Subsoiling is required to break up this pan and is more successful if done when the soil is dry than when wet. The soil has a perched water table in winter and early in spring. Tile systems are difficult to install because of shallow depth to the hardpan. Tile systems are installed across the slope to intercept ground water. Subsoiling should be across the tile lines. Sprinkler irrigation can be used to increase crop production in dry periods in summer. Water needs to be applied slowly to prevent runoff. Grain and grass crops respond to nitrogen. Legumes respond to phosphorus, potassium, sulfur, and lime and in places, to boron. Berries respond to nitrogen, phosphorus, potassium, and sulfur and in places, to boron.

This soil is along a fringe area that is transitional from valley to forested hills. Openland and woodland are almost equal in extent. A wide variety of grain and grasses along with shrubs and trees furnishes good food and cover for wildlife.

Resident and seasonal wildlife in areas of this soil, include black-tailed deer, Roosevelt elk, black bear, coyote, bobcat, raccoon, skunks, foxes, oppossum, rabbits, squirrels, mice, moles, and gophers. Common birds are hawks, owls, jays, ravens, crows, vultures, woodpeckers, insect eaters, mourning dove, band-tailed pigeon, ruffed grouse, blue grouse, mountain quail, California quail, ring-necked pheasant, and many kinds of small birds. Most of the potential for wildlife habitat depends on the management of existing plant communities, but some potential depends on growing desirable vegetation.

Increased population growth has resulted in increased homesite construction on this soil. The main limitations for urban development are a seasonal high water table, slow permeability, low strength, a fragipan at a depth of 20 to 30 inches, and slopes of 15 to 30 percent. Dwellings and roads need to be designed to offset these limitations. Excavating during summer is difficult because of the strongly compacted fragipan. Slumping is possible in areas of cut and fill, and additional maintenance is required for banks, roads, and building foundations. A seasonal water table is perched on top of the fragipan and requires drainage for best results with basements and crawl spaces. Septic tank absorption fields do not function properly during rainy periods because of wetness, steep slopes, and slow permeability. Drainage is required for best results with lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables, and irrigation during summer is desirable. Recreational uses are limited by the seasonal high water table. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass IVe.

7E—Cascade silt loam, 30 to 60 percent slopes. This steep, somewhat poorly drained soil is on side slopes of broad, rolling ridgetops. This soil formed in silty materials. Elevation is 250 to 1,400 feet. The average annual precipitation is 50 to 60 inches, the average annual air temperature is 50 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark brown silt loam about 8 inches thick. The subsoil is dark brown silt loam about 19 inches thick. The substratum is a dark brown, mottled, silt loam fragipan to a depth of 60 inches or more.

Included with this soil in mapping are areas of Goble, Cornelius, Saum, and Wauld soils and other Cascade soils. The included soils make up as much as 15 percent of this unit. Also included in Tps. 1 N. and 1 S., R 1 E., are areas of Cascade soils, but in places these soils have basalt bedrock at a depth of 40 to 60 inches.

Permeability is slow. Effective rooting depth is 20 to 30 inches. Available water capacity is 5 to 7.5 inches. Water-supplying capacity is 17 to 19 inches. Runoff is rapid, and the hazard of erosion is high. A water table is at a depth of 18 to 30 inches from December through April.

This soil is used for timber production, urban development, and wildlife habitat.

The native vegetation is Douglas-fir, western redcedar, red alder, grand fir, western hemlock, bigleaf maple, willow, Pacific dogwood, wild cherry, western hazel, thimbleberry, salal, vine maple, trailing blackberry, Cascade Oregon-grape, roses, swordfern, common snowberry, forbs, and grasses.

This soil is suited to Douglas-fir. The site index for Douglas-fir on this soil ranges from 150 to 165. Based on a site index of 157, this soil is capable of producing beaver, rabbits, and squirrels. Resident or seasonally abundant birds are hawks, owls, jays, ravens, vultures, woodpeckers, grouse, mountain quail, band-tailed pigeon, and many small birds. Fur-bearing animals such as beaver, mink, and otter are common along larger streams. Most of the potential for wildlife habitat depends on the management of existing plant communities.

This soil has moderate limitations for homesites and other uses. The main limitations for urban development are the seasonal high water table and the slowly permeable fragipan at a depth of 30 to 48 inches. Excavating during summer is difficult because of the strongly compacted fragipan. A seasonal water table is perched on top of the fragipan and requires drainage for best results with basements. Irrigation during summer is desirable for lawn grases, shrubs, vines, vegetables, and most shade and ornamental trees. To establish plants in areas in which the surface layer has been removed and the fragipan exposed is difficult. Mulching and fertilizing cut areas help establish plants. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass VIe.

17D—Goble silt loam, 15 to 30 percent slopes. This moderately well drained soil is on rolling ridgetops. Slopes are convex. This soil formed in silty materials mixed with volcanic ash. Elevation is 200 to 1,600 feet. The average annual precipitation is 60 to 70 inches, the average annual air temperature is 47 to 50 degrees F, and the frost-free period is 120 to 165 days.

Typically, the surface layer is very dark grayish brown silt loam about 14 inches thick. The upper part of the subsoil is dark brown silt loam and silty clay loam about 23 inches thick. The lower part of the subsoil is a mottled, dark yellowish brown, silty clay loam fragipan to a depth of 60 inches or more.

Included with this soil in mapping are areas of Cascade soils and other Goble soils. The included soils make up as much as 15 percent of this map unit. Also included in T. 1 S., R. 1 E., are areas of Goble soils, but these soils have bedrock at a depth of 40 to 60 inches.

Permeability is moderate above the fragipan and slow in the fragipan. Effective rooting depth is 30 to 48 inches. Available water capacity is 8 to 10 inches. Water-supplying capacity is 20 to 22 inches. Runoff is medium, and the hazard of erosion is high. A water table is within a depth of 4 feet from December through April.

This soil is used for timber production, forage crops, urban development, and wildlife habitat.

This soil is poorly suited to farming. The major crops are hay and pasture. Grasses respond to nitrogen. Legumes respond to phosphorus, potassium, sulfur, lime and in places, to boron. Legumes are restricted by the short growing season and cool temperatures.

Vegetation is Douglas-fir, western hemlock, grand fir, western redcedar, red alder, bigleaf maple, red huckleberry, vine maple, western hazel, willow, thimbleberry, Cascade Oregon-grape, trailing blackberry, salal, common snowberry, swordfern, and forbs, including Pacific trillium and violets.

This soil is suited to Douglas-fir. The site index for Douglas-fir on this soil ranges from 145 to 155. Based on a site index of 149 this soil is capable of producing about 9,920 cubic feet from a fully stocked stand of 70-year old trees, or 55,020 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 80-year old trees. Brushy species, including salal, Cascade Oregon-grape, and common snowberry, restrict natural regeneration of Douglas-fir.

The main limitations for timber production are the slowly permeable fragipan at a depth of 30 to 45 inches and the resultant perched water table during December through April. Some windthrow of trees is possible because of the restricted rooting depth. When the soil is wet, the use of some conventional logging methods is limited. Roads and landings can be protected from erosion by constructing water bars and by seeding cuts and fills. All-season roads on this soil need a heavy base of rock.

In the mild, high rainfall areas of the Coast Range Mountains, vegetation grows rapidly on this soil. Vegetational stages change dramatically as a result of clear-cut logging and fires.

The potential for wildlife, especially black-tailed deer, depends upon the clearing of land and on the availability of new growth of trees, shrubs, and grasses. As new forest develops and most of the ground vegetation decreases, the deer population returns to a low level. As the trees grow larger, species such as blue grouse are favored. Habitat commonly is suitable for such species as Roosevelt elk, black bear, coyote, bobcat, skunks, weasels, raccoon, mountain beaver, rabbits, and squirrels. Resident or seasonal abundant birds are hawks, owls, jays, ravens, vultures, woodpeckers, grouse, mountain quail, band-tailed pigeon, and many small birds. Furbearing animals such as beaver, mink, and otter are common along larger streams. Most of the potential for wildlife habitat depends on the management of existing plant communities.

This soil has moderate limitations for homesites and other uses. The main limitations for urban development are the seasonal high water table, slope, low bearing strength, and the slowly permeable fragipan at a depth of 30 to 45 inches. Excavating during summer is difficult because of the strongly compacted fragipan. Slumping is possible in areas of cut and fill, and additional maintenance of banks, roads, and building foundations is required. A seasonal water table is perched on top of the fragipan and drainage is required for best results with basements. Irrigation during summer is required for lawn grasses, shrubs, vines, vegetables, and most shade and ornamental trees. To establish plants in areas in which the surface layer has been removed and the fragipan exposed is difficult. Mulching and fertilizing cut areas help establish plants. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass VIe.

17E—Goble silt loam, 30 to 60 percent slopes. This steep, moderately drained soil is on convex side slopes of ridgetops. This soil formed in silty materials mixed with volcanic ash. Elevation is 200 to 1,600 feet. The average annual precipitation is 60 to 70 inches, the average annual air temperature is 47 to 50 degrees F, and the frost-free period is 120 to 165 days.

Typically, the surface layer is very dark grayish brown silt loam about 14 inches thick. The upper part of the subsoil is dark brown silt loam and silty clay loam about 23 inches thick. The lower part of the subsoil is a mottled, dark yellowish brown, silty clay loam fragipan to a depth of 60 inches or more.

Included with this soil in mapping are areas of Cascade and Wauld soils and other Goble soils. The included soils make up as much as 15 percent of this map unit. Also included in mapping in T. 1 S., R. 1 E., are areas of Goble soils, but these soils have basalt bedrock at a depth of 40 to 60 inches.

Permeability is moderate above the fragipan and slow in the fragipan. Effective rooting depth is 30 to 48 inches. Available water capacity is 8 to 10 inches. Water-supplying capacity is 20 to 22 inches. Runoff is rapid, and the hazard of erosion is high. A water table is within a depth of 4 feet from December through April.

This soil is used for timber production, urban development, and wildlife habitat.

Vegetation is Douglas-fir, western hemlock, grand fir, western redcedar, red alder, bigleaf maple, red huckleberry, western hazel, vine maple, willow, thimbleberry, Cascade Oregon-grape, trailing blackberry, salal, common snowberry, swordfern, and forbs, including Pacific trillium and violets.

This soil is suited to Douglas-fir. The site index for Douglas-fir on this soil ranges from 145 to 155. Based on a site index of 149 this soil is capable of producing about 9,920 cubic feet from a fully stocked stand of 70-year old trees, or 55,020 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 80-year old trees. Brushy species including salal, Cascade Oregon-grape, and common snowberry restrict natural regeneration of Douglas-fir.

The main limitations for timber production are the slowly permeable fragipan at a depth of 30 to 45 inches and the resultant perched water table from December through April. Some windthrow is possible because of the restricted rooting depth. Because of the steep slopes, such logging methods as aerial, high-lead, or skyline should be used for tree harvesting. Roads and landings can be protected from erosion by constructing water bars and by seeding cuts, fills, and skidroads. Slumping occurs on road cuts and requires additional maintenance. All-season roads on this soil need a heavy base of rock.

In the mild, high rainfall areas of the Coast Range Mountains vegetation grows rapidly on this soil. Vegetational stages change dramatically as a result of clear-cut logging and fires.

The potential to produce wildlife, especially black-tailed deer, depends on the clearing of land and on the availability of new growth of trees, shrubs, and grasses. As new forest develops and most of the ground vegetation decreases, the deer population returns to a low level. As the trees grow larger, species such as blue grouse are favored. Suitable habitat is common for species such as Roosevelt elk, black bear, coyote, bobcat, skunks, weasels, raccoon, mountain beaver, rabbits, and squirrels. Resident or seasonally abundant birds are hawks, owls, jays, ravens, vultures, woodpeckers, grouse, mountain quail, band-tailed pigeon, and many small birds. Fur-bearing animals such as beaver, mink, and otter are common along larger streams. Most of the potential for wildlife habitat depends on the management of existing plant communities.

Increased population growth has resulted in increased home construction on this soil. This soil has severe limitations for dwellings and roads because of steep slopes. Other limitations are the seasonal high water table, low bearing strength, and the slowly permeable fragipan at a depth of 30 to 45 inches. Excavating during summer is difficult because of the strongly compacted fragipan. Slumping is possible in areas of cut and fill, and additional maintenance of banks, roads, and building foundations is required. A seasonal water table is perched on top of the fragipan, and drainage is required for best results with basements. Irrigation during summer is desirable for lawn grasses, shrubs, vines, vegetables, and most shade and ornamental trees. To establish plants in areas in which the surface layer has been removed and the fragipan exposed is difficult. Mulching and fertilizing cut areas help establish plants. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass VIe.

18C—Goble-Urban land complex, 3 to 15 percent slopes. This complex consists of moderately well drained Goble soils. In most areas of this complex the soils have been graded, cut, filled, or otherwise disturbed. This complex is on rolling ridgetops. Slopes are convex. Areas are generally irregular in shape and 25 to 100 acres in size. The Goble soils and Urban land are in such an intricate pattern or so small in area that to separate them in mapping was not practical. Elevation is 200 to 1,600 feet. The average annual precipitation is 60 to 70 inches, the average annual air temperature is 47 to 50 degrees F, and the frost-free period is 120 to 165 days.

About 20 percent of this complex are areas of Goble soils that are relatively undisturbed. Typically, the surface layer is very dark grayish brown silt loam about 14 inches thick. The upper part of the subsoil is dark brown silt loam and silty clay loam about 23 inches thick. The lower part of the subsoil is a mottled, dark yellowish brown, silty clay loam fragipan to a depth of 60 inches or more.

About 30 percent of this complex are areas of Goble soils that have been disturbed. These soils have been covered by as much as 30 inches of fill material, or as much as 50 inches of the original profile has been removed by cutting or grading. The fill material is generally from adjacent areas of Goble soils that have been cut or graded.

About 40 percent of this complex is Urban land. The areas are largely covered by concrete, asphalt, buildings, or other impervious surfaces that so obscure or alter the soils that their identification is not feasible.

Included with this complex in mapping are areas of Cascade soils, other Goble soils, and soils that have basalt bedrock at a depth of 40 to 60 inches. The included soils make up as much as 10 percent of this map unit.

In areas where the soils are relatively undisturbed, permeability is moderate above the fragipan and slow in the fragipan, and available water capacity is 8 to 10 inches. In areas dominated by cuts, fills, and Urban land, permeability and available water capacity are variable. Undisturbed areas of Goble soils have a water table within a depth of 30 to 48 inches during December to April. The water table is commonly perched on the fragipan. Runoff is medium, and the hazard of erosion is moderate.

Areas of this complex that have not been disturbed include yards and openland around and between buildings. The main limitations to urban development are the seasonal high water table and the slowly permeable fragipan at a depth of 30 to 48 inches. The seasonal water table on top of the fragipan requires drainage for best results with basements.

Large areas of this map unit are artificially drained by sewer systems, gutters, drainage tiles, and surface ditches. Septic tank absorption fields do not function properly during rainy periods because of wetness and slow permeability. Drainage is required for best results with most lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables. To establish plants in areas in which the surface layer has been removed and the fragipan has been exposed is difficult. Mulching and fertilizing cut areas help establish plants. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This map unit is not assigned to a capability subclass.

18D—Goble-Urban land complex, 15 to 30 percent slopes. This complex consists of moderately well drained Goble soils. In most areas of this complex the soils have been graded, cut, filled, or otherwise disturbed. This complex is on rolling ridgetops. Slopes are convex. Areas are generally irregular in shape and 25 to 100 acres in size. The Goble soils and Urban land are in such an intricate pattern or so small in area that to separate them in mapping was not practical. Elevation is 200 to 1,600 feet. The average annual precipitation is 60 to 70 inches, the average annual air temperature is 47 to 50 degrees F, and the frost-free period is 120 to 165 days.

About 15 percent of this complex are Goble soils that are relatively undisturbed. Typically, the surface layer is very dark grayish brown silt loam about 14 inches thick. The upper part of the subsoil is dark brown silt loam and silty clay loam about 23 inches thick. The lower part of the subsoil is a mottled, dark yellowish brown, silty clay loam fragipan to a depth of 60 inches or more.

About 35 percent of this complex are areas of Goble soils that have been disturbed. These soils have been covered by as much as 30 inches of fill material, or as much as 50 inches of the original profile has been removed by cutting or grading. The fill material is generally from adjacent areas of Goble soils that have been cut or graded.

About 40 percent of the complex is Urban land. The areas are largely covered by concrete, asphalt, buildings, or other impervious surfaces that so obscure or alter the soils that their identification is not feasible.

Included with this complex in mapping are areas of Cascade soils, other Goble soils, and soils that have basalt bedrock at a depth of 40 to 60 inches. The included soils make up as much as 10 percent of this unit.

In areas where the soils are relatively undisturbed, permeability is moderate above the fragipan and slow in the fragipan, and available water capacity is 8 to 10 inches. In areas dominated by cuts, fills, and Urban land, permeability and available water capacity are variable. Undisturbed areas of Goble soils have a water table within a depth of 30 to 48 inches during December to April. The water table is commonly perched on the fragipan. Runoff is medium, and the hazard of erosion is high.

Areas of this complex that have not been disturbed include yards and openland around and between buildings. The main limitations to urban development are the seasonal high water table, slowly permeable fragipan at a depth of 30 to 48 inches and slopes of 15 to 30 percent. Slumping is possible in areas of cut and fill, and additional maintenance of banks, roads, and building foundations is required. The seasonal water table requires drainage for best results with basements.

Large areas of this map unit are artificially drained by sewer systems, gutters, drainage tiles, and surface ditches. Septic tank absorption fields do not function properly during rainy periods because of wetness and slow permeability. Drainage is required for best results with most lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables. To establish plants in areas in which the surface layer has been removed and the fragipan has been exposed is difficult. Mulching and fertilizing cut areas help establish plants. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This map unit is not assigned to a capability subclass.

19E—Haploxerolls, steep. These well drained and moderately well drained soils are on long, narrow escarpments along the small streams that have cut deeply into the valley terraces. They are also on the junction of terraces with bottom lands and flood plains along major streams and rivers. These soils formed in a mixture of silt and sand and in the accumulated material from soil creep downslope. These soils have slopes of 20 to 50 percent. Slopes are short. Elevation is 50 to 400 feet. The average annual precipitation is 40 to 60 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark brown and brown fine sandy loam, sandy loam, silt loam, loam, or silty clay loam 6 to 10 inches thick. The subsoil is dark yellowish brown or brown sandy loam, silt loam, loam, or silty clay loam. It has 0 to 65 percent coarse fragments. The substratum is silty or sandy and yellowish brown or brown and extends to a depth of many feet in places.

Included with these soils in mapping are areas of Latourell, Quafeno, and Quatama soils and soils that have a dark colored surface layer 10 to 15 inches thick. These soils make up as much as 20 percent of this map unit. Also included are small seep spots and wet season springs.

Permeability is moderate to moderately slow. Effective rooting depth is more than 60 inches. Available water capacity is 10 to 12 inches. Water-supplying capacity is 20 to 26 inches. Runoff is medium to rapid, and the hazard of erosion is moderate to high. These soils are subject to slumping.

These soils are used for wildlife habitat, urban development, and farming.

The vegetation in areas not cultivated is Douglas-fir, Oregon white oak, bigleaf maple, vine maple, western hazel, common snowberry, trailing blackberry, roses, grasses, and forbs.

These soils are around areas of farmland where the extent of openland and woodland is almost equal. A wide variety of grain and grasses along with shrubs and trees furnishes good food and cover for wildlife. Wildlife species, both resident and seasonal, on this soil include ring-necked pheasant, California quail, and mourning dove. Other common wildlife species include foxes, skunks, raccoon, oppossum, squirrels, rabbits, and mice. Birdlife includes hawks, owls, jays, crows, hummingbirds, robins, woodpeckers, blackbirds, larks, starlings and many other kinds of small birds. The potential for improving wildlife habitat is good. Planting desirable vegetation and protecting existing vegetation improves the habitat.

Increased population growth has resulted in increased homesite construction on these soils. The main limitation for urban development is slopes of 20 to 50 percent. Slumping occurs in areas of cut and fill, and because of this additional maintenance of banks, roads, and building foundations is required in places. Irrigation in summer is desirable for lawn grasses, shrubs, vines, vegetables, and most shade and ornamental trees. Mulching and fertilizing cut areas help establish plants. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

These soils are in capability subclass VIe.

20C—Haplumbrepts, moderately steep. These well drained and moderately well drained soils are on dissected mountainous terrain along the Sandy and Columbia Rivers. These soils formed in a mixture of silt and sand and in the accumulated material from downslope soil creep. These soils have slopes of 3 to 25 percent. The average annual precipitation is 10 to 90 inches, the average annual air temperature is 50 to 52 degrees F, and the frost-free period is 160 to 200 days.

Typically, the surface layer is very dark brown or dark brown silt loam, loam, or silty clay loam 10 to 12 inches thick. The subsoil is dark yellowish brown or dark brown silt loam, loam, or silty clay loam and has as much as 65 percent pebbles or cobbles. The substratum is silty or sandy and cobbly or gravelly and extends to a depth of many feet in places.

Included with these soils in mapping are areas of Haplumbrepts, very steep; Quatama, Quafeno, Bull Run, Cazadero, and Dabney soils; and soils that are similar to Haplumbrepts but are 20 to 60 inches deep to bedrock. The included soils make up as much as 20 percent of this map unit. Also included in mapping are small seep spots and wet season springs.

Permeability is moderate to moderately slow. Effective rooting depth is more than 60 inches. Available water capacity is 3 to 12 inches. Water-supplying capacity is 20 to 26 inches. Runoff is slow to medium, and the hazard of erosion is slight to moderate. These soils are subject to slumping.

These soils are used for timber production, wildlife habitat, and homesites. They are also used for such recreational activities as picnicking, hiking, and camping.

The vegetation (fig. 8) is Douglas-fir, western hemlock, western redcedar, bigleaf maple, red alder, black cottonwood, vine maple, western hazel, willow, common snowberry, trailing blackberry, roses, Cascade Oregon-grape, salal, brackenfern, swordfern, grasses, and forbs.

These soils are suited to Douglas-fir. The site index for Douglas-fir on these soils ranges from 120 to 135. Based on a site index of 130, these soils are capable of producing about 8,600 cubic feet from a fully stocked stand of 70-year old trees, or 42,600 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 80-year old trees. Brushy species, including salal, Cascade Oregon-grape, common snowberry, bigleaf maple, and red alder, restrict natural regeneration of Douglas-fir.

When these soils are wet, the use of some conventional logging methods is limited. Roads and landings can be protected from erosion by constructing water bars and by seeding cuts and fills. Road cuts require additional maintenance because of slumping. All-season roads on this soil need a heavy base of rock.

These soils are in the fringe area that is transitional from the valley to forested hills. Openland and woodland are almost equal in extent. Wildlife populations are rela-

Figure 8.—A wide variety of plants in a native plant community on Haplumbrepts, moderately steep.

tively stable in these habitats. Most of the potential for wildlife habitat depends on management of existing plant communities, but some potential depends on growing desirable vegetation. Resident and seasonal wildlife species include black-tailed deer, coyote, bobcat, raccoon, skunks, foxes, oppossum, rabbits, squirrels, mice, moles, and gophers. Common birds are hawks, jays, ravens, crows, vultures, woodpeckers, insect eaters, doves, band-tailed pigeon, ruffed grouse, blue grouse, mountain quail, California quail, ring-necked pheasant, and many kinds of small birds.

These soils are severely limited for homesites and other urban uses. The main limitation for urban development is steep slopes. Slumping occurs in places in areas of cut and fill, and because of this additional maintenance of banks, roads, and building foundations is required. Irrigation during summer is desirable for lawn grasses, shrubs, vines, vegetables, and most shade and ornamental trees. Mulching and fertilizing cut areas help establish plants. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

These soils are in capability subclass VIe.

20F—Haplumbrepts, very steep. These well drained and moderately well drained soils are on broken landscapes along the Sandy and Columbia Rivers. These soils formed in a mixture of silt and sand and in the accumulated material from downslope soil creep. These soils have slopes of 50 to 90 percent. The average annual precipitation is 60 to 90 inches, the average annual air temperature is 50 to 52 degrees F, and the frost-free period is 160 to 200 days.

Typically, the surface layer is very dark brown, very dark grayish brown, or dark brown silt loam, loam, or silty clay loam 10 to 12 inches thick. The subsoil is dark yellowish brown, brown, or dark brown silt loam, loam, or silty clay loam and has as much as 65 percent pebbles or cobbles. The substratum is silty or sandy and cobbly or gravelly and extends to a depth of many feet in places.

Included with these soils in mapping are areas of Haplumbrepts, moderately steep; Aschoff, Goble, Wahkeena, Quatama, Quafeno, Cazadero, Mershon, and Dabney soils; and soils that are similar to Haplumbrepts, but are 10 to 20 inches deep to bedrock. The included soils make up as much as 20 percent of this map unit. Also included in mapping are small seep spots and wet season springs.

Permeability is moderate to moderately slow. Effective rooting depth is more than 60 inches. Available water capacity is 10 to 13 inches. Water-supplying capacity is 20 to 26 inches. Runoff is slow to rapid, and the hazard of erosion is slight to high. These soils are subject to slumping.

These soils are used for timber production and wildlife habitat. They are also used for such recreational activities as picnicking, hiking, and camping.

The vegetation is Douglas-fir, western hemlock, western redcedar, bigleaf maple, red alder, black cottonwood, vine maple, western hazel, willow, common snowberry, trailing blackberry, blue elderberry, roses, Cascade Oregon-grape, salal, brackenfern, swordfern, grasses, and forbs.

These soils are suited to Douglas-fir. The site index for Douglas-fir on these soils ranges from 120 to 135. Based on a site index of 130, these soils are capable of producing about 8,600 cubic feet from a fully stocked stand of 70-year old trees or 42,600 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 80-year old trees. Brushy species, including salal, Cascade Oregon-grape, common snowberry, bigleaf maple, and red alder, restrict natural regeneration of Douglas-fir.

The main limitation for timber production is steep slopes. Because of the steep slopes, such logging methods as aerial, high-lead, or skyline should be used for tree harvesting. Roads and landings can be protected from erosion by constructing water bars and by seeding cuts and fills. Road cuts need additional maintenance because of slumping. All-season roads on this soil need a heavy base of rock.

These soils are in the fringe area that is transitional from the valley to forested hills. Openland and woodland are almost equal in extent. Wildlife populations are relatively stable in these habitats. Most of the potential for wildlife habitat depends on the management of existing plant communities, but some potential depends on growing desirable vegetation. Resident and seasonal wildlife species include black-tailed deer, coyote, bobcat, raccoon, skunks, foxes, oppossum, rabbits, squirrels, mice, moles, and gophers. Common birds are hawks, owls, jays, ravens, crows, vultures, woodpeckers, insect eaters, doves, band-tailed pigeon, ruffed grouse, blue grouse, mountain quail, California quail, ring-necked pheasant, and many kinds of small birds.

These soils are severely limited for homesite construction and other urban uses. The main limitations for urban development are slopes of 50 to 90 percent and low strength. Slumping occurs in places in areas of cut and fill, and because of this additional maintenance of banks, roads, and building foundations is required. Irrigation during summer is desirable for lawn grasses, shrubs, vines, and most shade and ornamental trees. Mulching and fertilizing cut areas help establish plants. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

These soils are in capability subclass VIIe.

21B—Helvetia silt loam, 3 to 8 percent slopes. This moderately well drained soil is on convex side slopes of old terraces. This soil formed in stratified old alluvium of mixed origin. Elevation is 250 to 500 feet. The average annual precipitation is 40 to 50 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark brown silt loam about 10 inches thick. The subsoil is dark yellowish brown silty clay loam and silty clay to a depth of 60 inches or more.

Included with this soil in mapping are areas of Cascade, Cornelius, Delena, and Saum soils, and more sloping Helvetia soils. The included soils make up as much as 10 percent of this map unit.

Permeability is moderately slow. Effective rooting depth is 60 inches or more. Available water capacity is 11 to 13 inches. Water-supplying capacity is 19 to 21 inches. Runoff is slow, and the hazard of erosion is slight. A water table is at a depth of 3 to 6 feet from December through April.

This soil is used for farming, urban development, and wildlife habitat.

This soil is well suited to farming. If it is drained, most climatically adapted crops do well. Irrigation during summer is required for maximum production of most crops. The major crops are berries, grain, hay, and pasture. Returning all crop residue to the soil and including grasses, legumes, or grass-legume mixtures in the cropping system help maintain fertility and tilth. If the soil is to be left bare during winter, it should be fertilized and planted to a cover crop in fall. Grassed waterways help control erosion in drainageways. Limiting tillage to seedbed preparation and weed control helps control runoff and erosion. A cloddy condition helps protect the soil against erosion during rainy periods.

Excessive cultivation can result in formation of a tillage pan in this soil. Subsoiling is required to break up this pan and is more successful if used when the soil is dry than when wet. Tile systems are installed across the slope to intercept ground water. Sprinkler irrigation can be used to increase crop production in dry periods in summer. Water needs to be applied slowly to prevent runoff. Grain and grass crops respond to nitrogen. Legumes respond to phosphorus, potassium, sulfur, and lime and in places, to boron. Berries respond to nitrogen, phosphorus, potassium, and sulfur and in places, to boron. Strawberries, alfalfa, and other crops that require good drainage can be grown if a deep, random tile system is installed.

The vegetation in areas not cultivated is Douglas-fir, Oregon white oak, bigleaf maple, western hazel, willow, creambush oceanspray, roses, common snowberry, forbs, and grasses.

A wide variety of vegetation grows on this soil and furnishes good food and cover for ring-necked pheasant, California quail, bobwhite quail, and mourning dove. Other common wildlife species are black-tailed deer, foxes, skunks, raccoon, oppossum, rabbits, and mice. Birdlife includes hawks, owls, vultures, jays, crows, woodpeckers, flycatchers, blackbirds, larks, starlings, and many kinds of small birds. The potential for wildlife habitat is good. Planting desirable vegetation and protecting existing vegetation improves the habitat.

Increased population growth has resulted in increased urban development on this soil. The main limitations to urban development are the seasonal high water table, be designed to offset these limitations if sewers are provided. In places, septic tank absorption fields do not function properly during rainy periods because of wetness and the moderately slow permeability. Drainage is required for best results with lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables. Irrigation during summer is desirable for lawn grasses, shrubs, vines, vegetables, and most shade and ornamental trees. Plants that tolerate droughty growing conditions should be selected when irrigation is not provided.

This soil is in capability subclass IIw.

37B—Quatama loam, 3 to 8 percent slopes. This moderately well drained soil is on low terraces. This soil formed in old alluvium. Elevation is 75 to 400 feet. The average annual precipitation is 40 to 50 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark brown loam about 9 inches thick. The subsoil is dark yellowish brown loam and clay loam about 39 inches thick. It is mottled in the lower part. The substratum is dark brown, mottled loam and sandy loam to a depth of 60 inches or more.

Included with this soil in mapping are areas of Cascade, Aloha, Powell, Quafeno, and Latourell soils. The included soils make up as much as 10 percent of this map unit.

Permeability is moderately slow. Effective rooting depth is 60 inches or more. Available water capacity is 8 to 10 inches. Water-supplying capacity is 18 to 20 inches. Runoff is slow, and the hazard of erosion is slight. A water table is at a depth of 2 to 3 feet from December through April.

This soil is used for farming, urban development, and wildlife habitat.

This soil is well suited to farming. If it is drained, most climatically adapted crops do well. Irrigation during summer is required for maximum production of most crops. The major crops are berries, grain, hay, and pasture. Returning all crop residue to the soil and including grasses, legumes, or grass-legume mixtures in the cropping system help maintain fertility and tilth. If the soil is to be left bare during winter, it should be fertilized and planted to a cover crop in fall. Grassed waterways help control erosion in drainageways. Limiting tillage to seedbed preparation and weed control helps control runoff and erosion. A cloddy condition helps protect the soil from erosion during rainy periods.

Excessive cultivation can result in formation of a tillage pan in this soil. Subsoiling is required to break up this pan and is more successful if done when the soil is dry then when wet. Tile drainage systems are installed across the slope to intercept ground water. Sprinkler irrigation can be used to increase crop production in dry periods in summer. Water needs to be applied slowly to prevent runoff. Grain and grass crops respond to nitrogen. Legumes respond to phosphorus, potassium, sulfur, and lime and in places, to boron. Berries respond to nitrogen, phosphorus, potassium, and sulfur and in places, to boron. Strawberries, alfalfa, and other crops that require good drainage can be grown if a deep, random tile system is installed.

The vegetation in areas not cultivated is Douglas-fir, Oregon white oak, western redcedar, bigleaf maple, willow, western hazel, creambush oceanspray, roses, trailing blackberry, salal, tall Oregon-grape, common snowberry, Pacific dogwood, brackenfern, forbs, and grasses.

A wide variety of grasses, grain, and fruit and vegetable crops along with shrubs and trees grow on this soil. This variety of plants furnishes good food and cover for ring-necked pheasant and California quail. Other common wildlife species are some black-tailed deer, foxes, skunks, raccoon, oppossum, rabbits, squirrels, and mice. Birdlife includes hawks, owls, jays, crows, woodpeckers, robins, blackbirds, larks, starlings, and many kinds of small birds. The potential for wildlife habitat is good. Planting desirable vegetation and protecting existing vegetation improve the habitat.

Increased population growth has resulted in increased urban development on this soil. The main limitations for urban development are a seasonal high water table and moderately slow permeability. Dwellings and roads can be designed to offset these limitations if sewers are provided. In places, septic tank absorption fields do not function properly during rainy periods because of wetness and the moderately slow permeability. Drainage is required for best results with lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables. Irrigation in summer is desirable for lawn grasses, shrubs, vines, vegetables, and most shade and ornamental trees. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass IIe.

37C—Quatama loam, 8 to 15 percent slopes. This moderately well drained soil is on short escarpment fronts of low terraces. This soil formed in old alluvium. Elevation is 75 to 400 feet. The average annual precipitation is 40 to 50 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark brown loam about 9 inches thick. The subsoil is dark yellowish brown loam and clay loam about 39 inches thick. It is mottled in the lower part. The substratum is dark brown, mottled loam and sandy loam to a depth of 60 inches or more.

Included with this soil in mapping are areas of Cascade, Aloha, Powell, Latourell, and Quafeno soils and other Quatama soils. The included soils make up as much as 10 percent of this map unit.

Permeability is moderately slow. Effective rooting depth is 60 inches or more. Available water capacity is 8 to 10 inches. Water-supplying capacity is 18 to 20 inches. Runoff is medium, and the hazard of erosion is moderate. A water table is at a depth of 2 to 3 feet from December through April.

This soil is used for farming, urban development, and wildlife habitat.

This soil is well suited to farming. If it is drained, most climatically adapted crops do well. Irrigation during summer is required for maximum production of most crops. The major crops are berries, grain, hay, and pasture. Returning all crop residue to the soil and including grasses, legumes, or grass-legume mixtures in the cropping system help maintain fertility and tilth. If the soil is to be left bare during winter, it should be fertilized and planted to a cover crop. Cross-slope farming, grassed waterways, and limiting tillage to seedbed preparation and weed control help control runoff and erosion. A cloddy condition helps protect the soil from erosion during rainy periods.

Excessive cultivation can result in formation of a tillage pan in this soil. Deep subsoiling is required to break up this pan and is more successful if done when the soil is dry than when wet. Tile drainage systems are installed across the slope to intercept ground water. Sprinkler irrigation can be used to increase crop production in dry periods in summer. Water needs to be applied slowly to prevent runoff. Grain and grass crops respond to nitrogen. Legumes respond to phosphorus, potassium, sulfur, and lime and in places, to boron. Berries respond to nirogen, phosphorus, potassium, and sulfur and in places, to boron. Strawberries, alfalfa, and other crops that require good drainage can be grown if a deep, random tile system is installed.

The vegetation in areas not cultivated is Douglas-fir, Oregon white oak, western redcedar, bigleaf maple, willow, western hazel, creambush oceanspray, roses, trailing blackberry, salal, tall Oregon-grape, common snowberry, Pacific dogwood, brackenfern, forbs, and grasses.

A wide variety of grasses, grain, and fruit and vegetable crops along with shrubs and trees grow on this soil. This variety of plants furnishes good food and cover for ring-necked pheasant and California quail. Other common wildlife species are some black-tailed deer, foxes, skunks, raccoon, oppossum, rabbits, squirrels, and mice. Birdlife includes hawks, owls, jays, crows, woodpeckers, robins, blackbirds, larks, starlings, and many kinds of small birds. The potential for wildlife habitat is good. Planting desirable vegetation and protecting existing vegetation improve the habitat.

Increased population growth has resulted in increased urban development on this soil. The main limitations for urban development are a seasonal high water table, moderately slow permeability, low strength, and slopes of 8 to 15 percent. Dwellings and roads can be designed to offset the limitations if sewers are provided. In places, septic tank absorption fields do not function properly during rainy periods because of wetness and the moderately slow permeability. Drainage is required for best results with lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables, and irrigation during summer is desirable. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass IIIe.

37D—Quatama loam, 15 to 30 percent slopes. This moderately well drained soil is on short escarpment fronts of low terraces. This soil formed in old alluvium. Elevation is 75 to 400 feet. The average annual precipitation is 40 to 50 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark brown loam about 9 inches thick. The subsoil is dark yellowish brown loam and clay loam about 39 inches thick. It is mottled in the lower part. The substratum is dark brown, mottled loam and sandy loam to a depth of 60 inches or more.

Included with this soil in mapping are areas of Cascade, Aloha, Powell, Latourell, and Quafeno soils and other Quatama soils. The included soils make up as much as 10 percent of this map unit.

Permeability is moderately slow. Effective rooting depth is 60 inches or more. Available water capacity is 8 to 10 inches. Water-supplying capacity is 18 to 20 inches. Runoff is medium, and the hazard of erosion is high. A water table is at a depth of 2 to 3 feet from December through April.

This soil is used for farming, urban development, and wildlife habitat.

This soil is poorly suited to farming. If it is drained, most climatically adapted crops do well. Irrigation during summer is required for maximum production of most crops. The major crops are berries, grain, hay, and pasture. Returning all crop residue to the soil and including grasses, legumes, or grass-legume mixtures in the cropping system help maintain fertility and tilth. If the soil is to be left bare during winter, it should be fertilized and planted to a cover crop in fall. Limiting slope length by stripcropping or terracing helps reduce sheet and rill erosion. Cross-slope farming, grassed waterways, and limiting tillage to seedbed preparation and weed control help control runoff and erosion. A cloddy condition helps protect the soil from erosion during rainy periods.

Excessive cultivation can result in formation of a tillage pan in this soil. Deep subsoiling is required to break up this pan and is more successful if done when the soil is dry than when wet. Tile drainage systems are installed across the slope to intercept ground water. Sprinkler irrigation can be used to increase crop production in dry periods in summer. Water needs to be applied slowly to prevent runoff. Grain and grass crops respond to nitrogen. Legumes respond to phosphorus, potassium, sulfur, and lime and in places, to boron. Berries respond to nitrogen, phosphorus, potassium, and sulfur and in places, to boron. Berries respond to nitrogen, phosphorus, potassium, and sulfur and in places, to boron. Strawberries, alfalfa, and other crops that require good drainage can be grown if a deep, random tile system is installed.

The vegetation in areas not cultivated is Douglas-fir, Oregon white oak, western redcedar, bigleaf maple, willow, western hazel, creambush oceanspray, roses, trailing blackberry, salal, tall Oregon-grape, common snowberry, Pacific dogwood, brackenfern, forbs, and grasses.

A wide variety of grasses, grain, and fruit and vegetable crops along with shrubs and trees grow on this soil. This variety of plants furnishes good food and cover for ring-necked pheasant and California quail. Other common wildlife species are black-tailed deer, foxes, skunks, raccoon, oppossum, rabbits, squirrels, and mice. Birdlife includes hawks, owls, jays, crows, woodpeckers, robins, blackbirds, larks, starlings, and many kinds of small birds. The potential for wildlife habitat is good. Planting desirable vegetation and protecting existing vegetation improve the habitat.

Increased population growth has resulted in increased urban development on this soil. The main limitations for urban development are a seasonal high water table, moderately slow permeability, low strength, and slopes of 15 to 30 percent. Dwellings and roads can be designed to offset these limitations if sewers are provided. In places, septic tank absorption fields do not function properly during rainy periods because of wetness, steep slopes, and the moderately slow permeability. Drainage is required for best results with lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables, and irrigation during summer is desirable. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass IVe.

38A—Quatama-Urban land complex, 0 to 3 percent slopes. This complex consists of moderately well drained Quatama soils. In most areas of this complex the soils have been graded, cut, filled, or otherwise disturbed. This complex is on short escarpment fronts of low terraces. Areas are generally long and narrow and 15 to 50 acres in size. The Quatama soils and Urban land are in such an intricate pattern or so small in area that to separate them in mapping was not practical. Elevation is 75 to 400 feet. The average annual precipitation is 40 to 50 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

About 20 percent of this complex are areas of Quatama soils that are relatively undisturbed. Typically, the surface layer is dark brown loam about 9 inches thick. The subsoil is dark yellowish brown loam and clay loam. It is mottled in the lower part and is about 39 inches thick. The substratum is dark brown, mottled loam and sandy loam to a depth of 60 inches or more.

About 30 percent of this complex are areas of Quatama soils that have been disturbed. These soils have been covered by as much as 30 inches of fill material, or as much as 40 inches of the original profile has been removed by cutting or grading. The fill material is generally from adjacent areas of Quatama soils that have been cut or graded.

About 40 percent of this complex is Urban land. The areas are largely covered by concrete, asphalt, buildings, or other impervious surfaces that so obscure or alter the soils that their identification is not feasible.

Included with this complex in mapping are areas of Cascade, Aloha, Powell, Quafeno, and Latourell soils. The included soils make up about 10 percent of this map unit.

In areas where the soils are relatively undisturbed, permeability is moderately slow and available water capacity is 8 to 10 inches. In areas dominated by cuts, fills, and Urban land, permeability and available water capacity are variable. The areas of Quatama soils that are undisturbed have a water table within a depth of 3 feet during December to April. Runoff is slow, and the hazard of erosion is slight.

Areas of this complex that have not been disturbed include yards and openland around and between buildings. The main limitations for urban development are moderately slow permeability and a seasonal high water table. Large areas of this map unit are drained by sewer systems, gutters, drainage tiles, and surface ditches. Septic tank absorption fields do not function properly during rainy periods because of wetness and the moderately slow permeability. Drainage is required for best results with most lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables. Irrigation during summer is desirable for most lawn grasses, shrubs, vines, vegetables, shade trees, and ornamental trees. Plants that tolerate a seasonal water table and droughty conditions should be selected if drainage and irrigation are not provided.

This map unit is not assigned to a capability subclass.

39—Rafton silt loam. This very poorly drained soil is on broad flood plains of the Columbia River. This soil formed in recent alluvium with some mixing of volcanic ash. Elevation is 10 to 20 feet. Slopes are 0 to 2 percent. The average annual precipitation is 40 to 60 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark grayish brown, mottled silt loam about 9 inches thick. The subsoil is grayish brown, brown, and gray, mottled silt loam about 31 inches thick. The substratum is dark grayish brown, mottled silt loam over very dark gray silt loam to a depth of 60 inches or more.

Included with this soil in mapping are areas of Moag, Pilchuck, and Sauvie soils. The included soils make up as much as 10 percent of this unit.

Permeability is moderate. Effective rooting depth is 60 inches or more. Available water capacity is 11 to 13 inches. Water-supplying capacity is 21 to 25 inches. Runoff is very slow. The hazard of erosion from overflow is high. The soil is subject to frequent flooding from December to June. A water table is within a depth of 12 inches from December through July.

This soil is used for farming and wildlife habitat.

This soil is very poorly suited to farming. Only plants that can withstand prolonged inundation by flooding and long periods of a high water table are adapted. Grasses respond to nitrogen. Legumes respond to phosphorus, boron, sulfur, and lime. Irrigation during summer is required for maximum crop production.

The native vegetation is black cottonwood, willow, roses, common snowberry, sedges, cattails, and grasses.

A wide variety of vegetation grows on this soil and furnishes good food and cover for ring-necked pheasant, California quail, bobwhite quail, mourning dove, and wintering waterfowl. Other common wildlife species are black-tailed deer, foxes, skunks, raccoon, oppossum, rabbits, and mice. Birdlife includes hawks, owls, vultures, jays, crows, woodpeckers, flycatchers, shore birds, blackbirds, larks, starlings, and many kinds of small birds. Where this soil is adjacent to large bodies of water, it provides food and habitat for beaver, muskrat, nutria, mink, and otter. The potential for wildlife habitat is good. Planting desirable vegetation and protecting existing vegetation improve the habitat.

This soil is severely limited for homesites and other urban uses. The main limitations for urban development are frequent flooding and a seasonal high water table.

This soil is in capability subclass VIw.

40—Rafton silt loam, protected. This very poorly drained soil is on broad flood plains of the Columbia River. It formed in recent alluvium with some mixing of volcanic ash. Elevation is 10 to 20 feet. Slopes are 0 to 2 percent. The average annual precipitation is 40 to 60 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark grayish brown, mottled silt loam about 9 inches thick. The subsoil is grayish brown, brown, and gray, mottled silt loam about 31 inches thick. The substratum is dark grayish brown, mottled silt loam over very dark gray silt loam to a depth of 60 inches or more.

Included with this soil in mapping are areas of Moag, Pilchuck, and Sauvie soils. The included soils make up as much as 10 percent of this map unit.

Permeability is moderate. Effective rooting depth is 60 inches or more. Available water capacity is 11 to 13 inches. Water-supplying capacity is 21 to 25 inches. Runoff is very slow, and the hazard of erosion is slight. The soils are protected from flooding by dikes and levees but are subject to frequent ponding from December to April. A water table is from 2 feet above the surface to 12 inches below the surface from December through April.

This soil is used for farming and wildlife habitat.

This soil is well suited to farming. Large areas have been drained and are farmed. If this soil is drained and crops are protected from ponding, most climatically adapted crops do well. Perennial crops that withstand ponding during winter are adapted. The major crops are sweet corn, row crops, and spring barley. Returning all crop residue to the soil and including grasses, legumes, or grass-legume mixtures in the cropping system help maintain fertility and tilth. Crops can be irrigated by sprinkler, furrow, or border systems; however, sprinklers are generally used. Irrigation helps increase crop production during dry periods in summer. Grain and grasses respond to nitrogen. Legumes respond to phosphorus, boron, sulfur, and lime.

The vegetation in areas not cultivated is black cottonwood, willow, roses, common snowberry, sedges, cattails, and grasses.

A wide variety of grain, grasses, and vegetable crops along with shrubs and trees grow on this soil. This variety of plants furnishes good food and cover for ring-necked pheasant, California quail, bobwhite quail, and mourning dove. Ponded areas are excellent for waterfowl in winter. Other common wildlife species are black-tailed deer, foxes, skunks, raccoon, oppossum, rabbits, and mice. Birdlife includes hawks, owls, vultures, jays, crows, woodpeckers, flycatchers, shore birds, blackbirds, larks, starlings, and many kinds of small birds. Where this soil is adjacent to large bodies of water, it provides food and habitat for beaver, muskrat, nutria, mink, and otter. The potential for wildlife habitat is good. Planting desirable vegetation and protecting existing vegetation improve the habitat. Numerous undrained areas of this soil provide small ponds, which can be managed for waterfowl.

This soil is severely limited for homesites and other urban uses. The main limitations for urban development are frequent ponding and very poor drainage.

This soil is in capability subclass IIIw.

41—Riverwash. These miscellaneous areas are narrow, irregular strips in the bends of stream channels along the Columbia, Willamette, and Sandy Rivers and along most drainageways in the survey area. Areas are 2 to 10 feet above the common water level of the stream. Slopes are 0 to 3 percent. The average annual precipitation is 40 to 80 inches, the average annual air temperature is 50 to 54 degrees F, and the frost-free period is 140 to 200 days.

Riverwash is used for recreation, a source of gravel, and wildlife habitat.

Riverwash is variable, but generally consists of well rounded sand, gravel, cobbles, stones, and boulders derived from basalt or andesite.

Included with this miscellaneous area in mapping are areas of Dabney and Pilchuck soils. The included soils make up as much as 10 percent of this map unit.

Permeability is very rapid. Effective rooting depth is 60 inches or more. Available water capacity and water-supplying capacity are variable. Runoff is slow, but the hazard of erosion is high. Riverwash is subject to overflow when the water is high and is extremely droughty when the water is low. During each new overflow, new deposits are received or material is removed.

The vegetation is occasional bunches of grass and scattered shrubs, such as willows.

Permeability is moderately slow. Effective rooting depth is 40 to 60 inches. Available water capacity is 6 to 8 inches. Water-supplying capacity is 20 to 22 inches. Runoff is rapid, and the hazard of erosion is high.

This soil is used for timber production, urban development, and wildlife habitat.

Vegetation is Douglas-fir, Oregon white oak, western hazel, poison oak, creambush oceanspray, tall Oregon-grape, common snowberry, roses, forbs, and grasses.

This soil is suited to Douglas-fir. The site index for Douglas-fir on this soil ranges from 130 to 140. Based on a site index of 136, this soil is capable of producing about 9,125 cubic feet from a fully stocked stand of 70-year old trees, or 47,400 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 80-year old trees. Brushy species, including western hazel, poison oak, common snowberry, roses, and Oregon white oak, restrict natural regeneration of Douglas-fir.

The main limitations for timber production are the long, dry summer and the resultant droughty condition that limits establishment of young trees. Because of steep slopes, such logging methods as aerial, high-lead, or skyline should be used for tree harvesting. Roads and landings can be protected from erosion by constructing water bars and by seeding cuts and fills. All-season roads on this soil need a base of rock.

A wide variety of grasses, shrubs, and trees grow on this soil. The variety of plants furnishes food and cover for ring-necked pheasant, California quail, bobwhite quail, and ruffed grouse. Other common wildlife species are black-tailed deer, gophers, squirrels, raccoon, oppossum, skunks, and rabbits. Birdlife includes hawks, owls, jays, ravens, crows, vultures, woodpeckers, insect eaters, mourning dove, band-tailed pigeon, and many kinds of small birds. The potential for wildlife habitat is good. Planting desirable vegetation and protecting existing vegetation improve the habitat.

This soil has severe limitation for homesites because of slopes of 30 to 60 percent. Other limitations include bedrock at a depth of 40 to 60 inches, low strength, and moderately slow permeability. Dwellings and roads can be designed to offset these limitations if sewers are provided. Septic tank absorption fields do not function properly in places because of steep slopes and moderately slow permeability. Irrigation during summer is desirable for most lawn grasses, shrubs, vines, vegetables, shade trees, and ornamental trees. Plants that tolerate droughty conditions should be selected if irrigation is not provided. In places, cut areas require mulching and fertilizing to establish plants.

This soil is in capability subclass VIe.

44—Sauvie silt loam. This poorly drained soil is on broad flood plains of the Columbia River. This soil formed in recent alluvium with some mixing of volcanic ash. Elevation is 10 to 20 feet. Slopes are 0 to 2 percent. The average annual precipitation is 40 to 50 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is very dark grayish brown silt loam about 15 inches thick. The subsoil is mainly dark grayish brown silty clay loam. The subsoil is mottled and is about 24 inches thick. The substratum is dark grayish brown, mottled very fine sandy loam to a depth of 60 inches or more.

Included with this soil in mapping are areas of Sauvie silty clay loam and areas of Moag, Pilchuck, and Rafton soils. The included soils make up as much as 10 percent of this map unit.

Permeability is moderately slow. Effective rooting depth is 60 inches or more. Available water capacity is 11 to 13 inches. Water-supplying capacity is 21 to 25 inches. Runoff is slow, and the hazard of erosion from overflow is high. This soil is subject to frequent flooding from December to June. A water table is within a depth of 12 inches during May and June.

This soil is used for farming and wildlife habitat.

This soil is very poorly suited to farming. Adapted plants are those that can withstand prolonged inundation by flooding and the presence of a high water table for long periods. Disturbed areas require protection from washing during winter. Grasses respond to nitrogen. Legumes respond to phosphorus, boron, sulfur, and lime. Irrigation during dry periods in summer is required for maximum crop production.

The native vegetation is Oregon white oak, Oregon ash, black cottonwood, willow, roses, common snowberry, trailing blackberry, forbs, and grasses.

A wide variety of vegetation grows on this soil and furnishes good food and cover for ring-necked pheasant, California quail, bobwhite quail, mourning dove, and wintering waterfowl. Other common wildlife species are a few black-tailed deer, foxes, skunks, raccoon, oppossum, rabbits, and mice. Birdlife includes hawks, owls, vultures, jays, crows, woodpeckers, flycatchers, shore birds, blackbirds, larks, starlings, and many kinds of small birds. Where this soil is adjacent to large bodies of water, it provides food and habitat for beaver, muskrat, nutria, mink, and otter. The potential for wildlife habitat is good. Planting desirable vegetation and protecting existing vegetation improve the habitat.

This soil is severely limited for homesites and other urban uses. The main limitations for urban development are frequent flooding and a seasonal high water table. Recreational uses are limited by seasonal flooding.

This soil is in capability subclass VIw.

45—Sauvie silt loam, protected. This poorly drained soil is on broad flood plains of the Columbia River. This soil formed in recent alluvium with some mixing of volcanic ash (fig. 16). Elevation is 10 to 20 feet. Slopes are 0 to 2 percent. The average annual precipitation is 40 to 60 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

from 80 to 90. Based on a site index of 82, this soil is capable of producing about 3,840 cubic feet from a fully stocked stand of 70-year old trees, or 15,840 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 100-year old trees.

The main limitations to the Talapus soil for timber production are the cold soil temperatures, steep slopes, acid soil condition, and high content of coarse fragments. Because of the steep slopes, such methods of logging as aerial, high-lead, or skyline should be used for tree harvesting. During periods of heavy snow pack and when soils are wet, logging is restricted. Roads and landings need to be protected from erosion by constructing water bars and by seeding cuts and fills.

The Lastance soil is suited to noble fir and western hemlock. The site index for noble fir on this soil ranges from 50 to 70. Based on a site index of 52, this soil is capable of producing about 3,700 cubic feet from a fully stocked stand of 70-year old trees, or 14,300 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 100-year old trees.

The main limitations to the Lastance soil for timber production are the cold soil temperatures, steep slopes, acid soil condition, and high content of coarse fragments. Because of the steep slopes, methods of logging as aerial, high-lead, or skyline should be used for tree harvesting. During periods of heavy snow pack and when soils are wet, logging is restricted. Roads and landings need to be protected from erosion by constructing water bars and by seeding cuts and fills.

In the high rainfall areas at high elevations on western slopes of the Cascade Mountains, a limited variety of trees, shrubs, grasses, and forbs grow on these soils. Vegetational stages change dramatically as a result of clear-cut logging and fires. Because of the cold soil temperatures, plant recovery and growth are slower than at a lower elevation.

The potential for wildlife, especially black-tailed deer, depends on openings in the canopy created by clearcutting and on the availability of new vegetation. Other species of wildlife are black bear, cougar, bobcat, coyote, marten, coney, rabbits, squirrels, and chipmunks. Birds include blue grouse, ravens, hawks, owls, Clark's nutcracker, jays, wrens, and other small birds. Most of the potential for wildlife habitat depends on the management of existing plant communities. The ecosystem is fragile, and recovery from drastic changes is very slow.

These soils have severe limitations for urban development. The main limitations for urban development are steep slopes and the high concentration of coarse fragments. Climatic conditions are severe during winter. Plants adapted to a long, cold winter and a short, cool summer should be used for landscaping in developed areas and for erosion control in cut and fill areas. Mulching and fertilizing help establish plants in disturbed areas.

This association is in capability subclass VIIs.

50A—Urban land, 0 to 3 percent slopes. This miscellaneous area is throughout the central part of Multnomah County, but is mainly in the city of Portland along the flood plains of the Willamette River. Areas of this map unit are on the Ingram geomorphic surface as described in the section, "Geomorphic surfaces and soil development." They are subject to flooding (fig. 20). The degree of flooding depends on the flood structures present and on the magnitude of the flooding. Elevation is 20 to 30 feet.

Areas of this map unit are used mainly for commercial purposes. Ninety five percent or more of the soils are covered with buildings, streets, sidewalks, parking lots, railroads, and other works and structures.

Some areas are not covered by works and structures, but most of these areas have been so altered during construction that to separate them in mapping was not practical. The original soils were gravelly loam, silt loam, or silty clay loam with some sandy materials. Cuts and fills and grading and compaction by machinery during construction have severely altered the characteristics of the original soils.

This map unit is not assigned to a capability subclass.

50C—Urban land, 3 to 15 percent slopes. This miscellaneous area is in the central part of Multnomah County, mainly in the city of Portland on first terraces above the flood plains. Areas of this map unit are on the Winkle and Champoeg geomorphic surfaces as de-

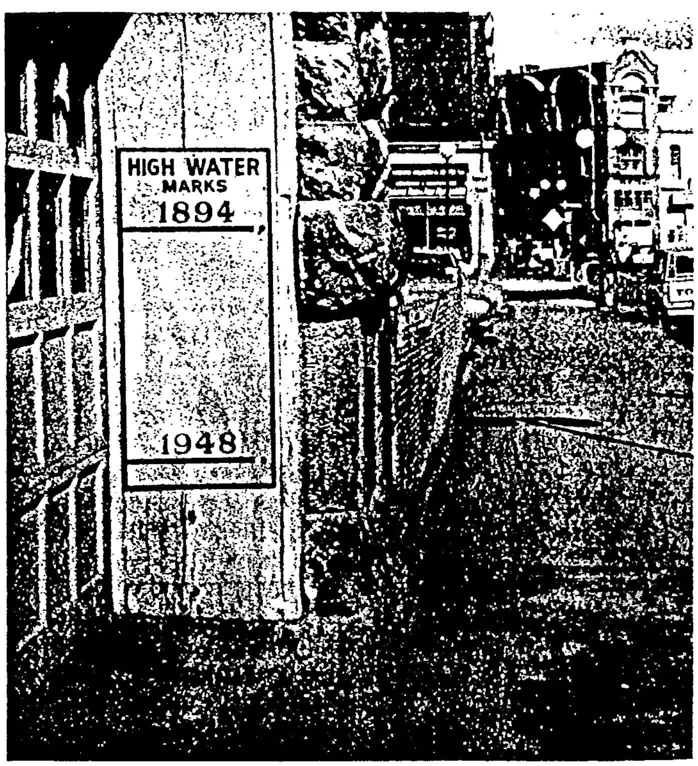


Figure 20.—Level of water during floods in 1894 and 1948 on Urban land, 0 to 3 percent slopes.

54B—Urban land-Quatama complex, 3 to 8 percent slopes. This complex consists of Urban land and moderately well drained Quatama soils. In most areas of this complex, the soils have been graded, cut, filled, or otherwise disturbed. This complex is on short escarpment fronts of low terraces. Areas are generally long and narrow and are 15 to 50 acres in size. The Urban land and Quatama soils are in such an intricate pattern or so small in area that to separate them in mapping was not practical. Elevation is 75 to 400 feet. The average annual precipitation is 40 to 50 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

About 50 percent of this complex is Urban land. The areas are largely covered by concrete, asphalt, buildings, or other impervious surfaces that so obscure or alter the soils that their identification is not feasible.

About 15 percent of this complex are areas of Quatama soils that are relatively undisturbed. Typically, the surface layer is dark brown loam about 9 inches thick. The subsoil is dark yellowish brown loam and clay loam about 39 inches thick. It is mottled in the lower part. The substratum is dark brown, mottled loam and sandy loam to a depth of 60 inches or more.

About 25 percent of this complex are areas of Quatama soils that have been disturbed. This soil has been covered by as much as 30 inches of fill material, or as much as 40 inches of the original profile has been removed by cutting or grading. The fill material is generally from adjacent areas of Quatama soils that have been cut or graded.

Included with this complex in mapping are areas of Cascade, Aloha, Powell, Quafeno, and Latourell soils. The included soils make up about 10 percent of this map unit.

In areas where the soils are relatively undisturbed, permeability is moderately slow and available water capacity is 8 to 10 inches. In areas dominated by cuts, fills, and Urban land, permeability and available water capacity are variable. Undisturbed areas of Quatama soils have a water table within a depth of 3 feet during December to April. Runoff is slow, and the hazard of erosion is slight.

Areas of this complex that have not been disturbed include yards and openland around and between buildings. The main limitations for urban development are moderately slow permeability and a seasonal high water table. Large areas of this map unit are artificially drained by sewer systems, gutters, drainage tiles, and surface ditches. Septic tank absorption fields do not function properly during rainy periods because of wetness and the moderately slow permeability. Drainage is required for best results with most lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables, and irrigation during summer is desirable. Plants that tolerate a seasonal water table and droughty growing conditions should be selected if drainage and irrigation are not provided.

This map unit is not assigned to a capability subclass.

54C—Urban land-Quatama complex, 8 to 15 percent slopes. This complex consists of Urban land and moderately well drained Quatama soils. In most areas of this complex, the soils have been graded, cut, filled, or otherwise disturbed. This complex is on short escarpment fronts of low terraces. Areas are generally long and narrow and are 15 to 50 acres in size. The soils in this complex are in such an intricate pattern or so small in size that to separate them in mapping was not practical. Elevation is 75 to 400 feet. The average annual precipitation is 40 to 50 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

About 50 percent of this complex is Urban land. The areas are largely covered by concrete, asphalt, buildings, or other impervious surfaces that so obscure or alter the soils that their identification is not feasible.

About 15 percent of this complex are areas of Quatama soils that are relatively undisturbed. Typically, the surface layer is dark brown loam about 9 inches thick. The subsoil is dark yellowish brown loam and clay loam about 39 inches thick. It is mottled in the lower part. The substratum is dark brown, mottled loam and sandy loam to a depth of 60 inches or more.

About 25 percent of this complex are areas of Quatama soils that have been disturbed. These soils have been covered by as much as 40 inches of fill material, or as much as 60 inches of the original profile has been removed by cutting or grading. The fill material is generally from adjacent areas of Quatama soils that have been cut or graded.

Included with this complex in mapping are areas of Cascade, Aloha, Powell, Quafeno, and Latourell soils. The included soils make up about 10 percent of this map unit.

In areas where the soils are relatively undisturbed, permeability is moderately slow and available water capacity is 8 to 10 inches. In areas dominated by cuts, fills, and Urban land, permeability and available water capacity are variable. Undisturbed areas of Quatama soils have a water table within a depth of 3 feet during December to April. Runoff is medium, and the hazard of erosion is moderate.

Areas of this complex that have not been disturbed include yards and openland around and between buildings. The main limitations for urban development are the moderately slow permeability and a seasonal high water table. Large areas of this map unit are artificially drained by sewer systems, gutters, drainage tiles, and surface ditches. Septic tank absorption fields do not function properly during rainy periods because of wetness and the moderately slow permeability. Drainage is required for best results with most lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables, and irrigation during summer is desirable. Plants that tolerate a seasonal high water table and droughty conditions should be selected if drainage and irrigation are not provided.

This map unit is not assigned to a capability subclass.

55—Wapato silt loam. This poorly drained soil is on flood plains. This soil formed in recent alluvium. Slopes are 0 to 3 percent. Elevation is 100 to 600 feet. The average annual precipitation is 40 to 60 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is dark brown, mottled silt loam about 12 inches thick. The subsoil is grayish brown, mottled silt loam about 33 inches thick. The substratum is dark greenish gray, mottled gravelly sandy clay loam to a depth of 60 inches or more.

Included with this soil in mapping are areas of Aloha, Delena, Quatama, Powell, and Wollent soils. The included soils make up as much as 10 percent of this map unit.

Permeability is moderately slow. Effective rooting depth is 60 inches or more. Available water capacity is 10 to 12 inches. Water-supplying capacity is 17 to 19 inches. Runoff is slow, and the hazard of erosion is slight. From December through April, this soil is subject to a seasonal high water table at or near the surface and is subject to overflow from adjacent streams.

This soil is used for farming and wildlife habitat.

This soil is suited to farming. If it is drained, most climatically adapted crops do well. Irrigation during summer is required for maximum production of most crops. Major crops include grain, hay, pasture, and vegetables. Only hay and pasture species that can withstand periodic inundation and a high water table during winter are adapted to undrained areas. Returning all crop residue to the soil and including grasses, legumes, or grass-legume mixtures in the cropping system help maintain fertility and tilth. Crops can be irrigated by sprinkler, furrow, or border systems; however, sprinklers are generally used to increase crop production in dry periods in summer. Grain and grasses respond to nitrogen. Legumes respond to phosphorus, boron, sulfur, and lime.

Native vegetation is red alder, black cottonwood, Oregon ash, willow, western redcedar, trailing blackberry, common snowberry, sedges, rushes, and grasses.

A wide variety of vegetation grows on this soil and furnishes good food and cover for ring-necked pheasant, California quail, mourning dove, and band-tailed pigeon. Habitat is also suitable for foxes, raccoon, oppossum, squirrels, skunks, rabbits, mice, moles, gophers, muskrat, nutria, and mink. Nongame birds include hawks, owls, jays, crows, woodpeckers, flycatchers, hummingbirds, larks, robins, and many kinds of small birds.

This soil is severely limited for homesites and other urban uses. The main limitations for development are periodic flooding, moderately slow permeability, and a seasonal high water table. Dwellings and roads can be designed to offset these limitations if flood protection and sewers are provided. Septic tank absorption fields do not function properly during rainy periods because of wetness and the moderately slow permeability. Drainage is required for best results with most lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables, and irrigation during summer is desirable. Plants that tolerate a high seasonal water table and droughty conditions should be selected if drainage and irrigation are not provided. Recreational uses are limited because of a seasonal high water table and flooding.

This soil is in capability subclass IIIw.

56E—Wauld very gravelly loam, 30 to 70 percent slopes. This well drained soil is in mountainous areas along the Columbia River. This soil formed in residuum and colluvium weathered from basalt. Elevation is 250 to 1,000 feet. The average annual precipitation is 60 to 70 inches, the average annual air temperature is 50 to 52 degrees F, and the frost-free period is 145 to 200 days.

Typically, the surface layer is very dark brown very gravelly loam about 6 inches thick. The subsoil is very dark grayish brown and dark brown very gravelly clay loam about 24 inches thick. Depth to basalt is 30 inches.

Included with this soil in mapping are areas of Goble and Cascade soils, Haplumbrepts, very steep soils that are similar to Wauld soils but have bedrock at a depth of less than 20 inches, and soils that are similar to Wauld soils but have bedrock at a depth of 40 inches or more. The included soils make up as much as 20 percent of this map unit.

Permeability is moderate. Effective rooting depth is 20 to 40 inches. Available water capacity is 2 to 4 inches. Water-supplying capacity is 15 to 17 inches. Runoff is slow to medium, and the hazard of erosion is slight to high.

This soil is used for wildlife habitat, timber production, and recreational activities.

The vegetation is Douglas-fir, red alder, bigleaf maple, western redcedar, western hemlock, vine maple, creambush oceanspray, Cascade Oregon-grape, wild cherry, salal, swordfern, and forbs.

This soil is suited to Douglas-fir. The site index for Douglas-fir on this soil ranges from 130 to 145. Based on a site index of 138, this soil is capable of producing about 9,440 cubic feet from a fully stocked stand of 70-year old trees, or 50,280 board feet (international rule, one-fourth inch kerf) of merchantable timber from a fully stocked stand of 80-year old trees. Brushy species, including salal, Cascade Oregon-grape, vine maple, and red alder, restrict natural regeneration of Douglas-fir.

The main limitation for timber production is the high content of coarse fragments. Other limitations include bedrock at a depth of 20 to 40 inches. Some windthrow of trees occurs in places where rooting depth is restricted. Because of the steep slopes, such logging methods as aerial, high-lead, or skyline should be used for tree harvest. Roads and landings need to be protected from erosion by constructing water bars and by seeding cuts and fills.

In the mild, high rainfall areas of the Coast Range Mountains, vegetation grows rapidly on this soil. Vegetational stages change dramatically as a result of clear-cut logging and fires.

The potential for wildlife, especially black-tailed deer, depends on the clearing of land and the availability of new plant growth. As new forest develops and most of the ground vegetation decreases, the deer population returns to a low level. As the trees grow larger, species such as blue grouse are favored. Habitat is suitable for such species as Roosevelt elk, black bear, coyotes, bobcat, skunks, weasels, raccoon, mountain beaver, rabbits, and squirrels. Birds that are resident or seasonal include hawks, owls, jays, ravens, vultures, woodpeckers, ruffed and blue grouse, mountain quail, band-tailed pigeon, and many small birds. Fur-bearing animals such as beaver, mink, and otter are common along larger streams. Most of the potential for wildlife habitat depends on the management of existing plant communities.

This soil has severe limitations for homesites and other uses. The major limitations for urban development are depth to bedrock, high concentration of coarse fragments, and slopes of 30 to 70 percent. Irrigation during summer is desirable for best results with grasses, shrubs, and trees. Mulching and fertilizing help establish plants in disturbed areas. Plants that tolerate droughty conditions should be selected if irrigation is not provided.

This soil is in capability subclass VIIs.

57—Wollent silt loam. This poorly drained soil is on concave side slopes of broad rolling terraces. This soil formed in old alluvium. Elevation is 200 to 400 feet. The average annual precipitation is 50 to 60 inches, the average annual air temperature is 52 to 54 degrees F, and the frost-free period is 165 to 210 days.

Typically, the surface layer is very dark grayish brown, mottled silt loam about 10 inches thick. The subsoil is gray, mottled silt loam about 14 inches thick. The substratum is gray, mottled silty clay loam to a depth of 60 inches or more.

Included with this soil in mapping are areas of Aloha, Powell, and Wapato soils. The included soils make up as much as 10 percent of this map unit.

Permeability is moderately slow. Available water capacity is 10 to 12 inches. Water-supplying capacity is 17 to 19 inches. Effective rooting depth is 40 to 60 inches or more. Runoff is slow, and the hazard of erosion is slight. A water table ranges from 12 inches above the surface to 12 inches below the surface from November through May.

This soil is used for farming, urban development and wildlife habitat.

This soil is suited to farming. If it is drained and irrigated, most climatically adapted crops do well. The major crops are berries, truck crops, nursery stock, hay, and pasture. Returning all crop residue to the soil helps maintain fertility and tilth. Where grain crops are grown, fertility can be maintained by cover crops, green-manure crops, and a cropping system that includes such soil-building crops as pasture or hay. A perched water table forms in this soil during rainy periods. Crops that require good drainage can be grown if a deep, random tile system is installed to remove the perched water. If the soil is to be left bare during winter, it should be fertilized and planted to a cover crop in fall.

Excessive cultivation can result in formation of a tillage pan in this soil. Subsoiling is required to break up this pan and is more successful if done when the soil is dry than when wet. Grain and grass crops need nitrogen. Legumes respond to phosphorus, lime, boron, and sulfur. Vegetable crops and berries respond to nitrogen, phosphorus, and potassium and in places, to sulfur.

The vegetation in areas not cultivated is western redcedar, Oregon ash, common snowberry, willow, roses, brackenfern, sedges, grasses, and forbs.

In areas not disturbed, this soil supports a rich mixture of trees, shrubs, and grasses that provides excellent food and cover for many wildlife species. Under the present monoculture, along with increasing demands for urban uses, this soil does not furnish a balanced distribution of cover and food for maximum wildlife population. The potential for wildlife habitat is good. Resident and seasonal wildlife using this area include ring-necked pheasant, California quail, mourning dove, band-tailed pigeon, foxes, raccoon, oppossum, squirrels, skunks, rabbits, mice, moles, and gophers. Nongame birds include hawks, owls, jays, crows, woodpeckers, flycatchers, hummingbirds, larks, and many kinds of small birds.

Increased population growth has resulted in increased urban development on this soil. The main limitation for urban uses is a seasonal water table (fig. 21). Dwellings and roads can be designed to offset this limitation if sewers are provided. Septic tank absorption fields do not function properly during rainy periods because of wetness and the moderately slow permeability. Drainage is required for best results with most lawn grasses, shade trees, ornamental trees, shrubs, vines, and vegetables, and irrigation during summer is desirable. Plants that tolerate a seasonal high water table and droughty conditions should be selected if drainage and irrigation are not provided. Recreational uses are limited by the seasonal high water table.

This soil is in capability subclass IIIw.

58D—Zygore gravelly loam, 5 to 30 percent slopes. This well drained soil is on broad ridgetops in mountainous areas. This soil formed in colluvium and glacial till from basalt and andesite mixed with volcanic ash. Elevation is 1,500 to 3,000 feet. The average annual precipitation is 80 to 100 inches, the average annual air temperature is 42 to 45 degrees F, and the frost-free period is 30 to 100 days.

Typically, the surface layer is dark brown gravelly loam about 10 inches thick. The subsoil is dark brown very cobbly loam about 14 inches thick. The substratum is

Appendix 4

Groundwater Report

GRI

Geotechnical Resources Incorporated

Consulting Engineers, Geologists, and Environmental Scientists

August 3, 1993 J\FINRPT-1.343

W&H Pacific
P.O. Box 80040
Portland, OR 97280

Attention: Jim Lenhart

SUBJECT: GROUNDWATER EVALUATION, BURLINGTON BOTTOMS, BURLINGTON, OREGON

At your request, Geotechnical Resources, Inc. (GRI) has conducted a limited groundwater evaluation at the above-referenced site. The evaluation consisted of a review of available geologic and hydrogeologic information for the site area, installation of a 2-in.-diameter groundwater monitoring well, and review of limited groundwater and surface water-level data from the monitoring well and adjacent lakes. This letter report documents the monitoring well installation and provides our general conclusions regarding the local groundwater regime.

Geologic Setting

The site occupies the western edge of the Columbia/Willamette floodplain. The floodplain is underlain by Quaternary-age alluvium consisting primarily of interbedded silt and sand. The alluvium laps against the Columbia River Basalt along the western edge of the floodplain and reaches a maximum thickness of about 150 ft near the middle of the floodplain.

Boring and Groundwater Monitoring Well

A 26.5-ft-deep boring was made on July 9, 1993, at the location shown on the Site Plan, Figure 1. The location of the boring was selected on the basis of discussions with W&H Pacific personnel and site access considerations. The boring was made with a trailer-mounted, continuous-flight, hollow-stem auger provided and operated by Vandehey Soil Exploration of Banks, Oregon. Disturbed soil samples were obtained from the boring at 2.5-ft intervals. The drilling was observed by an engineer/geologist from GRI who maintained a detailed log of the materials and conditions encountered in the boring, as shown on the Boring Log, Figure 2.

A 2-in.-diameter groundwater monitoring well was installed in the completed boring. Details of the monitoring well installation are shown on the Boring Log, Figure 2. On July 9, 1993, five well volumes of water were purged from the monitoring well with a sample bailer.

No chemical odors or discoloration were observed in subsurface soil samples or in water purged from the well.

Subsurface Conditions

From the ground surface to a depth of 13 ft, the boring encountered soft to stiff, brown mottled rust and gray silt with a trace of sand and clay. The silt was underlain to the bottom of the boring by loose, brown, sandy silt/silty sand.

9725 SW Beaverton-Hillsdale Hwy
Suite 140
Beaverton, Oregon 97005-3364
Phone (503) 641-3478
FAX (503) 644-8034

On July 13, 1993, groundwater in the monitoring well was measured at a depth of 4.6 ft below the ground surface (below the top of the 2-in. casing). Based on W&H Pacific's surveyed top-of-casing elevation of 17.49 ft, the groundwater elevation in the monitoring well is 12.9 ft. W&H Pacific provided a July 20, 1993, groundwater depth and elevation for the monitoring well of 5.2 and 12.3 ft, respectively. W&H Pacific measured a surface water elevation of 10.27 and 12.97 ft for the "lower" and "upper" lakes located northwest and northeast of the monitoring well, respectively.

Groundwater Regime

Based on our experience with groundwater conditions in the alluvial deposits along the Columbia/Willamette floodplain and the limited groundwater and surface water data obtained from the site, the groundwater table at the site is hydraulically connected to the Multnomah Channel of the Willamette River and roughly follows its seasonal fluctuations. Overall groundwater flow is likely to be toward the river, but may be away from the river during rapid rises in river levels.

Local groundwater levels are influenced by surface water levels in the lakes at the site. We understand that water backs up into the lakes during high stages in the Multnomah Channel. Elevated lake levels persist as channel levels drop as a result of inflow of creeks from the southwest and restrictions in lake outflow caused by beaver dams.

Limitations

This report has been prepared to aid the engineer and/or planner in an understanding of the groundwater regime at the Burlington Bottoms site. The scope was limited to a review of available geologic and hydrogeologic information for the site area, installation of a groundwater monitoring well, and review of limited groundwater and surface water data. Significant limitations are inherent in a study of this type, and additional investigations may be warranted to better define groundwater conditions.

Please contact the undersigned if you have any questions.

Sincerely,

GEOTECHNICAL RESOURCES, INC.

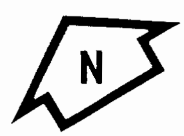
12/93

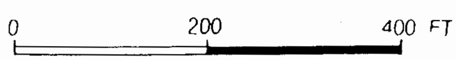
Dwight J. Hardin, P.E.
Principal

Kevin M. Foster, C.E.G., P.E.
Senior Geologist/Engineer

● 2-IN.-DIA. GROUNDWATER MONITORING WELL INSTALLED BY GEOTECHNICAL RESOURCES, INC. (JULY 9, 1993)

SITE PLAN PROVIDED BY W&H PACIFIC



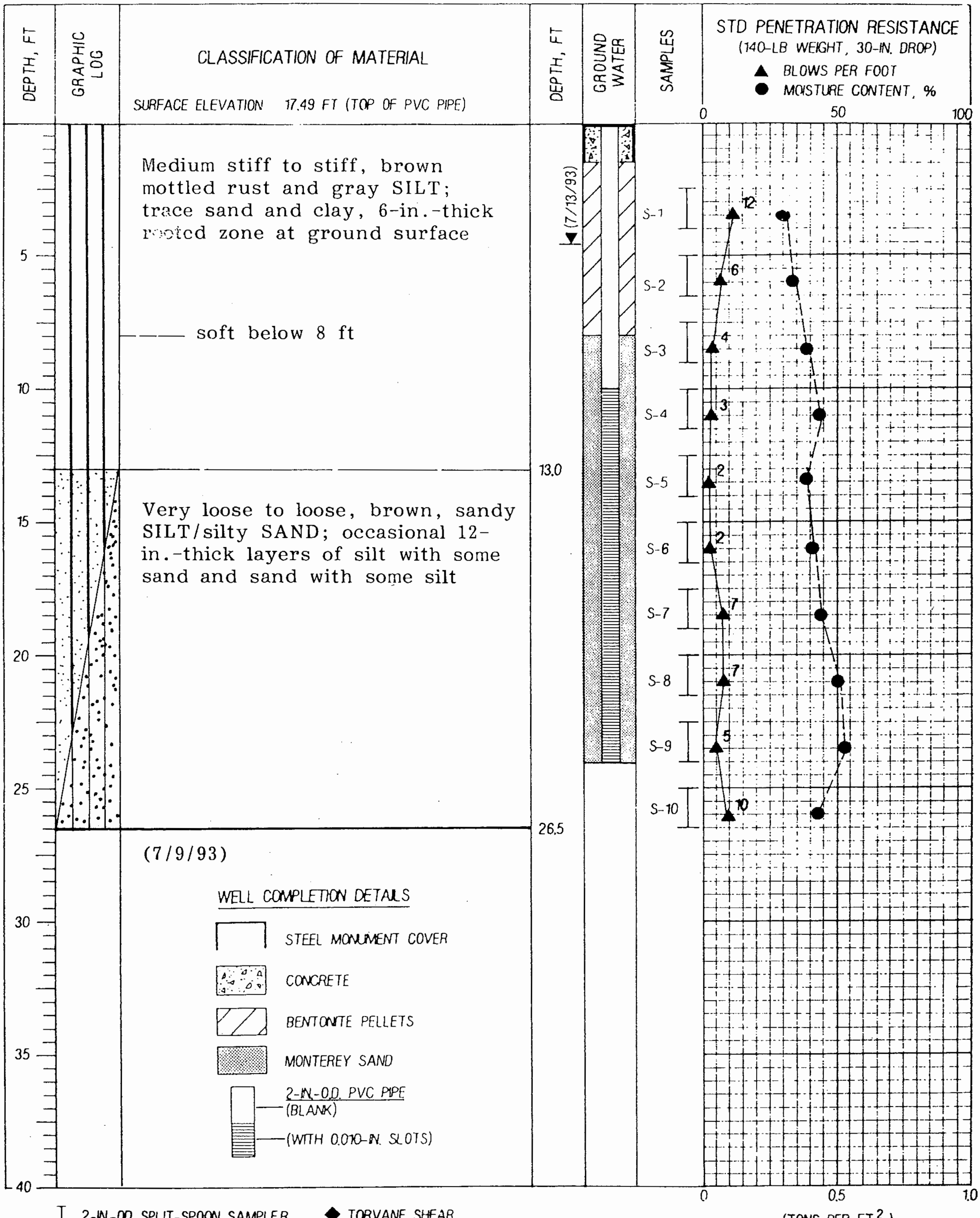


GRI

W&H PACIFIC
BURLINGTON BOTTOMS GROUNDWATER EVALUATION

SITE PLAN

AUG. 1993 JOB NO. 1343 FIG. 1



I 2-IN.-OD SPLIT-SPOON SAMPLER

II 3-IN.-OD THIN-WALLED SAMPLER

G GRAB SAMPLE OF DRILL CUTTINGS

▌ NX CORE RUN

| SLOTTED PVC PIPE

▼ WATER LEVEL (DATE)

◆ TORVANE SHEAR STRENGTH, TSF

■ UNDRAINED SHEAR STRENGTH, TSF

LIQUID LIMIT

MOISTURE CONTENT

PLASTIC LIMIT

GRI

BORING B-1

AUG. 1993 JOB NO. 1343 FIG. 2

Appendix 5

Water Quality Data

CHAIN OF CUSTODY RECORD

AMTEST

AmTest Inc.
Professional Analytical Services
9205 S.W. Nimbus Av
Beaverton, OR 97005
Tel: 503 292 0554

DATE: 6-25-93.

Project Manager James Lenhart
Company Name W & H Pacific
Address
City, State ZIP
Phone and FAX

P.O. # or Project Number 167-07-01
Project Name Burlington Bottoms.
Project Location Burlington Bottoms.

Lab Project Number 17606-9-R
Lab Location R6-S1

RUSH? YES NO

LAB USE ONLY	SAMPLE IDENTIFICATION ID #, LOCATION, DATE, TIME, DEPTH	SAMPLE MATRIX	ANALYSIS REQUIRED
17606	culvert ~~X~~ 14 ICP, O	Water	ICP, O&G, N.P.K., TSS
17607	culvert 2 8	↓	↓
17608	upper Lake 1		
17609	~~lower~~ lake. 1		
	HORSESHOE not enough	sample for TKN	
	O&G, TSS, ICP, Nitrite, N+N, ~~TKN~~, Total	Phos, Dissolved Phos,	
	Ortho-Phos, Potassium (in ICP), pH		

Relinquished By	Received By	Time	Date	Reason For Change
[signature]	[signature]	9am	6-25-93	to lab
Relinquished By	Received By	Time	Date	Reason For Change
Relinquished By	Received By	Time	Date	Reason For Change

AMTEST

AmTest Inc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 626 7424
Fax: 503 643 1460

ANALYSIS REPORT

C
L Jim Lenhart
I W & H Pacific
E 8405 SW Nimbus Avenue
N Beaverton OR 97005
T

Date Received: 6/25/93
Date Analyzed: 6/25/93
Date Reported: 6/29/93
Job Number: 17606-9-R

P.O. #167-07-01
Project - Burlington Bottoms
Sample Type - Water

Lab Number	Client Identification	pH Analysis - EPA Method 150.1 Results
17606	**Culvert** ~~1~~ 14	**8.1**
17606-Dup	**Culvert** ~~1~~ 14	**8.2**
17607	**Culvert** ~~2~~ 8	**7.1**
17608	**Upper Lake** 1	**7.2**
17609	HORSESHOE ~~**Lower**~~ **Lake**	**10.4**

pH - Taken upon receipt 6/25/93

QC Information
Buffer (pH 7.0) - 7.02 at 25° C.

Reported By ____________

QA Check ____________

____
Greg Bolt
Laboratory Manager

AMTEST

AmTest Inc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 626 7424
Fax: 503 643 1460

ANALYSIS REPORT

CLIENT
Jim Lenhart
W & H Pacific
8405 SW Nimbus Avenue
Beaverton OR 97005

Date Received: 6/25/93
Date Analyzed: 6/25/93 & 7/8/93
Date Reported: 7/12/93
Job Number: 17606-9-R

P.O. #167-07-01
Project - Burlington Bottoms
Sample Type - Water

Nitrate + Nitrite & Nitrite Nitrogen
EPA Method 353.2 & EPA Method 354.1

Lab Number	Client Identification	Results mg/L (ppm) Nitrate + Nitrite	Nitrite
17606	**Culvert ~~1~~ 14**	**0.12**	**0.035**
17607	**Culvert ~~2~~ 8**	**0.23**	**0.039**
17608	**Upper Lake**	**ND**	**0.031**
17609	HORSESHOE **~~Lower~~ Lake**	**ND**	**0.075**
17609-Dup	HORSESHOE **~~Lower~~ Lake**	**-**	**0.073**
Lab Blank	6/25/93	ND	ND
	Detection Limit	0.02	0.005

ND = None Detected

QC Information
Spike (Nitrite) Recovery - 93%
Matrix Spike (Nitrite) Recovery - 95%

Reported By R

QA Check GB

Greg Bolt
Greg Bolt
Laboratory Manager

AMTEST

AmTestInc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel:503 626 7424
Fax:503 643 1460

ANALYSIS REPORT

C
L Jim Lenhart
I W & H Pacific
E 8405 SW Nimbus Avenue
N Beaverton OR 97005
T

Date Received: 6/25/93
Date Analyzed: 6/29/93
Date Reported: 6/30/93
Job Number: 17606-9-R

P.O. #167-07-01
Project - Burlington Bottoms
Sample Type - Water

Lab Number	Client Identification	Total Settleable Solids Analysis - EPA Method 160.2 Results mg/L (ppm)
17606	**Culvert** ~~1~~ 14	**ND**
17607	**Culvert** ~~2~~ 8	**ND**
17608	**Upper Lake**	**ND**
17609	HORSESHOE ~~Lower~~ **Lake**	**34**

Detection Limit - 5 mg/L

Reported By Hugh A Healey
QA Check GB

Greg Bolt
Laboratory Manager

AMTEST

AmTest Inc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 626 7424
Fax: 503 643 1460

ANALYSIS REPORT

C
L Jim Lenhart
I W & H Pacific
E 8405 SW Nimbus Avenue
N Beaverton OR 97005
T

Date Received: 6/25/93
Date Analyzed: 6/30/93
Date Reported: 6/30/93
Job Number: 17606-9-R

P.O. #167-07-01
Project - Burlington Bottoms
Sample Type - Water

Lab Number	Client Identification	Oil & Grease Analysis - EPA Method 413.2 Results mg/L (ppm)
17606	**Culvert ~~1~~ 14**	**ND**
17607	**Culvert ~~2~~ 8**	**ND**
17608	**Upper Lake**	**ND**
17609	HORSESHOE **~~Lower~~ Lake**	**0.5**

Detection Limit - 0.5 mg/L

QC Information
Spike (Reference Oil) Recovery - 85%

Reported By ____________

QA Check ____________

Greg Bolt
Laboratory Manager

AMTEST

AmTest Inc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 626 7424
Fax: 503 643 1460

ANALYSIS REPORT

C
L Jim Lenhart
I W & H Pacific
E 8405 SW Nimbus Avenue
N Beaverton OR 97005
T

Date Received: 6/25/93
Date Analyzed: 6/25/93
Date Reported: 6/30/93
Job Number: 17606-9-R

P.O. #167-07-01

Project - Burlington Bottoms

Sample Type - Water

Dissolved, Ortho, & Total Phosphorus
EPA Method 365.3
Results mg/L (ppm)

Lab Number	Client Identification	Dissolved	Ortho	Total
17606	**Culvert ~~1~~ 14**	**ND**	**ND**	**0.04**
17606-Dup	**Culvert ~~1~~ 14**	-	-	**0.05**
17607	**Culvert ~~2~~ 8**	**ND**	**0.05**	**0.04**
17608	**Upper Lake**	**Interference**	**ND**	**0.05**
17609	HORSESHOE **~~Lower~~ Lake**	**0.04**	**ND**	**0.39**
17609-Dup	HORSESHOE **~~Lower~~ Lake**	-	**ND**	-
Lab Blank	6/25/93	0.02	ND	ND
	Detection Limit	0.02	0.02	0.02

ND = None Detected

QC Information

Spike (Phosphorus) Recovery - 92%
Spike (Phosphorus) Recovery - 143%
Matrix Spike (Total Phosphorus) Recovery - 132%
Matrix Spike (Ortho-Phosphorus) Recovery - 116%

Reported By [signature]

QA Check [signature]

Greg Bolt
Laboratory Manager

ANALYSIS REPORT

AMTEST

AmTest Inc.
Professional Analytical Services
9205 S.W. Nimbus Ave.
Beaverton, OR
97005
Tel: 503 626 7424
Fax: 503 643 1460

CLIENT
Jim Lenhart
W & H Pacific
8405 SW Nimbus Avenue
Beaverton OR 97005

Date Received: 6/25/93
Date Analyzed: 7/8/93
Date Reported: 7/12/93
Job Number: 17606-9-R
Page 6 of 7

Analysis - ICP Metals (EPA Method 200.7)
Project - Burlington Bottoms P.O. # 167-07-01
Sample Type - Water

Laboratory Sample Number / Client Identification	17606 Culvert ~~1~~ 14	17607 Culvert ~~2~~ 8	Lab Blank	Detection Limit
Element	Results mg/L	Results mg/L	Results mg/L	mg/L
Aluminum	0.06	0.92	ND	0.01
Antimony	ND	ND	ND	0.02
Arsenic	ND	ND	ND	0.03
Boron	ND	ND	ND	0.1
Barium	0.05	0.024	ND	0.003
Beryllium	ND	ND	ND	0.005
Calcium	29	7.8	ND	0.1
Cadmium	ND	ND	ND	0.002
Cobalt	ND	ND	ND	0.003
Chromium	ND	ND	ND	0.006
Copper	ND	ND	ND	0.002
Iron	1.9	0.92	ND	0.01
Mercury	ND	ND	ND	0.01
Potassium	2	1.1	ND	1
Lithium	ND	ND	ND	0.02
Magnesium	7.9	2.6	ND	0.1
Manganese	0.4	0.027	ND	0.002
Molybdenum	ND	ND	ND	0.01
Sodium	5.8	5.4	ND	0.1
Nickel	ND	ND	ND	0.01
Phosphorus	0.13	0.13	ND	0.05
Lead	ND	ND	ND	0.02
Sulfur	2.7	2.1	ND	0.1
Selenium	ND	ND	ND	0.03
Silicon	8.4	12	ND	0.1
Silver	ND	ND	ND	0.01
Tin	ND	ND	ND	0.02
Strontium	0.18	0.05	ND	0.003
Titanium	ND	0.05	ND	0.01
Thallium	ND	ND	ND	0.03
Vanadium	ND	ND	ND	0.002
Yttrium	ND	ND	ND	0.001
Zinc	0.01	0.021	0.007	0.002

ND = None Detected

R
Reported By

GB
QA Check

Greg Bolt
Greg Bolt
Laboratory Manager

ANALYSIS REPORT

AMTEST

AmTestInc.

Professional Analytical Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 626 7424
Fax: 503 643 1460

CLIENT

Jim Lenhart
W & H Pacific
8405 SW Nimbus Avenue
Beaverton OR 97005

Date Received: 6/25/93
Date Analyzed: 7/8/93
Date Reported: 7/12/93
Job Number: 17606-9-R

Analysis - ICP Metals (EPA Method 200.7)
Project - Burlington Bottoms P.O. # 167-07-01
Sample Type - Water

Laboratory Sample Number Client Identification	17608 **Upper Lake**	17608-Dup **Upper Lake**	17609 HORSESHOE ~~Lower~~ Lake	Detection Limit
Element	Results mg/L	Results mg/L	Results mg/L	mg/L
Aluminum	**0.03**	**0.02**	**0.32**	**0.01**
Antimony	**ND**	**ND**	**ND**	**0.02**
Arsenic	**ND**	**ND**	**ND**	**0.03**
Boron	**0.16**	**0.15**	**ND**	**0.1**
Barium	**0.022**	**0.022**	**0.008**	**0.003**
Beryllium	**ND**	**ND**	**ND**	**0.005**
Calcium	**18**	**18**	**11**	**0.1**
Cadmium	**ND**	**ND**	**ND**	**0.002**
Cobalt	**ND**	**ND**	**ND**	**0.003**
Chromium	**ND**	**ND**	**ND**	**0.006**
Copper	**ND**	**ND**	**ND**	**0.002**
Iron	**1.8**	**1.8**	**0.62**	**0.01**
Mercury	**ND**	**ND**	**ND**	**0.01**
Potassium	**1.2**	**1.1**	**ND**	**1**
Lithium	**ND**	**ND**	**ND**	**0.02**
Magnesium	**5.8**	**6**	**3.7**	**0.1**
Manganese	**0.19**	**0.16**	**0.055**	**0.002**
Molybdenum	**ND**	**ND**	**ND**	**0.01**
Sodium	**8.9**	**9.2**	**5.9**	**0.1**
Nickel	**ND**	**ND**	**ND**	**0.01**
Phosphorus	**0.1**	**0.15**	**0.44**	**0.05**
Lead	**ND**	**ND**	**ND**	**0.02**
Sulfur	**1.9**	**2**	**1.3**	**0.1**
Selenium	**ND**	**ND**	**ND**	**0.03**
Silicon	**4**	**4**	**2.9**	**0.1**
Silver	**ND**	**ND**	**ND**	**0.01**
Tin	**ND**	**ND**	**ND**	**0.02**
Strontium	**0.12**	**0.12**	**0.055**	**0.003**
Titanium	**ND**	**ND**	**0.02**	**0.01**
Thallium	**ND**	**ND**	**ND**	**0.03**
Vanadium	**ND**	**ND**	**0.008**	**0.002**
Yittrium	**ND**	**ND**	**ND**	**0.001**
Zinc	**ND**	**ND**	**ND**	**0.002**

ND = None Detected

R
Reported By

GB
QA Check

Greg Bolt
Greg Bolt
Laboratory Manager

CHAIN OF CUSTODY RECORD

AMTEST

AmTestInc.
Professional Analytical Services
9205 S.W. Nimbus Ave
Beaverton, OR 97005
Tel: 503 626 7424
Fax: 503 643 1460

DATE: 7·27·93

Project Manager Jim Lenhart
Company Name W&H Pacific, Inc.
Address 8405 SW Nimbus Avenue
City, State ZIP Beaverton, OR 97005
Phone and FAX 626·0455

Lab Project Number 20802·5-R

P.O. # or Project Number 4·167·0701
Project Name Burlington Bottoms
Project Location US Hwy. 30 @ Sauvies Island Bridge

Lab Location R4S3, R2S1

RUSH? YES NO

LAB USE ONLY	SAMPLE IDENTIFICATION ID #, LOCATION, DATE, TIME, DEPTH	SAMPLE MATRIX	ANALYSIS REQUIRED
20802	S.W. Well #1 7·27·93, 13:30, 5'-2"	Water	pH
20803	S.W. Well #2 7·27·93, 13:35, 5'-2"		Oil+Grease
20804	~~Horse Shoe~~ HORSESHOE Lake 2 7·27·93, 14:00, Surface	Small Samples	ICP Metals
20805	UPPER ~~Lower~~ Lake 2 7·27·93, 14:20, Surface		Nitrate/Nitrite
			TSS, TKN,
			Ortho, Dissolved
			and total Phos
	RUSH on ICP Metals per Jim php		

Relinquished By	Received By	Time	Date	Reason For Change
Mike Smyth	[signature]	15:30	7·27·93	to LAB
Relinquished By	Received By	Time	Date	Reason For Change
Relinquished By	Received By	Time	Date	Reason For Change

AmTest Inc.
Professional Analytical Services
9205 S.W. Nimbus Ave.
Beaverton, OR 97005
Tel: 503 292 0554

ANALYSIS REPORT

CLIENT
Jim Lenhart
W & H Pacific
8405 SW Nimbus Avenue
Beaverton OR 97005

Date Received: 7/27/93
Date Analyzed: 7/27/93
Date Reported: 8/3/93
Job Number: 20802-5-R

P.O. # 4-167-0701
Project - Burlington Bottoms
Sample Type - Water

Lab Number	Client Identification	pH Analysis - EPA Method 150.1 Results
20802	**GW Well #1**	**6.6**
20803	**GW Well #2**	**6.6**
20804	UPPER **~~Horse Shoe~~ Lake** 2	**8.5**
20805	HORSESHOE **~~Lower~~ Lake** 2	**10.2**

Reported By Hugh Healey

QA Check GB

Greg Bolt
Laboratory Manager

AMTEST

AmTest Inc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 292 0554

ANALYSIS REPORT

CLIENT
Jim Lenhart
W & H Pacific
8405 SW Nimbus Avenue
Beaverton OR 97005

Date Received: 7/27/93
Date Analyzed: 8/2/93
Date Reported: 8/3/93
Job Number: 20802-5-R

P.O. # 4-167-0701
Project - Burlington Bottoms
Sample Type - Water

Lab Number	Client Identification	Total Suspended Solids Analysis - EPA Method 160.2 Results mg/L
20802	**GW Well #1**	**28**
20803	**GW Well #2**	**300**
20804	UPPER ~~Horse Shoe~~ **Lake** 2	**ND**
20804-Dup	UPPER ~~Horse Shoe~~ **Lake** 2	**ND**
20805	HORSESHOE ~~Lower~~ **Lake** 2	**21**
Lab Blank	8/2/93	**ND**

Detection Limit - 5 mg/L

ND = None Detected

Reported By Hugh Healey

QA Check GB

Greg Bolt
Laboratory Manager

AMTEST

AmTest Inc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 292 0554

ANALYSIS REPORT

C
L Jim Lenhart
I W & H Pacific
E 8405 SW Nimbus Avenue
N Beaverton OR 97005
T

Date Received: 7/27/93
Date Analyzed: 8/2/93
Date Reported: 8/3/93
Job Number: 20802-5-R

P.O. # 4-167-0701
Project - Burlington Bottoms
Sample Type - Water

Lab Number	Client Identification	Oil & Grease Analysis - EPA Method 413.2 Results mg/L
20802	**GW Well #1**	**ND**
20803	**GW Well #2**	**ND**
20804	UPPER **~~Horse Shoe~~ Lake** 2	**ND**
20805	HORSESHOE **~~Lower~~ Lake** 2	**ND**
Lab Blank	8/2/93	**ND**

Detection Limit - 0.5 mg/L

ND = None Detected

QC Information
Spike (Reference Oil) Recovery - 86%

Reported By [signature]

QA Check [signature]

[signature]
Greg Bolt
Laboratory Manager

AMTEST

AmTest Inc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 292 0554

ANALYSIS REPORT

C
L Jim Lenhart
I W & H Pacific
E 8405 SW Nimbus Avenue
N Beaverton OR 97005
T

Date Received: 7/27/93
Date Analyzed: 7/28 & 8/2/93
Date Reported: 8/3/93
Job Number: 20802-5-R

P.O. # 4-167-0701
Project - Burlington Bottoms
Sample Type - Water

Nitrate + Nitrite & Nitrite Nitrogen
EPA Method 353.2 & EPA Method 354.1

Lab Number	Client Identification		Results mg/L (ppm) Nitrate + Nitrite	Nitrite
20802	**GW Well #1**		**1**	**ND**
20803	**GW Well #2**		**0.93**	**ND**
20803-Dup	**GW Well #2**		**-**	**ND**
20804	UPPER **~~Horse Shoe~~ Lake** 2		**0.44**	**ND**
20805	HORSESHOE **~~Lower~~ Lake** 2		**ND**	**ND**
Lab Blank	7/28/93		ND	ND
		Detection Limit	0.01	0.005

ND = None Detected

QC Information
Spike (Nitrite) Recovery - 94%
Matrix Spike (Nitrite) Recovery - 99%
Spike (N+N) Recovery - 116%

Reported By R

QA Check GB

Greg Bolt
Laboratory Manager

ANALYSIS REPORT

AmTest Inc.
Professional Analytical Services
9205 S.W. Nimbus Ave.
Beaverton, OR
97005
Tel: 503 292 0554

AMTEST

C
L Jim Lenhart
I W & H Pacific
E 8405 SW Nimbus Avenue
N Beaverton OR 97005
T

Date Received: 7/27/93
Date Analyzed: 8/2/93
Date Reported: 8/4/93
Job Number: 20802-5-R

Analysis - ICP Metals (EPA Method 200.7)
Project - Burlington Bottoms #4-167-0701
Sample Type - Water

Laboratory Sample Number / Client Identification	20802 GW Well #1	20803 GW Well #2	20804 UPPER ~~Horseshoe~~ Lake 2	Detection Limit
Element	Results mg/L	Results mg/L	Results mg/L	mg/L
Aluminum	0.41	17	0.11	0.01
Antimony	ND	0.03	ND	0.02
Arsenic	ND	ND	ND	0.03
Boron	ND	ND	0.26	0.1
Barium	0.016	0.13	0.013	0.003
Beryllium	ND	ND	ND	0.005
Calcium	15	21	22	0.1
Cadmium	ND	ND	ND	0.002
Cobalt	0.031	0.042	0.03	0.003
Chromium	ND	0.018	ND	0.006
Copper	ND	0.01	ND	0.002
Iron	0.69	27	0.7	0.01
Mercury	ND	ND	ND	0.01
Potassium	1.3	3.4	ND	1
Lithium	ND	ND	ND	0.02
Magnesium	6.9	11	7.1	0.1
Manganese	0.012	0.3	0.023	0.002
Molybdenum	ND	ND	ND	0.01
Sodium	6.7	8.7	13	0.1
Nickel	0.02	0.01	ND	0.01
Phosphorus	0.14	1.5	ND	0.05
Lead	ND	ND	ND	0.02
Sulfur	4.3	6	1.7	0.1
Selenium	ND	ND	ND	0.03
Silicon	26	55	2.6	0.1
Silver	ND	ND	ND	0.01
Tin	ND	0.03	ND	0.02
Strontium	0.075	0.13	0.15	0.003
Titanium	0.05	2.6	ND	0.01
Thallium	0.06	0.1	ND	0.03
Vanadium	0.011	0.081	ND	0.002
Yttrium	ND	0.011	ND	0.001
Zinc	0.003	0.076	ND	0.002

ND = None Detected

R
Reported By

GB
QA Check

Greg Bolt
Greg Bolt
Laboratory Manager

ANALYSIS REPORT

C
L Jim Lenhart
I W & H Pacific
E 8405 SW Nimbus Avenue
N Beaverton OR 97005
T

AMTEST

Date Received: 7/27/93
Date Analyzed: 8/2/93
Date Reported: 8/4/93
Job Number: 20802-5-R

AmTest Inc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 292 0554

Analysis - ICP Metals (EPA Method 200.7)
Project - Burlington Bottoms #4-167-0701
Sample Type - Water

Laboratory Sample Number / Client Identification	20805 HORSESHOE ~~Lower~~ Lake 2	Lab Blank	Spike	Detection Limit
Element	Results mg/L	Results mg/L	% Recovery	mg/L
Aluminum	0.08	ND	96	0.01
Antimony	ND	ND	109	0.02
Arsenic	ND	ND	90	0.03
Boron	0.17	ND	-	0.1
Barium	0.006	ND	92	0.003
Beryllium	ND	ND	94	0.005
Calcium	17	ND	100	0.1
Cadmium	ND	ND	88	0.002
Cobalt	0.037	ND	-	0.003
Chromium	ND	ND	95	0.006
Copper	ND	ND	97	0.002
Iron	0.43	ND	107	0.01
Mercury	ND	ND	-	0.01
Potassium	ND	ND	95	1
Lithium	ND	ND	100	0.02
Magnesium	6.2	ND	90	0.1
Manganese	0.023	ND	97	0.002
Molybdenum	ND	ND	-	0.01
Sodium	10	ND	100	0.1
Nickel	ND	ND	90	0.01
Phosphorus	0.21	ND	-	0.05
Lead	ND	ND	90	0.02
Sulfur	0.5	ND	-	0.1
Selenium	0.04	ND	90	0.03
Silicon	2.8	ND	-	0.1
Silver	ND	ND	-	0.01
Tin	ND	ND	100	0.02
Strontium	0.11	ND	98	0.003
Titanium	ND	ND	-	0.01
Thallium	0.04	ND	78	0.03
Vanadium	ND	ND	-	0.002
Yittrium	ND	ND	90	0.001
Zinc	ND	ND	88	0.002

ND = None Detected

R
Reported By

GB
QA Check

Greg Bolt
Greg Bolt
Laboratory Manager

AMTEST

AmTest Inc.

Professional
Analytical
Services

9205 S.W. Nimbus Ave.
Beaverton, OR
97005

Tel: 503 292 0554

ANALYSIS REPORT

CLIENT
Jim Lenhart
W & H Pacific
8405 SW Nimbus Avenue
Beaverton OR 97005

Date Received: 7/27/93
Date Analyzed: 7/29/93 & 8/3/93
Date Reported: 8/3/93
Job Number: 20802-5-R
Page 7 of 7

P.O. # 4-167-0701
Project - Burlington Bottoms
Sample Type - Water

Dissolved, Ortho, & Total Phosphorus
EPA Method 365.3
Results mg/L (ppm)

Lab Number	Client Identification	Dissolved	Ortho	Total
20802	**GW Well #1**	**0.09**	**0.12**	**0.16**
20803	**GW Well #2**	**0.09**	**0.29**	**0.37**
20804	UPPER **~~Horse Shoe~~ Lake** 2	**0.01**	**0.01**	**0.05**
20805	HORSESHOE **~~Lower~~ Lake** 2	**0.02**	**0.03**	**0.15**
20805-Dup	HORSESHOE **~~Lower~~ Lake** 2	-	**0.02**	-
Lab Blank	7/29/93	ND	ND	ND
	Detection Limit	0.01	0.01	0.01

ND = None Detected

QC Information
Spike (Phosphorus) Recovery - 97%
Spike (Phosphorus) Recovery - 96%
Matrix Spike (Total Phosphorus) Recovery - 87%
Matrix Spike (Ortho-Phosphorus) Recovery - 94%

Reported By ____________

QA Check ____________

Greg Bolt
Laboratory Manager

Exhibit 9

BOOK 2355 PAGE 1112

0

574282

DEED OF CONSERVATION EASEMENT

THIS GRANT DEED OF CONSERVATION EASEMENT is made this 14th day of September, 1990, by CROWN PACIFIC, LTD., having an address at 121 S.W. Morrison Street, Suite 900, Portland, Oregon 97204

("Grantors"), in favor of FRIENDS OF FOREST PARK a nonprofit corporation in the State of Oregon, having an address at

P.O. Box 2413, Portland, Oregon 97208 ("Grantee").

Recorded By Ticor Title Insurance Company

WITNESSETH:

WHEREAS, Grantors are the sole owners in fee simple of certain real property in Multnomah County, Oregon, more particularly described in Dwelling Site Plan attached hereto and incorporated by this reference (the "Property"; and

WHEREAS, Grantors intend to promote conservation values over a portion of said property, herein referred to as "Easement Area" and more particularly described as Conservation Easement on Dwelling Site Plan attached hereto, and

WHEREAS, Grantors intend to convey to Grantee the right to aid in preserving and protecting the conservation values of the Easement Area, and

WHEREAS, Grantee agrees by accepting this grant to honor the intentions of the Grantors stated herein to aid in preserving and protecting the conservation values of the Easement Area;

NOW, THEREFORE, in consideration of the above and the mutual covenants, terms, conditions, and restrictions contained herein, and pursuant to the laws of the State of Oregon, Grantors hereby voluntarily grant and convey to the Grantee a conservation easement over the Property of the nature and character and to the extent hereinafter set forth ("Easement").

1. Rights of the Grantee. Grantee has the right to:

(a) Enter the Easement Area for the wildlife conservation purposes set forth in this easement. All property inspections must be coordinated with, and approved by, the Grantor. Inspection times, locations, and number of visitors must be approved by Grantor. No less than three visits per year must be allowed if so requested by Grantee.

(b) Prevent any activity on or use of the Easement Area that is prohibited by this agreement and to require restoration of such areas or features of the Easement Area that may be damaged by any prohibited activity or use.

AFTER RECORDING, RETURN TO

Friends of Forest Park
P.O. Box 2413
Portland, Oregon 97208

UNTIL A CHANGE IS REQUESTED, ALL TAX STATEMENTS SHOULD BE SENT TO:

Crown Pacific, Ltd.
121 S.W. Morrison Street, Suite 900
Portland, Oregon 97204

10-23-90

2. Prohibited and Permitted Uses of the Easement Area.

(a) Vehicles. Use of unmuffled motorized vehicles is prohibited, as is off-road recreational use of vehicles. Recreational use of motorcycles anywhere in the Easement Area is prohibited. Continuous, repetitious vehicular trips for purposes other than land and resource management are prohibited. Motorized vehicular use is permitted for the usual and accustomed uses of forest management and quiet enjoyment of the property.

(b) Stream Protection Areas. The cutting, topping, or removal of native vegetation, including replanted trees, and woody debris is prohibited within 75 feet of either side of all streams, perennial or intermittent, mechanically or by any other means except for maintenance of, or creation of access roads or trails required for the forest or resource management of the land. New stream crossings shall be reviewed by the U.S. Soil Conservation Service. Under no circumstances shall a new crossing be within 300 feet of another crossing of the same stream. Grantor shall not cut trees greater than 14-inch diameter (measured 1 foot from ground) as a result of access construction or maintenance within the stream protection area without notification of and approval by Grantee. Grantee's approval shall not be unreasonably withheld and Grantee shall cooperate such that timber management outside the Stream Protection Area is not adversely affected.

(c) Snags and Large Woody Debris. It is prohibited to fell snags of more than 14-inch diameter in the native forest. Any badly damaged, broken or otherwise unmerchantable trees of more than 14-inch diameter (measured 1 foot from ground) must be left as is except with notification of and approval by Grantee. Use of these trees for firewood is prohibited.

(d) Reforestation. Notwithstanding compliance with all state and local laws and regulations regarding post-harvest reforestation, replanted species in the Easement Area shall be a mix of Douglas fir and shade tolerant conifers, native to the Pacific Northwest, planted and grown without chemical herbicide use. Species shall include no less than 10% grand fir, 15% western Hemlock, and 15% western red cedar.

(e) Timber Harvest. All provisions of (b) and (c) above apply. Additionally, a clear cut is to be not more than 10 acres maximum in area, and no clear cut shall occur where clear cutting on the same property has taken place within the previous seven years.

(f) Hunting and Firearms. Hunting and the discharge of firearms are prohibited in the Easement Area.

10-23-90

(g) Improvements. Water storage and delivery systems construction and maintenance are permitted on the Easement Area.

(h) Subdivision and Dwellings. Subdivision of land for any purpose is prohibited. Construction of dwellings in the Easement Area is prohibited.

(i) Invasive, Exotic Ornamental Plants. The planting of English Ivy, Vinca major, Vinca minor and English holly is prohibited anywhere on the property. The planting of any non-native species in the Easement Area is prohibited, except as part of a county, state, or Federally approved soil conservation plan.

(j) Logging and Access Roads. Roads other than driveways to dwellings and garages may be maintained as firelanes. They must be securely gated at McNamee Road to preclude any unauthorized, or prohibited as in (a) above, motorized vehicle use.

(k) Fencing. No fencing of any kind is permitted within the Easement Area or along the Easement Area borders except where the Easement Area borders private land not under Conservation Easement status.

(l) Domestic Animals. Unattended domestic animals, such as cows and horses, are prohibited within the Easement Area.

(m) Dogs and Cats. Dogs are to be securely confined in areas outside the Easement Area unless accompanied by owner. In no event shall a dog be allowed to run wild in the Easement Area. Domestic cats shall be belled when outside the house.

3. Grantee's Approval. Where Grantee's approval is required for any action, Grantee shall grant or withhold its approval in writing within 30 days receipt of Grantor's written request thereof. Grantee's approval may be withheld only upon a reasonable determination by Grantee that the action as proposed would be inconsistent with the purpose of this Easement.

4. Costs of Enforcement. Any costs incurred by Grantee in the legal enforcement of the terms of the Easement against Grantors shall be borne by Grantors in the event that Grantees prevail in any legal action. If Grantors prevail in any action to enforce the terms of this Easement, Grantor's costs of suit shall be borne by Grantee.

5. Acts Beyond the Grantors' Control. Nothing contained in this Easement shall be construed to entitle Grantee to bring any action against Grantors for any injury to or change in the Property resulting from causes beyond Grantors' control or from any prudent action taken by Grantors under

10-23-90

emergency conditions to prevent, abate, or mitigate significant injury to the Property resulting from such causes.

6. Access. No right of access by the general public to any portion of the Property is conveyed by this Easement.

7. Termination of Rights and Obligations. A party's rights and obligations under this Easement terminate upon transfer of the party's interest in the Easement or Property, except that liability for acts or omissions occurring prior to transfer shall survive transfer.

8. Successors. Grantee shall not transfer or assign this easement to any other party or agent without the written agreement of Grantor. Such agreement shall not be unreasonably withheld. If Grantee terminates their rights and obligations, a suitable successor organization, either public or private, whose primary mission is conservation, shall be selected by Grantor to become Grantee. Grantee shall give 90 days notice before termination.

TO HAVE AND TO HOLD unto Grantee, its approved successors, and approved assigns forever.
IN WITNESS WHEREOF Grantors and Grantee have set their hands on the day and year first above written.

CROWN PACIFIC, LTD.

Roger Krage, Sect

Grantors

FRIENDS OF FOREST PARK

Grantee

by James D. Hays

its President

10-23-90

STATE OF OREGON)
) ss
County of Multnomah)

The foregoing Deed of Conservation Easement was acknowledged before me this 14th day of September, 1990, by Roger L. Krage, who is the Secretary of Crown Pacific, Ltd., on behalf of the corporation.

Resa R. DeWitt
Notary Public for Oregon
My Commission Expires: 04/15/94

Resa R. DeWitt
RESA R. DeWITT
NOTARY PUBLIC - OREGON
My Commission Expires 04/15/94

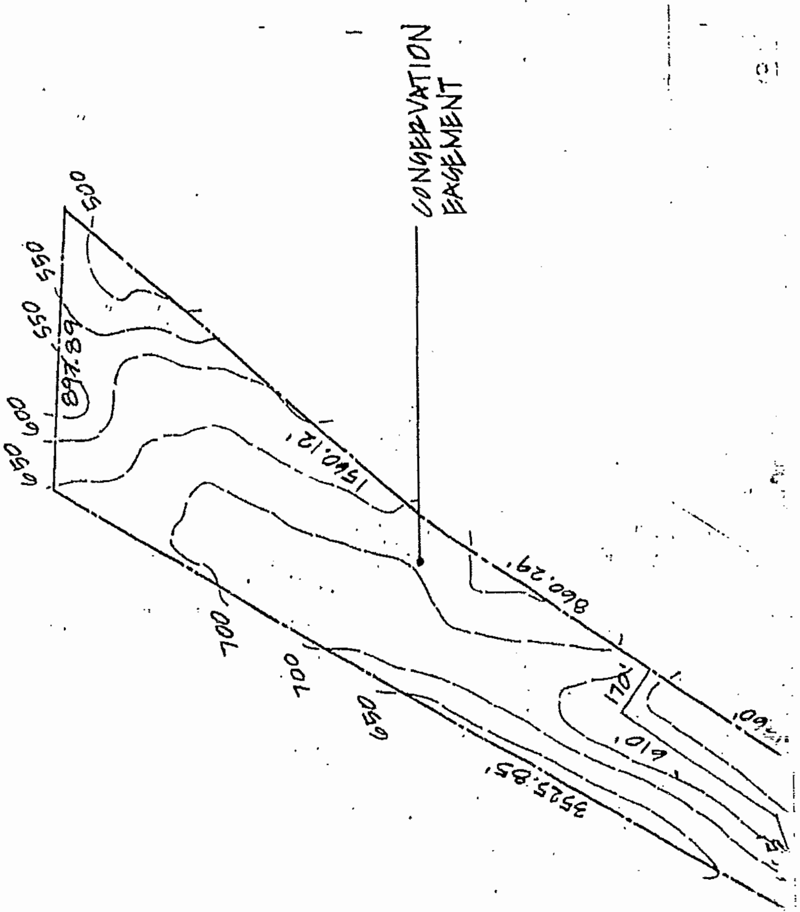
STATE OF OREGON)
) ss
County of Multnomah)

The foregoing Deed of Conservation Easement was acknowledged before me this 14th day of September, 1990, by James D. Thayer, who is the President of Friends of Forest Park, on behalf of the corporation.

Resa R. DeWitt
Notary Public for Oregon
My Commission Expires: 04/15/94

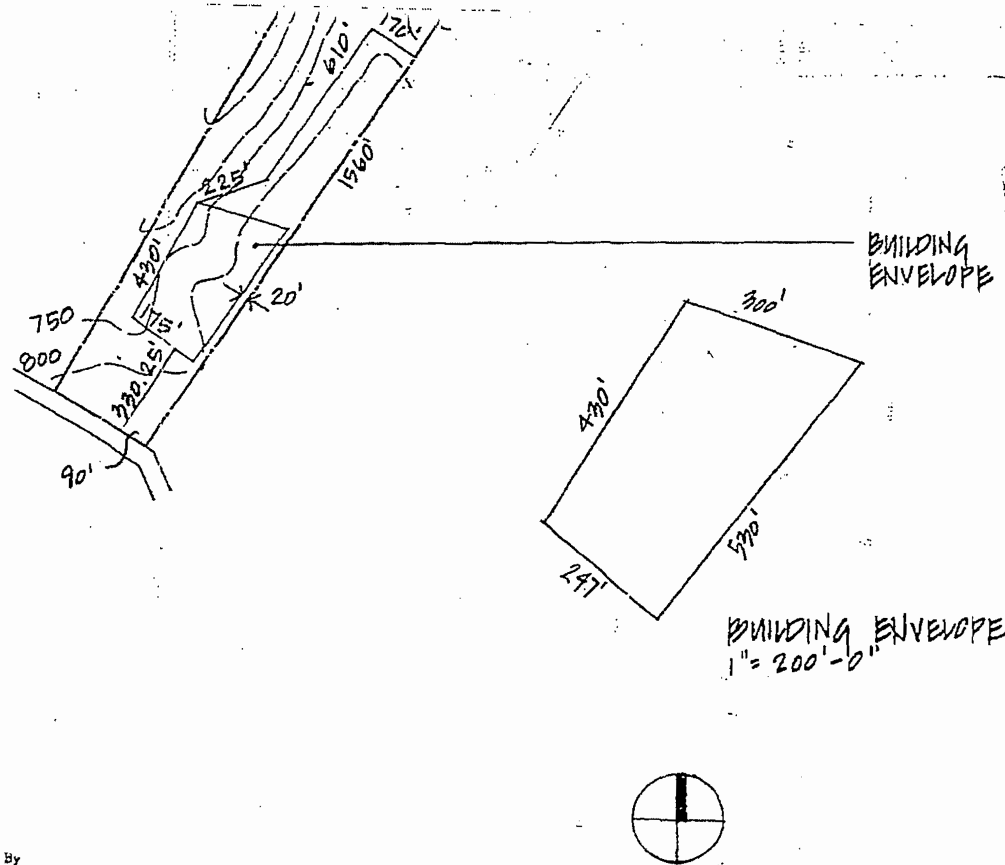
Resa R. DeWitt
RESA R. DeWITT
NOTARY PUBLIC - OREGON
My Commission Expires 04/15/94

10-23-90


CONSERVATION
EASEMENT
897.89'
1560.12'
860.29'
3525.85'
500
550
550
600
650
700
700
650
610'
170'

10-23-90

BOOK 2355 PAGE 1118



DWELLING SITE PLAN
FOR LOT 2C OF LD 30-89
BOOK 1990 PAGE 30
DEMUTH GLICK CONSULTANTS
SCALE 1" = 400'-0"

10-23-90

10-23-90

098392

STATE OF OREGON }
Multnomah County } ss.

I, a Deputy for the Recorder of Conveyances, in and for said County, do hereby certify that the within instrument of writing was received for record and recorded in the record of said County.

Multnomah County, Oregon

AM OCT 23 1990 PM
7 8 9 10 11 12 1 2 3 4 5 6

In Book 4 On Page

BOOK 2355 PAGE 1112

witness my hand and seal of office affixed.

Recorder of Conveyances

M Burns
Deputy

35
3
20

BOOK 2355 PAGE 1119

EXHIBIT B

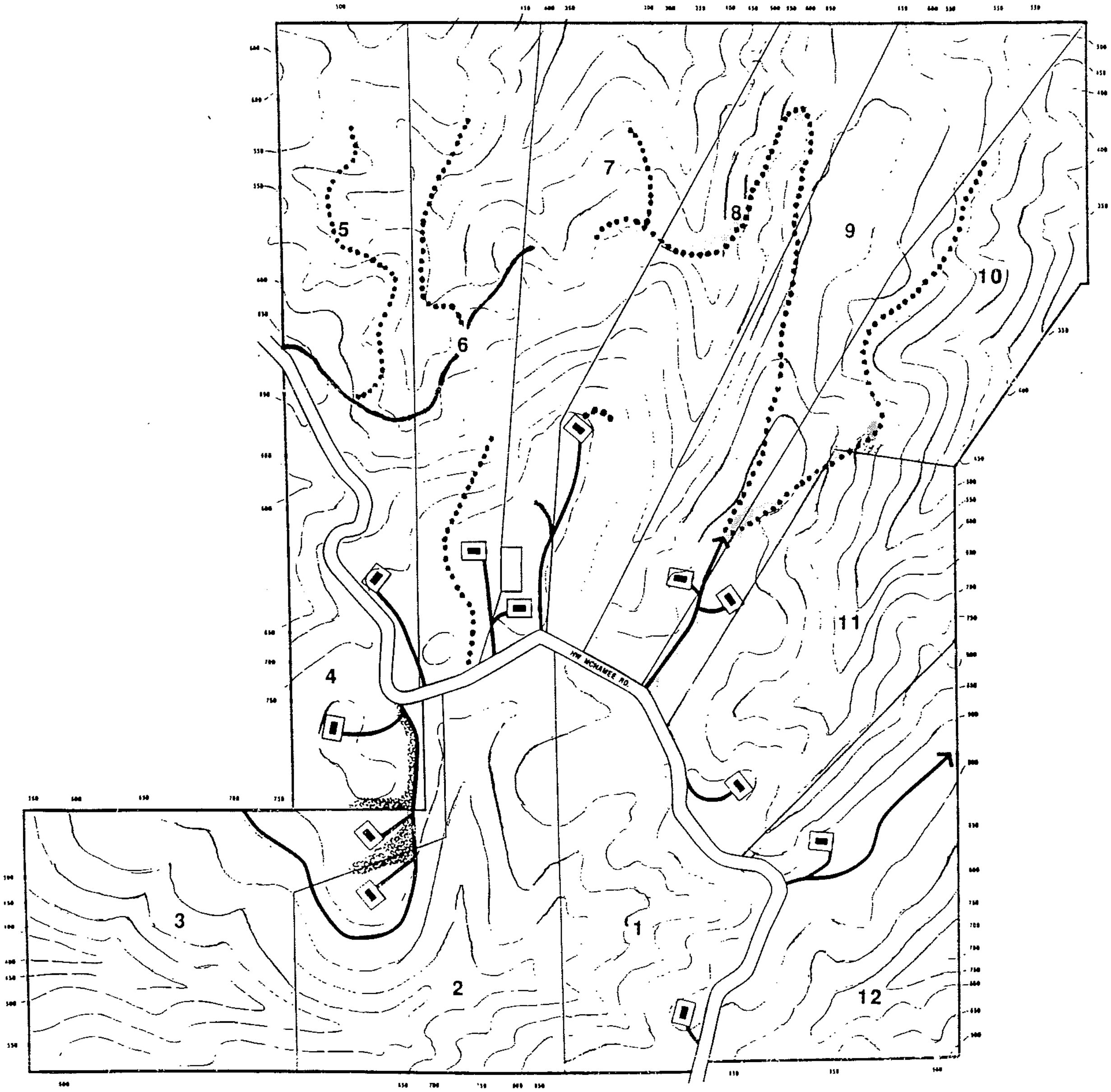
FOREST TRAILS ESTATES

for file copy

A UNIQUE RESIDENTIAL & WILDLAND COMMUNITY

APPROXIMATE
EASEMENT LOCATION OVER ADJOINING LOTS

FOR INGRESS & EGRESS



KEY:

HOUSE SITE OPTIONS

ACCESS ROADS -(EASEMENTS)

PROPOSED TREE PLANTINGS

NATURAL BUFFER AREAS

FOREST MANAGEMENT ACCESS EASEMENT

SCALE: 1 INCH = 200 FEET

N

3-23-90

CROWN PACIFIC LTD.
Portland, Oregon

FRED GLICK ASSOCIATES

MARKETED BY: TIMBERNET,INC.

4000 KRUSEWAY PL. #3-160 635-2800

LAKE OSWEGO, OR. 97035

Exhibit 10

ORIOREGON DEPARTMENT OF FISH AND WILDLIFE

LIVING WITH WILDLIFE: AMERICAN BEAVER

Contents

Facts about Oregon's Beavers
Viewing Beavers
Beavers on the Landscape
Preventing Conflicts and Solving Problems: plants and trees, flooding
Moving Beavers
Lethal Control
Species Status
Regulated Trapping
Public Health Concerns

FACTS ABOUT OREGON'S BEAVERS

The American Beaver (*Castor canadensis*) is the largest living rodent in North America. Adults average 40 pounds in weight and measure more than three feet in length, including the tail. They have a nose and ears that seal out water. These semi-aquatic mammals have webbed hind feet, large incisor teeth and a broad flat tail. They have poor eyesight, but excellent hearing and sense of smell. The beaver's sharp incisors, which are used to cut trees and peel bark while eating, are harder on the front surface than on the back so the back wears faster creating a sharp edge that enables a beaver to easily cut through wood. The incisors continually grow, but are worn down by grinding, tree cutting and feeding. Beavers are territorial and to mark their territory by creating small mounds of mud, leaves, and sticks, which they then cover with pungent oil called castoreum.

Once among the most widely distributed mammals in North America, beavers were trapped virtually to extinction in the 1800s to meet demand for beaver pelts. A subsequent decline in demand coupled with proper wildlife management allowed beavers to become reestablished in much of their former range and are now common in many areas, including urban settings.

Beavers are found where preferred foods are in good supply—along rivers and small streams, lakes, marshes and even roadside ditches that have adequate year-round water flow. In areas where deep, calm water is not available, beavers with enough building material available will create ponds by building dams across creeks or other watercourses to impound water.

Food and Feeding Habitats

- Beavers eat the leaves, inner bark, and twigs of aspen, alder, cottonwood, willow and other deciduous trees. They also eat shrubs, ferns, aquatic plants, grasses, blackberries and agricultural crops.
- Most foraging is done within 165 feet of the water's edge. In areas with few predators and a lean food supply, toppled trees and other signs of foraging may be found twice that distance from the den site.
- Foraging levels are most intense during late fall (earlier in cold winter areas of Oregon) as beavers prepare for winter.
- Fermentation by special intestinal microorganisms allows beavers to digest 30 percent of the cellulose they ingest from vegetation.
- When the surface of the water is frozen, beavers eat bark and stems from a food cache anchored to the bottom of the waterway for winter use. Food caches are seldom found where winters are comparatively mild, such as in the lowlands of western Oregon.

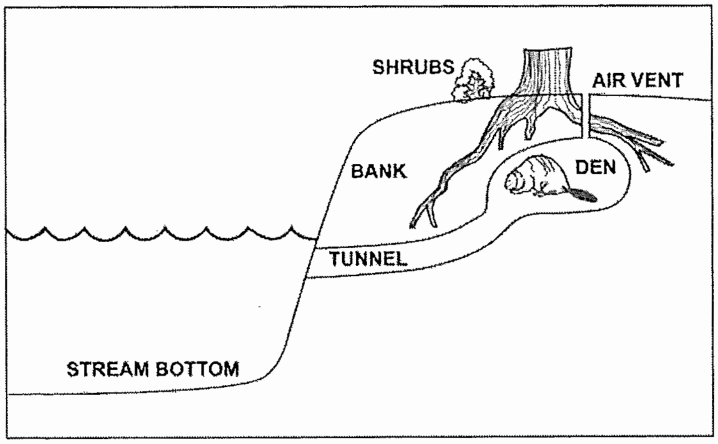


Figure 1. Like many rodents, beavers construct nesting dens for shelter and for protection against predators.

Beaver Dams

- Beavers build dams to create deep water for protection from predators, for access to their food supply and to provide underwater entrances to their den. Resultant moist soil promotes growth of favored foods.
- Beavers living on water bodies that maintain a constant level (lakes or large rivers) do not build dams.
- Dams are constructed and maintained with whatever materials are available—wood, stones, mud and plant parts. They vary in size from a small accumulation of woody material to structures 10 feet high and 165 feet wide.
- The sound of flowing water stimulates beavers to build dams; however, they routinely let a leak in a dam flow freely, especially during times of high waters.
- Beavers keep their dams in good repair and will constantly maintain the dams as the water level increases in their pond. A family of beavers may build and maintain one or several dams in their territory.
- In cold areas, dam maintenance is critical. Dams must be able to hold enough water so the pond won't freeze to the bottom, which would eliminate access to the winter food supply.

Lodges and Bank Dens

- Depending on the type of water body and the geographic area they occupy, beavers construct lodges or bank dens as a place to rest, stay warm, give birth and raise young. These may be burrows in a riverbank or the more familiar lodges in the water or on the shore. Both burrows and lodges consist of one or more underwater entrances, a feeding area, a dry nest den and a source of fresh air.
- Lodges consist of a mound of branches and logs plastered with mud. One or more underwater openings lead to tunnels that meet at the center of the mound where a single chamber is created.
- Bank dens are dug into the banks of streams and large ponds, and beavers may or may not build a lodge over them (Fig. 1). Bank dens may also be located under stumps, logs, or docks.
- All family members concentrate on repairing the family lodge or den in late fall (earlier in cold winter areas of Oregon) in preparation for winter.

Reproduction and Family Structure

- A mated pair of beaver will live together for many years, sometimes for life.
- Beavers breed between January and March, and litters of one to eight kits (average four) are produced between April and June. The number of kits born is closely related to the amount of food available (more food, more kits) and the female's age.
- The female nurses the kits until they are weaned at 10 to 12 weeks of age.
- Most kits remain with adults until they are about two years old although some leave as early as 11 months and a few females stay until they are three years old. The kits then go off on their own in search of mates and suitable spots to begin colonies, which may be several miles away.
- Beavers live in colonies that may contain two to 12 individuals. The colony is usually made up of an adult breeding pair, kits of the year, and kits of the previous year or years.
- Populations are limited by habitat availability; the density of beavers appears not to exceed one colony per one-half mile under the best of conditions.

Mortality and Longevity

- Because of their size, behavior and habitat, adult beavers have few natural enemies.
- When foraging on shore or migrating overland, beavers may be killed by bears, coyotes, bobcats, cougars or dogs.
- Other causes of death include severe winter weather, winter starvation, disease, water fluctuations and floods, falling trees and collisions with vehicles along roadways.
- Historically, beavers were one of the most commonly trapped furbearers.
- Beavers live five to 10 years in the wild.

VIEWING BEAVERS

Although beavers are nocturnal, they are occasionally active during the day. They do not hibernate but are less active during winter, spending most of their time in the lodge or den. Freshly cut trees and shrubs and prominent dams and lodges are sure indicators of beaver presence. Look for signs of beavers during the day; look for the animals themselves before sunset or after sunrise. Look for a V-shaped series of ripples on the surface of calm water. A closer view with binoculars may reveal the nostrils, eyes and ears of a beaver swimming.

If you startle a beaver and it goes underwater, wait quietly in a secluded spot and chances are that it will reemerge within one or two minutes. However, beavers are able to remain underwater for at least 15 minutes by slowing their heart rate. In order to warn each other of danger, beavers slap their tails against the water, creating a loud splash. Sounds also include whining (noise made by kits), a breathy greeting noise and loud blowing when upset.

When seen in the water, beavers are often mistaken for muskrats or nutria. Try to get a look at the tail. Beavers have a broad, flat tail that doesn't show behind them when swimming, whereas muskrats and nutria have a thin tail that is either held out of the water or sways back and forth on the water's surface as the animal swims. When on land, beavers will generally stand their ground and should not be approached or cornered. They will face the aggressor, rear up on their hind legs and hiss or growl loudly before lunging forward to deliver extremely damaging bites.

Forage Sites

Beavers cut down trees, shrubs and other available vegetation for food and building materials. There will be a pile of wood chips on the ground around the base of recently felled trees. Limbs that are too large to be hauled off are typically stripped of bark over the course of several days. The cut on small wood usually involves a 45-degree cut typical of rodents, but at a larger scale. Branches and twigs under ¾ inch in diameter are usually eaten entirely.

Slides and Channels

Slides are the paths beavers make where they enter and leave the water. They are 15 to 20 inches wide, at right angles to the shoreline, and have a slicked down or muddy appearance. Beavers construct channels or canal systems leading to their ponds, using them to float food—such as small, trimmed trees—from cutting sites. With receding water levels during summer, beaver activity shifts toward building and maintaining channels to access new food supplies. Channels often look man-made, have soft, muddy bottoms and are filled with 15 to 25 inches of water.

Food Storage Sites

Beavers that live in cold climates store branches of food trees and shrubs for winter use by shoving them into the mud at the bottom of ponds or streams near the entrance to their bank den or lodge.

Droppings

Beaver droppings are seldom found on land—those that are will commonly be found in the early morning at the water's edge. Individual beaver droppings are usually cylindrical, up to 2½ inches long and look as if they were formed of compressed sawdust. The diameter is an indication of the animal's size—1 inch is average for adults. The color of fresh deposits is dark brown, with lighter-colored bits of undigested wood, all turning pale with age.

BEAVERS ON THE LANDSCAPE

Beaver ponds and dams benefit Oregon's native fish and other wildlife

- Beaver dams create ponds that provide fish protection from strong winter flows. They increase the storage of water resulting in a more stable water supply and maintenance of higher flows downstream for a longer period of time.
- By providing plenty of woody debris in which juvenile fish can hide from predators, beaver dams help young trout and salmon survive their first vulnerable year. They also provide winter pool habitat that is important for fish such as cutthroat trout and coho.
- Beaver ponds help store leaf litter in the water and in turn support aquatic insect production, an important food for fish, amphibians, waterfowl, bats and songbirds.
- Beaver dams contribute to improved nesting and brood rearing areas for waterfowl in ponds and surrounding areas. The increased growth of vegetation provides additional forage and cover for a variety of wildlife such as big game and songbirds.
- Beaver ponds attract and provide habitat for mink, river otter, muskrats, turtles, frogs and salamanders.
- The trees that die as a result of rising water levels behind beaver dams attract insects that are a food source for many wildlife species such as woodpeckers. The tree snags also provide homes for cavity-nesting birds.

Beavers can help private landowners

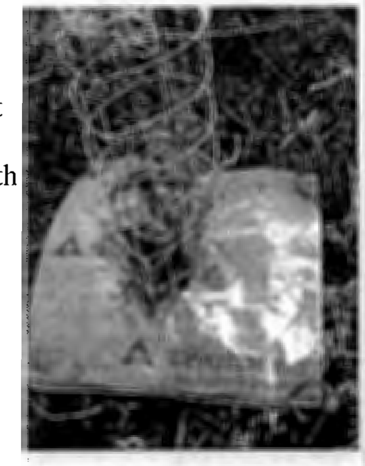
- Beaver dams create wetlands which help control downstream flooding by storing and slowly releasing water, reducing the severity of high stream flows particularly after winter storms and spring snow melt.
- Beaver created wetlands improve water quality by removing or transforming excess nutrients, trapping silt, binding and removing toxic chemicals and filtering out sediment.
- Beaver dams facilitate ground water recharge and help raise the ground water table. This promotes vegetative growth, which in turn helps stabilize stream banks and minimize erosion. In some areas, beaver dams have been a major factor in building up soil in meadows and reducing the impact of invasive vegetation.
- Beaver dams reduce water velocity, reducing channel scouring and streambank erosion.
- Wetlands created by beavers attract a variety of fish and wildlife that provides recreational and aesthetic values to landowners.

Beavers can cause damage on public and private lands

- Beavers can become a problem if their foraging habits or building activities cause flooding or damage property.
- Beaver activity may result in damage to timber, crops, ornamental or landscape plants.
- Beaver dams and subsequent increased water levels may jeopardize the integrity of septic systems, roads or other human structures.
- There are several options for landowners in dealing with problem beavers that are covered in the following sections: preventing conflicts and remedying existing problems; lethal control; and moving beaver.

PREVENTING CONFLICTS AND SOLVING PROBLEMS: PLANTS AND TREES, FLOODING

Knowing that beavers fulfill an important role in creating wetlands that provides multiple benefits to a variety of fish and wildlife as well as landowners, one approach to dealing with beavers is to learn to live with them.



Newly planted tree protected from beaver damage using rebar and fencing. Rebar stake is used to hold up protective cage. (Photo by Doug Ray.)

PROTECTING PLANTS AND TREES

Choose and place plants carefully
Plant areas with Sitka spruce, elderberry, cascara, osoberry (Indian plum), ninebark, and twinberry, because they are not the beavers' preferred food plants. Densely plant aspen, cottonwood, willow, spirea (hardhack), and red-twig dogwood because once their roots are well established the plants often resprout after being eaten. Planting preferred plants away from known beaver trails will limit losses. *Note:* Beavers do use plants as construction materials that they might not eat.

Install barriers around trees
Wire cages around trees can prevent beavers from chewing on them. The trunks of individual large trees can be loosely wrapped with galvanized welded wire fencing, hardware cloth, or multiple layers of chicken wire (Fig. 2). Metal flashing can also be used. Trunks should be wrapped to a height of at least four feet, or in areas where flooding is common, at least two feet above the high-water mark. A 6 to 12 inch space should be left between the wire cage and the tree trunk as beavers may try to chew between the wires. Some form of stake or support is needed to keep beavers from pushing fencing against tree trunk and chewing. Check wire barrier every year to make sure they do not inhibit tree growth. Barriers can be painted to make them less noticeable. Welded wire fencing coated with green vinyl that helps the fencing blend in is also available. Lengths of corrugated plastic drainpipe can be attached around the trunks of narrow-diameter trees. *Note:* Dark-colored pipe can burn trunks in full sun; wider diameter pipe or pipe with holes in it may prevent overheating problems.

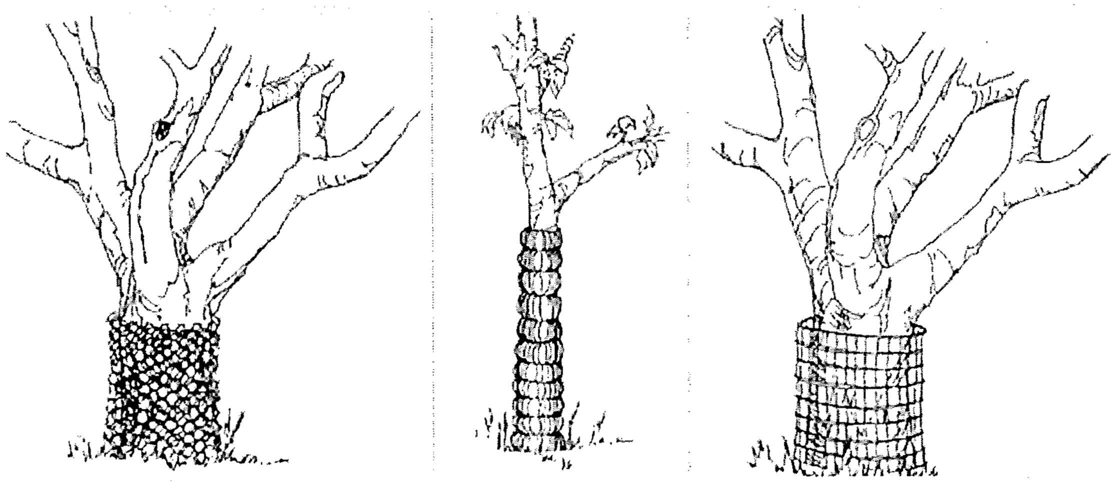


Figure 2. Various barriers can be used to protect plants from beaver damage. All plants should be protected to at least 4 feet above ground—or the snow line—and inspected regularly to ensure that wire does not become imbedded in the bark. (Drawing by Jenifer Rees.)

Surround groups of trees and shrubs with 4-foot high barriers made of galvanized, welded wire field fencing or other sturdy material (Fig. 3). A beaver's weight will pull down chicken wire and other lightweight material. Stake the barriers to prevent beavers from pushing them to the side or entering from underneath. An electric fence with two hot wires suspended 8 and 12 inches off the ground is also effective at protecting groups of plants. Consult local codes and experts before installing electrical fencing.

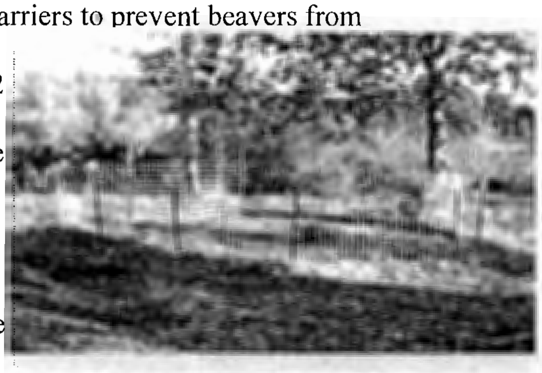


Figure 3. Groups of plants can be protected from beaver damage by surrounding them with wire fencing. (Photo by Russell Link)

Protect large areas that border beaver habitat by installing 4-foot high field fencing. Keep the bottom of the fence flush to the ground, or include an 18-inch wide skirt on the beaver side of the fence to prevent beavers from entering underneath. *Note:* Preventing access to food sources may force beavers to eat other nearby plants, including roses and other ornamentals.

Apply repellents on trees

Painting tree trunks with a sand and paint mix (2/3 cup masonry grade sand per quart of latex paint) has proven somewhat effective at protecting trees from beaver damage. The animals presumably don't like the gritty texture.

Commercial taste and odor repellents have provided mixed results, perhaps because they need to be reapplied often, particularly in moist weather. Taste and odor repellents are most effective when applied at the first sign of damage, when other food is available, and during the dry season. Two repellents that have had some success are Big Game Repellent® and Plantskydd®. Taste repellents are usually most effective when used at the first indication of beaver activity.

PREVENTING FLOODING

Before starting ***any*** of the following treatments or activities, landowner approval must be obtained. In addition, as these activities typically require some work in wetlands or streams, permits may be required from various local, state, and federal agencies before work is started. Please refer to the *State Water-Related Permits Users Guide* for more information or contact the Department of State Lands to determine if a removal-fill permit may be required.

Help maintain beaver dams and ponds with flow devices

It may be possible to make a change in the depth of a beaver pond to prevent flooding by installing a flow device at the intended depth that extends upstream and downstream of the dam. The flow device, a beaver deceiver or flexible leveler, keeps the rise in water level in the pond at a minimum by using one or more plastic pipes to continually drain the pond area. In general, at least three feet of water in the pond area will need to be maintained for the beavers to stay. See a diagram of a flexible leveler on page 11.

Installation of flow devices may require an approved fish passage plan to ensure that fish are able to navigate the flow control device. To learn more and to review the Oregon State fish passage laws, visit the fish passage section of the ODFW Web site. People may also contact their local ODFW office for more information.

Dam removal

Removing beaver dams may alleviate a damage situation temporarily, but generally dam removal is a futile effort because beaver will quickly rebuild the dam, sometimes overnight.

For information on beaver dams while conducting forest management activities on private land, contact the Oregon Department of Forestry. Except as needed for road maintenance, operators must submit a written plan to ODF prior to the removal of beaver dams and other natural obstructions from waters of the state during forest operations. In compliance with the Forest Practices rules, removal of any beaver dam that is within 25 feet of a culvert can be considered necessary for road maintenance. See Oregon Department of Forestry Forest Practices rules and (Oregon Administrative Rule 629-660-0050). Implemented by Oregon Department of Forestry.

See Department of State Lands sources list at the end of this document.

Removal of beaver lodges or dens

In western Oregon, most lodges are bank dens, not in-water structures. ODFW does not generally recommend that lodges or dens be removed, but removal does not require a permit from ODFW. Check with your local ODFW office for more information. *Note:* Muskrat lodge removal is prohibited.

Blocked culverts

To a beaver, a culvert probably looks like a hole in an otherwise fine dam, and when they plug the hole, a flooded road can result. One option to keep beavers from plugging a culvert is to create an alternative location for the dam. In overview, a series of 3 to 5 inch diameter non-treated lumber posts or live willow posts spaced 18 to 24 inches apart can serve as a foundation for the beavers to build a new dam. If you place the woody material from the removed dam upstream from the posts, beavers will use it to start the new dam. See diagram on page 12.

Other options to prevent beavers from plugging a culvert are available but some may prevent fish passage so you are encouraged to contact your local ODFW biologist for the best option for the property in question.

MOVING BEAVERS

It is illegal for anyone to ***move*** beaver in Oregon without a permit from ODFW. Contact your local ODFW biologist to request a permit.

ODFW is currently developing guidelines for live-trapping and relocating beaver. The intent of the guidelines is to maximize the ecological benefits provided by beaver while minimizing potential conflicts (e.g., damage to private property) where beaver relocation is deemed appropriate and is authorized by ODFW.

Lethal Control

After assessing beaver activity, determine if beavers are causing damage or creating a hardship that requires lethal control. Sometimes, the very presence of beavers is seen as a problem when, in fact, the beavers are causing no harm.

Private landowners or their agents may lethally remove beaver without a permit from ODFW. Beavers are defined in state statues as a predatory animal on private land. See section below on Species Status.

Once lethal control is decided upon, the landowners can trap the beaver themselves, hire an ODFW-permitted Wildlife Control Operator who works directly with property owners to resolve problem beaver situations on a fee basis, or allow an ODFW-licensed regulated trapper to remove beaver during the established trapping season. Call your local ODFW office or visit the ODFW Web site for a current list of Wildlife Control Operators.

Note: Removing beavers is often a short-term solution as other beavers will move into the area if suitable habitat is present.

SPECIES STATUS

Beavers on Public land: Beavers are classified as Protected Furbearers by Oregon Revised Statute (ORS) 496.004 and Oregon Administrative Rule (OAR) 635-050-0050 on public land. Statute implemented by ODFW.

Beavers on Private land: Beaver are defined as a Predatory Animal by Oregon Revised Statute (ORS) 610.002 on private land. Statute implemented by Oregon Department of Agriculture.

Explanation of terms

- "Predatory animals" means coyotes, rabbits, rodents, and feral swine which are or may be destructive to agricultural crops, products and activities. This definition is applicable where wildlife is taken under the authority of one who owns leases, occupies, possesses or has charge or dominion over the land. On public land this typically includes one who has a grazing lease. Refer to ORS 610.105.

- "Take" means to kill, attempt to kill or obtain possession or control of any wildlife (ORS 496.004).

REGULATED TRAPPING

Trapping, like most technologies, has changed dramatically during the last two hundred years. Traps and trapping systems have made tremendous advances since the 1800s when beaver were nearly eliminated. Today, all regulated trappers in Oregon must first complete a study course and successfully pass a written test showing an acceptable level of knowledge of animal behavior, current laws and regulations and trapping skills. Modern science based information is used to establish strict laws, enforced by Oregon State Police, which allows regulated trappers to harvest beaver during authorized seasons using state-of-the-art traps and techniques. Such trapping systems are a benefit by removing damage-causing beaver while maintaining healthy and abundant beaver population. The vast majority of beaver trapped today fall into this damage category. ODFW Furbearer Regulations can be found on the ODFW Web site.

PUBLIC HEALTH CONCERNS

There are few public health concerns to the general public in regard to beaver. Trappers and biologists should follow safety rules when dealing with beaver. Beavers can be infected with the bacterial disease tularemia, which is fatal to animals and is transmitted to them by ticks, biting flies and via contaminated water. Animals with this disease may be sluggish, unable to run when disturbed or appear tame. Tularemia may be transmitted to humans if they drink contaminated water, eat undercooked, infected meat, or allow an open cut to contact an infected animal. The most common source of tularemia for humans is to be cut or nicked by a knife when skinning an infected animal. A human who contracts tularemia commonly has a high temperature, headache, body ache, nausea, and sweats. A mild case may be confused with the flu and ignored. Humans can be easily treated with antibiotics. Contact your family doctor immediately if you believe that you have contracted tularemia.

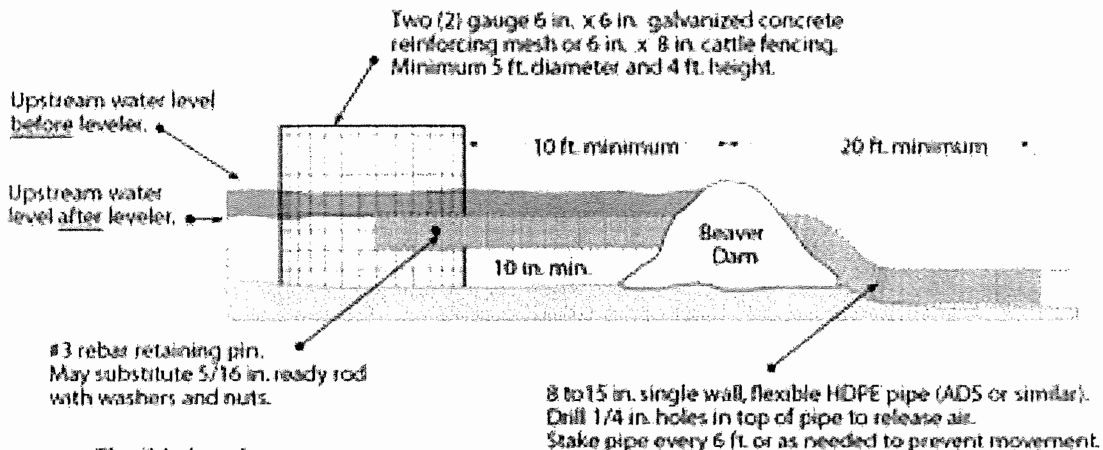
OTHER INFORMATION

Oregon Department of State Lands
Oregon Department of State Lands Removal-Fill Guidelines
ODFW Furbearer Regulations
ODFW Web Site
ODOT Beaver Bafflers (pdf)
State Water-Related Permits Users Guide
USDA Extension Service: Beaver (pdf)
USDA Living with Wildlife: Beaver, suitable for children (pdf)

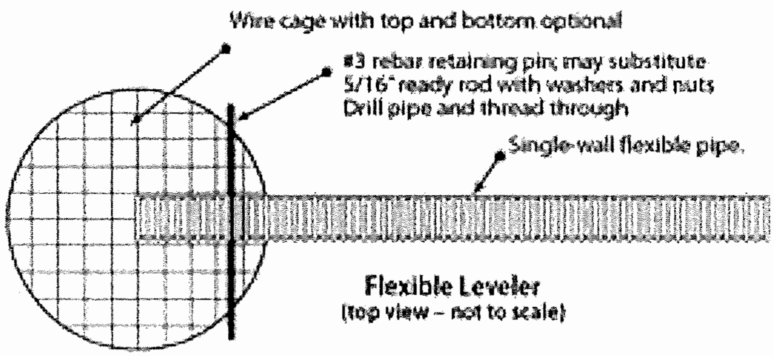
Oregon Department of Fish and Wildlife
3406 Cherry Ave. NE
Salem, OR 97303
www.dfw.state.or.us
(503) 947-6000

See diagrams on pages 11 and 12.

Note: The use of trade, firm, or corporation names and links in this publication is for the information of the reader. Such use does not constitute an official endorsement or approval by the Oregon Department of Fish and Wildlife.



Flexible Leveler
(side view – not to scale)



Flexible Leveler
(top view – not to scale)

Construction notes:

1. Construct wire cage using hog rings or similar devices for fasteners. Overlap one section for cage wall.
2. Cut out hole for flexible pipe in cage wall.
3. Remove dam as needed to place flexible pipe. Replace dam after leveler is installed.
4. Stake single-wall HDPE pipe every 6 ft. To prevent it from floating or beavers from moving it, use two T-posts and wire between them and over the top of the pipe to secure the pipe.
5. Drill 3/8th in. hole in culvert for rebar to allow for friction fit. If ready rod is used, place washers next to pipe and secure with double nuts.
6. One (1) 16 foot section of fencing will construct a cage wall approximately 5 feet in diameter. An additional section is needed to construct the top and bottom of each cage.
7. Pipe diameter should be sized to pass the stream base flow.
8. Final layout of the pipe should allow for a shallow gradient to facilitate fish passage.

Prevent beavers from plugging culverts

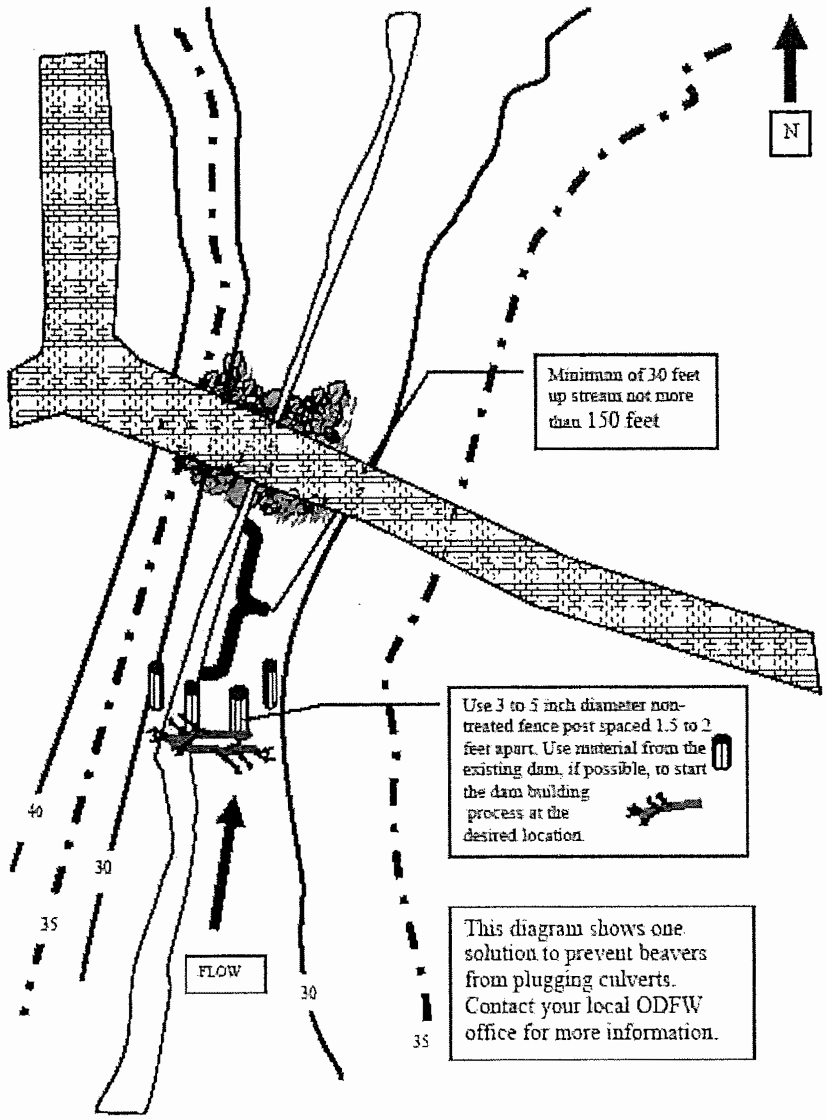


Exhibit 11

8.0 LANDSLIDES

8.1 Landslide Overview and Definitions

The term “landslide” refers to a variety of slope instabilities that result in the downward and outward movement of slope-forming materials, including rocks, soils and artificial fill. Four types of landslides are distinguished based on the types of materials involved and the mode of movement. These four types of landslides are illustrated in Figures 8.1 to 8.4 on the following page.

> **Rockfalls** are abrupt movements of masses of geologic materials (rocks and soils) that become detached from steep slopes or cliffs. Movement occurs by free-fall, bouncing and rolling. Falls are strongly influenced by gravity, weathering, undercutting or erosion.
>
> **Rotational Slides** are those in which the rupture surface is curved concavely upwards and the slide movement is rotational about an axis parallel to the slope. Rotational slides usually have a steep scarp at the upslope end and a bulging “toe” of the slid material at the bottom of the slide. Roads constructed by cut and fill along the side of a slope are prone to slumping on the fill side of the road. Rotational slides may creep slowly or move large distances suddenly.
>
> **Translational Slides** are those in which the moving material slides along a more or less flat surface at some depth within the ground. Translational slides occur on surfaces of weaknesses, such as faults and bedding planes or at the contact surface between firm rock and overlying loose soils. Translational slides can either creep slowly or move large distances rather suddenly.
>
> **Debris Flows** (mudflows) are movements in which loose soils, rocks and organic matter combine with entrained water to form slurries that flow rapidly downslope.

All of these types of landslides may cause road blockages by depositing debris on road surfaces or road damage if the road surface itself slides downhill. Utility lines and pipes are prone to breakage in slide areas. Buildings impacted by slides may suffer minor damage from small settlements or be completely destroyed by large ground displacements or by burial in slide debris. Landslides may also result in casualties, as evidenced by 1997 winter storms in Oregon.

There are three main factors that determine susceptibility (potential) for landslides:

1) slope,
2) soil/rock characteristics, and
3) water content.

Steeper slopes are more prone to all types of landslides. Loose, weak rock or soil is more prone to landslides than is more competent rock or dense, firm soils. Finally, water saturated soils or rock with a high water table are much more prone to landslides because the water pore pressure decreases the shear strength of the soil and thus increases the probability of sliding.

Figures 8.1 to 8.4
Major Types of Landslides

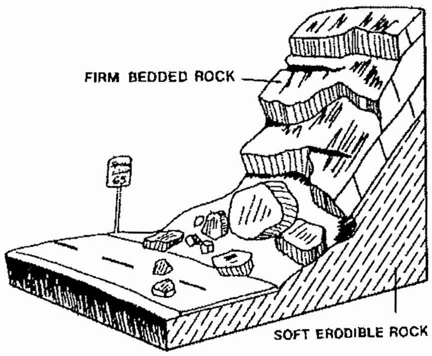


Fig. 8-1. Rockfall

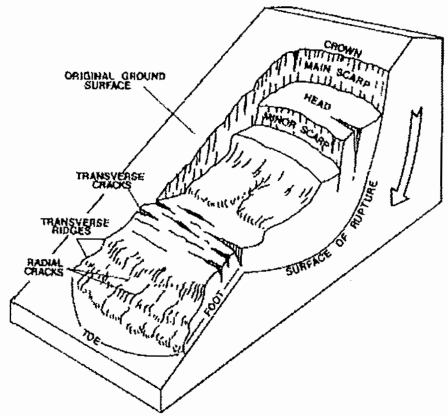


Fig. 8-2. Rotational Landslide

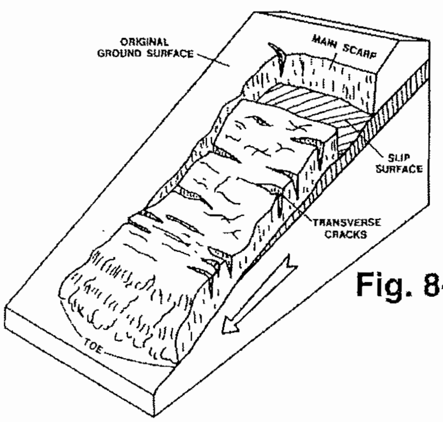


Fig. 8-3. Translational Landslide

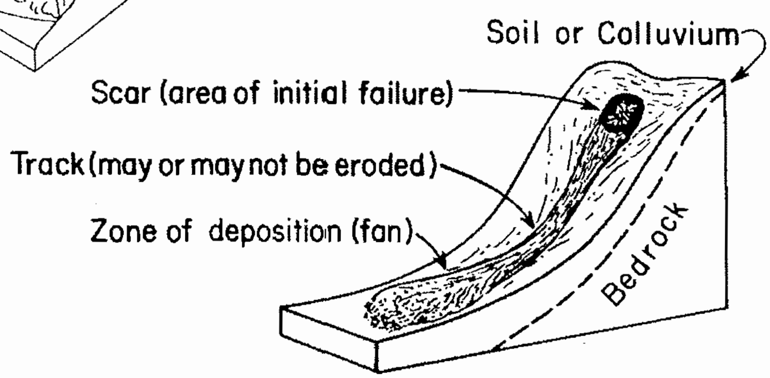


Fig. 8-4. Debris Flow

As noted above, the water content of soils/rock is a major factor in determining the likelihood of sliding for any given slide-prone location. Thus, most landslides happen during rainy months when soils are saturated with water. However, landslides may happen at any time of the year.

In addition to landslides triggered by a combination of slope stability and water content, landslides may also be triggered by earthquakes. Areas prone to seismically triggered landslides are exactly the same as those prone to ordinary (i.e., non-seismic) landslides. As with ordinary landslides, seismically triggered landslides are more likely from earthquakes that occur when soils are saturated with water.

8.2 Landslide Hazard Assessment for Multnomah County

Areas with potential landslide hazards within Multnomah County are shown in Figures 8.5 to 8.8. Landslide hazard areas are locations where landslides have occurred in the past or appear likely to occur in the future. These mapped areas include both developed and undeveloped areas.

Figures 8.5 and 8.6 are DOGAMI mapped potential landslide areas. Figures 8.7 to 8.8 are DOGAMI mapped historical landslide areas.

As shown in these figures, there are two areas of most concern for landslides:

- The west Portland Hills area, including U.S. Highway 30 and the adjacent rail line, and
- The area along Interstate 84 and the Historic Columbia River Highway from Troutdale east to the Multnomah County border.

In addition to these areas, large landslide hazard areas also exist in the hilly eastern portion of Multnomah County. However, this area is lightly developed. As shown on the figures, there are also smaller areas of landslide hazards scattered throughout Multnomah County

More detailed landslide hazard assessment requires a site-specific analysis of the slope, soil/rock and groundwater characteristics at specific sites. Such assessments are often conducted prior to development projects in areas with moderate to high landslide potential, to evaluate the specific hazard at the development site.

Figure 8.5
Landslide Hazard Areas: West

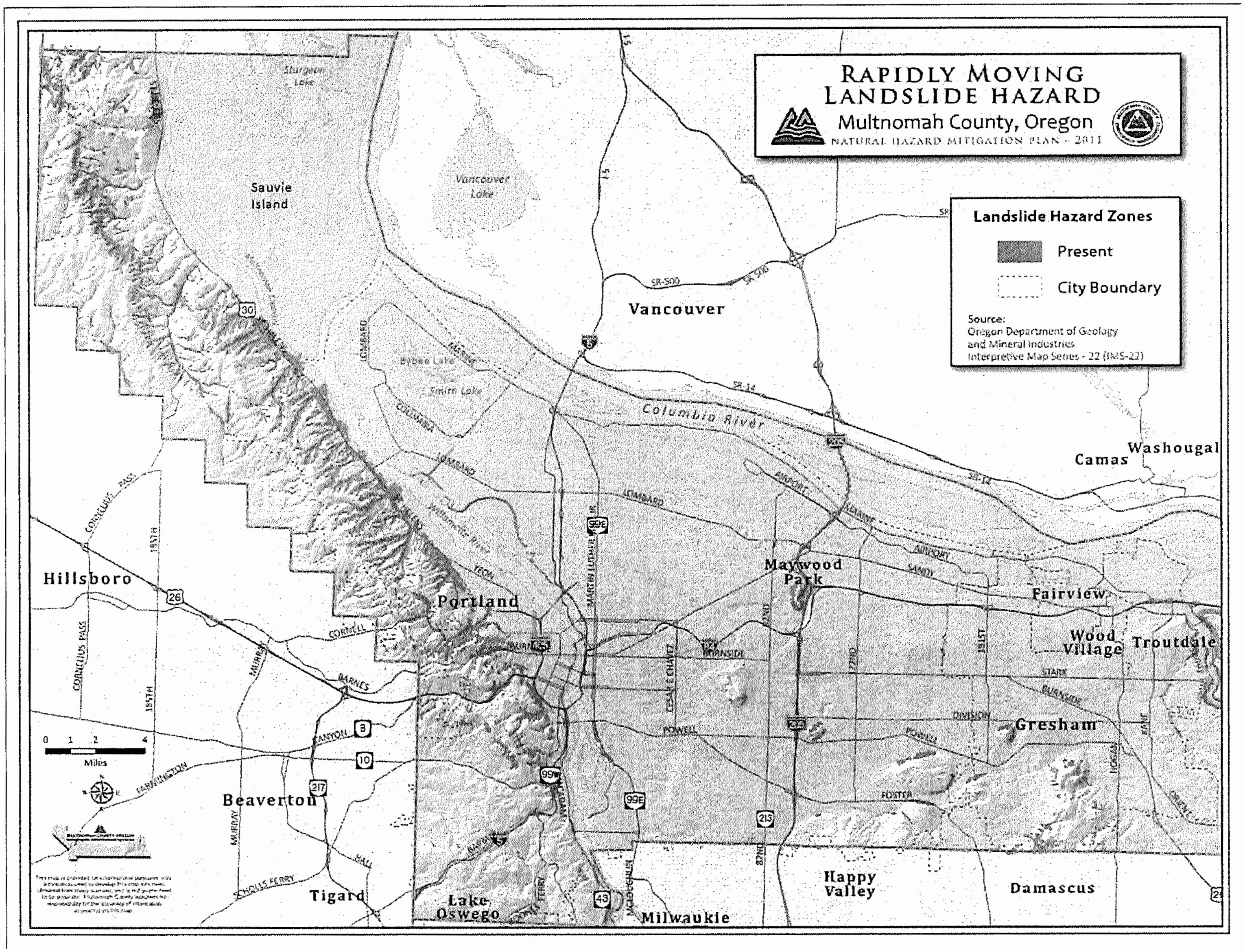


Figure 8.6
Landslide Hazard Areas: East

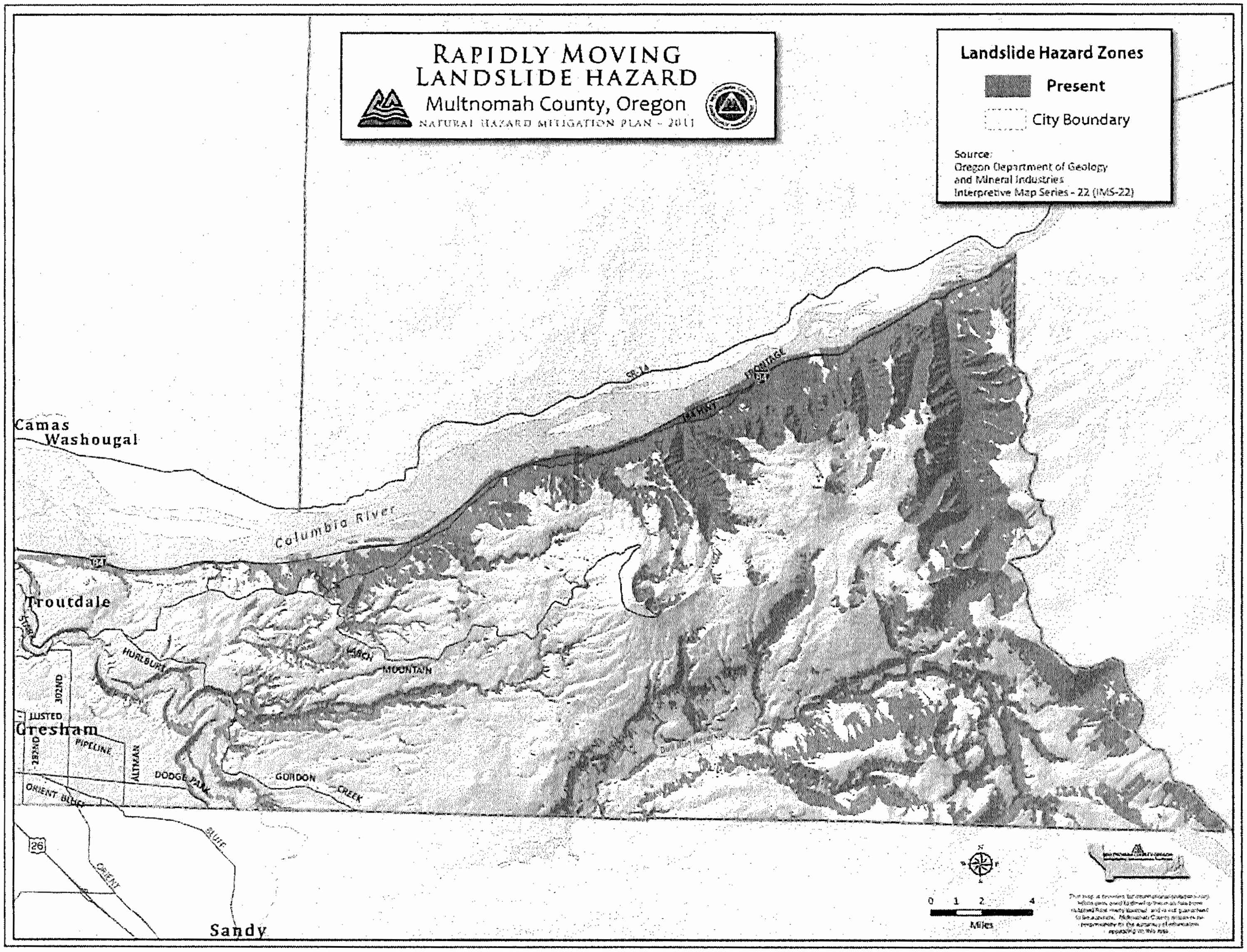


Figure 8.7
DOGAMI Mapped Historical Landslide Areas: West

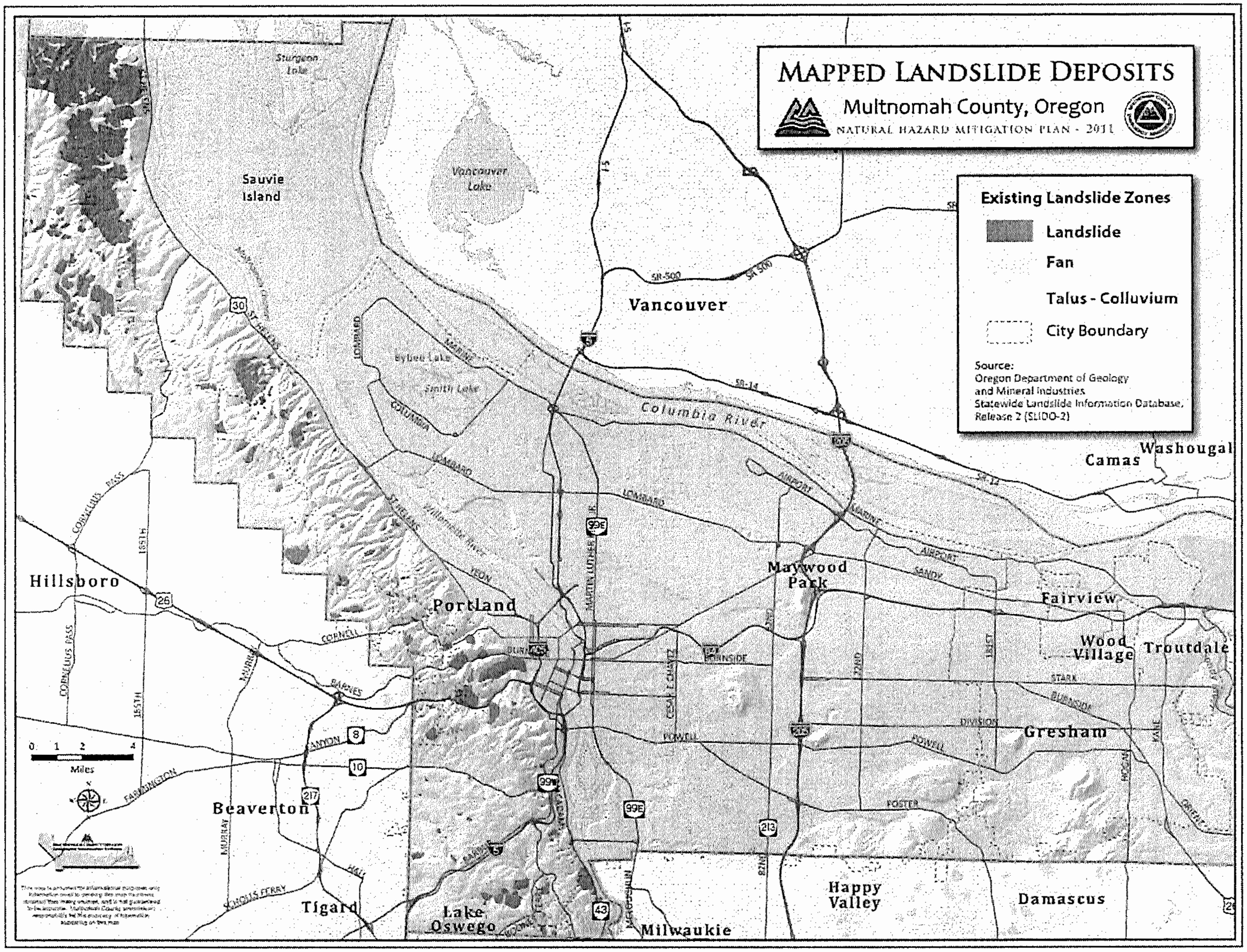
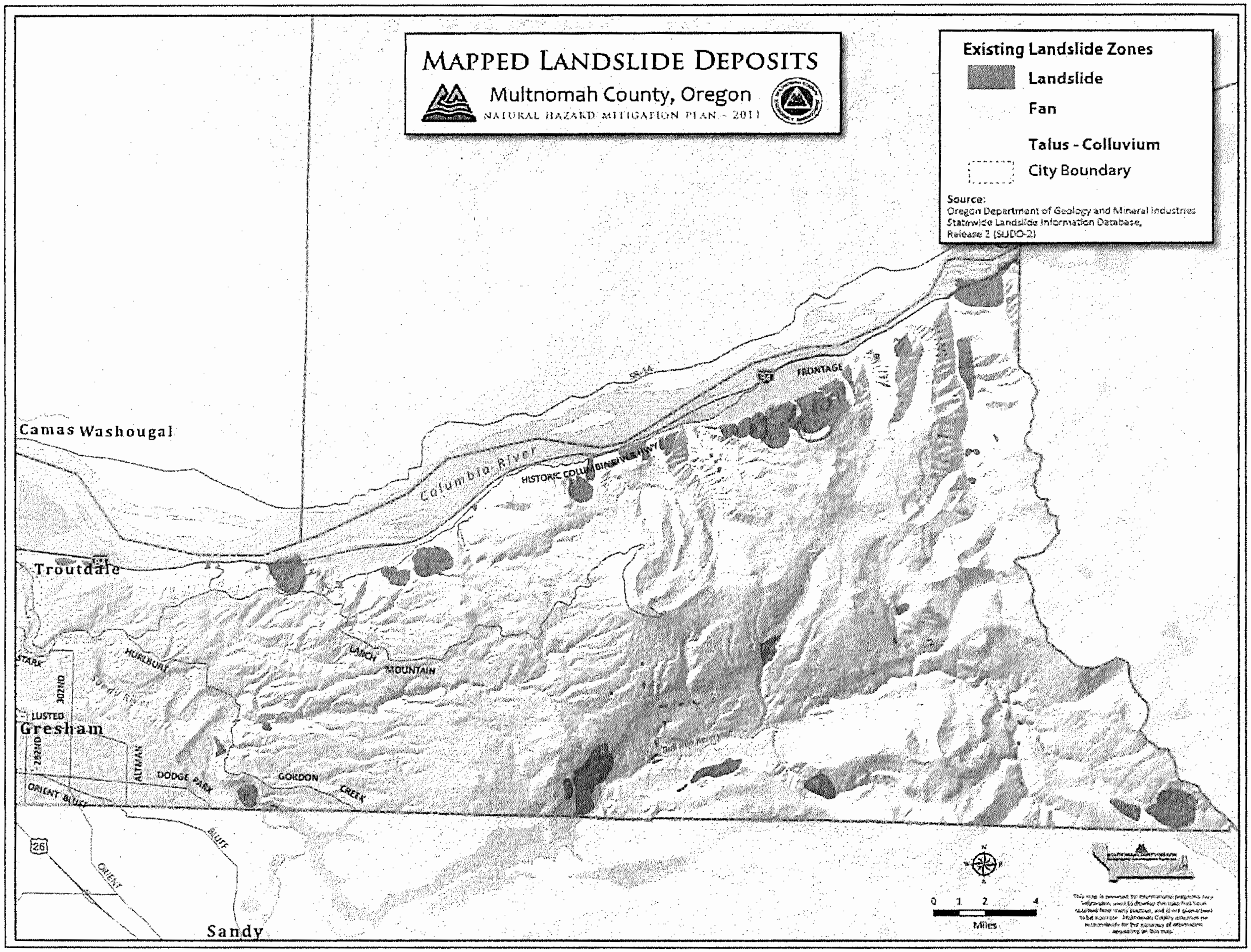


Figure 8.8
DOGAMI Mapped Historical Landslide Areas: East



8.3 Landslide Risk Assessment for Multnomah County

A fully quantitative risk assessment for landslides in Multnomah County, including estimates of the probabilities or return periods of landslides in specific locations, requires far more detailed data than is currently available. Therefore, we address landslide risks only in semi-quantitative terms.

High risk areas for landslides are locations where landslides have occurred in the past or appear likely to occur in the future and there are buildings or infrastructure in these areas. The overlap of landslide hazard areas with developed areas is what results in risk – threats to buildings and infrastructure.

The maps in Figures 8.5, 8.6, 8.7 and 8.8 show that many areas within Multnomah County are likely subject to landslides, including developed areas in the west Portland Hills and important transportation routes (Interstate 84 and the Historic Columbia River Highway in eastern Multnomah County). Significant parts of these areas are within the jurisdictions of incorporated cities and thus not within the County's area of jurisdiction.

There are also landslide hazard areas in undeveloped or very lightly developed areas. Many of these areas are federally owned, including Mt. Hood National Forest and portions of the Columbia River Gorge National Scenic Area.

The tables below show the numbers of buildings within the mapped landslide hazard areas.

Table 8.1
Mapped Landslide Hazard Areas

Landslide Hazard Areas: Unincorporated Portions of Multnomah County									
Data Set	**Indust**	**Commer**	**MultiFamRes**	**ParksOpenSpc**	**MixUseRes**	**SingleFamRes**	**MixUseEmpl**	**Rural**	**Total**
Buildings	0	0	0	0	0	104	0	375	479
County Buildings	0	0	0	0	0	0	0	0	0

Landslide Hazard Area: Incorporated Cities									
Data Set	**Indust**	**Commer**	**MultiFamRes**	**ParksOpenSpc**	**MixUseRes**	**SingleFamRes**	**MixUseEmpl**	**Rural**	**Total**
Buildings	225	0	247	24	165	1,279	26	2	1,968
County Buildings	0	0	0	0	0	0	0	0	0

The potential landslide risk areas within Multnomah County include nearly 500 single family and rural buildings in the unincorporated portions of the county and nearly 2,000 buildings in the incorporated cities. As shown above, there are no county buildings located in mapped landslide hazard areas.

In addition to posing risks for buildings, landslides also pose risks for roads, rail lines and utility systems. Underground utilities such as water, wastewater and natural gas pipes are particularly prone to damage from landslides. Even very small ground displacements of a few inches often result in pipe failures. The consequences of landslides also include the economic impacts of road closures and utility outages.

Landslides also pose life safety risks. Occupants of buildings or vehicles may be injured or killed by landslides.

The 1996 winter storms resulted in many landslides in Oregon. Areas within Multnomah County where landslides occurred included areas west of the Sandy River: Wilson Road south of Kerslake Road and SE Stark Road about ½ mile west of the Sandy River. There were also several landslides, mostly rockfalls on very steep slopes, along the Historic Columbia River Highway. A debris flow area approximately 3 miles long occurred in the Dodson and Warrendale areas on February 7 and 8, 1996. Interstate 84 and the Union Pacific Railroad were closed for several days, and several residences were destroyed.

The potential impacts of landslides on Multnomah County are summarized in Table 8.2 below.

Table 8.2
Potential Impacts of Landslides on Multnomah County

Inventory	Probable Impacts
Portion of Multnomah County affected	Landslides or debris flows are possible in any of the mapped landslide hazard areas shown in Figures 8.5 to 8.8.
Buildings	In the unincorporated parts of the county, most buildings at risk are residential buildings.
Streets within communities	Street closures possible, but impacts generally limited because of short detour routes.
Roads within and to/from Multnomah County	Potential closures of major highways due to landsides, including Highway 30 and Interstate 84 and many secondary roads.
Rail transportation	Disruptions of rail service possible along the Highway 30 and Interstate 84 corridors.
Electric power	Potential for localized loss of electric power due to landslides affecting power lines in or near Multnomah County.
Other Utilities	Potential outages of water, wastewater and natural gas from pipe breaks from landslides. Probable impacts are localized.
Casualties	Landslides that impact buildings or roads could result in a small number of casualties (deaths and injuries).

The damages and economic losses from landslides are generally low to moderate, with damages and losses ranging from a few thousand dollars to hundreds of thousands of dollars. Damages and losses are generally low because the geographic areas affected are usually small. However, large landslides that affect dozens of homes could result in damages in the range of several million dollars.

Similarly, damages to roads and utilities are generally limited to small areas, often in residential areas, with low to moderate damages and economic losses. However, as with building damages, larger landslides or landslides which affect major roads or highways, including bridges, overpasses and viaducts, or major utility lines could have significantly larger economic impacts.

8.4 Mitigation of Landslide Risk

Mitigation of landslide risks is often quite expensive. In some cases, slope stability can be improved by addition of drainage to reduce pore water pressure, by construction of appropriate retaining walls or by other types of geotechnical remediation. In some cases, buildings can be hardened to reduce damages. An alternative mitigation strategy for already built buildings or infrastructure with high potential for landslide losses is to relocate the facilities outside of known slide areas. Relocation outside of landslide hazard areas is especially important for high occupancy buildings and critical facilities.

The impacts of slide damage on road systems can also be partially addressed by identifying areas of high slide potential or of repetitive past slide damages so that alternative routes for emergency response can be pre-determined.

Mitigation of landslide risk can also be accomplished by effective land use planning to minimize development in slide-prone areas. Generally, such land use planning requires rather detailed geotechnical mapping of slide potential so that high hazard areas can be demarcated without unnecessarily including other areas of low slide potential.

The Multnomah County Hillside Development and Erosion Control Ordinance contains provisions that are intended to minimize loss due to earth movement hazards in rural areas shown on the County's adopted "Slope Hazard Maps" shown on figures 8.9 and 8.10. This mapping was developed based on an engineering study of the county that was completed in 1978. The County mapping was supplemented based on a 1996 engineering study of the Dodson-Warrendale area after debris flow losses there in that year.

New construction on land located in mapped hazard areas or with an average slope of 25% or more requires a Hillside Development Permit. However, there are several exemptions that can allow development to proceed without review. One example is a situation where a parcel having slopes less than 25% but which is located immediately downhill from a steep slope subject to failure (or even downhill from an active landslide) is exempt from review.

Multnomah County's regulatory role for landslides in areas within the Urban Growth Boundary is limited by the Urban Planning Area Agreement (UPAA) between the county and cities, which gives the cities' planning authority within the UPAA. The only unincorporated area that is not covered by city zoning under the UPAA is part of Pleasant Valley along Foster Road. This area is not within the mapped landslide hazard areas.

The table on page 8-13 includes landslide mitigation action items from the master Action Items table in Chapter 4.

Table 8-9
Regulatory Landslide Hazard Map: West

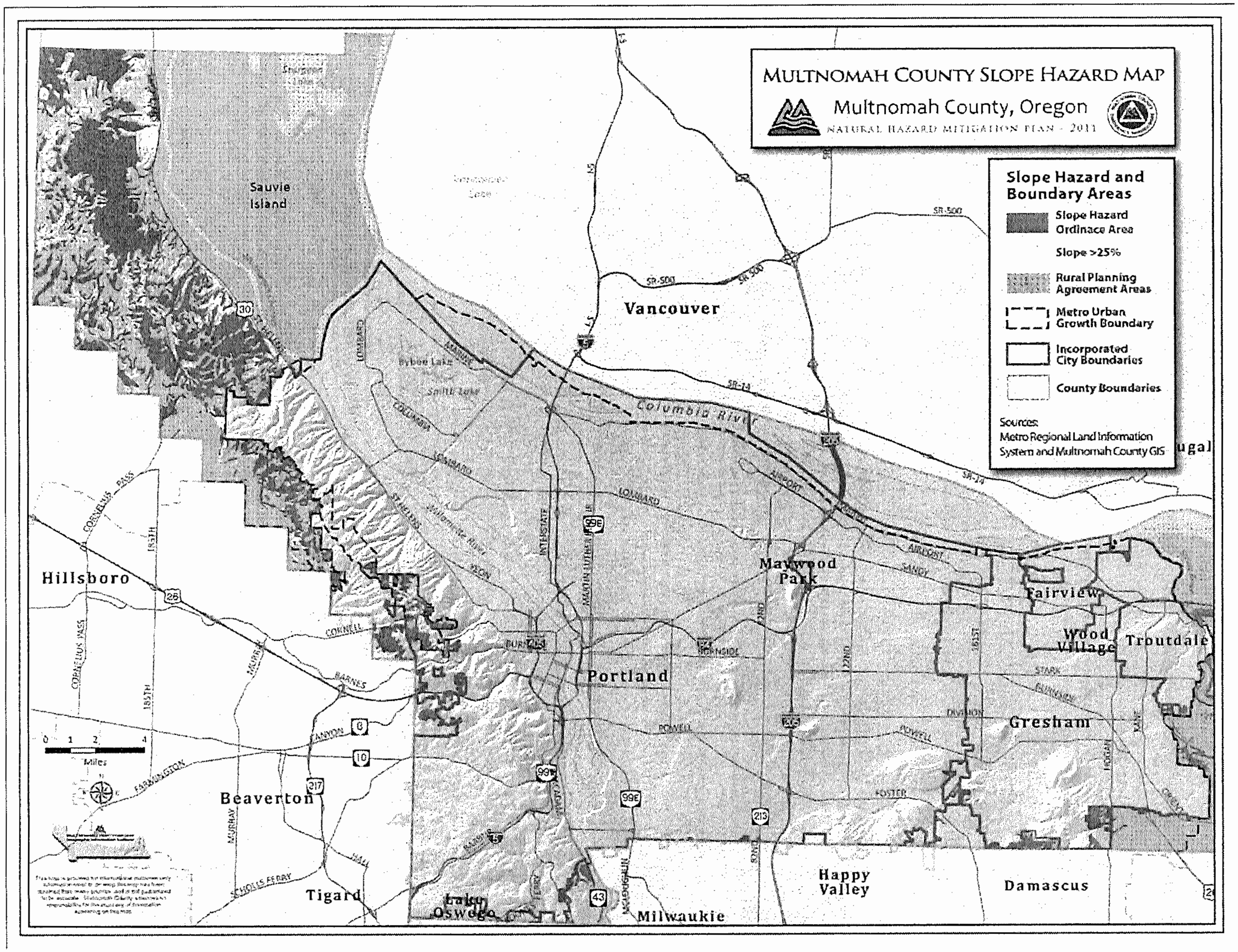


Figure 8-10
Regulatory Landslide Hazard Map: East

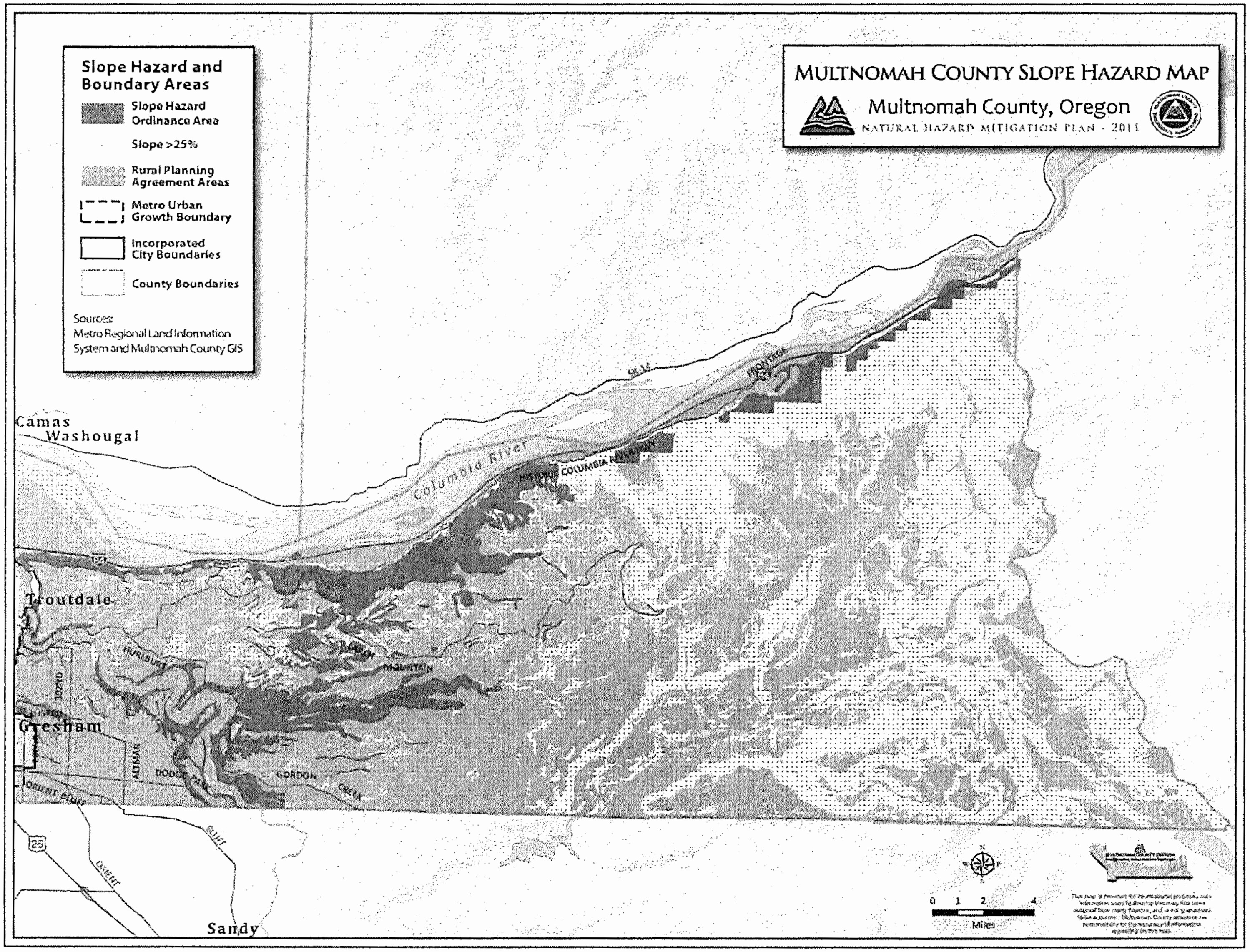


Table 8.3
Landslide Mitigation Action Items

Hazard	Action Item	Coordinating Organizations	Timeline	Plan Goals Addressed: Life Safety	Protect Property and Infrastructure	Emergency Management Capabilities	Public Awareness and Education	Environmental Stewardship
Landslide Mitigation Action Items								
Short-Term #1	Inventory utility and communication infrastructure in areas with a history of landslides or which are within mapped landslide hazard areas.	GIS	1-2 Years		X	X	X	
Short-Term #2	Compile inventory of county road segments with a history of landslides or which are within mapped landslide hazard areas.	Transportation	3 Years		X	X		
Short-Term #3	Review the Hillside Development ordinance to consider amendments that address areas at risk from landslides for areas not already identified on the County Slope Hazard Map or otherwise subject to the Hillside Development zoning code.	Planning	3 Years	X	X		X	X
Short-Term #4	Obtain completed detailed lidar-based inventory of historical and active landslides and areas with high landslide risk to update the County's slope hazard maps.	GIS	Ongoing		X	X	X	
Long-Term #1	Encourage the relocation of identified critical or essential facilities and high occupancy facilities in high landslide hazard areas or mitigation of the landslide hazard if feasible.	Multnomah County Emergency Management	Ongoing	X	X	X	X	

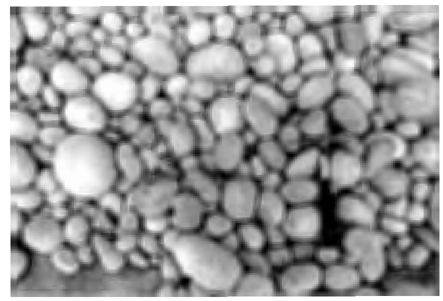
WIKIPEDIA

Exhibit 12

Sediment

For sediment in beverages, see dregs.

Sediment is a naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and/or by the force of gravity acting on the particles. For example, sand and silt can be carried in suspension in river water and on reaching the sea be deposited by sedimentation and if buried this may eventually become sandstone and siltstone, (sedimentary rocks).



Cobbles on a beach

Sediments are most often transported by water (fluvial processes), but also wind (aeolian processes) and glaciers. Beach sands and river channel deposits are examples of fluvial transport and deposition, though sediment also often settles out of slow-moving or standing water in lakes and oceans. Desert sand dunes and loess are examples of aeolian transport and deposition. Glacial moraine deposits and till are ice-transported sediments.

River Rhône flowing into Lake Geneva. Sediments make the water appear brownish-grey; they are an indicator of increased water runoff, land degradation, erosion due to intensive industrialized land use, land sealing, and poor soil management.

Contents

Classification
- Grain size
- Composition

Sediment transport
- Fluvial processes: rivers, streams, and overland flow
  - Particle motion
  - Fluvial bedforms
  - Surface runoff
  - Key fluvial depositional environments
- Aeolian processes: wind
- Glacial processes
- Mass balance

Shores and shallow seas
- Key marine depositional environments

Environmental issues
- Erosion and agricultural sediment delivery to rivers
- Coastal Development and Sedimentation near Coral Reefs

See also

References

Classification

Sediment can be classified based on its grain size and/or its composition.

Grain size

Sediment size is measured on a log base 2 scale, called the "Phi" scale, which classifies particles by size from "colloid" to "boulder".

φ scale	Size range (metric)	Size range (inches)	Aggregate class (Wentworth)	Other names
< -8	> 256 mm	> 10.1 in	Boulder	
-6 to -8	64–256 mm	2.5–10.1 in	Cobble	
-5 to -6	32–64 mm	1.26–2.5 in	Very coarse gravel	Pebble
-4 to -5	16–32 mm	0.63–1.26 in	Coarse gravel	Pebble
-3 to -4	8–16 mm	0.31–0.63 in	Medium gravel	Pebble
-2 to -3	4–8 mm	0.157–0.31 in	Fine gravel	Pebble
-1 to -2	2–4 mm	0.079–0.157 in	Very fine gravel	Granule
0 to -1	1–2 mm	0.039–0.079 in	Very coarse sand	
1 to 0	0.5–1 mm	0.020–0.039 in	Coarse sand	
2 to 1	0.25–0.5 mm	0.010–0.020 in	Medium sand	
3 to 2	125–250 μm	0.0049–0.010 in	Fine sand	
4 to 3	62.5–125 μm	0.0025–0.0049 in	Very fine sand	
8 to 4	3.9–62.5 μm	0.00015–0.0025 in	Silt	Mud
> 8	< 3.9 μm	< 0.00015 in	Clay	Mud
>10	< 1 μm	< 0.000039 in	Colloid	Mud


Sediment billowing out from Italy's shore into the Adriatic Sea


Sediment in the Gulf of Mexico

Composition

Composition of sediment can be measured in terms of:

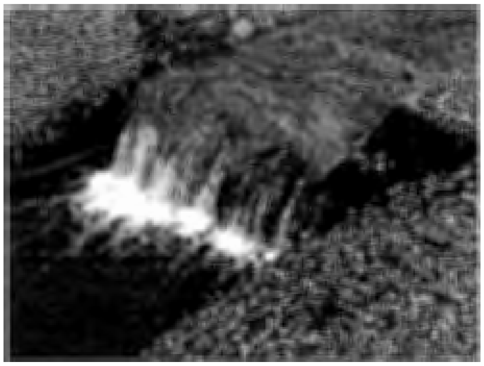
- parent rock lithology
- mineral composition
- chemical make-up.

This leads to an ambiguity in which clay can be used as both a size-range and a composition (see clay minerals).


Sediment off the Yucatán Peninsula

Sediment transport

Sediment is transported based on the strength of the flow that carries it and its own size, volume, density, and shape. Stronger flows will increase the lift and drag on the particle, causing it to rise, while larger or denser particles will be more likely to fall through the flow.


Sediment builds up on human-made breakwaters because they reduce the speed of water flow, so the stream cannot carry as much sediment load.

Fluvial processes: rivers, streams, and overland flow

Particle motion

Rivers and streams carry sediment in their flows. This sediment can be in a variety of locations within the flow, depending on the balance between the upwards velocity on the particle (drag and lift forces), and the settling velocity of the particle. These relationships are shown in the following table for the Rouse number, which is a ratio of sediment fall velocity to upwards velocity.

$$\textbf{Rouse} = \frac{\text{Settling velocity}}{\text{Upwards velocity from lift and drag}} = \frac{w_s}{\kappa u_*}$$

where

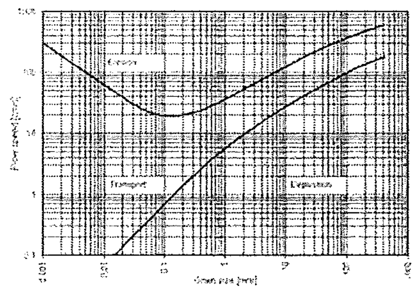
- w_s is the fall velocity
- κ is the von Kármán constant
- u_* is the shear velocity


Glacial transport of boulders. These boulders will be deposited as the glacier retreats.

Mode of Transport	Rouse Number
Bed load	>2.5
Suspended load: 50% Suspended	>1.2, <2.5
Suspended load: 100% Suspended	>0.8, <1.2
Wash load	<0.8

If the upwards velocity approximately equal to the settling velocity, sediment will be transported downstream entirely as suspended load. If the upwards velocity is much less than the settling velocity, but still high enough for the sediment to move (see Initiation of motion), it will move along the bed as bed load by rolling, sliding, and saltating (jumping up into the flow, being transported a short distance then settling again). If the upwards velocity is higher than the settling velocity, the sediment will be transported high in the flow as wash load.

As there are generally a range of different particle sizes in the flow, it is common for material of different sizes to move through all areas of the flow for given stream conditions.



Hjulström curve: The velocities of currents required for erosion, transportation, and deposition (sedimentation) of sediment particles of different sizes.

Fluvial bedforms

Sediment motion can create self-organized structures such as ripples, dunes, antidunes on the river or stream bed. These bedforms are often preserved in sedimentary rocks and can be used to estimate the direction and magnitude of the flow that deposited the sediment.

Modern asymmetric ripples developed in sand on the floor of the Hunter River, New South Wales, Australia. Flow direction is from right to left.

Surface runoff

Overland flow can erode soil particles and transport them downslope. The erosion associated with overland flow may occur through different methods depending on meteorological and flow conditions.

- If the initial impact of rain droplets dislodges soil, the phenomenon is called rainsplash erosion.
- If overland flow is directly responsible for sediment entrainment but does not form gullies, it is called "sheet erosion".
- If the flow and the substrate permit channelization, gullies may form; this is termed "gully erosion".

Sinuous-crested dunes exposed at low tide in the Cornwallis River near Wolfville, Nova Scotia

Key fluvial depositional environments

The major fluvial (river and stream) environments for deposition of sediments include:

- Deltas (arguably an intermediate environment between fluvial and marine)
- Point bars
- Alluvial fans
- Braided rivers
- Oxbow lakes
- Levees
- Waterfalls

Aeolian processes: wind

Wind results in the transportation of fine sediment and the formation of sand dune fields and soils from airborne dust.

Ancient channel deposit in the Stellarton Formation (Pennsylvanian), Coalburn Pit, near Thorburn, Nova Scotia.

Glacial processes

Glaciers carry a wide range of sediment sizes, and deposit it in moraines.

Mass balance

The overall balance between sediment in transport and sediment being deposited on the bed is given by the Exner equation. This expression states that the rate of increase in bed elevation due to deposition is proportional to the amount of sediment that falls out of the flow. This equation is important in that changes in the power of the flow changes the ability of the flow to carry sediment, and this is reflected in patterns of erosion and deposition observed throughout a stream. This can be localized, and simply due to small obstacles: examples are scour holes behind boulders, where flow accelerates, and deposition on the inside of meander bends. Erosion and deposition can also be regional: erosion can occur due to dam removal and base level fall. Deposition can occur due to dam emplacement that causes the river to pool, and deposit its entire load or due to base level rise.

Glacial sediments from Montana

Shores and shallow seas

Seas, oceans and lakes accumulate sediment over time. The sediment could consist of *terrigenous* material, which originates on land, but may be deposited in either terrestrial, marine, or lacustrine (lake) environments; or of sediments (often biological) originating in the body of water. Terrigenous material is often supplied by nearby rivers and streams or reworked marine sediment (e.g. sand). In the mid-ocean, the exoskeletons of dead organisms are primarily responsible for sediment accumulation.

Deposited sediments are the source of sedimentary rocks, which can contain fossils of the inhabitants of the body of water that were, upon death, covered by accumulating sediment. Lake bed sediments that have not solidified into rock can be used to determine past climatic conditions.

Key marine depositional environments

The major areas for deposition of sediments in the marine environment include:

- Littoral sands (e.g. beach sands, runoff river sands, coastal bars and spits, largely clastic with little faunal content)
- The continental shelf (silty clays, increasing marine faunal content).

- The shelf margin (low terrigenous supply, mostly calcareous faunal skeletons)
- The shelf slope (much more fine-grained silts and clays)
- Beds of estuaries with the resultant deposits called "bay mud".

One other depositional environment which is a mixture of fluvial and marine is the turbidite system, which is a major source of sediment to the deep sedimentary and abyssal basins as well as the deep oceanic trenches.


Holocene eolianite and a carbonate beach on Long Island, Bahamas.

Any depression in a marine environment where sediments accumulate over time is known as a sediment trap.

The null point theory explains how sediment deposition undergoes a hydrodynamic sorting process within the marine environment leading to a seaward fining of sediment grain size.

Environmental issues

Erosion and agricultural sediment delivery to rivers

One cause of high sediment loads from slash and burn and shifting cultivation of tropical forests. When the ground surface is stripped of vegetation and then seared of all living organisms, the upper soils are vulnerable to both wind and water erosion. In a number of regions of the earth, entire sectors of a country have become erodible. For example, on the Madagascar high central plateau, which constitutes approximately ten percent of that country's land area, most of the land area is devegetated, and gullies have eroded into the underlying soil in furrows typically in excess of 50 meters deep and one kilometer wide. This siltation results in discoloration of rivers to a dark red brown color and leads to fish kills.

Erosion is also an issue in areas of modern farming, where the removal of native vegetation for the cultivation and harvesting of a single type of crop has left the soil unsupported. Many of these regions are near rivers and drainages. Loss of soil due to erosion removes useful farmland, adds to sediment loads, and can help transport anthropogenic fertilizers into the river system, which leads to eutrophication.

Coastal Development and Sedimentation near Coral Reefs

Watershed development near coral reefs is a primary cause of sediment-related coral stress.The stripping of natural vegetation in the watershed for development exposes soil to increased wind and rainfall, and as a result, could cause exposed sediment to become more susceptible to erosion and delivery to the marine environment during rainfall events. Sediment can negatively affect corals in many ways, such as by physically smothering them, abrading their surfaces, causing corals to expend energy during sediment removal, and causing algal blooms that can ultimately lead to less space on the seafloor where juvenile corals (polyps) can settle.

When sediments are introduced into the coastal regions of the ocean, the proportion of land, marine and organic-derived sediment that characterizes the seafloor near sources of sediment output is altered. In addition, because the source of sediment (i.e. land, ocean, or organically) is often correlated with how coarse or fine sediment grain sizes that characterize an area are on average, grain size distribution of sediment will shift according to relative input of land (typically fine), marine (typically coarse), and organically-derived (variable with age) sediment. These alterations in marine sediment characterize the amount of sediment that is suspended in the water column at any given time and sediment-related coral stress.

See also

- Bar (river morphology)
- Beach cusps
- Biorhexistasy
- Bioswale
- Decantation
- Deposition (geology)
- Erosion
- Exner equation
- Particle size (grain size)
- Regolith
- Sand
- Sediment precipitation
- Sediment trap
- Sedimentary depositional environment
- Settling
- Surface runoff

References

- Prothero, Donald R.; Schwab, Fred (1996), *Sedimentary Geology: An Introduction to Sedimentary Rocks and Stratigraphy*, W. H. Freeman, ISBN 0-7167-2726-9
- Siever, Raymond (1988), *Sand*, New York: Scientific American Library, ISBN 0-7167-5021-X
- Nichols, Gary (1999), *Sedimentology & Stratigraphy*, Malden, MA: Wiley-Blackwell, ISBN 0-632-03578-1
- Reading, H. G. (1978), *Sedimentary Environments: Processes, Facies and Stratigraphy*, Cambridge, MA: Blackwell Science, ISBN 0-632-03627-3

WIKIPEDIA

Exhibit 13

Fish kill

The term **fish kill**, known also as **fish die-off**, refers to a localized die-off of fish populations which may also be associated with more generalized mortality of aquatic life.[1][2] The most common cause is reduced oxygen in the water, which in turn may be due to factors such as drought, algae bloom, overpopulation, or a sustained increase in water temperature. Infectious diseases and parasites can also lead to fish kill. Toxicity is a real but far less common cause of fish kill.[3]


There are many causes of fish kill, but oxygen depletion is the most common cause.

Fish kills are often the first visible signs of environmental stress and are usually investigated as a matter of urgency by environmental agencies to determine the cause of the kill. Many fish species have a relatively low tolerance of variations in environmental conditions and their death is often a potent indicator of problems in their environment that may be affecting other animals and plants and may have a direct impact on other uses of the water such as for drinking water production. Pollution events may affect fish species and fish age classes in different ways. If it is a cold-related fish kill, juvenile fish or species that are not cold-tolerant may be selectively affected. If toxicity is the cause, species are more generally affected and the event may include amphibians and shellfish as well. A reduction in dissolved oxygen may affect larger specimens more than smaller fish as these may be able to access oxygen richer water at the surface, at least for a short time.

Contents

Causes
- Oxygen depletion
- Diseases and parasites
- Toxins
- Algae blooms and red tides
- Biological decay
- Nutrient pollution and eutrophication
- Spawning fatalities
- Water temperature
- Underwater explosions
- Droughts and overstocking

Estimation

Prevention and investigation

Notable events

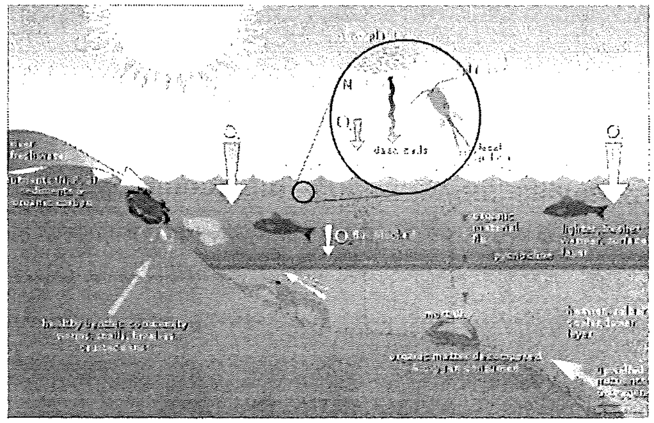
See also

References

External links

Causes

Fish kills may result from a variety of causes. Of known causes, fish kills are most frequently caused by pollution from agricultural runoff or biotoxins. Ecological hypoxia (oxygen depletion) is one of the most common natural causes of fish kills. The hypoxic event may be brought on by factors such as algae blooms, droughts, high temperatures[4] and thermal pollution. Fish kills may also occur due to the presence of disease, agricultural runoff, sewage discharges, oil or hazardous waste spills, hydraulic fracturing wastewater, sea-quakes, inappropriate re-stocking of fish, poaching with chemicals, underwater explosions, and other catastrophic events that upset a normally stable aquatic population.[2] Because of the difficulty and lack of standard protocol to investigate fish kills, many fish kill cases are designated as having an 'unknown' cause.[5][6]



Depleted oxygen levels are the most common cause of fish kills. In this way eutrophication can have devastating consequences for the health of benthic life

Oxygen depletion

Dead and dying European carp in Lake Albert. Fish kills are often a sign of environmental stress.

Oxygen enters the water through diffusion. The amount of oxygen that can be dissolved in water depends on the atmospheric pressure, the water temperature and whether the water is salty.[7] For example, at 20 °C (68 °F) and one atmosphere of pressure, a maximum of 8 mg/l of oxygen can dissolve in sea water (35 mg/l salinity) while a maximum of 9 mg/l of oxygen can dissolve in fresh water. The amount of oxygen that can be dissolved in the water decreases by about 1 mg/l for each 10 °C increase in water temperature above 20 °C.

Many cold water fish that live in clean cold waters become stressed when oxygen concentrations fall below 8 mg/l while warm water fish generally need at least 5 ppm (5 mg/l) of dissolved oxygen. Fish can endure short periods of reduced oxygen. Depleted oxygen levels are the most common cause of fish kills. Oxygen levels normally fluctuate even over the course of a day and are affected by weather, temperature, the amount of sunlight available, and the amount of living and dead plant and animal matter in the water.[8] In temperate zones oxygen levels in eutrophic rivers in summertime can exhibit very large diurnal fluctuations with many hours of oxygen supersaturation during daylight followed by oxygen depletion at night.[9] Associated with these photosynthetic rhythms there is a matching pH rhythm as bicarbonate ion is metabolised by plant cells. This can lead to pH stress even when oxygen levels are high.

Additional dissolved organic loads are the most common cause of oxygen depletion and such organic loads may come from sewage, farm waste, tip leachate and many other sources.

Diseases and parasites

Fish are subject to various viruses, bacteria and fungi in addition to parasites such as protozoans, flukes and worms, or crustaceans. These are naturally occurring in many bodies of water, and fish that are stressed for other reasons, such as spawning or suboptimal water quality, are more susceptible. Signs of disease include sores, missing scales or lack of slime, strange growths or visible parasites, and abnormal behavior–lazy, erratic, gasping at the water surface or floating head, tail or belly up.

This pond in New Forest, England, has been restored following a viral infection which killed all the fish.

For example, since 2004 fish kills have been observed in the Shenandoah River basin in the spring, from the time water temperatures are in the 50s (°F) until they reach the mid-70s. So far, investigators suspect certain bacteria, along with environmental and contaminant factors that may cause immune suppression.[10]

In fish farming, where populations are optimized for the available resources, parasites or disease can spread quickly. In channel catfish aquaculture ponds, for example, the "hamburger gill disease" is caused by a protozoan called *Aurantiactinomyxon* and can kill all the fish in an affected pond. In addition to altered behavior, affected fish have swollen gills that are mottled and have the appearance of ground hamburger meat.[8]

Some early warning signs of fish suffering from disease or parasite infections include:[11]

1. Discolouration, open sores, reddening of the skin, bleeding, black or white spots on the skin
2. Abnormal shape, swollen areas, abnormal lumps, or popeyes
3. Abnormal distribution of the fish such as crowding at the surface, inlet, or pond edges (though crowding at the surface during specific times of day, such as early morning, is more likely a sign of low oxygen)
4. Abnormal activity such as flashing, twisting, whirling, convulsions, loss of buoyancy
5. Listlessness, weakness, sluggishness, lack of activity
6. Loss of appetite or refusal to feed.

Toxins

Agricultural runoff, sewage, surface runoff, chemical spills and hazardous waste spills can all potentially lead to water toxicity and fish kill. Some algae species also produce toxins. In Florida, these include *Aphanizomenon*, *Anabaena* and *Microcystis*. Some notable fish kills in Louisiana in the 1950s were due to a specific pesticide called endrin.[12] Natural instances of toxic conditions can occur, especially in poorly buffered water. Aluminium compounds can cause complete fish kills, sometimes associated with autumn turn-over of lakes leading to complex chemical interactions between pH, calcium ions and complex polymeric salts of aluminium.[13]

Human-induced fish kills are unusual, but occasionally a spilled substance causes direct toxicity or a shift in water temperature or pH that can lead to fish kill. For example, in 1997 a phosphate plant in Mulberry, Florida, accidentally dumped 60 million US gal (0.23 million kl) of acidic process water into Skinned Sapling Creek, reducing the pH from about 8 to less than 4 along 36 miles (58 km) of creek, resulting in the death of about 1.3 million fish.[8]

It is often difficult or impossible to determine whether a potential toxin is the direct cause of a fish kill. For example, hundreds of thousands of fish died after an accidental spill of bourbon whiskey into the Kentucky River near Lawrenceburg. However, officials could not determine whether the fish kill was due to the bourbon directly or to oxygen depletion that resulted when aquatic microbes rapidly began to consume and digest the liquor.[8]

Cyanide is a particular toxic compound that has been used to poach fish. In cyanide poisoning the gills turn a distinctive cherry red. Chlorine introduced as alkaline hypochlorite solution is also extremely toxic,[14] leaving pale mucilaginous gills and an over-production of mucilage across the whole body. Lime produces similar symptoms but is also often associated with milk eyes.

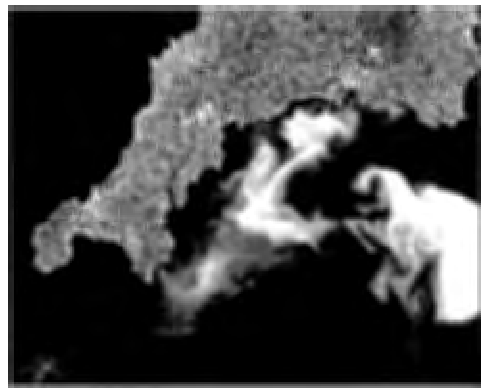
Algae blooms and red tides

An algae bloom is the appearance of a large amount of algae or scum floating on the surface of a body of water. Algae blooms are a natural occurrence in nutrient-rich lakes and rivers, though sometimes increased nutrient levels leading to algae blooms are due to fertilizer or animal waste runoff. A few species of algae produce toxins, but most fish kills due to algae bloom are a result of decreased oxygen levels. When the algae die, decomposition uses oxygen in the water that would be available to fish. A fish kill in a lake in Estonia in 2002 was attributed to a combination of algae bloom and high temperatures.[15] When people manage algae blooms in fish ponds, it is recommended that treatments be staggered to avoid too much algae dying at once, which may result in a large drop in oxygen content.


A small algae bloom on River Cam near Trinity College

Some diseases result in mass die-offs.[16] One of the more bizarre and recently discovered diseases produces huge fish kills in shallow marine waters. It is caused by the ambush predator dinoflagellate *Pfiesteria piscicida*. When large numbers of fish, like shoaling forage fish, are in confined situations such as shallow bays, the excretions from the fish encourage this dinoflagellate, which is not normally toxic, to produce free-swimming zoospores. If the fish remain in the area, continuing to provide nourishment, then the zoospores start secreting a neurotoxin. This toxin results in the fish developing bleeding lesions, and their skin flakes off in the water. The dinoflagellates then eat the blood and flakes of tissue while the affected fish die.[17] Fish kills by this dinoflagellate are common, and they may also have been responsible for kills in the past which were thought to have had other causes.[17] Kills like these can be viewed as natural mechanisms for regulating the population of exceptionally abundant fish. The rate at which the kills occur increases as organically polluted land runoff increases.[18]

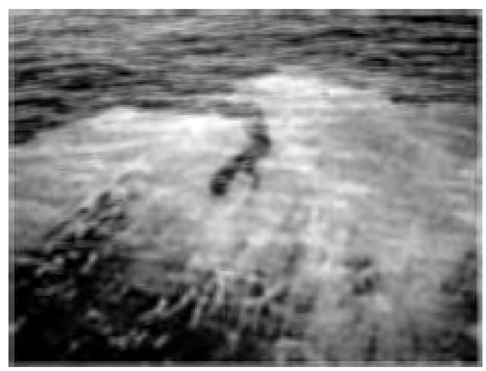
Red tide is the name commonly given to an algal bloom of *Karenia brevis*, a microscopic marine dinoflagellate which is common in Gulf of Mexico waters. In high concentrations it discolors the water which often appears reddish-brown in color. It produces a toxin which paralyses the central nervous system of fish so they cannot breathe. Dead fish wash up on beaches around Texas and Florida. Humans can also become seriously ill from eating oysters and other shellfish contaminated with the red tide toxin.[19][20] The term "red tide" is also commonly used to describe harmful algal blooms on the northern east coast of the United States, particularly in the Gulf of Maine. This type of bloom is caused by another species of dinoflagellate known as *Alexandrium fundyense*.[21] These blooms are natural phenomenon, but the exact cause or combination of factors that result in red tides outbreak not fully understood.[22]



A large algae bloom off the southern coast of England in 1999

Biological decay

Just as an algae bloom can lead to oxygen depletion, introduction of a large amount of decaying biological material in general to a body of water leads to oxygen depletion as microorganisms use up available oxygen in the process of breaking down organic matter. For example, a 10 miles (16 km) fish kill in September, 2010, in the Sangamon River in Illinois was traced to discharge of animal waste into the river from a large dairy operation. The illegal discharge resulted in a complete kill of fish, frogs, mussels and mudpuppies.[23]



Red tide is a reddish algae bloom caused by a microorganism common in the Gulf of Mexico

Nutrient pollution and eutrophication

Excessive anthropogenic nutrient enrichment of phosphorus and nitrogen allow for rapid growth and multiplication of phytoplankton in the Mississippi River. As phytoplankton continue to rapidly grow under optimal conditions, their biomass is almost doubled every 24 hours. In the water, higher concentrations of organic matter are present because of the high reproductive rate of the phytoplankton over a short period of time. The rapid growth of phytoplankton causes turbidity in the waters of the Mississippi and the Gulf of Mexico. Turbidity is defined as the measure of water clarity by how much the suspended material, such as algae and phytoplankton, constrict the passage of sunlight through water. Hence, as phytoplankton begin to multiply more rapidly, turbidity in the river and gulf increases.[24] The increasing turbidity blocks plants from absorbing sunlight. The process of turbidity results in limited photosynthesis production, and sometimes even death from sunlight deprivation of the submerged aquatic vegetation that are affected by the opaque turbid water accumulating at the surface.

Furthermore, a significant detrimental outcome caused by eutrophication in the Mississippi River is the increased uptake of dissolved oxygen by bacteria, in response to higher concentrations of organic matter. After eutrophication starts and is in progress, the phytoplankton reach their maximum population density and begin to die.[24] As the dead phytoplankton accumulate, detritus, or organic matter waste, forms at the surface along with other bacteria and algae. As more phytoplankton die, the higher the concentration of organic matter becomes; and with a higher concentration of organic matter, more bacteria will reproduce.

Consequently, as more bacteria, phytoplankton, and algae exponentially grow and multiply, the more submerged aquatic vegetation die, because they do not have access to sunlight due to eutrophication. Once this snowball-like course of action is in full motion, a dead zone has been created. As a result of the excess nutrient enrichment in the Mississippi River, dead zones appear in the Gulf of Mexico, created from the process of eutrophication. The dead zones in the gulf are mainly created by the nitrogen and phosphorus enrichment of the Lower Mississippi River.

Spawning fatalities

Some species of fish exhibit mass simultaneous mortality as part of their natural life cycle. Fish kill due to spawning fatalities can occur when fish are exhausted from spawning activities such as courtship, nest building, and the release of eggs or milt (sperm). Fish are generally weaker after spawning and are less resilient than usual to smaller changes in the environment. Examples include the Atlantic salmon and the Sockeye salmon where many of the females routinely die immediately after spawning.

A salmon which has died after spawning

Water temperature

A fish kill can occur with rapid fluctuations in temperature or sustained high temperatures. Generally, cooler water has the potential to hold more oxygen, so a period of sustained high temperatures can lead to decreased dissolved oxygen in a body of water. An August, 2010, fish kill in Delaware Bay was attributed to low oxygen as a result of high temperatures.[25]

A massive (hundreds of thousands) fish kill at the mouth of the Mississippi River in Louisiana, September, 2010, was attributed to a combination of high temperatures and low tide. Such kills are known to happen in this region in late summer and early fall, but this one was unusually large.[26]

A short period of hot weather can increase temperatures in the surface layer of water, as the warmer water tends to stay near the surface and be further heated by the air. In this case, the top warmer layer may have more oxygen than the lower, cooler layers because it has constant access to atmospheric oxygen. If a heavy wind or cold rain then occurs (usually during the autumn but sometimes in summer), the layers can mix. If the volume of low oxygen water is much greater than the volume in the warm surface layer, this mixing can reduce oxygen levels throughout the water column and lead to fish kill.

Fish kills can also result from a dramatic or prolonged drop in air (and thus, water) temperature. This kind of fish kill is selective – usually the dead fish are species that cannot tolerate cold. This has been observed in cases where a fish native to a more tropical region has been introduced to cooler waters, such as the introduction of the tilapia to bodies of water in Florida. Native to Africa's Nile River, the tilapia stop feeding when water temperatures drop below 60 °F (16 °C) and die when it reaches 45 °F (7 °C). Thus, tilapia that have survived and successfully reproduced in Florida are occasionally killed by a winter cold front.[8]

In January, 2011, a selective fish kill affecting an estimated 2 million juvenile spot fish was attributed to a combination of cold stress and overpopulation after a particularly large spawn.[27]

Underwater explosions

Underwater explosions can lead to fish kill, and fish with swim bladders are more susceptible. Sometimes underwater explosions are used on purpose to induce fish kills, a generally illegal practice known as blast fishing. Underwater explosions may be accidental or planned, such as for construction, seismic testing, mining or blast testing of structures under water. In many places, an assessment of potential effects of underwater explosions on marine life must be completed and preventive measures taken before blasting.[28]

Droughts and overstocking

Droughts and overstocking can also result in inland fish kills.

A drought can lead to lower water volumes so that even if the water contains a high level of dissolved oxygen, the reduced volume may not be enough for the fish population. Droughts often occur in conjunction with high temperatures so that the oxygen carrying capacity of the water may also be reduced. Low river flows also reduce the available dilution for permitted discharges of treated sewage or industrial waste. The reduced dilution increases the organic demand for oxygen further reducing the oxygen concentration available to fish

Overstocking of fish (or an unusually large spawn) can also result in inland fish kills. Fish kill due to insufficient oxygen is really a matter of too much demand and too little supply for whatever reason(s). Recommended stocking densities are available from many sources for bodies of water ranging from a home aquarium or backyard pond to commercial aquaculture facilities.

Estimation

Estimating the magnitude of a kill presents a number of problems.[29]

1. Polluted waters are often very turbid or have low transparency making it difficult or impossible to see fish that have sunk
2. Rivers and streams can move fish downstream out of the investigation area.
3. Small fish and fry can decompose or become buried in sediments very quickly and are lost from the count.
4. Predators and scavengers remove and eat fish.
5. Stressed fish may swim up tributaries and die there

6. Many kills are reported only when dead fish resurface due to decompositional gas formation, often several hours after the kill has occurred.

Some very large fish kills may never be estimated because of these factors. The discharge of red aluminium sludge from a reservoir in Hungary into the Marcai River is acknowledged as causing environmental devastation,[30] The loss of adult fish also can have long term impacts on the success of the fishery as the following year's spawning stock may have been lost and recovery of the pre-kill population may take years. The loss of food supplies or recreational income may be very significant to the local economy.[31]

Prevention and investigation

Fish kills are difficult to predict. Even when conditions that contribute to fish kill are known to exist, prevention is hard because often conditions cannot be improved and fish cannot be safely removed in time. In small ponds, mechanical aeration and/or removal of decaying matter (such as fallen leaves or dead algae) may be reasonable and effective preventive measures.

Many countries in the developed world have specific provisions in place to encourage the public to report fish kills[32] so that a proper investigation can take place.[33] Investigation of the cause of a kill requires a multi-disciplinary approach including on-site environmental measurements, investigation of inputs, review of meteorology and past history, toxicology, fish autopsy, invertebrate analysis and a robust knowledge of the area and its problems.[34]

Notable events

The counts given below are all estimates. They tend to be underestimates, and may omit, for example, small fish, those removed by scavengers and those that settle to the bottom.[29]

Event/Location	Date	Count	Species	Remarks
Gulf of Mexico (Corpus Christi)	1935	22,000,000		Caused by red tide. This event caused coughing, sneezing and watery red eyes in humans.[35]
River Aeron	1974	10,000	salmon, trout	Discharge of creamery waste through poorly maintained sewer. Successful prosecution followed.
River Neath	1976	50,000	salmon, trout	Extreme drought left fish stranded in stagnant pools into which sewers drained.
River Ogmore	1979	50,000	salmon, trout	Spillage of Kymene from a paper mill on the River Llynfi a tributary of the Ogmore. Successful prosecution followed and substantial compensation.
Gulf of Mexico	1986	22,000,000	Gulf menhaden, striped mullet, various other species[36]	Caused by red tide.[35]
Rhine River	1986 01	500,000		Caused by spill from Swiss chemical warehouse[37]

Texas coast	1997–1998	21,000,000		Caused by a bloom of *Karenia brevis*[38][39]
White River; West Fork, Indiana	1999	4,800,000		Caused by an automotive parts maker in Anderson, Indiana, which had discharged 10,000 gallons of the chemical HMP 2000 into the river.
River Dee (United Kingdom)	2000 07	100,000[40]	salmon, trout, perch	Unconfirmed link to release of whey into river
Klamath River	2002 09	70,000[41]	salmon	Low flow of water due to drought and water diversions for agriculture led to heated and shallow water, increasing vulnerability to a gill disease.
Neuse River, North Carolina	2004 09	1,900,000	menhaden	"Natural upwelling" of an acknowledged polluted river. Hydrogen sulfide smell reported[42]
Taal Lake, Luzon, Philippines	2008 01 05	50 metric tons	tilapia	May be linked to volcanic activity and large fish farms
Liuxihe River Guangzhou People's Republic of China	2008 09 09	10,000	carp	Unknown[43][44]
Beaches at Thanet, Kent, England	2010 01	20,000	velvet crab	20000 + dead crabs – along with dead starfish, lobsters, sponges and anemones. Probably killed by hypothermia.[45][46]
Ting River Fujian People's Republic of China	2010 07	>1,000,000 Enough to feed 70,000 people a year[47]		Part of the Zijin mining disaster[48]
Mississippi River; Plaquemines Parish, Louisiana	2010 09	100,000[49]	redfish, trout, flounder	
Arkansas River; Ozark, Arkansas	2010 12	100,000[50]	freshwater drum	Coincided with death of 5,000 red-winged blackbirds that fell from the sky.
Chesapeake Bay	2011 01	2,000,000	spot croakers	Included some juvenile croakers. Cold water stress was believed to be the cause.[51]
Jiaxing Xiuzhou District People's Republic of China	2011 01 06	250,000	bream, carp, murrel, silver carp, grass carp	Fish caught and transported to market held in large fish tanks fed with river water. Very rapid die-off and loss exceeded 100 tonnes. Only fish caught from a river under China National Highway 320 east died.[52][53]
Redondo Beach, California	2011 03	millions	anchovies, mackerel, sardines and other small fish	Caused by oxygen deprivation[54]
Taal Lake, Batangas, Philippines	2011 05 29	750 metric tons	Tilapia, milkfish	Caused by oxygen deprivation and large fish farms

Lingayen Gulf, Anda, Pangasinan, Philippines	2011 05 30	500 metric tons	Milkfish	Oxygen depletion and change of water climate
Nordreisa, Troms, Norway	2011 12 31	several tons	herring	[55][56]
Guangxi, People's Republic of China	2012 01 15	40,000 kilograms	Various	Caused by 2012 Guangxi cadmium spill[57]

See also

- Aflockalypse
- Aquatic biomonitoring
- Bird kill
- Fish-kill tree
- Paramoebiasis
- Roadkill
- Sentinel species

References

1. U.S. Environmental Protection Agency. Washington, DC (2000). "The Quality of Our Nation's Waters - A Summary of the National Water Quality Inventory: 1998 Report to Congress." (http://www.epa.gov/305b/98report/98brochure.pdf) Archived (https://web.archive.org/web/20080724052358/http://www.epa.gov/305b/98report/98brochure.pdf) 24 July 2008 at the Wayback Machine. Document no. EPA-841-S-00-001. p. 18.
2. University of Florida. Gainesville, FL (2005). "Fish kill." (http://aquat1.ifas.ufl.edu/guide/fiskil.html) Archived (https://web.archive.org/web/20080924135959/http://aquat1.ifas.ufl.edu/guide/fiskil.html) 24 September 2008 at the Wayback Machine. *Plant Management in Florida's Waters.*
3. Noga, Fish Disease: Diagnosis and Treatment, 2010, John Wiley and Sons ISBN 0-8138-0697-6, p. 316
4. Oregon State University (2006). "Deadly hypoxic event finally concludes" (http://www.eurekalert.org/pub_releases/2006-10/osu-dhe103006.php) Archived (https://web.archive.org/web/20110314083456/http://www.eurekalert.org/pub_releases/2006-10/osu-dhe103006.php) 14 March 2011 at the Wayback Machine.,
5. La, V. and S. J. Cooke. (2011). "Advancing the science and practice of fish kill investigations." (http://vantla.com/wordpress/wp-content/uploads/2010/12/RFS-La-Cooke-2011.pdf) Archived (https://web.archive.org/web/20120425145844/http://vantla.com/wordpress/wp-content/uploads/2010/12/RFS-La-Cooke-2011.pdf) 25 April 2012 at the Wayback Machine. Reviews in Fisheries Science. 19(1): 21-33.
6. Saraghan, M. (October, 2011). EPA Scientist Points at Fracking in Fish-Kill Mystery. (http://www.scientificamerican.com/article.cfm?id=epa-scientist-points-at-fracking-in-fish-kill-mystery&page=3) Archived (https://web.archive.org/web/20131213233127/http://www.scientificamerican.com/article.cfm?id=epa-scientist-points-at-fracking-in-fish-kill-mystery&page=3) 13 December 2013 at the Wayback Machine. Scientific American. Retrieved September 8, 2012.
7. Oxygen Solubility in Fresh and Sea Water (http://www.engineeringtoolbox.com/oxygen-solubility-water-d_841.html) Archived (https://web.archive.org/web/20110103230758/http://www.engineeringtoolbox.com/oxygen-solubility-water-d_841.html) 3 January 2011 at the Wayback Machine.. Engineeringtoolbox.com. Retrieved on 2012-05-23.
8. A Beginner's Guide to Water Management – Fish Kills, Information Circular 107, University of Florida IFAS Extension,

2003 read online (http://edis.ifas.ufl.edu/topic_fish_kills) Archived (https://web.archive.org/web/20110504040737/http://edis.ifas.ufl.edu/topic_fish_kills) 4 May 2011 at the Wayback Machine.

9. Ambient Water Quality Criteria for Dissolved Oxygen (http://www.env.gov.bc.ca/wat/wq/BCguidelines/do/do-02.htm) Archived (https://web.archive.org/web/20100811091231/http://www.env.gov.bc.ca/wat/wq/BCguidelines/do/do-02.htm) 11 August 2010 at the Wayback Machine.. Env.gov.bc.ca. Retrieved on 2012-05-23.
10. information from the Department of Environmental Quality, Virginia, USA (http://www.deq.state.va.us/info/srfishkill.html) Archived (https://web.archive.org/web/20110524035958/http://www.deq.state.va.us/info/srfishkill.html) 24 May 2011 at the Wayback Machine.; see also History of fish kills in the Shenandoah watershed, Virginia (http://www.deq.state.va.us/info/srfishkillhistory.html) Archived (https://web.archive.org/web/20110524044853/http://www.deq.state.va.us/info/srfishkillhistory.html) 24 May 2011 at the Wayback Machine.
11. Fish Kills - Their Causes and Prevention, Virginia Tech, Virginia Cooperative Extension Publication 420-252, 2009 (https://web.archive.org/web/20100610081128/http://pubs.ext.vt.edu/420/420-252/420-252.pdf). (PDF)
12. Larson et al., 1997. Pesticides in Surface Waters: distribution, trends and governing factors. CRC Press ISBN 1-57504-006-9 p. 278
13. http://www.sekj.org/PDF/anzf33/anzf33-517p.pdf Archived (https://web.archive.org/web/20110828232501/http://www.sekj.org/PDF/anzf33/anzf33-517p.pdf) 28 August 2011 at the Wayback Machine.. Retrieved on 2012-05-23.
14. Fish Kills in New South Wales (https://web.archive.org/web/20110317032617/http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/202794/nsw-fish-kill.pdf)
15. Estonian Academy Publishers (2005). *Proceedings of the Estonian Academy of Sciences, Biology and Ecology* (https://books.google.com/books?id=zGqUHtmTCuoC&pg=PA67). Estonian Academy Publishers. p. 67.
16. Moyle and Cech, 2004, page 466
17. Burkholder JM, Glasgow HB and Hobbs CW (1995) "Fish kills linked to a toxic ambush-predator dinoflagellate: distribution and environmental conditions" (http://www.int-res.com/articles/meps/124/m124p043.pdf) Archived (https://web.archive.org/web/20120223203635/http://www.int-res.com/articles/meps/124/m124p043.pdf) 23 February 2012 at the Wayback Machine. *Marine Ecology Progress Series*.
18. Magnien RE (2001) "The Dynamics of Science, Perception, and Policy during the Outbreak of Pfiesteria in the Chesapeake Bay" (http://www.bioone.org/doi/abs/10.1641/0006-3568(2001)051%5B0843:TDOSPA%5D2.0.CO%3B2) *BioScience* 51(10):843-852.
19. "Red Tide FAQ - Is it safe to eat oysters during a red tide?" (http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/redtide/faq.phtml#q9). Texas Parks and Wildlife Department. Archived (https://web.archive.org/web/20090706100608/http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/redtide/faq.phtml#q9) from the original on 6 July 2009. Retrieved 23 August 2009.
20. "Harmful Algal Blooms: Red Tide: Home" (https://www.cdc.gov/hab/redtide/). US Centers for Disease Control. Archived (https://web.archive.org/web/20090509084035/http://www.cdc.gov/hab/redtide/) from the original on 9 May 2009. Retrieved 23 August 2009.
21. "Red Tide Fact Sheet - Red Tide (Paralytic Shellfish Poisoning)" (http://www.mass.gov/?pageID=eohhs2modulechunk&L=4&L0=Home&L1=Provider&L2=Guidance+for+Businesses&L3=Food+Safety&sid=Eeohhs2&b=terminalcontent&f=dph_environmental_foodsafety_p_red_tide&csid=Eeohhs2). Massachusetts Department of Public Health. Archived (https://web.archive.org/web/20090826001901/http://www.mass.gov/?pageID=eohhs2modulechunk&L=4&L0=Home&L1=Provider&L2=Guidance+for+Businesses&L3=Food+Safety&sid=Eeohhs2&b=terminalcontent&f=dph_environmental_foodsafety_p_red_tide&csid=Eeohhs2) from the original on 26 August 2009. Retrieved 23 August 2009.
22. "Red Tide FAQ" (http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/redtide/faq.phtml). Texas Parks and Wildlife Department. Archived (https://web.archive.org/web/20090706100608/http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/redtide/faq.phtml) from the original on 6 July 2009. Retrieved 23 August 2009.

23. Contaminated Water Kills Fish in Central Illinois (http://www.pantagraph.com/news/local/contaminated-water-kills-fish-in-central-illinois/article_a64ef8bc-bf50-11df-9804-001cc4c002e0.html) Archived (https://web.archive.org/web/20160415154155/http://www.pantagraph.com/news/local/contaminated-water-kills-fish-in-central-illinois/article_a64ef8bc-bf50-11df-9804-001cc4c002e0.html) 15 April 2016 at the Wayback Machine.
24. Wright, Richard T.; Boorse, Dorothy F. (2014). *Environmental Science: Toward a Sustainable Future*. Boston: Pearson Education. pp. 523–578.
25. August 2010 fish kill in Delaware Bay linked to high temperatures – low oxygen (http://www.newjerseynewsroom.com/science-updates/fish-kill-in-delaware-bay-still-a-mystery-to-nj-dep) Archived (https://web.archive.org/web/20100818072307/http://www.newjerseynewsroom.com/science-updates/fish-kill-in-delaware-bay-still-a-mystery-to-nj-dep) 18 August 2010 at the Wayback Machine.. Newjerseynewsroom.com (2010-08-12). Retrieved on 2012-05-23.
26. Slideshow: Massive fish kill (https://www.reuters.com/news/pictures/slideshow?articleId=USRTR2IDT7) Archived (https://web.archive.org/web/20140222203924/http://www.reuters.com/news/pictures/slideshow?articleId=USRTR2IDT7) 22 February 2014 at the Wayback Machine. Reuter's News Service report of massive fish kill at the mouth of the Mississippi River in September, 2010. The Division of Wildlife stated that the fish kill was unrelated to the oil spill that had recently occurred in the Gulf of Mexico: http://www.aolnews.com/2010/09/16/massive-mississippi-river-fish-kill-not-bps-fault/ Massive Fish Kill Not BP's Fault (http://www.aolnews.com/2010/09/16/massive-mississippi-river-fish-kill-not-bps-fault/) Archived (https://web.archive.org/web/20121007233913/http://www.aolnews.com/2010/09/16/massive-mississippi-river-fish-kill-not-bps-fault/) 7 October 2012 at the Wayback Machine.
27. CNN story on Jan 6, 2011 Fish kill in Maryland (http://www.cnn.com/2011/US/01/06/maryland.fish.kill/index.html?iref=obinsite) Archived (https://web.archive.org/web/20121109035058/http://www.cnn.com/2011/US/01/06/maryland.fish.kill/index.html?iref=obinsite) 9 November 2012 at the Wayback Machine.. Cnn.com (2011-01-06). Retrieved on 2012-05-23.
28. Lewis, 1996, Effects of Underwater Explosions on Life in the Sea, report DSTO-GD-0080 to the Australian Department of Defence read online (http://dspace.dsto.defence.gov.au/dspace/bitstream/1947/3763/1/DSTO-GD-0080%20PR.pdf) Archived (https://web.archive.org/web/20110706121631/http://dspace.dsto.defence.gov.au/dspace/bitstream/1947/3763/1/DSTO-GD-0080%20PR.pdf) 6 July 2011 at the Wayback Machine.; Govoni, et al., 2008, Effects of Underwater Explosions on Larval Fish: Implications for a Coastal Engineering Project, Journal of Coastal Research 2(S):228-233 doi:10.2112/05-0518.1 (https://doi.org/10.2112%2F05-0518.1)
29. Labay, Andrew A.; Bizan, Dave (1999). "A Comparison of Fish Kill Counting Procedures on a Small, Narrow Stream" (http://afsjournals.org/doi/abs/10.1577/1548-8675%281999%29019%3C0209:ACOFKC%3E2.0.CO%3B2). *North American Journal of Fisheries Management*. American Fisheries Society. 19 (1): 209–214. doi:10.1577/1548-8675(1999)019<0209:ACOFKC>2.0.CO;2 (https://doi.org/10.1577%2F1548-8675%281999%29019%3C0209%3AACOFKC%3E2.0.CO%3B2).
30. "Hungarian chemical sludge spill reaches Danube" (http://www.bbc.co.uk/news/world-europe-11491412). *BBC News*. 7 October 2010. Archived (https://web.archive.org/web/20110120200728/http://www.bbc.co.uk/news/world-europe-11491412) from the original on 20 January 2011.
31. Environment Agency, UK (2009). "Life after a fish mortality." (http://www.environment-agency.gov.uk/static/documents/Business/Preventing_fish_mortalities_-_Life_after_a_fish_mortality.pdf) Archived (http://webarchive.nationalarchives.gov.uk/20110203111515/http%3A//www.environment%2Dagency.gov.uk/static/documents/Business/Preventing_fish_mortalities_%2D_Life_after_a_fish_mortality.pdf) 3 February 2011 at the UK Government Web Archive
32. Florida Fish and Wildlife Research Institute - Submit A Fish Kill Report (http://research.myfwc.com/fishkill/submit.asp) Archived (https://web.archive.org/web/20110405022446/http://research.myfwc.com/fishkill/submit.asp) 5 April 2011 at the Wayback Machine.. Research.myfwc.com. Retrieved on 2012-05-23.
33. Environment Agency, UK (2010-12-22). "Fish mortality investigations." (http://www.environment-agency.gov.uk/research/commercial/40101.aspx) Archived (https://web.archive.org/web/20120314024852/http://www.environment-agency.gov.uk/research/commercial/40101.aspx) 14 March 2012 at the Wayback Machine.

gov.uk/research/commercial/40101.aspx) 14 March 2012 at the Wayback Machine.

34. Pierce, Robert A.; May, Thomas W.; Suppes, V. Charles (1994). "Collection and Submission of Samples for Fish-Kill Investigation and Toxic-Substance Analysis." (http://extension.missouri.edu/explorepdf/agguides/wildlife/g09402.pdf) University of Missouri Extension, Columbia, MO. Publication No. G9402.
35. Reisinger, E. Anthony (2000). "Red Tide." (http://www.utpa.edu/csl/redtide.html) Archived (https://web.archive.org/web/20101213033922/http://www.utpa.edu/csl/redtide.html) 13 December 2010 at the Wayback Machine. Coastal Studies Laboratory, University of Texas-Pan American. Edinburg, TX.
36. Trebatoski, Bob (1988). "Observations on the 1987-1987 Texas Red Tide (*Ptychodiscus brevis*)." (http://repositories.tdl.org/tamug-ir/bitstream/handle/1969.3/18723/10246-Observations%20on%20the%201986-1987%20Texas%20Red%20Tide%20(Ptychodiscus%20brevis).pdf?sequence=1) Archived (https://web.archive.org/web/20110728083110/http://repositories.tdl.org/tamug-ir/bitstream/handle/1969.3/18723/10246-Observations%20on%20the%201986-1987%20Texas%20Red%20Tide%20%28Ptychodiscus%20brevis%29.pdf?sequence=1) 28 July 2011 at the Wayback Machine. Texas Water Commission, Austin TX. Report No. 88-02.
37. Environmental History Timeline (http://www.radford.edu/wkovarik/envhist/majorEvents.disasters.html) Archived (https://web.archive.org/web/20110103222307/http://www.radford.edu/wkovarik/envhist/majorEvents.disasters.html) 3 January 2011 at the Wayback Machine.. Radford.edu. Retrieved on 2012-05-23.
38. Science House (North Carolina State University). "Algae Blooms." (http://www.science-house.org/nesdis/algae/background.html) Archived (https://web.archive.org/web/20101201025428/http://www.science-house.org/nesdis/algae/background.html) 1 December 2010 at the Wayback Machine. *Investigating the Ocean*. Accessed 2011-01-07.
39. Bushaw-Newton, K.L. and Sellner, K.G.(1999). "Harmful Algal Blooms." (http://oceanservice.noaa.gov/websites/retiredsites/sotc_pdf/hab.pdf) Archived (https://web.archive.org/web/20110727002805/http://oceanservice.noaa.gov/websites/retiredsites/sotc_pdf/hab.pdf) 27 July 2011 at the Wayback Machine. *NOAA's State of the Coast Report*. Silver Spring, MD: National Oceanic and Atmospheric Administration.
40. "Pollution toll rises to 100,000 fish" (http://news.bbc.co.uk/1/hi/wales/876571.stm). *BBC News*. 11 August 2000. Archived (https://web.archive.org/web/20040705023646/http://news.bbc.co.uk/1/hi/wales/876571.stm) from the original on 5 July 2004.
41. Steve Pedery (2007-07-05). "In Klamath Basin, politics trump science" (https://news.google.com/newspapers?id=ZF5WAAAAIBAJ&sjid=d_ADAAAAIBAJ&pg=4994,751693). *The Register-Guard*. Retrieved May 25, 2011.
42. Book, Sue (4 September 2009). "Neuse fish kill estimate now closer to 2 million" (http://www.newbernsj.com/articles/neuse-47734-fish-million.html). *Sun Journal*. New Bern, NC. Archived (https://web.archive.org/web/20110727155840/http://www.newbernsj.com/articles/neuse-47734-fish-million.html) from the original on 27 July 2011.
43. Chinadaily.com.cn. "Chinadaily.com.cn (http://www.chinadaily.com.cn/china/2008-09/12/content_7020664.htm) Archived (https://web.archive.org/web/20121023144838/http://www.chinadaily.com.cn/china/2008-09/12/content_7020664.htm) 23 October 2012 at the Wayback Machine.." *Dead fish mystery in Guangzhou probed*. Retrieved on 2010-01-08.
44. hk.apple.nextmedia.com. "hk.apple.nextmedia.com (http://www1.hk.apple.nextmedia.com/template/apple/art_main.php?iss_id=20080911&sec_id=15335&art_id=11585511) Archived (https://web.archive.org/web/20110714181512/http://www1.hk.apple.nextmedia.com/template/apple/art_main.php?iss_id=20080911&sec_id=15335&art_id=11585511) 14 July 2011 at the Wayback Machine.." *廣州流溪河污染　魚屍數萬條*. Retrieved on 2010-01-08.
45. "Thousands of dead crabs wash up on Kent beaches" (http://news.bbc.co.uk/1/hi/england/kent/8456514.stm). BBC News. January 13, 2010. Retrieved January 10, 2011.
46. *Winter Crab deaths - the statistics and a ramble* - Thanet coast life (http://thanetcoastlife.blogspot.com/2011/01/winter-crab-deaths-statistics-and.html) Archived (https://web.archive.org/web/20110708065354/http://thanetcoastlife.blogspot.com/2011/01/winter-crab-deaths-statistics-and.html) 8 July 2011 at the Wayback Machine. Retrieved on 2011-01-08

47. National geographics. "National Geographic (http://news.nationalgeographic.com/news/2010/12/101221-next-water-pollution-disasters-/) Archived (https://web.archive.org/web/20101225112609/http://news.nationalgeographic.com/news/2010/12/101221-next-water-pollution-disasters-/) 25 December 2010 at the Wayback Machine.." *Water pollution disaster.* Retrieved on 2010-01-08.
48. Bloomberg.com. "Bloomberg.com (https://www.bloomberg.com/news/2010-12-28/zijin-mining-officials-fined-1-16-million-yuan-for-waste-spills-in-fujian.html) Archived (https://web.archive.org/web/20140304120438/http://www.bloomberg.com/news/2010-12-28/zijin-mining-officials-fined-1-16-million-yuan-for-waste-spills-in-fujian.html) 4 March 2014 at the Wayback Machine.." *Zijin mining officials fined 1.16 million yuan for waste spills in fujian.* Retrieved on 2010-01-08.
49. "Massive La. Fishkill Prompts Oil Spill Questions Hundreds of Thousands of Dead Fish in Bayou Near Mississippi River; Oil, Chemical Dispersant, Oxygen Levels Eyed as Culprits" (http://www.cbsnews.com/stories/2010/09/15/national/main6868602.shtml). *CBS News.* 15 September 2010. Archived (https://web.archive.org/web/20110120114351/http://www.cbsnews.com/stories/2010/09/15/national/main6868602.shtml) from the original on 20 January 2011. Retrieved 7 January 2011. "Hundreds of thousands of dead fish were floating west of the Mississippi River, in Bayou Chaland."
50. "Massive fish kill blankets Arkansas River" (http://edition.cnn.com/2011/US/01/02/arkansas.fish.kill/index.html). *CNN.* 3 January 2011. Archived (https://web.archive.org/web/20110104085200/http://edition.cnn.com/2011/US/01/02/arkansas.fish.kill/index.html) from the original on 4 January 2011. Retrieved 4 January 2011. "Dead drum fish floated in the water and lined the banks of a 20-mile stretch of the Arkansas River near Ozark, about 125 miles northwest of Little Rock, said Keith Stephens of the Arkansas Game and Fish Commission. A tugboat operator discovered the fish kill Thursday night, and fisheries officials collected some of the dying animals to conduct tests. ..."
51. Maryland Department of the Environment, Baltimore, MD (2011-01-05). "MDE Investigates Large Fish Kill in Chesapeake Bay." (http://www.mde.state.md.us/programs/PressRoom/Pages/010511.aspx) Archived (https://web.archive.org/web/20110109002334/http://www.mde.state.md.us/programs/PressRoom/Pages/010511.aspx) 9 January 2011 at the Wayback Machine. Press release.
52. News.big5.enorth.com.cn. "News.big5.enorth.com.cn (http://news.big5.enorth.com.cn/system/2011/01/07/005539358.shtml) Archived (https://web.archive.org/web/20110707015030/http://news.big5.enorth.com.cn/system/2011/01/07/005539358.shtml) 7 July 2011 at the Wayback Machine.." *嘉興一水產市場2.5萬斤魚暴斃 或有人投毒.* Retrieved on 2010-01-08.
53. Tech-food.com. "Tech-food.com (http://www.tech-food.com/news/2011-1-7/n0473675.htm) Archived (https://web.archive.org/web/20110111065159/http://www.tech-food.com/news/2011-1-7/n0473675.htm) 11 January 2011 at the Wayback Machine.." *浙江嘉兴市水产批发市场约2.5万斤鱼死亡.* Retrieved on 2010-01-08.
54. msnbc.com (http://www.msnbc.msn.com/id/41972653/ns/us_news-environment/?GT1=43001) Archived (https://web.archive.org/web/20110311000826/http://www.msnbc.msn.com/id/41972653/ns/us_news-environment/?GT1=43001) 11 March 2011 at the Wayback Machine.. MSNBC. Retrieved on 2012-05-23.
55. Lofstad, Ralf (2 January 2012). "Over natta var stranda full av død sild" (http://www.dagbladet.no/2012/01/02/nyheter/dyrenes_nyheter/innenriks/fiskedod/19632870/) [Overnight the beach was full of dead herring]. *Dagbladet* (in Norwegian). Archived (https://web.archive.org/web/20120107091519/http://www.dagbladet.no/2012/01/02/nyheter/dyrenes_nyheter/innenriks/fiskedod/19632870/) from the original on 7 January 2012. Retrieved 2 January 2012.
56. "Mass death of herring off northern Norway puzzles locals" (https://archive.is/20120914161505/http://www.monstersandcritics.com/news/europe/news/article_1683583.php/Mass-death-of-herring-off-northern-Norway-puzzles-locals). *Monsters & Critics.* Deutsche Presse-Agentur. January 2, 2012. Archived from the original (http://www.monstersandcritics.com/news/europe/news/article_1683583.php/Mass-death-of-herring-off-northern-Norway-puzzles-locals) on September 14, 2012. Retrieved January 2, 2012.
57. Officials fired over cadmium spillINation (http://www.chinadaily.com.cn/cndy/2012-02/04/content_14536059.htm)

Archived (https://web.archive.org/web/20120206103815/http://www.chinadaily.com.cn/cndy/2012-02/04/content_14536059.htm) 6 February 2012 at the Wayback Machine.. chinadaily.com.cn (2012-02-04). Retrieved on 2012-05-23.

External links

- Herring, and Scott (2002) *Fish Kill in the Gulf of Oman: A space-based diagnosis* (http://earthobservatory.nasa.gov/Features/oman/) NASA: Earth Observatory, featured article.
- La, V. and S.J. Cooke (2011). *Advancing the Science and Practice of Fish Kill Investigations* (http://vantla.com/wordpress/wp-content/uploads/2010/12/RFS-La-Cooke-2011.pdf) Reviews in Fisheries Science 19(1): 21–33.

External video

Red tide outbreak and fish kill (http://video.google.com/videoplay?docid=-1295443816859346212)

- Oxygen Depletion in Ponds, University of Georgia Cooperative Extension Service, Publication L233, 1993 (http://www.engineeringtoolbox.com/oxygen-solubility-water-d_841.html)
- Fish Kills – Their Causes and Prevention, Virginia Tech, Virginia Cooperative Extension Publication 420-252, 2009 (https://web.archive.org/web/20100610081128/http://pubs.ext.vt.edu/420/420-252/420-252.pdf)
- Fish Kills in Coastal Georgia Ponds and Lagoons, Georgia Department of Natural Resources (http://crd.dnr.state.ga.us/assets/documents/PondTurnoverBrochure.pdf)
- "The Fish Kill Mystery" (https://web.archive.org/web/20081120194631/http://www.sciencecases.org/fishkill/fishkill.asp) – Erica F. Kosal, North Carolina Wesleyan College (2003)
- Maryland DNR page on Pfiesteria (sometimes toxic dinoflagellate) (https://web.archive.org/web/20110420005905/http://www.dnr.state.md.us/bay/cblife/algae/dino/pfiesteria/facts.html#contact)
- Fish kill hotline in Florida to report observed fish kills (https://web.archive.org/web/20070323022621/http://research.myfwc.com/features/view_article.asp?id=13920)

Retrieved from "https://en.wikipedia.org/w/index.php?title=Fish_kill&oldid=822333818"

Exh. 14

Union of Concerned Scientists
Science for a healthy planet and safer world

Qsearch

Is Global Warming Linked to Severe Weather?

As Earth warms, powerful storms are becoming the new normal

Overhead, tall, dense clouds are poised to burst, their presence a sign of an imminent deluge.

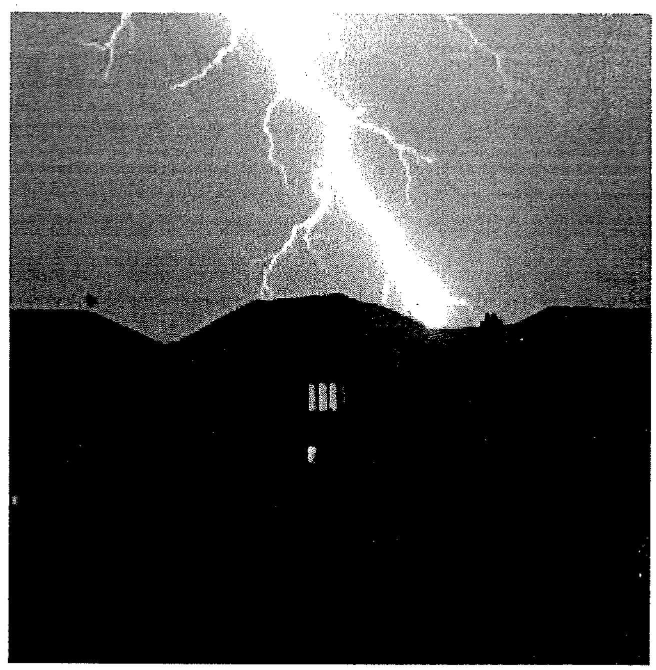


Image: Wikimedia Commons/Jok2000

These cumulonimbus masses are a reminder of the destructive floods that are occurring around the globe, which, taken together, are potent signals of one of the greatest environmental challenges of our time: global warming.

Powerful rain and snow storms—and, ironically, intense drought periods—are a well-known consequence of a warmer planet.

What is the relationship between global warming, climate, and weather?

Weather is what's happening outside the door right now; today a thunderstorm is approaching. Climate, on the other hand, is the pattern of weather measured over a number of decades.

Over the past 30 years there has been a pattern of increasingly higher average temperatures for the whole world. In fact, the first decade of this century (2001–2010) was the hottest decade recorded since reliable records began in the late 1800s.

These rising temperatures—caused primarily by an increase of heat-trapping emissions in the atmosphere created when we burn coal, oil, and gas to generate electricity, drive our cars, and fuel our businesses—are what we refer to as global warming.

One consequence of global warming is an increase in both ocean evaporation into the atmosphere, and the amount of water vapor the atmosphere can hold. High levels of water vapor in the atmosphere in turn create conditions more favorable for heavier precipitation in the form of intense rain and snow storms.

The United States is already experiencing more intense rain and snow storms.

As the Earth warms, the amount of rain or snow falling in the heaviest one percent of storms has risen nearly 20 percent on average in the United States—almost three times the rate of increase in total precipitation between 1958 and 2007.

In other words, the heaviest storms have very recently become even heavier.

The Northeast has seen a 74 percent increase in the amount of rain or snow falling in the heaviest storms.

Image: NOAA
As storms increase in intensity, flooding becomes a larger concern.

Flash floods, which pose the most immediate risks for people, bridges and roads, and buildings on floodplains, result in part from this shift toward more extreme precipitation in a warming world.

Regions previously thought to be safe from floods are increasingly threatened by them; agencies such as the National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), and the US Geological Survey (USGS), among others, are working to gather information that can be used to redraw flood maps to help anticipate vulnerable areas.

Their research found that Texas had the largest number of fatalities from flash floods and river floods over the study period. When standardized for population, South Dakota, Mississippi, West Virginia, and Montana had the highest numbers of fatalities from flooding per 100,000 people. Those between the ages of 10 and 29 and those over 60 years old were disproportionately at risk.In 2008 two scientists, Sharon Ashley and Walker Ashley, of Northern Illinois University, analyzed flood fatalities between 1959 and 2005 in the mainland United States, excluding those from Hurricane Katrina.

Does global warming create more frequent and more intense tornadoes?

Tornadoes are relatively small, short-lived phenomena and scientists don't have robust enough data to determine whether and how climate change may be affecting tornado frequency, intensity, or the geographic range where tornadoes are most likely to form.

Tornadoes often form when warm, moist air near the Earth's surface rises and interacts with cooler and drier air higher in the atmosphere. This creates unstable conditions that are favorable for thunderstorms and sometimes tornadoes.

Unlike thunderstorms, tornadoes need a rotational source such as when warm, moist air from the Gulf of Mexico wafts over the southeast and strong Jetstream air aloft arrives from a westerly direction, as during the tragic string of tornadoes in April 2011.

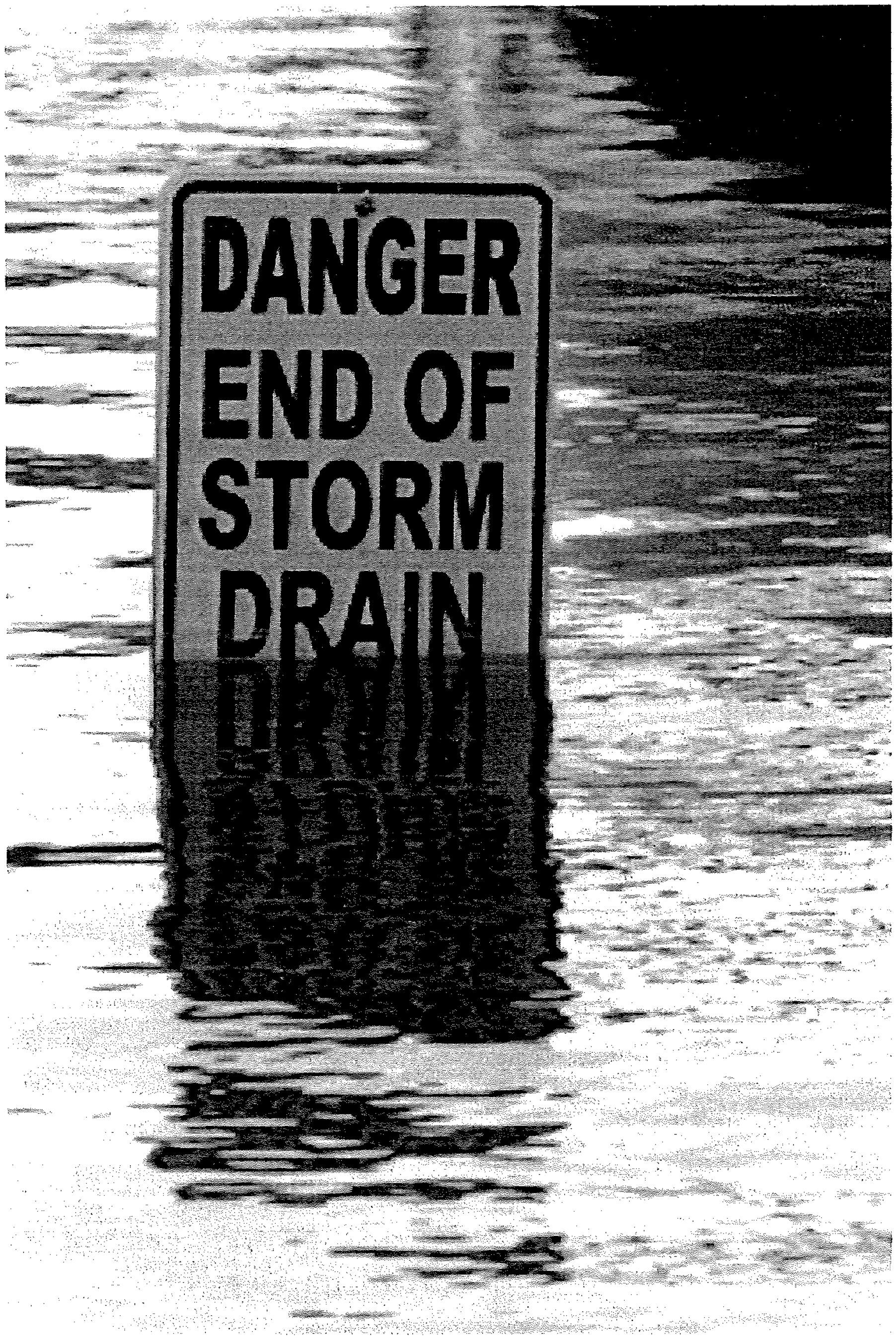
While one study found that the number of tornadoes reported in the United States has increased by around 14 per year over the past 50 years, the trend may have more to do with how tornadoes are tracked and reported rather than how many are actually forming.

Similarly, the study found that severity ratings for tornadoes are usually based on the damage they cause to structures and may not have been consistently applied over the past fifty years.

What can be done to deal with severe weather?

This pattern of intense rain and snow storms and periods of drought is becoming the *new normal* in our everyday weather as levels of heat-trapping gases in the atmosphere continue to rise.

If the emissions that cause global warming continue unabated, scientists expect the amount of rainfall during the heaviest precipitation events across country to increase more than 40 percent by the end of the century. Even if we dramatically curbed emissions, these downpours are still likely to increase, but by only a little more than 20 percent.



Regardless of what actions we take to cut emissions, **we must adapt to the likelihood that severe storms are becoming ever more commonplace**.

Efforts such as modifying local infrastructure to withstand floods, adjusting agricultural patterns to account for droughts, as well as establishing emergency planning in our homes, would be far less costly to implement when compared to the costs of responding to washed out bridges, deluged homes, or loss of life.

Clearly, the time has come to develop smart planning and engineering solutions to cope with storms of the future.

Last revised date: June 17, 2011

We Need Your Support to Make Change Happen

We *can* reduce global warming emissions and ensure communities have the resources they need to withstand the effects of climate change—but not without you. Your generous support helps develop science-based solutions for a healthy, safe, and sustainable future.

- $25
- $50
- $100
- $250
- $1000
- Other

Donate

Union of Concerned Scientists
Science for a healthy planet and safer world

Science for a healthy planet and safer world

- A **Normal Font Size**
- A **Larger Font Size**
- A **Largest Font Size**

Union of Concerned Scientists
2 Brattle Square, Cambridge MA 02138-3780

oregonmetro.gov

Metro

Exh. 15

Hiking, mountain biking and equestrian use in natural areas:

A recreation ecology literature review

September 2017

Lori Hennings
Senior Natural Resource Scientist, Metro Parks and Nature
600 NE Grand Avenue, Portland, OR 97232-2736
Lori.Hennings@oregonmetro.gov

Public service

We are here to serve the public with the highest level of integrity.

Excellence

We aspire to achieve exceptional results

Teamwork

We engage others in ways that foster respect and trust.

Respect

We encourage and appreciate diversity in people and ideas.

Innovation

We take pride in coming up with innovative solutions.

Sustainability

We are leaders in demonstrating resource use and protection.

Metro's values and purpose

We inspire, engage, teach and invite people to preserve and enhance the quality of life and the environment for current and future generations.

If you picnic at Blue Lake or take your kids to the Oregon Zoo, enjoy symphonies at the Schnitz or auto shows at the convention center, put out your trash or drive your car – we've already crossed paths.

So, hello. We're Metro – nice to meet you.

In a metropolitan area as big as Portland, we can do a lot of things better together. Join us to help the region prepare for a happy, healthy future.

Stay in touch with news, stories and things to do.
oregonmetro.gov/news

Follow oregonmetro

Metro Council President
Tom Hughes

Metro Councilors
Shirley Craddick, District 1
Carlotta Collette, District 2
Craig Dirksen, District 3
Kathryn Harrington, District 4
Sam Chase, District 5
Bob Stacey, District 6

Auditor
Brian Evans

600 NE Grand Ave.
Portland, OR 97232-2736
503-797-1700

Many thanks to the following peer reviewers, who substantially improved this document:

Mary Bushman, Botanist, City of Portland Bureau of Environmental
Services Kim Brown, Biologist/Principal, Ventus Environmental Solutions
Lisa Goorjian, Parks Planning and Operations Program Director, Metro
Nicole Lewis, Senior Regional Planner, Metro
Todd Mabee, The Wildlife Society Conservation Committee
Dan Moeller, Parks and Nature Conservation Program Director, Metro
Carol Murdock, Water Resource Program Manager, Clean Water Services
David Shepherdson, The Wildlife Society Conservation Committee
Jonathan Soll, Science and Stewardship Division Manager, Metro
Elaine Stewart, Senior Natural Resource Scientist, Metro
Olena Turula, Senior Regional Planner, Metro
Karen Vitkay, Senior Regional Planner, Metro
Jill Van Winkle, Trails Coordinator, City of Portland Parks & Recreation
Katy Weil, Senior Management Analyst, Metro
Rod Wojtanik, Parks and Nature Planning Manager, Metro
Yuxing Zheng, Senior Public Affairs Specialist, Metro

TABLE OF CONTENTS

1. Introduction 1
   - 1.1 Purpose of Literature Review 1
   - 1.2 Trends in Recreational Activities 3
   - 1.3 Key Findings 3
2. Effects of Recreation on Vegetation, Soil and Trail Condition 5
   - 2.1 Initial Trail Construction 5
   - 2.2 Vegetation Damage Adjacent to Trails 6
   - 2.3 Soil Erosion and Compaction 10
   - 2.4 Trail Widening and Incision 11
   - 2.5 Amount of Use 13
   - 2.6 Trail Effects by User Group 13
3. Effects of Unauthorized Trails 17
4. User Conflicts and Perceived Effects on Wildlife 21
5. Effects on Ecological Processes and Habitat 26
   - 5.1 Riparian Habitat and Water Quality 27
   - 5.2 Habitat Loss, Fragmentation, and Edge Effects 29
   - 5.3 Invasive Species 34
6. Overview of Effects on Wildlife 39
   - 6.1 Disturbance and the Antipredator Response 39
   - 6.2 Habituation, Sensitization and Tolerance 42
   - 6.3 Size Matters: Individuals and Herds 45
   - 6.4 Speed and Directness of Approach 46
   - 6.5 Habitat Structure and Nest or Perch Height 46
   - 6.6 Season, Reproductive Status and Time of Day 47

6.7 Noise and Light Pollution 48

7. Effects on Wildlife by Species Group 53

7.1 Species Group: Invertebrates 53

7.2 Species Group: Reptiles and Amphibians 54

7.3 Species Group: Birds 56

7.4 Species Group: Mammals 65

8. Tools to Help Manage Negative Effects 74

8.1 Trail Design and Construction Resources 74

8.2 Recreational Carrying Capacity and Visitor Use Frameworks 78

8.3 Monitoring Approaches 79

8.4 Addressing Unauthorized Trails 82

8.5 Protecting Riparian Habitat and Water Quality 83

8.6 Minimizing Fragmentation and Edge Effects 85

8.7 Minimizing Effects of Recreational Use on Wildlife 88

Gathering local wildlife information 88

Wildlife flight initiation and alert distances 90

8.8 Reducing Conflicts between User Groups 95

8.9 Notes about Signage and Educational Messaging 97

Literature Cited 99

TABLES

Table 1. Summary of understory plant life forms' resistance, resilience, and presumed tolerance

Table 2. Variables associated with increased erosion

Table 3. Summary of methods used to measure trail-induced fragmentation or related effects on formal (FT) or unauthorized trails (UT)

Table 4. Definitions of terms used in wildlife studies to measure antipredator response, including tolerance to human disturbance

Table 5. Classification of recreational-use impact on wildlife derived from interviews with refuge managers in the northeastern U.S.

Table 6. A sampling of available trail design and construction guidance documents

Table 7. Examples of indicators, thresholds and triggers to assess and address visitor impacts

Table 8. Summary statistics for species groups' Flight Initiation Distances or Alert Distances from the scientific literature

FIGURES

Figure 1. Some key factors influencing environmental outcomes when recreational access is introduced to a natural area

Figure 2. Comparison of Region 2 and Oregon statewide residents' recreational investment priorities

Figure 3. Illustration of the effect of trail slope on severity of erosion

Figure 4. Unauthorized trail at a Metro natural area

Figure 5. Unauthorized trail in a Metro natural area leading from a residence

Figure 6. Statistically significant trends for Oregon breeding birds by group, 1966-2013

Figure 7. The Lakeside pedestrian and wildlife undercrossing in Portland, Oregon

Figure 8. Typical habitat size requirements for selected wildlife species

Figure 9. Flight Initiation or alert distances for various wildlife species groups

Figure 10. Example of a simple way to use the data presented in Table 8 to consider potential effects of human disturbance on waterfowl from a planned wildlife viewing blind adjacent to a large wetland

APPENDICES

Appendix 1. Impacts of dogs literature review (previously completed)

Appendix 2. Scientific names for species discussed in text

Appendix 3. Flight Initiation Distance (FID), Alert Distance and related variables for various wildlife species that occur in the U.S.

1. INTRODUCTION

1.1 PURPOSE OF LITERATURE REVIEW

Metro is the regional government in the Portland, Oregon area. Thanks to the region's voters, the agency has acquired approximately 17,000 acres of natural areas to protect water quality, wildlife habitat and connect people with nature. The goal of this document is to better understand the trade-offs between different types and levels of recreational access in the context of our work to protect habitat and water quality, and provide access to nature in a growing urban area. Only by thoroughly understanding the effects of recreational activities on wildlife and water quality are we able to avoid, minimize and mitigate potential harm to the resources we are committed to protecting.

Recreation ecology is the scientific study of environmental impacts resulting from recreational activity in protected natural areas. The nature of a literature review is to summarize what has been studied, what has been learned, and what the experts have concluded. This document reviews the literature on overall and relative effects of three user groups – hikers, mountain bikers and equestrians – on trails, habitat, and wildlife to help inform ecologically appropriate placement and construction of trails in natural areas. Studies are reviewed from the U.S. and elsewhere, with a focus on soft-surface trails in natural areas. We included limited information about other non-motorized trail user groups such as trail runners and beach walkers. Motorized off-road vehicles were omitted from this review because they are generally not allowed on natural area trails within the urban and near-urban region. A previous literature review on the effects of dogs on wildlife and water quality is included as Appendix 1.

Studies vary in terminology for our recreational groups of interest. In this report "hiker" generally means a person walking along a trail for various reasons such as exercise, wildlife watching or moving between places. "Mountain biker" refers to a non-motorized bicycle rider on a soft or natural surface trail; alternative terms in the literature include off-road bicyclists or off-road cyclists. "Equestrian" refers to a person riding a horse on a trail. Throughout the text we refer to these as "user groups."

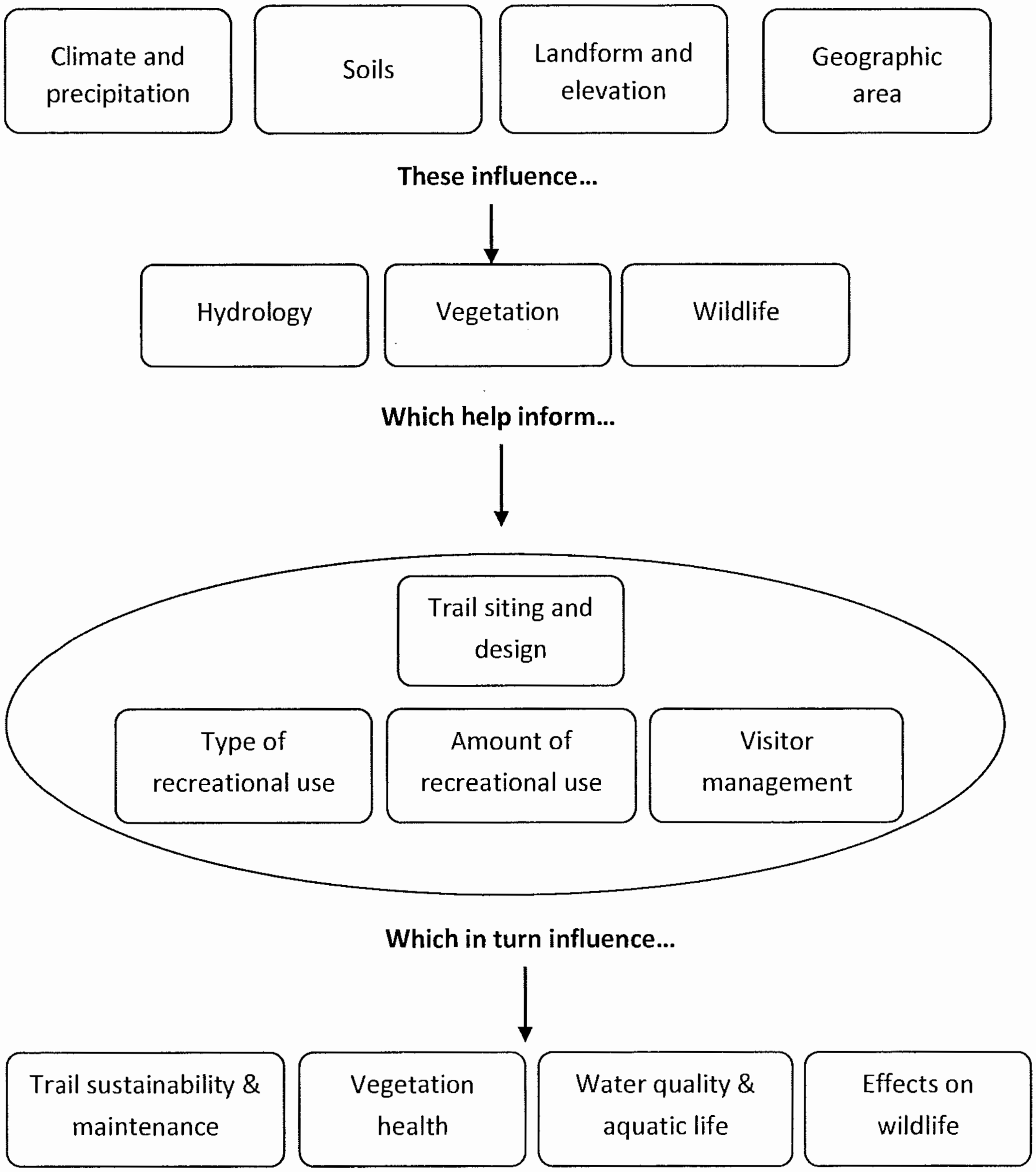
Trails provide people with important opportunities to improve health and well-being, and providing access to nature is especially important in urban areas.[2-5] However, as indicated in various literature reviews, trails and trail use can damage natural areas including negatively affecting soils, vegetation, water quality, plants, and animals.[6-27] Damage to trails or habitats and negative effects on wildlife are more likely when trails are inappropriately located, designed, constructed, maintained or used, or when unauthorized trails are allowed to proliferate. These issues can also increase trail maintenance costs[28-30] and negatively affect visitors' experience.[31-33]

This document reviews the types of recreational effects in Chapters 2-7, including information about user group-specific effects. Each chapter includes a summary of key points. Chapter 8 offers information on how to minimize, monitor and manage effects. Throughout the review we provide representative study examples with additional citations.

We paid close attention to the effects of recreation on wildlife (Chapters 6 and 7) because they are less well documented than physical effects such as erosion or vegetation damage. Scientific names for species mentioned in the text are in Appendix 2. For wildlife, human disturbance increases animals' stress and can cause them to hide, change behavior or flee. Some species, such as those that do well in urban areas, are generalists and can tolerate human disturbance. Other species such as pregnant animals, long-distance migrants, and habitat specialists tend to be more stressed and displaced by trail users. Some species may permanently leave a natural area.

Figure 1 illustrates the relationships between environmental, trail design, recreational use and their effects on trail damage, water quality, vegetation damage and wildlife.

Figure 1. Some key factors influencing environmental outcomes when recreational access is introduced to a natural area.



1.2 TRENDS IN RECREATIONAL ACTIVITIES

Natural areas are subject to competing demands by different user groups, and demand increases with population.[34] Nationwide and in Oregon, walking/hiking is typically the most common form of recreational use at parks and natural areas. Oregon's *Statewide Comprehensive Outdoor Recreation Plan* (SCORP)[34] identifies the most rapidly increasing U.S. adult recreational activities as walking for pleasure, viewing/photographing birds, and day hiking. Interest in mountain biking is rising in the U.S., with 8.3 million U.S. residents riding mountain bikes in 2015, a 22 percent increase since 2006.[35] The number of hikers increased even more during the same time period – up 24 percent, to 37.2 million participants. In Oregon, equestrian use demand is expected to increase, but hiking and mountain biking demand will still comprise the majority of terrestrial trail use.

In a recent survey, Oregonians identified their top priorities for future recreational access investments.[1] The report's data are compiled statewide, plus divided by county-based planning regions.[34] Region 2, the most populous, includes the greater Portland metropolitan region and areas around the cities of Newberg, Salem and Hood River (Washington, Multnomah, Clackamas, Yamhill, Columbia, Hood River, Polk and Marion Counties).

Figure 2. Comparison of Region 2 and Oregon statewide residents' recreational investment priorities

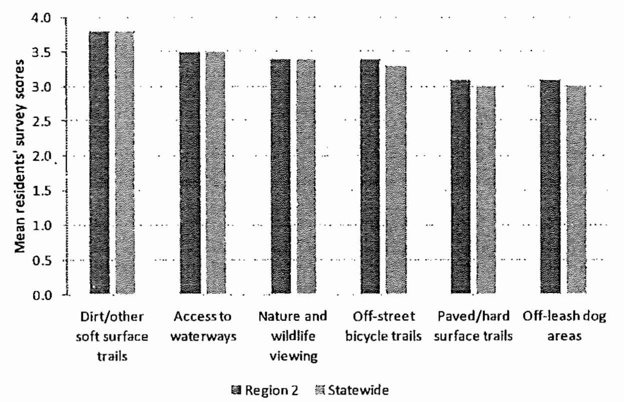


Figure 2 compares residents' recreational investment priorities at the Region 2 and statewide levels.[34] The top three priorities are identical for state and Region 2. However, Region 2 residents place slightly more value on investments in off-street bicycle trails (which include but are not limited to mountain bikes), paved/hard surface trails, and off-leash dog areas compared to residents throughout the state. Locally, some area residents have recently requested that Metro increase the amount of mountain biking and equestrian trails and allow dogs in its natural areas, triggering the need for this review as well as a recent review of the effects of dogs on wildlife and water quality (Appendix 1).

1.3 KEY FINDINGS

Our literature review identified four key themes differentiating recreational user effects on trails from users' effects on wildlife:

1. **Affected area:** The physical impacts from formal (planned) trail construction and use are typically limited to a relatively narrow corridor. In contrast, when people use trails the disturbance effects on wildlife may extend hundreds of meters from the trail into natural areas.

[1] Equestrian use was not offered as an option in this survey. Data related to picnic sites, playgrounds, sports fields, motorized vehicles and community gardens were excluded because this review's focus is on trails and natural areas.

2. **Predictability of effects:** Effects of user groups on trails are fairly predictable based on variables such as topography, soils and climate, but those same user groups' effects on wildlife are more complex because they vary by season, habitat, species, and individual animals' temperament.
3. **Effects of increased use:** For trails, the most significant damage usually occurs when a trail is first built, although higher levels of recreational cause additional damage. For wildlife, negative effects tend to grow stronger with increased trail use.
4. **How different user groups affect wildlife and trails:** While all trail user groups can cause trail damage or disturb wildlife, the results of this review suggest the following generalizations when comparing hiking, mountain biking and equestrian user groups:
    a. Trails – Equestrians cause the greatest amount of soil loss and trail damage compared to the other two user groups. The magnitude of trail effects from hikers and mountain bikers appear to be similar to one another.
    b. Wildlife – Equestrians appear to cause the least wildlife disturbance. Hikers disturb wildlife, with increased effects when talking or stopping to view or photograph wildlife. Fast-moving trail users such as mountain bikers and trail runners are particularly disturbing to wildlife due to the element of surprise.

Although this literature review focuses on potentially harmful effects of recreational trail use on wildlife and the environment, we recognize that providing access to nature fulfills an innate human need and creates opportunities for people to appreciate, benefit from and value the natural world. Such experiences and values are essential to the continued protection and long-term care of our natural environment. This report identifies specific effects and provides information for natural area planners and land managers to help evaluate and reduce these effects.

2. EFFECTS OF RECREATION ON VEGETATION, SOIL AND TRAIL CONDITION

Many recreational trail studies focus on user groups' effects on soils, vegetation, trail incision, trail widening, and trail proliferation. In general, the effects of recreational use on trails happen quickly but recovery is slow.[24] Several studies suggest that regardless of type of recreational use, the most significant physical effects occur during trail construction.[14, 15, 19, 24, 36] Once a trail is built, the magnitude of additional effects depends on the amount and type of visitor use, trail density, spatial distribution and environmental variables.[37-40] Slope, soil type, precipitation and vegetation type strongly influence the degree of trail damage from recreational use.

The following sections review effects of trail construction and use on vegetation, soil, and trail conditions, followed by a section on the effects of specific user groups. Understanding how habitat, wildlife and trail condition are affected by various types and degree of recreation use will enable more informed decision making about trail location, design and management, and to better understand or predict the tradeoffs of providing access to nature.

2.1 INITIAL TRAIL CONSTRUCTION

Trail construction causes temporary and permanent disturbance to a site. Vegetation is removed and soils are compacted within the width of the trail itself. Vegetation is cleared to maintain a specified clearance area to make trails safe and passable. In addition, trail construction often requires temporary disturbance to allow for construction activities such as grading. However, vegetation damage from initial trail construction is typically limited to a fairly narrow corridor.[41]

Damage from trail construction can include the following (note that the trail construction industry has standard best management practices for construction that are designed to minimize these impacts - see Chapter 8):

- vegetation loss [41]
- loss of leaf litter and organic material[42-44]
- changes in microclimate due to reduced shade[45]
- introduction of invasive weed seeds carried in on boots and equipment, with germination facilitated by ground disturbance[46]
- tree damage or root exposure[47]
- wildlife disturbance, habitat damage and potential loss of connectivity, depending on trail width and wildlife species (Chapters 5-7)[48, 49]

For poorly designed and sited trails, immediate and lasting environmental effects from trail construction may be more significant than those caused by trail use.[14, 15, 19, 36, 50] However, soft surface trails can sometimes be built without disturbing trees, and lasting habitat effects such as altered microclimate can be minimized if the trail is properly sited, designed and constructed and vegetation disturbance is minimized. For example, Metro constructs many of its trails without removing trees.

Trail clearing width and height influence the extent of vegetation damage from trail construction. The trail clearing width is the space to each side of the trail tread that is cleared for trail users; this is the widest area of direct physical effects resulting from trail construction.[51, 52] The clearing width is designed to protect trail users from obstructions that would physically extend into the trail corridor or impede travel progress. Clearing width and height needed vary by trail user group. For example, when appropriately designed, vertical clearance is higher for an equestrian trail compared to a hiking trail; wheelchair accessible or multi-use trail designs tend to be wider than other trail types.[53] Widths will also vary based on setting and numbers of visitors expected.[54, 55]

2.2 VEGETATION DAMAGE ADJACENT TO TRAILS

This section summarizes research related to vegetation trampling adjacent to trails. Trailside trampling can occur when trail users step aside to let other users pass, move off of the formal trail to avoid muddy conditions, walk or ride side-by-side, cut corners, or when the formal trail is indistinct.[16, 56-58]

Protecting trailside vegetation is important because plants intercept rainwater and their roots help soils absorb water, thereby slowing surface water flow, protecting water quality, and reducing trail-damaging runoff and erosion. Vegetation removal can alter local ("micro-") climate, resulting in more sun and wind exposure and causing dryer, warmer conditions (Section 5.2). Such circumstances can stress native and favor invasive plant species.[30, 59-61] Protecting trailside vegetation limits the total amount of habitat affected by the trail system. In addition, trees and shrubs can reduce stress on wildlife by providing a visual buffer between trail users and wildlife (Chapter 6).[62]

How damage occurs. Trail users cause two types of stress to plants: physical damage to the plant resulting in impaired food production, water loss and repair/regeneration energy demands; and altered soil habitats that impair root processes such as nutrient uptake and ability of the plant to spread.[12] These stressors can vary in severity depending on soils, drainage, elevation and aspect, habitat type (e.g., grassland or forest), and plant characteristics.[12]

Measuring plant tolerance to trampling. Many vegetation studies are trampling experiments – various user types taking a controlled number of passes to mimic varying intensity of use. Trampling studies are typically conducted where no trails currently exist.

Because most trampling studies are short term and use a limited number of passes (e.g., ranging from 25 to 1,500), they may underestimate effects that would emerge over long-term and higher intensity uses. They are however, quite useful for measuring effects of initial trail creation, informing trail layouts in areas with sensitive habitats, and prioritizing activities such as de-activating unauthorized trails. Trampling studies also hold the advantage of controlling for user group, habitat type and the number of users (trampling intensity).

> *Resistance* is the amount of damage caused by trampling
>
> *Resilience* is how well plants recover after trampling
>
> *Tolerance* combines resistance and resilience

Trampling studies focus on the resistance, resilience and sometimes, the tolerance of plants to trampling.[63] *Resistance* measures the amount of damage to plants caused by direct trampling via hiking, mountain biking or equestrian use. At higher uses, even resistant plant species' ability to withstand effects declines. *Resilience* measures plant recovery over time after trampling is halted. This is an important distinction because resistant plants are not necessarily resilient. *Tolerance* is a better measure but is less frequently used; tolerance combines resistance and resilience. Plants with high tolerance are less prone to long-term damage by trail users. Table 1 summarizes some of the information available on plant forms, resistance, resilience and tolerance.

Plant form characteristics and their susceptibility to trampling. Plant form – including characteristics such as woody versus herbaceous, rooting/propagation form, stature and erectness, and whether plants are grasses, forbs or shrubs – strongly influences how well plants can tolerate trampling, probably more than other factors such as soils.[12, 21, 63-65]

Some vegetation types, such as plants with tubers or bulbs, or many sun-loving plants, are more tolerant of trampling than others (Table 1). On the other hand, non-woody shade tolerant plants are susceptible to trampling damage because they tend to have large leaf surfaces supported by rigid, easily crushed stems.[66] Woody shrubs are also susceptible because when stems are broken or crushed, all of the buds are destroyed.

For example, in western Montana, trampling effects differed between vegetation community types.[67] Grassland habitat proved much more resistant than forested habitat types, with no noticeable grassland cover loss until 1,600 trampling passes. Other studies also found grasslands and meadows, which tend to occur in flatter areas, to be more resistant to trampling than shrub or forest communities. However, trail users in flat areas tend to spread out, causing wider and sometimes multiple parallel trails.[12, 58, 64, 68, 69]

In Australia, upright plants such as bracken ferns were least resistant to trampling; a tall grass understory was moderately resistant, and a short grass understory was most resistant.[64] Species richness decreased most rapidly in the least resistant plant community.

Cole and Trull conducted an experiment in the Okanagan National Forest within four vegetation types at varying trampling intensities.[70] They differentiated between resistance (direct damage) and resilience (recovery after one year). Both vegetation type and tramping intensity had significant effects. Sedge meadow was much more resistant than forbs, but recovery after a year was better in forbs. The lowest recovery was in the two woody vegetation types, which were susceptible even to low levels of trampling. High resistance was primarily determined by stature, arrangement, and toughness/flexibility of above-ground plant tissues. Resilience, on the other hand, was higher in plants with tough perennial vegetation and high growth rates. The most resistant and resilient (tolerant) plants were low growing and had either tufted growth form or leaves in basal whorls that grow flat against the ground (graminoids: grasses, sedges and rushes). Non-resistant plants that also had low resilience included certain tree seedlings and broad-leafed herbs; the latter were eliminated after as few as 25 passes.

> Non-resistant plants are common in forested settings, where just a few user passes can affect forest plant communities.

In a subsequent study Cole found that plant morphological characteristics explained more of the variation in response to trampling than the site characteristics that were assessed (altitude, tree canopy cover or total ground layer vegetation cover, although they did not measure soil moisture or fertility).[63] In this study, plant species' tolerance was more correlated with resilience than resistance – in fact, resilience and resistance were sometimes negatively correlated with one another. The most resilient plants were hemicryptophytes (buds at or near the soil surface, such as dandelions) and geophytes (resting buds lying beneath the surface of the ground as a rhizome, bulb or corm; see Table 1). Pescott's review of the literature on vegetation recovery after trampling had similar findings; plant form was the key variable and was more important than the amount of trampling.[21] Thus, placing trails in the most resilient – which appears to correlate more closely with tolerance – rather than resistant plant communities may result in less damage over time, particularly when trails are wider, in moister settings or where there is a high likelihood of unauthorized trails. Tolerant plant communities are better yet, but such plant communities may be uncommon in a given region.

Regardless of habitat type or the number of trampling passes, these studies suggest that predicting the effects of trail users on vegetation depends largely on plant form, although other factors such as proper trail siting and construction, trail slope, soil type, user group and amount of use also play roles. When plants next to trails are non-tolerant, trail users that step aside or go around other users can cause substantial vegetation damage and subsequent erosion and trail widening compared to areas with more tolerant species.

In summary, more trampling-sensitive plants have these characteristics: soft delicate leaves, a single exposed perennating[2] bud, growth activity throughout the traffic season, adaptation to moist habitats, and shade-tolerant species.[71] Plants that adapt well to trampling include weed-like characteristics: tough but flexible stems, annual reproduction with high numbers of small seeds, ability to penetrate compacted soils, and the ability to withstand quicker drying, high solar intensity, and higher maximum temperatures of unsheltered locations. A locally-specific list of native species with some or all of these characteristics could aid in selecting native planting palettes for revegetation or to withstand trampling, such as alongside trails.

---

[2] Perennation is the ability of plants to survive from one germinating season to another, especially through storage organs such as tubers or rhizomes. Typically these would have relatively high tolerance; however, an exposed perennating bulb is vulnerable to damage from trampling.

Table 1. Summary of understory plant life forms' resistance, resilience, and presumed tolerance to trampling. Derived primarily from data presented in Yorks et al.'s meta-analysis of vegetation tolerance to foot traffic.[71]

Plant life form	Root form	Life span	Other characteristics	Assumed tolerance based on resistance & resilience
Shrubs *Small to medium sized woody plants; tend to be vulnerable to trampling*	Root forms: fibrous or tap Resistance: Fibrous and tap roots are similar Resilience: Tap roots are more resilient than fibrous	Perennial	Resistance: deciduous and evergreen are similar Resilience: deciduous > evergreen	Most tolerant: shrubs with tap roots; deciduous shrubs.
Tree seedlings	Typically fibrous	Perennial	Resistance: evergreen > deciduous Resilience: deciduous > evergreen	Most tolerant: probably deciduous, because resilience correlates more strongly with tolerance than does resistance
Forbs *Herbaceous flowering plants that are not graminoids*	Root forms: fibrous, tap, fleshy Resistance: fairly similar; most resistant in this order: fibrous, tap, fleshy Resilience: tap roots are more resilient than fibrous or fleshy	Perennial – less resistant, less resilient Annual – more resistant, more resilient	Reproductive pathway[3] Resistance: Stolon > seed > rhizome Resilience: Stolon > seed > rhizome	Most tolerant: annual forbs with tap roots; stolon reproductive pathway
Graminoids *Grasses, sedges and rushes*	Root form: fibrous	Perennial – less resistant, less resilient Annual – more resistant, more resilient	Reproductive pathway Resistance: Tiller> seed and rhizome > stolon Resilience: Tiller > rhizome > stolon > seed	Most tolerant: annuals
Cryptophytes (specifically, geophytes subdivision) *Plants with reproductive structures underground, including corms or bulbs, such as onions and lilies*	Root form: fleshy	Perennial		Tend to be more tolerant than many other life forms
Hemicryptophytes *Buds at or near the soil surface, such as dandelions and daisies; many have rosette basal leaves*	Root form: typically tap or fibrous	Annual or perennial		Tend to be more tolerant than many other life forms

[3] Stolons are horizontal, above-ground stems. Rhizomes are specialized horizontal steams below the soil surface that eventually turn upward ("runners"). Tillers stems are produced by grass plants, and refer to all shoots that grow after the initial parent shoot grows from a seed.

2.3 SOIL EROSION AND COMPACTION

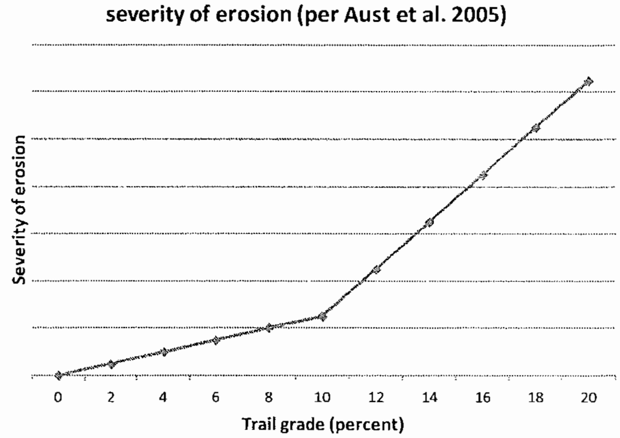
Soil loss through erosion can be a significant and long-term effect of recreational trail use.[19, 39, 72] Soil erosion has potential to harm at-risk aquatic wildlife and threaten downstream water quality (Section 5.1). Erosion occurs when water runs off the trail surface, carrying soil particles with it. Typical signs of erosion include exposed roots, bare rock, visible micro-channels on the trail surface and trail ruts.[54] Limiting soil erosion on trails is important because left unchecked it is likely to become increasingly severe, have negative environmental consequences, may impede trail use, and can contribute to trail widening over time due to users seeking to circumvent muddy areas.[16, 56]

Soil characteristics and susceptibility to erosion. Geomorphic processes – the natural mechanisms of weathering, erosion and deposition, including landform – are the most important drivers of trail erosion, and may be more important than the type of recreational use.[16, 73] Factors that correlate with the severity of erosion include soil texture, steepness of terrain, elevation, proximity to water resources, trail design and other variables (Table 2), vegetation characteristics (Section 2.2) and the weight and force of different types of trail user groups. Trail slope and erosion effects in general are magnified in wet areas and during wet seasons.[14, 29, 31, 54, 58, 68, 72-79]

How damage occurs. Trampling loosens the top layer of soils while simultaneously compacting soils below, both which increase the potential for erosion.[80, 81] Soil compaction is influenced by soil bulk density, defined as the weight of dry soil per unit volume. Although it may seem counter-intuitive, sandy soils tend to have high bulk density, while clay soils have low bulk density; it has to do with the size and shape of soil particles, their arrangement, and the voids between the particles.[82] Bulk density increases with soil compaction. Soils with lower bulk density such as clay are more prone to compaction, whereas denser soils are more prone to yielding sediment for erosion.[29, 79, 83, 84] More compacted soils have fewer pockets of air space (pores), and the fewer pores are available the longer it will take for water to infiltrate – generating more runoff, the agent for soil erosion.[85] Trails with deeper soils are also more prone to incision and erosion.[29]

Appropriate trail design can minimize risk of erosion. Trail grade (slope) and slope alignment angle (also called trail angle or cross slope) are two erosion-related factors to consider in trail design.[56] Trail grade refers to the steepness of the trail itself. Trail sections with grades above approximately 10-12 percent tend to be more erosion-prone (Figure 3),[29] and longer sections of trails with relatively steep trail grades can be problematic because runoff has a chance to accelerate down the slope, generating more force to dislodge soil particles and carry them further.[58, 84, 86] Frequent grade reversal, cross slope, and erosion control features on sloped trails can substantially reduce soil erosion and trail damage (Chapter 8).

Figure 3. Illustration of the effect of trail grade on severity of erosion (per Aust et al. 2005)



Trail slope alignment angle is the orientation of the trail (0-90 degrees) to the prevailing grade of the landform.[77] A low slope alignment angle trail section is oriented up- and down-slope; a high slope alignment angle trail section is oriented along the contour. Trails with low slope alignment angles take a steep, direct path up and down a hill and have poor drainage and higher erosion risk.[16, 52]

Guidance from the International Mountain Bicycling Association (IMBA), the Professional Trailbuilder's Association (PTBA) and others recommend following the "10 percent rule:" the average or overall trail grade should not exceed 10 percent.[28, 87-89] The IMBA, PTBA and other guidance documents also recommend following the "half rule" guidance, in which trail grades should not be greater than half the grade of the slope across which the trail is built,[28, 87-89] although Marion and Wimpey did not find any direct research backing this guidance.[90] Marion and Olive offer literature-derived guidance for maximum slopes depending on user type and setting.[77]

Olive and Marion reviewed the literature and identified key factors that make trails more susceptible to erosion (Table 2, with additional literature citations added).[72]

Table 2. Variables associated with increased erosion. (Adapted from Olive and Marion, 2009[72])

Variable associated with increased erosion	Characteristics
Soil texture	Homogenous texture, fine- or course-grained textures. Clayey soils are most at risk because they have low bulk density and can be heavily compacted when dry, but also have high ability to retain water, swelling when inundated.[73]
Vegetation	Some types of plants are more vulnerable than others (Section 2.2). Trails in more vulnerable plant communities may expose soil and increase erosion risk.
Steep terrain	Steep terrain elevates the risk of erosion.[77]
Higher elevation	The greater rainfall typically found at higher elevations can increase erosion rates.[29, 54]
Proximity to water resources	Moist soils in riparian areas are especially vulnerable to erosion. Riparian vegetation is easily damaged, which can expose bare soil.[31, 73, 76, 77, 79]
Vegetation	Lack of tree cover increases erosion risk. Tree cover can protect trail treads by reducing the amount of water reaching the ground and reducing "splash erosion."[91]
Trail design	Trails with low slope alignment angles and those exceeding the "half rule" are more at risk of erosion.[72, 90]
Maintenance	No or ineffective tread drainage features. Erosion reduction features such as tread outslope, grade reversals or rolling grade dips reduce trail erosion. Traditional water bars are no longer considered a best practice because they can exacerbate trail erosion when they fail.[29]
Visitor management	Failure to regulate amount or type of use; lack of education to reduce effects. [92]
User-related	High use in sensitive vegetation/soil types, improper use for environmental and design factors, failure to stay on formal paths, high use during wet conditions.

2.4 TRAIL WIDENING AND INCISION

Leung and Marion state that the most critical problems associated with trails are soil compaction, trail widening, trail incision and resultant soil loss.[16] The variations in vegetation, soils, landform and moisture discussed above influence the degree of unintended trail widening and incision (deepening).[39] Wider trails tend to occur in flat areas where users seek to avoid wet areas associated with standing water and mud, whereas more incised trails tend to occur on sections with steeper trail slope alignments (Section 2.4).[29, 58, 75, 76]

Trail widening. Trail widening and multiple treads often occur in open, flat areas where people can walk or ride side by side and easily pass other trail users, or when trail users are trying to avoid muddy, puddled, or other problematic trail sections.[16, 24, 93] Heavily used trails tend to become wider because hikers, mountain bikers and equestrians move off trail to pass stopped or slower-moving groups of people.[93] Horses tend to create rougher trails, leading to wider trails when other visitors step around the trail to find a smoother trail surface.[79, 94] However, Dale and Weaver found little difference between hiking-only trails in meadows versus those used by both hikers and horses.[95]

Several studies have compared trail widths for formal and unauthorized trails. In their expansive study of mountain biking effects in the American southwest, Foti et al. compared the mean width and depth of formal versus unauthorized mountain biker trails and found that unauthorized trails were wider, but formal trails were deeper[58]. A study in woodland habitat in Tennessee and Kentucky also documented wider unauthorized trails compared to formal trails.[77] In Foti et al.'s mountain biking study, maximum trail depth increased significantly from shallow (<5 percent) to steeper trail grades; slopes greater than 12 percent were strongly correlated with high soil and vegetation degradation. Mountain bikers often "cut the corners" at 90-degree trail intersections, substantially widening trails there. Signs were placed at the trail intersections, and the researchers postulated that signage placed before fast-moving bikes enter the intersection may help reduce this effect.

> Trail widening often occurs in flat, open habitats or when trails are muddy.
>
> Compaction and erosion of the trail tread lead to trail incision.

Trail incision. Trail incision is a result of compaction and erosion of the trail tread.[77] Trails constructed on soils with fine, homogenous textures or on steeper slopes are prone to incision.[77] On the large-scale Appalachian Trail in Great Smoky Mountains National Park, trail incision was associated with trail grade, soil type, vegetation type, elevation, precipitation, and visitor use whereas trail width was related only to soil and vegetation types.[39]

On a smaller scale, Godwin investigated how the processes of soil erosion and compaction influence trail incision along the New World Gulch Trail in Montana.[76] Trail grade, amount of water runoff and estimated soil bulk density were significant factors. Steeper trail grades led to more erosion, and both trail grade and erosion were associated with trail incision. Trail use led to soil compaction, which tends to exacerbate erosion.[29, 79, 83, 84] These studies emphasize the importance of accounting for trail grade, soil characteristics and vegetation in order to minimize incision when planning trails.

Trail surface can help reduce the effect of slope on trail incision, with thicker gravel being associated with lower erosion and incision. Aust et al. studied the effects of horses on trails in Virginia hardwood forests.[29] Trail incision was deepest on trails with bare soil; at medium and high (but not at low) levels of use, application of gravel mitigated but did not prevent incision. On un-graveled or lightly graveled trails, soil erosion increased dramatically after approximately 12 percent trail grade; maximum incision peaked in the 12-17 percent trail grade range, but declined along steeper trails. The thickest, 3.5-inch gravel depth led to less incision even on higher trail grades, although the authors noted that management actions such as grading may have mitigated effects at higher slopes.

The types of use can also influence the degree of trail incision. For example, in the northern Rocky Mountains, multi-use trails (horses and hikers) became more incised over time compared to hikers alone.[95] There were not enough horse-only trails to include in the data analysis.

2.5 AMOUNT OF USE

The topic of recreational carrying capacity or the acceptable amount of use, for individual trails or at a site, arises repeatedly in the literature.[17, 93, 96-98] In this case, by carrying capacity we mean the amount, and sometimes type, of recreation that can occur without causing excessive trail or environmental damage (related wildlife issues are described in Chapters 6 and 7). Carrying capacity can also refer to the amount of use beyond which user conflict or negative user experience may occur. Carrying capacity is a critical trail management issue, and can be increased by avoiding placing trails in sensitive plant communities and wildlife areas. Visitor use frameworks can be used to help identify the upper limits of recreational users or negative effects for any given site (Section 8.2).

Once a trail is established, vegetation and trail damage tend to increase incrementally with the number of users up to a certain point, although vegetation damage tends to stay within a few meters of trails.[58, 77, 95, 99] For example, Dale and Weaver studied subalpine forest trails in the Rocky Mountains.[95] Trail widths increased slowly with increasing traffic. Trails used by both hikers and horses were deeper, but not wider, than hiking trails. Most vegetation damage was within 1-2 meters of the trail. When the amount of use is held uniform or substantial use has already occurred, factors such as soil properties, moisture, vegetation type and landform, and different types of recreational use tend to drive additional on and near-trail damage.[12, 21, 100]

Trampling studies (Section 2.2) often attempt to test trail use thresholds, beyond which substantial vegetation damage may occur. This type of threshold study can provide a quantifiable indicator of the environmental damage caused by trail users and can provide habitat-specific information about a site's potential carrying capacity. The literature provides numerous examples of thresholds of use, beyond which unacceptable damage on or near trails may occur.[58, 67, 69, 70, 99, 101-106]

2.6 TRAIL EFFECTS BY USER GROUP

Many studies have examined the effects on trails by individual user groups. Most focus on hiking, but several also investigated mountain biking or equestrian use, including several literature reviews. [7, 15, 18, 20, 22, 27, 31, 41, 66, 72, 73, 80, 99, 107-109] Several comparative studies document damage at lower levels of use for some user groups compared to others.[78, 79, 99, 102, 105, 109]

Studies document that within our three user groups, horses tend to be most damaging to trails even at low levels of use, due to the concentrated weight of the horse and rider on a relatively small area (hooves).[7, 14, 20, 72, 77, 79, 84, 103, 109-111] Several researchers recommended a reduced number or length of dedicated equestrian trails in natural areas.[14, 72, 110]. Horses tend to kick up topsoil and compact the soils below; with the topsoil gone, the finer soils that remain are more easily eroded, and trails are also more prone to becoming muddy.[72, 112]

On formal trails, the effects from hikers and mountain bikers appear to be similar in type and severity.[68, 78, 105, 113] Some mountain bikers prefer trails with steeper slopes, downhill features and sharp curves[75, 113], which can cause significant impacts on poorly designed and maintained trails or on unauthorized trails. Mountain bikers can cover more ground than hikers[113] and can cause incision and excess soil and vegetation damage from skidding, jumps, bridges and other technical features.[9, 86, 105, 114] However, there are usually more hikers than mountain bikers on mixed use trails, and hikers may create more unauthorized trails than mountain bikers because it is easy to walk off trails. Without more specific studies, we are unable to determine on a one-to-one basis whether one user group (hikers versus mountain bikers) causes more trail damage than the other.

In Tennessee and Kentucky oak woodlands, the type of use was more important to trail condition than the number of users.[77] Equestrian trails were substantially more degraded than hiking and mountain biking trails; hiking trails were slightly more degraded than mountain biking trails. For example:

- Soil loss from erosion was lowest for mountain biking trails, somewhat higher for hiking trails, and nearly an order of magnitude higher for equestrian trails.
- Percentage of trails with severe erosion (>12.7 cm deep) was 9 percent for equestrian trails, 1.4 percent for hiking trails and 0.6 percent for bike trails.
- Equestrian trails were widest, followed by hiking and biking trails. However, the researchers did not state whether this was use-related or due to original trail design.

Researchers in Montana and Wyoming forests found that increased traffic of any kind led to wider trails, and that equestrian trails were deeper but not wider than hiking trails.[95] Other studies also document deeper trails from horses than other uses.[77, 109, 111] Whitaker found that horse trails in the Great Smoky Mountains National Park were wider and deeper than hiking trails. Studies also suggest that soils may be especially important when considering equestrian use; trails with deeper soils are more prone to incision and erosion,[29] and equestrian trails may be ill-advised in such circumstances.

In Montana researchers conducted a trampling study comparing hiker, equestrian and motorcycle effects in meadow and forested habitats.[68] Although our literature review does not address motorcycles as a user group, the results help tease out relative effects of different user groups. Hikers were less damaging than the other two user groups. Hikers and equestrians were most damaging when going downhill, with the reverse pattern seen in motorcycles. Damage was generally worse on steeper slopes and curves, and damage occurred less quickly in grassy compared to woody vegetation types.

In contrast, Pickering's trampling study in subalpine Australian habitats found that mountain bikers caused more damage on up- or downhill slopes compared to hikers, which finding was only apparent at the higher 500-pass use.[99] Because some trampling studies test only 100-250 passes, such user-specific differences may not always be revealed.

In Finland, researchers compared the effects of hiking, skiing and equestrian use on trails.[109] Effects were related to recreational activity, research site and forest type. Equestrian trails were as deep as hiking trails but hiking trails had 150 times more users. Hiking trail plots had little to no vegetation cover; equestrian plots had lower vegetation cover than controls. Equestrian trails had more forbs and grasses, many of them non-native (Section 5.3).

Horses tend to damage trails more than hikers or mountain bikers.

Four trampling studies from Montana also reveal that horses create more erosion and rougher trails than other user groups. In the first study, one third of total sediment mobilization was due to user groups, with the remainder due to soil texture and slope.[73] Horses and hikers made more sediment available than mountain bikers, particularly on wet trails. These effects occurred on newly created trails at only 100 passes. The second, third and fourth Montana studies compared the relative effects of hikers, horses and llamas on trail erosion. DeLuca et al. found that all user groups made sediment available for erosion.[79] Hiker and llama effects were similar; horses caused greater soil compaction, yielded more sediment and caused rougher trails. More passes resulted in more damage. Cole and Spildie assessed user group trampling effects at the time of the study and one year later.[103] Horse traffic caused the strongest effects, which were still visible after one year. Hiker and llama effects were lowest, less permanent and similar. The degree of effects differed by vegetation. In the fourth study, Patterson simulated rainfall to assess erosion potential.[84] User groups did not compact soils on wet trails, but did on dry trails. Horses caused the most erosion in wet and dry plots and at both low and high intensity, causing rougher trails than other user groups.

Horses cause specific effects including manure on or near trails, which introduces excess nutrients, invasive species seeds and can trigger conflict with other user groups (Section 5.3).[29, 112, 115, 116] In addition, grazing can affect vegetation, especially in riparian areas.[105, 117, 118]

Landsberg et al. reviewed the scientific literature to guide management for appropriate equestrian use on trails.[14] Effects were generally strongest on sections of established trails that were wet, boggy or steep. The authors recommended limiting trails in such areas, prohibiting dogs on equestrian trails because of the potential for accident, injury and disturbance, and other best practices.

The research is clear that equestrians are more damaging to formal trails than hikers or mountain bikers on a per-user basis. It is unclear whether hikers or mountain bikers differ substantially in this respect. In contrast, visitor effects on wildlife are often least for equestrians, followed by hikers and mountain bikers (Chapter 7). It is crucial to understand the potential effects of different user groups on both trails and wildlife to develop appropriate trail placement, design and construction methods, and management practices.

CHAPTER 2 SUMMARY – User impacts on trail condition and vegetation

Initial trail construction

- Trail construction causes loss of vegetation, leaf litter and organic material.
- Reduced tree and shrub cover can cause locally warmer, dryer conditions (microclimate effects).
- Weed seeds may be carried in on boots and equipment, with germination facilitated by ground disturbance.
- For poorly designed and sited trails, immediate and lasting environmental effects from trail construction may be more significant than those caused by trail use.

Vegetation impacts

- Trampling causes direct physical vegetation damage. It also alters soil habitats that support plants.
- The ability of plants to resist and recover from trampling influence erosion and trail width over time.
- Plant life form is a major factor determining the ability to resist and recover from trampling.
- Herbaceous perennial plants with primary growth points at or near the soil line (e.g. grasses, clover and dandelions) and plants with bulbs, corms, rhizomes and tubers withstand more trampling over time.
- Woody and shade-tolerant plants are generally not as tolerant to trampling as other types of plants.
- Vegetation damage and loss lead to soil erosion.

Soil impacts

- Water runoff is the energy that moves soil particles. Runoff is related to landform, climate and seasonality.
- Vegetation damage, loosening of soil surface, soil compaction and steep slopes set the stage for erosion.
- Lighter soils are more prone to compaction, whereas heavier soils are more prone to erosion.
- Clayey soils are at high erosion risk because they are easily compacted when dry, but swell when inundated.
- Trails in naturally moist places such as springs, wetlands, floodplains and streamside areas, or higher elevations with more rainfall, are particularly prone to soil erosion and associated trail damage.
- Erosion potential increases linearly with trail grade up to approximately 10% grade; the effect is magnified above 10-12%. Trails with low slope alignment angles and those exceeding the "half rule" are more at risk of erosion.
- Effective trail tread drainage features are important to reducing soil erosion.

Trail widening and incision

- Wider trails tend to occur in more flat areas.
- Steeper trail grades can lead to lead to trail incision. Soil amendments including thick layers of gravel and water diversion features on unpaved trails may reduce this impact.
- Heavily used or muddy/puddled areas lead people to step or travel off-trail, causing wider, braided trails.
- Easily eroded soils are more prone to incision.

Amount of use

- Once a trail is established, damage tends to increase incrementally with higher use.
- In some cases, there may be a threshold effect beyond which little further damage is evident.
- Trampling studies fail to account for high use and impacts from long-term ongoing use.

Trail effects by user group

- Hikers and mountain bikers appear to have fairly similar types and severity of trail impacts on formal trails.
- Horses typically cause more trail damage compared to hikers and mountain bikers.

3. EFFECTS OF UNAUTHORIZED TRAILS

Trails can be roughly divided into three categories: surfaced formal trails (paved, gravel, stonework, etc.), unsurfaced or natural surface formal trails, and unauthorized trails created by trail users outside of the formal trail system. Unauthorized trails are also known as user-created, informal, social, or demand trails.[56, 119] All user groups tend to create unauthorized trails.[14, 19, 47]

Unauthorized trails are created when visitors want to see or do something that cannot be accessed on formal trails, such as scenic views or stream and river corridors; for "bathroom breaks;" or to avoid poor trail conditions or other trail users.[94, 120, 121] User-created trail effects can be formidable because the trails are new,[14, 19] unplanned, unmaintained, are often in steep terrain[122] or in sensitive or muddy habitats, and can spread weeds and damage riparian areas.[14, 16] Unauthorized trails create the same sort of effects as described in previous sections. Unauthorized trails can also create edge effects and may increase habitat fragmentation, as discussed in Section 5.2. They also cause significant wildlife disturbance; people walking, cycling or riding horses off-trail are more disturbing to wildlife because they are less predictable than on formal trails with regular use (Chapters 6 and 7).[123, 124]

Why do visitors go off-trail? Although unauthorized trails can often be found throughout a site, they tend to be clustered around formal access areas, neighborhoods and roads.[32, 121, 125, 126] Van Winkle mapped 23 km of unauthorized trails branching off from formal trails in Portland's Forest Park.[121] Twenty-eight percent of unauthorized trails were linked to "hidden" behaviors including bathroom stops, party spots, waste dumping and illegal encampments. Another 29 percent of unauthorized trails provided access from private properties into the park. Unauthorized trails were common near trailheads, intersections and to gain access to water, and tended to be clustered in higher use areas.

Figure 4. Unauthorized trail at a Metro natural area. *Photo credit: Chris Hagel.*

Hockett et al. surveyed trail users about their off-trail experiences in Maryland and tested methods to reduce unauthorized trails.[92] In controls with no treatment, 70 percent of survey respondents reported hiking off-trail intentionally for an average of 2.8 different reasons or motivations. The most common self-reported motivations were to get to a scenic vista or take a photo (51 percent), to avoid or pass others (45 percent), or because of poor or challenging trail conditions (43 percent). In treatment areas that included educational and "stay on trail" types of signs, unobtrusive observers recording actual visitor behavior found that off-trail rates declined to 6.5 percent compared to 29.7 percent in the control. Observed numbers were lower than self-reported rates because treatment areas provided only a small representation of the total area. Signage clearly reduced off-trail effects (Section 8.9).

In Virginia, Wimpey and Marion identified the following motivations and behaviors for off-trail traffic and the creation of unauthorized trails:[94]

- Access – users leave the formal trail network to access park areas not reached by formal trails. *(Author's addition: users desire access to nature close to home, creating trails from backyards or nearby roads.)*
- Avoidance – visitors leave formal trails due to undesirable conditions on the trail (e.g., mud, erosion, crowding, conflicts or difficult terrain).
- Exploration – visitors are drawn away from formal trails to investigate unknown areas.
- Accidental – visitors follow an unauthorized trail due to poor formal trail marking or inattentiveness.
- Shortcuts – visitors leave a formal trail to reduce hiking time.
- Attraction – visitors leave a formal trail to see, study, or photograph interesting wildlife, plants, vistas, or to investigate interesting sounds or an inviting unauthorized trail's destination.
- Activities – visitors leave unauthorized trails to engage in off-trail recreational activities such as orienteering and geocaching.

In addition, illegal encampments can cause significant environmental damage including creation of unauthorized trails, destruction of vegetation, litter, debris from shelter structures and human waste that can enter waterways. [127, 128] Illegal encampments are likely to be located near pedestrian access points such as trails or near transportation facilities such as light rail stations, and are often found in natural areas.[128] This can be difficult to handle without suddenly displacing homeless people who are not connected to available social services and resources, or for whom such resources are unavailable.

People sometimes leave trails to appreciate nature, damaging the very resource they want to see. In an observational study in an Australian biodiversity hotspot, 41 of 213 visitors (19 percent) left trails to observe wildflowers and trampled vegetation in the process.[69] Visitors followed the least path of resistance, moving through areas with bare ground and stepping around shrubs and trees. Vegetation height and cover declined in response to tourist use.

Figure 5. Unauthorized trail leading from a residence in a Metro natural area. *Photo credit: Chris Hagel.*

Recreational activities such as geocaching, letterboxing and more recently, "Pokemon Go" can also lead to unauthorized trails in sensitive habitat areas.[19, 56, 94, 129-131] Some land management organizations have implemented policies that prohibit off-trail geocaching and associated damage to natural resources.[130]

Effects of unauthorized trails on habitat. Unauthorized trails often substantially increase the total length of trails in a natural area (see also Chapter 5).[14, 32, 105, 121, 122, 132, 133] For example, in San Diego County 45 percent of mapped trails were user-created with contributions from bikers, hikers and equestrians.[132] An Australian urban forest study found that nearly 60 percent of all trails were user-created; unauthorized biking and hiking trails were common and overall, approximately 6 percent of all habitat was lost or damaged due to unauthorized trails and adjacent edge effects.[32]

From this review it is difficult to state unequivocally whether one user group creates more, or more damaging unauthorized trails than another on a per-user basis; damage may relate most strongly to the number of users and user behavior. Hikers are often the largest user group and can easily move off-trail, creating their own trails for a variety of reasons including viewpoints, visiting riparian areas and short-cutting switchbacks.[14, 28, 92] Equestrians are especially damaging to the ground surface therefore any off-trail activity by this user group is likely to be destructive,[20, 103] but equestrian use is and will likely remain less common in parks and natural areas than hiking and mountain biking in Oregon.[34] Several studies described unauthorized trail effects from mountain bikes, and this appears to be an emerging or increasing issue in some natural areas.[134-136]

Mountain bikers sometimes create their own trails to increase technical features. These features can cause environmental and safety issues, posing a challenge for park planners and managers that can be difficult to address.[17, 133, 137, 138] For example, a mountain bike study in a 29-ha Australian forest remnant identified 116 unauthorized features, mostly jumps, ditches and mounds, collectively resulting in 1,601 m^2 of bare soil and 4,010 m^2 of undergrowth cleared, about 2 percent of the total natural area.[137] A large scale mountain biking study conducted for Shimano Corporation found numerous unauthorized trails in the southwestern U.S., likely from both hikers and mountain bikers.[58] Unauthorized bike trails tended to be wider, steeper, and often with braided trails compared to hiking trails. Mountain bikes caused additional damage at curves and junctions and multiple trailing was common in riparian areas. While these studies document that certain effects were more serious from mountain bikers than from hikers, they do not determine whether one user group is more damaging than the other at the site level.

A local example illustrates the difficulties of managing unauthorized trails. In 2010, The City of Portland's Parks & Recreation staff discovered significant effects on habitat along an unauthorized mile-long trail in the 5,172-acre natural area, which is an important wildlife corridor where deer and elk are active.[134] The unauthorized trail had been used previously by hikers and illegal campers, but new damage was caused by mountain bikers who greatly modified the trail tread to create technical features and water drainage crossings. They cut down trees, built a bridge, dammed a stream, and carefully camouflaged the trail entry with shrubs. The park includes 28 miles of authorized mountain bike trails on park roads and fire lanes,[139] but these types of trails are not necessarily attractive for some mountain bikers.[140] City ecologists estimated that the trail would take up to 15 years of ongoing restoration for the habitat to fully recover. The mountain biking advocacy community condemned the trail, asked mountain bikers to avoid its use, and assisted Park staff in closing and reclaiming the trail.

The potential for added trail length and damage from unauthorized trails is one of the most compelling reasons to monitor and maintain recreational sites, enforce regulations, and provide signage and educational information for trail users.[14, 58, 92] Table 7 in Section 8.4 offers some methods for surveying and monitoring unauthorized trails, and Chapter 8 includes approaches to reduce creation of unauthorized trails, including recommendations for signage.[56, 141, 142] One way to limit unauthorized trails is to install rocks, logs or other features to limit users to the intended tread.[143].

CHAPTER 3 SUMMARY – Unauthorized trails

- All user groups create unauthorized trails.
- Unauthorized trails may comprise more than half of the trails in a natural area.
- Unauthorized trails tend to have steeper trail grades compared to formal trails leading to more erosion and trail incision than formal trails.
- Edge effects are substantially increased by unauthorized trails.
- Unauthorized trails tend to be clustered around formal access areas, neighborhoods and roads.
- Users frequently create unauthorized trails to access special features such as views, streams and wetlands, or for secret activities such as bathroom break hideouts.
- Illegal encampments can cause substantial environmental damage. Encampments may be located near trails or transportation facilities such as light rail stations. Encampments are associated with unauthorized trails, destruction of vegetation, litter and human waste.
- Hikers are typically the most common recreationists and can readily move off of formal trails to create their own unauthorized trails.
- User-created technical mountain biking features such as steep slopes, jumps, and mounds can significantly damage natural resources.
- Horses can do substantial damage when creating unauthorized trails due to the amount of weight concentrated on a small area (hooves).

4. USER CONFLICTS AND PERCEIVED EFFECTS ON WILDLIFE

Previous sections discussed the effects of recreation on and near trails. This chapter bridges on- and near-trail effects, human behavior and the effects of recreation on wildlife. Chapters 5-7 address how recreational use influences habitat and wildlife.

User group conflicts. Hikers are the most ubiquitous trail users in most public natural areas.[35] Mountain biking is a relatively new sport that began in the 1970's, but is gaining in popularity.[144] Although many trails are dedicated solely to hiking, there are relatively few devoted only to mountain biking or equestrian use.

Conflicts between user groups on multi-use trails may arise from a variety of situations, such as:

- a feeling of being crowded[96]
- perceptions of safety hazards (e.g., mountain bikers move quickly and quietly)[145]
- a sense of propriety from regular visitors[146]
- discomfort with non-traditional uses (e.g., hikers question whether bikes should be allowed)[144]
- negative attitudes towards perceived environmental damage from other user groups[96, 145]
- belief from hikers that mountain biking is inappropriate in a natural setting[145]
- interference with the reason for the visit (e.g., other visitors scaring wildlife away from birdwatchers)[116, 144, 147]
- lack of courtesy from or irresponsibility by other users[144]
- poor trail design, such as blind corners[144]
- mountain bikers, hikers or equestrians on trails not designated for that use[148]
- encountering trail users with dogs, especially off-leash[78, 116, 149, 150]

While hikers and mountain bikers may have fairly similar physical effects on formal trails, the social aspects may differ. Trail users that visit a natural area more than once tend to internalize a set of rules of conduct, attitudes or opinions that influence the way they perceive other visitors.[96] Specific user groups tend to share these "social norms" which reflect their experiential expectations in a natural area.[144, 151] For example, hikers may expect a quiet, private walk in nature where they may see wildlife. Mountain bikers may desire exercise and challenge in a beautiful setting, and equestrians may seek a more social nature experience with friends.

If one group perceives that another user group does not share the same social norms, conflicts may arise. Some of the conflicts reflect more theoretical concerns rather than actual negative encounters between, for example, hikers and mountain bikers.[116, 144, 145, 152] Hikers often perceive mountain bikers and equestrians as sources of conflict, but the other user groups don't feel the same, or feel as strongly, about hikers – a sort of one-way conflict.[78, 86, 144, 145, 150-155]

One researcher suggested that equestrian use differs slightly from hikers and mountain bikers, in that equestrians are more physically separated from the environment; these differences can cause perceived social conflict.[96] It is also possible that the sheer size and bulk of a rider and horse is physically intimidating to other trail users. Researchers studied conflicts between hikers and pack "stock" animals (primarily horses and mules), in several California wilderness areas.[115] Over half of hikers surveyed found it undesirable or very undesirable to meet stock users, but only ten percent of stock users felt the same about hikers. Conflicts appeared to relate more to user groups' attitudes toward one another than actual on-the-trail conflicts. In addition, hikers disliked encountering horse dung on trails. The authors stated, "While persuasive and educational messages may reduce conflict between hikers and horse users, if managers fail to reduce the number of encounters that create conflict or effects of horse use that hikers label as inappropriate, they may find some restrictions on horse use to be necessary."

Conflicts among user groups can arise without any actual contact occurring. In fact, perceived conflict is sometimes greater for people who haven't encountered other user groups on the trail.[115, 116, 145] For instance, visitor surveys in New Zealand revealed that overall, 21 percent of hikers anticipated or encountered negative interactions with mountain bikers.[145] Of those, more negative perceptions came from hikers that had not encountered a biker; a higher percentage of older trail users (58 percent) fell in this category than younger ones. If visitors expected to share trails with mountain bikers they perceived fewer conflicts. Most hikers (74 percent) felt that any conflicts with mountain bikers arose from just a few irresponsible riders. Nearly 60 percent of respondents disagreed that biking and hiking have similar effects on the environment, whereas studies suggest that they actually have fairly similar effects, provided they stay on formal trails.[68, 78, 105, 113] Tire tracks are more visible than boot tracks, which may partially explain this opinion. The researchers suggested that the following actions may decrease user conflicts: (a) increasing awareness that bike encounters are likely, and that those encounters are likely to be amicable and non-threatening; (b) ensuring that biking advocates promote a code of conduct reinforcing positive encounters; and (c) land managers wishing to reduce perceived conflicts may want to devote extra attention to older hikers, particularly when considering an aging population.

> Setting expectations is crucial to managing user conflicts. Hikers that expect to see mountain bikers and equestrians perceive fewer conflicts.

Equestrians can elicit similar concerns among other user groups.[14] Beeton found that survey respondents with negative views about equestrians had not encountered any on trails, noting the need for better education of both land managers and visitors to improve compatibility between user groups on trails. [14, 146] However, some research suggests that fewer numbers of equestrians are acceptable to other user groups compared to mountain bikers or hikers.[115] In addition, although equestrian use is often restricted to certain trails in natural areas, most equestrian trails also allow other user groups, leading to a different problem: Horses may be frightened by hikers, mountain bikers and dogs.[14] It is also more difficult to align equestrian trails near roads because traffic noise can frighten the animals.

Direct user group conflict does occur. Researchers in Montana assessed the extent of and reasons for conflict between hikers and mountain bikers.[152] Only six percent of hikers said they had never encountered a mountain biker there. They found that mountain bikers tended to perceive mountain bikers and hikers as more similar than did hikers. Nearly two-thirds of hikers disliked sharing trails with mountain bikers but most had trouble saying why, although discourteous and too-fast bikers were mentioned. Real differences between the two groups such as environmental attitudes did not match hikers' perceptions. The researchers suggested that to reduce feelings of conflict between the two groups, managers should educate mountain bikers about behaviors that others consider unacceptable, and educate hikers about the similarities in values between hikers and mountain bikers. They also believed that more direct management approaches such as regulations and enforcement must also be considered, especially to target non-compliant users. Chiu and Kriwoken found that hikers' primary conflicts with mountain bikers were due to excessive speed and failure of bikers to give adequate warning of their approach.[78] However, conflicts between the two user groups were uncommon and the two groups were fairly amenable to mixed use trails.

Although hikers, mountain bikers and equestrians tend to have similar environmental values,[144, 147, 152] these values sometimes vary by group. In Australia researchers surveying various user groups found that environmental values differed by users' age, level of education and gender.[147] People over age 45, those that received a university education, and females had the strongest environmental values. However, the general orientation towards environmental values did not dignificantly differ between hikers, joggers and mountain bikers. Other studies also suggest that older and more educated visitors tend to have more robust environmental knowledge.[151, 156, 157]

Trail runners' reasons for being in a natural area differ from other on-foot user groups, and that may be reflected in their values and knowledge. Australian researchers found that trail joggers/runners were less concerned about weeds than other user groups, especially compared to older visitors and hikers.[157] In another study runners and cyclists were least likely (1 percent) to stop and read signs such as "share the trail, manage your dog, private property;" walkers were most likely (6.1 percent).[92] However, research on this topic is sparse and these studies may not pertain to other places and settings.

There may be perceptual and actual use differences among recreational users in suburban versus rural settings. Scientists in Switzerland interviewed hikers and mountain bikers about their perceptions of forest health, recreational effects on the environment and conflicts between user groups.[151] Interviewees' habitat knowledge increased with age and education. Over half of the suburban forest survey respondents reported experiencing conflicts with other forest visitors, especially mountain bikers. Only approximately one-fourth of mountain bikers reported experiencing conflict with hikers. Twenty-five percent of hikers and 29 percent of the bikers at the suburban site felt that recreation was causing a decrease in biodiversity; in contrast, at the rural site, 31 percent of hikers but only 9 percent of mountain bikers felt that their user group negatively affected biodiversity. If this holds true for other areas, education about visitors' effects on wildlife may be especially important in rural areas.

Perceived value differences - real or not - can lead to conflict between different user groups.

Our review suggests that these factors may influence user group conflicts on trails:

- User group – hikers tend to anticipate and perceive more conflicts with other groups than vice versa.
- Experience – hikers that encounter mountain bikers or equestrians are less likely to perceive conflicts than hikers that haven't encountered mountain bikers or equestrians.
- Age and education – older, more educated trail users tend to have more concern for the environment, and perceived or actual differences in these values can cause conflict.
- Social values – one user group may perceive (sometimes incorrectly) that another group's values are different, such as environmental values or codes of conduct.
- Expectations – If two or more user groups are authorized to use trails from the outset, the two groups perceive and experience less conflict with one another.

These studies suggest that differences between user groups' expectations and social values, rather than interpersonal conflict, are key sources of perceived conflict.[144] However, the literature suggests that users' experiential expectations may be modified through several means, such that user groups experiencing conflict in one setting may co-exist in relative harmony elsewhere.

Several researchers found that trails that are multi-use from the beginning have fewer perceived or actual user group conflicts.[116, 145, 158, 159] This is an important consideration when contemplating multi-use trails in a natural area.

Self-perception about effects on wildlife. Several studies demonstrate that natural area visitors often don't believe or acknowledge that they are having much of an effect on wildlife, or assign blame to different user groups rather than accepting responsibility themselves.[19, 113, 160-162] Some natural area visitors assume that when they see wildlife it means that they are not disturbing the animals or conversely, that because they didn't see any wildlife they didn't disturb any.[161, 163] Neither of these is likely to be true.

Visitors often don't understand that they are disturbing wildlife, or assume other user groups are most disturbing to wildlife.

For example, in Utah about half of recreational visitors surveyed did not believe that recreation was having a negative effect on wildlife; of those that did, each user group blamed other groups for the strongest effects.[113] In Austria, 56 percent of people surveyed at a national park agreed that wildlife is in general disturbed by human activity.[161] However, half of the recreationists felt that their own recreational uses were not having a negative effect on wildlife and only 12 percent believed that they had disturbed wildlife in their visit that day. Dog-walkers ranked their activities as less disturbing than other user groups' activities, but an ample body of research demonstrates that people with dogs actually cause a stronger wildlife response than people without dogs (Appendix 1).

A European study exploring user groups' views about their effects on amphibians found that nearly half of respondents felt that their effects were low or zero, but if there were effects they often blamed other user groups.[156] However, mountain bikers thought their activities damaged amphibian habitat, but felt that walkers and dog-walkers did not. Dog walkers felt that dogs on leash did not disturb amphibians at all, and that off-leash dogs had little effect. People who visited the forest most frequently thought they had the least impact on amphibians. Actual effects of these user groups on amphibians were not studied therefore the real answer is unclear.

CHAPTER 4 SUMMARY - User conflicts and perceived effects on wildlife

- Conflicts on multi-use trails may arise from a variety of situations – for example feelings of being crowded, a sense of propriety from regular visitors, safety concerns or discourteous trail users.
- Many factors can influence user group conflicts on trails including user group, experience, age, education, social values and visitor expectations.
- Perceived or actual differences in environmental values can cause conflicts.
- Older and more educated visitors, but not necessarily different user groups, tend to have stronger environmental values than younger or less educated visitors.
- Other user groups generally do not consider hikers a major source of conflict, whereas hikers often perceive mountain bikers and equestrians as sources of conflict.
- Mountain bikers tend to be amenable to sharing trails with hikers.
- Hikers' negative perceptions about mountain bikers are higher if they have not actually encountered them.
- Trails that start out multi-use have fewer perceived or actual user group conflicts.
- Most people understand in theory that human use impacts wildlife.
- Many trail users do not recognize that their visit that day impacted wildlife.

5. EFFECTS ON ECOLOGICAL PROCESSES AND HABITAT

Ecological processes are actions that result from the interacting physical, chemical and biological attributes of ecosystems.[164] Examples of ecological processes include photosynthesis, nutrient and hydrologic cycles, dynamic aspects of food webs, succession, evolution, migration, and the movement of disturbances across a landscape. Research demonstrates that recreational disturbance alters habitat, wildlife communities and food webs (Chapters 6 and 7). Some effects are unavoidable, but the severity of effects can be reduced by implementing good practices during and after trail construction (Chapter 8).

Trails and trail users can alter ecological processes in several ways, such as:

1. Vegetation damage or removal, altered species composition and changes in the amount of light around trails can affect photosynthesis.[12, 45, 63, 69, 70, 80, 165]
2. Soil compaction, erosion and vegetation loss change stormwater run-off patterns, thereby altering the hydrologic cycle.[14, 29, 54, 58, 68, 72-78, 80, 81, 166]
3. Human disturbance can differentially influence wildlife species' behavior and distribution, thereby altering food webs.[26, 167] For example, large carnivores tend to avoid areas with busy trails, leading to increased deer and elk herbivory on shrubs, resulting in fewer seed-dispersing songbirds.[168-173]
4. Recreational disturbance can alter densities and reduce reproductive success for some species with potential for population-level effects.[174-181]
5. Invasive species delivered by feet, wheels and hooves can alter plant communities, thereby introducing disturbance and changing the amount and type of food and cover available to wildlife.[14, 22, 23, 105, 157, 182-189]
6. Physical or behavioral habitat fragmentation and edge effects may favor generalist wildlife species, leading to changes in functional groups and communities and potentially deterring migration.[32, 56, 59, 94, 122, 133, 167]

As an example of the effects of recreation on ecological processes, Ballantyne and Pickering found that trail users substantially reduced a keystone[4] shrub species on and near the trail.[190] The shrub species was a "nurse shrub," which facilitated the establishment of multiple rare dwarf herbaceous and graminoid species that grew beneath its canopy. The reduction of the keystone shrub species led to reduced abundance of the associated rare species and facilitated growth of taller, leafier plants; this altered habitat structure and species composition. These changes along ridgelines altered wind profiles and further reduced the keystone shrub species' ability to reproduce, thrive and serve as a nurse shrub for the rare dwarf species.

Naaem et al. state that the loss of biodiversity in an ecosystem often causes the following impacts on ecosystem functioning:[191]

- Plant production may decline as regional and local diversity declines.
- Ecosystem resistance to environmental perturbations, such as drought, may be lessened as biodiversity is reduced.
- Ecosystem processes such as soil nitrogen levels, water use, plant productivity, and pest and disease cycles may become more variable as diversity declines.

[4] Keystone species are those that have a disproportionately large effect on other species; examples include beaver and large carnivores.

Trails can cause population-level effects for some wildlife species, although this is seldom documented due to the amount of space and time required for such studies.[192] In southern English heathlands, recreational trail use reduced the probability of woodlarks colonizing suitable habitat to less than 50 percent at only eight walkers per hour.[193] Even though birds breeding in disturbed patches responded by producing more chicks per pair of birds, per season, it was not enough to make up for the loss of productivity because hundreds of disturbed patches of otherwise suitable habitat were not colonized. The researchers estimated an overall 17 percent reduction in productivity in the disturbed versus undisturbed sites.

In another example of potential population-level effects from recreation, scientists conducted a 5-year study comparing the productivity of elk in undisturbed settings to animals that were repeatedly approached by humans on foot.[194] The treatment group had fewer calves than undisturbed elk. Although elk resumed normal reproductive output over the next two study years, it did not make up for the loss of productivity from the treatment year. Although this short-term study was not designed to monitor long-term population effects, the example suggests that if elk are unable to habituate to direct human disturbance, recreational foot traffic could cause population declines over time.

5.1 RIPARIAN HABITAT AND WATER QUALITY

Changes in riparian habitat and water quality influence the types of species that can utilize such habitats, resulting in changes in ecological processes. If not built and managed appropriately (Section 8.2), trails can damage riparian habitat and impair water quality to varying degrees through trampling, altering drainage patterns and introducing excess runoff and sediments to streams.[18, 56]

People like to visit streams, wetlands and rivers and will often create their own trails there.[77, 121] For example, some heavily used riparian trails can experience excessive damage anywhere the stream is not protected by fence or steep slopes.[121]

In her literature review, Pickering summarized the potential direct and indirect effects of equestrian use on riparian areas and water quality, which with one noted exception apply to other user groups as well:[22]

- defoliation of riparian vegetation
- introduction of invasive aquatic and terrestrial species
- soil loss and compaction (which can also prevent re-establishment of native plants)
- increased turbidity associated with soil erosion and eroded streambanks
- degraded water quality
- altered composition of instream and streambank biota
- increased input of sediments
- increased input of nutrients [associated with horse manure and urine] with potential for excessive algal growth
- impaired aquatic ecosystem health

Defoliation and soil compaction from any source will decrease water infiltration, creating more runoff into streams.[14, 72] When these issues occur in riparian areas increased stream bank erosion may occur, leading to channel widening and further sedimentation.

Trails can alter patterns of water distribution, as discussed in Section 2.3. In their 2007 review of the environmental impacts of mountain biking, Marion and Wimpey commented, "Poorly designed trails can also alter hydrologic functions – for instance, trails can intercept and divert water from seeps or springs, which serve important ecological functions. In those situations, water can sometimes flow along the tread, leading to muddiness or erosion and in the case of cupped and eroded treads, the water may flow some distance before it is diverted off the trail, changing the ecology of small wetland or riparian areas."[18] Due to their linear nature, mountain bike treads can re-direct trail runoff water into undesirable areas or cause new small channels to form.[195]

Stream crossings. Bridges and culverts tend to cause fewer water quality issues than at-grade crossings such as fords, although all types of crossings may degrade water quality.[29, 196] In Virginia, researchers studied the effects of 11 multi-use (hikers, mountain bikers and equestrians) stream crossings on water quality.[196] Crossing types included fords and culverts. The researchers documented impaired water quality below versus above stream crossings, as indicated by degraded macroinvertebrate communities. Their models estimated that soil erosion rates for non-motorized trail users would be 13 times higher along stream crossing approaches compared to undisturbed nearby forest, and 2.4 times higher than a nearby 2-year old clear-cut.

An instream hiking study in Utah found that as more hikers crossed stream fords, they kicked up increasing amounts of streambed invertebrates and organic matter, reaching a threshold at approximately 120 hikers per hour. The researchers suggested that streambed invertebrates were washed away after this amount of disturbance.[197] Hikers also displaced stream bed sediments, increasing stream turbidity. These effects were spatially limited and suggest a relatively minimal effect on water quality in Utah, an area that is prone to flash-flooding and where invertebrates are adapted to disturbance.

In contrast, researchers at California's Yosemite National Park found longer term effects in a two-year study of stream fords used by mules, horses and hikers.[198] They compared benthic (stream bottom) invertebrates, which are excellent water quality indicators, above and below two crossings during spring and fall. Differences were clear immediately below fords with finer substrate, a thick periphyton[5] layer, and higher pollution-tolerant but lower pollution-intolerant taxa, indicating impaired water quality. Seasonal differences corresponding with higher visitor use were evident: the difference in upstream versus downstream water quality was greater in fall than in spring, suggesting cumulative effects from recreationists crossing the fords throughout the summer tourist season. Horses likely defecated in the stream, as suggested by bits of hay found in downstream pools. The researchers postulated that urine and feces inputs could be reduced by halting horses for a short time prior to entering the stream. Horses also tend to urinate and defecate near trailheads.[51] Several other studies suggested that horse dung and urine may increase nutrients in streams,[22, 51, 105, 112, 117] although none of them actually measured this potential effect.

Stream crossings, especially fords, can cause water quality issues and harm aquatic wildlife.

We found no studies testing whether stream crossings affect vertebrate species. However, members of the salmon family require cold, clear water and lay their eggs in gravels along stream bottoms.[199] Sediments introduced or

[5] Periphyton refers to freshwater organisms attached to or clinging to plants and other objects projecting above the bottom sediments.

kicked up by people near or crossing streams may clog fish gills and reduce reproductive success for some species, and may also carry excess nutrients that can de-oxygenate water and cause algal blooms.[18]

It is possible to mitigate some of these water quality effects. McClaran recommended focusing monitoring and management for pack stock on soil erosion and defoliation near streambanks.[117] Marion and Wimpey offered a set of best practices to reduce trail effects on streams and riparian areas (Chapter 8).[18]

5.2 HABITAT LOSS, FRAGMENTATION, AND EDGE EFFECTS

Habitat fragmentation is the process of dividing large areas of habitat into multiple smaller, increasingly disconnected patches.[200, 201] Habitat fragmentation changes ecological processes by diminishing the landscape's capacity to sustain viable native wildlife populations. The primary drivers of this effect include habitat loss, reduced habitat patch size, increased edge habitat, loss of connectivity between habitat patches and modification of disturbance regimes. Effects can increase over time as species are extirpated for various reasons and there is no means of recolonizing isolated habitat patches.[202, 203]

As habitats are divided, the edges of each patch are subject to changes in light, wind, moisture, invasive seed sources, and human disturbance that reduce habitat quality for some plant and animal species.[59, 119, 167, 169, 204-207] While fragmentation and habitat edges sometimes benefit edge dwelling and generalist species, they are detrimental to more sensitive wildlife such as large carnivores,[169, 170, 208-210] species needing large home ranges and many Neotropical migratory songbirds.[132, 201, 205, 211-214]

Trails can cause habitat loss[32, 45, 121, 215] and are associated with invasive species (Section 5.3), but do they literally fragment wildlife habitat? In terms of the traditional physical reductions of habitat patch size and isolation associated with fragmentation, perhaps not to a large degree. Trail disturbance is typically limited to a fairly narrow corridor, and trails do not usually create new barriers within a habitat patch that would physically prevent most wildlife movement, although there may be exceptions such as raised trails blocking amphibian or turtle movement. However, trails do alter habitat and create edge effects. Various studies document trail-associated changes in vegetation structure, composition, and increased non-native species similar in nature to edge effects around the outside of a forest.[7, 125, 165, 216] Disturbance from trail use also triggers wildlife avoidance behavior in many species, which may be as impactful as physical habitat fragmentation (Chapters 7 and 8).

Edge effects. Trails and trail use create edge effects when habitat along the trail corridor is altered. Invasive species introductions are associated with edge effects (Section 5.3), as are structural changes in forests adjacent to formal and unauthorized trails including loss of tree and shrub cover.[32, 56, 122, 125, 204, 217] Such changes alter the quality and amount of habitat available to wildlife. Because even narrow trails may cause edge effects, unauthorized trails can substantially increase the total amount of edge habitat at a site.

There is evidence that edge effects in forests are both vertical and horizontal. We found two studies that examined the three-dimensional nature of edge effects. In the first, to test for edge effects in fragmented New Zealand temperate forests, researchers placed 25 data loggers at five heights from tree canopy to ground level, at five distances of up to 16 m from forest edges.[165] The scientists measured microclimate variables including air temperature, vapor pressure deficit and incident light. Compared to forest interior habitat, the loggers showed a breakdown of vertical stratification at forest edges for all microclimate variables measured.

In the second study, Yan et al. studied edge effects from trails in Chinese fir forests based on epiphytic bryophytes[6] on trees and microclimate variables.[45] Altered microclimates were apparent at trail edges which had more light, warmer air temperatures, fewer leaves and lower humidity compared to controls. It is worth noting that these types of microclimate changes would favor invasive plant species over natives in many settings. Bryophyte species richness and percent cover were significantly lower at trail edges. The authors concluded that the presence of a hiking trail – even as narrow as 1.5 meters – indirectly influenced epiphytic bryophyte communities by altering microclimate. They recommended minimizing disturbance by reducing the number of trees cut during trail construction so as to reduce the size of the canopy opening.

These studies documented vertical and horizontal effects that altered both microclimate conditions and living organisms, thereby altering habitat. Because wildlife keys in on habitat types and characteristics, it follows that such changes may also alter wildlife communities.

Measuring edge effects and fragmentation caused by formal and unauthorized trails. Trail planners may wish to estimate edge effects or related variables to assess existing conditions or compare potential effects between different proposed trail alignments. We found several studies in which researchers developed or used tools to estimate the amount of habitat loss, edge effects and loosely defined "fragmentation" caused by formal and unauthorized trails.[32, 56, 94, 121, 122, 125, 217] Appropriate methodologies depend on the research need (e.g., planned versus existing trail networks) and availability of funds and technically skilled staff or contractors. Each method employs GIS, and most studies with existing trail networks will require some fieldwork for the most reliable results. However, these techniques can provide quantifiable, biologically meaningful measures of fragmentation to inform trail design and management without conducting more resource-intensive wildlife or habitat studies. The studies below and in Table 3 provide examples of such approaches.

> Trails – both formal and unauthorized – cause edge effects and damage habitat.

Researchers in Australia developed a detailed GIS- and field-based approach to assess the extent and characteristics of trail-induced fragmentation in an existing forested natural area. To calculate habitat loss they buffered trail centerlines based on field-measured averages for each trail type then added actual habitat loss adjacent to trails.[32] Formal and unauthorized trails did not differ in the loss of structural components of the forest, although soil loss was greater on unauthorized trails. Trails caused an estimated edge effect plus habitat loss area of more than 47 ha (6 percent of the total study area). Over half of this loss was due to unauthorized trails (Chapter 3). Fragmentation was most correlated with the number of access points per remnant and the total length of trails. Newsome and Davies built on some of these methodologies to assess mountain biking effects at a national park in western Australia; their methods included mounting a GPS unit set to "tracking" on a bike, recording the unauthorized trail routes and noting unauthorized technical and erosion features.[133]

Scientists in Virginia used GIS- and field-based methods to explore the geographic and physical/topographic characteristics of unauthorized and formal trails in four study areas.[94] One research question was whether landscape fragmentation metrics can be used to summarize the relative effects of formal and unauthorized trail networks on a protected natural area. Unauthorized trails were on average twice as steep as formal trails, but narrower (0.9 m mean unauthorized trail width, 2.5 m formal). Unauthorized trails created a smaller total

[6]Ephiphytic refers to something that grows harmlessly on another living organism, in this case bryophytes – the group including mosses, liverworts and hornworts.

disturbance area than formal trails, even when the total length of unauthorized trails was greater. However, fragmentation metrics suggested strong additive effects when including unauthorized trails. For example, the number of habitat "patches" created by all trails compared to formal trails alone doubled in high use recreation areas and was as much as 1,900 percent higher than in low use recreation areas. Similarly, Marion and Leung found a high density of unauthorized trails, especially near the river, and when those were included in fragmentation metrics the number of discrete patches increased from 70 to 443; 48 percent of unauthorized trails fell in the "highly impacted" category.[56]

Ballantyne and Pickering compared trail surface condition, loss of forest strata and changes in tree structure between formal and unauthorized trails in 17 urban forest remnants in Australia.[125] Loss of forest cover and maximum widths were similar between formal and unauthorized trails. Wider trails had the most canopy loss, but unauthorized trails led to the greatest cumulative forest loss. Unauthorized mountain bike trails accounted for 65 percent of the lost canopy. Other studies indicate that formal multi-use trails tend to be wider than single-use trails because there tends to be more users, and hikers are generally expected to step off of trails to allow equestrians to pass by.[115, 204]

These studies indicate that unauthorized trails contribute significantly to edge effects, effects may vary from one site to another, and measuring such effects can help inform recreational access planning and site management. Table 3 summarizes some methods used to measure or estimate edge effects from formal and informal trails.

A note about wildlife habitat fragmentation and edge effects due to trail use. Although a few wildlife species are attracted to trails, many more species avoid trails or change their behavior to varying degrees (Chapter 7). The result is a zone of influence around trails that alters the distribution and abundance of wildlife, similar to trail-induced changes in plant communities. In addition, heavily used trails or recreational areas may cause the most disturbance-sensitive wildlife to avoid an area altogether, thereby effectively fragmenting their habitat. These effects on wildlife are conceptually similar to the traditional definitions of edge effects and physical habitat fragmentation.

Table 3. Summary of methods used to measure trail-induced fragmentation or related effects on formal (FT) or unauthorized trails (UT).

Reference and location	Study purpose	Habitat type(s)	Methods	Results
Ballantyne, Pickering et al., 2014 [125] and related studies [32, 122, 217][7] Coastal Queensland in eastern Australia	Compare relative effects of FT/UT mountain bike trails in 17 remnants endangered forest type, urban areas	Forest remnants near urban area; tall open Blackbutt (*Eucalyptus pilularis* dominated) forest	Mapped all trails, FT & UT. Measured maximum width, depth and slope of the trail and distance from trail edges to the litter layer, understory, midstory and trees – 40 FT, 40 UT. Measured Weighted Mean Patch Index (WMPI) and Largest 5 Patches Index (L5PI) and then compared remnants using ANOVA.	• Most trails were UT (bare earth, 32.1km, 74%); the rest were hardened formal trails. • Maximum widths were similar; UTs had greater slopes, more soil loss. • 17.1 ha lost to trails and adjacent habitat; 65% of this was due to UT, which had greater length. • UTs tended to be in denser urban areas; there were numerous UT points of entry. • Formal trails caused more canopy loss than UT. • Fragmentation as measured by WMPI was greater in forest remnants dominated by UTs, but no differences in fragmentation per the L5PI index.
Marion and Leung, 2011[56] Great Falls Park in Virginia, and Boston Harbor Islands National Recreation Area in Massachusetts	Test cases for different monitoring protocols for visitor impacts. Procedures were developed, field tested, refined, and applied to a selection of four park trails. Field-located all trails. Also tested trail condition methods at Zion National Park.	Great Falls Park: Several rare ecosystems with >200 local, national or global rare, threatened and endangered species. Boston Harbor: 34 islands and peninsulas within Boston Harbor; variety of habitat types including river gorge, rocky islands and forested floodplains and bluffs	• <u>Great Falls Park</u>: used park boundary polygon as base • Buffered trails by ½ trail width each side, FT and UT • Intersected buffered trail segments, removed from base layer to create 2 shapefiles: 1 FT only and 1 FT + UT • Used shapefiles to calculate landscape fragmentation metrics including Mean Patch Size (MPS) and # patches • <u>Boston Harbor:</u> buffered trails for threats to rare T&E species using 50-m buffer	• <u>Great Falls</u>: High UT densities leading to river or adjacent cliffs (views) were of great concern. • Nearly half of UTs were in the lowest condition classes, in which erosion was initiated or prevalent. • UT lengths nearly equaled FT lengths. • Number of discrete patches increased from 70 using FT to 440 when UT trails were added. • Mean patch size was reduced from 40,239 m^2 using only FTs to 6,273m^2 for all trails. • UTs = high concern for invasive species. • <u>Boston Harbor:</u> 141 m of UT found within 50 m of known T&E species.

[7] These papers are related and conducted partially on the same study sites. Some different information was in each study but the results were generally similar.

Reference and location	Study purpose	Habitat type(s)	Methods	Results
Wimpey and Marion, 2011[94] Great Falls Park, VA	Compared FTs and UTs: physical, topographic, fragmentation, and biodiversity hotspots	Several rare ecosystems with >200 local, nationally or globally rare, threatened and endangered species.	• Collected linear trail features using GPS • Measured condition class per Marion et al. [77] and average tread width by trail segment • Fragmentation: similar to [56]; removed infrastructure first • Hotspot analysis: used ArcMAP 9.3's spatial analyst line density tool • Used four landscape fragmentation indices: # patches, MPS, larges patch index, mean perimeter:area ratio	• UTs had higher grades, were in steeper terrains, aligned more closely to fall-line, and were narrower than FTs. • Hotspot findings similar to [56]. • Developed typologies of visitor motives, behaviors leading to UT creation: access to other areas of park; avoiding poor trail conditions or other trail users; exploring unknown areas; accidental – poor trail signage; shortcuts; attraction – visitors want to see or photograph wildlife, plants, etc. vistas; activities such as orienteering or geocaching.
Van Winkle, 2014[121] Forest Park, Portland, OR	Characterize the effects of UTs on understory plant communities	Predominantly deciduous and coniferous forest	• Mapped, quantitatively evaluated 382 UTs. • Used line density spatial analysis tools. • Established 30 transects along UTs to characterize understory communities, plus 30 paired controls.	• 28% of UTs were linked to "hidden" behaviors including bathroom stops, party spots, waste dumping and camps. • 29% of total unauthorized trail length provided park access from private properties, which tended to be longer than other UTs. • UT hotspots were associated with trailheads, intersections and to gain access to water; tended to be clustered in higher use areas. • UTs showed plant community and structural changes, and led to exotic species invasions; effects similar to FT but in narrower band (approx. 2m FT, 1 m UT for the most intense effects).

5.3 INVASIVE SPECIES

According to the U.S. Fish and Wildlife Service, invasive species are a leading cause of wildlife population declines and extinctions.[218] Invasive species are also expensive, causing at least $34 billion in damage and control costs each year in the U.S.[219]. Trails are key vectors for invasive species introductions into natural areas, creating an edge effect on each side of a trail.

All trail user groups introduce weeds and pathogens to natural areas including hikers,[23, 157, 182-185] mountain bikers[105, 185, 186] and equestrians.[14, 22, 23, 187-189]. Formal and unauthorized trails in a natural area can lead to substantial increases in invasive species over large areas.[32, 217, 220] A review paper found that hikers, mountain bikers and equestrians dispersed at least 225 species of non-native seeds; most were of European origin.[23] Scientists in South Africa used brushes to scrape seeds off of the shoes of hikers, dog walkers and cyclists, and also surveyed non-native plant species near the three different types of trails.[185] The highest incidence of seeds was on dog walkers' shoes, although they concluded that any type of tourist can be a vector for alien seed dispersal. All three types of trails had invasive species, while non-trail controls had few invasive species.

In her 2000 literature review on recreation ecology, Jordan commented that "it is not possible to tell from reports of weeds along trail sides if the weedy species were out-competing native species, or if they were just 'filling in' ecological space opened up by reduction of native species due to unfavorable environmental change (due to trampling, microclimate change, etc.). Some of both probably may occur, depending on circumstances."[7]

Many invasive species thrive in disturbed areas or with more available light, and trails can provide conditions that facilitate those species.[30, 59-61] Invasive plants also tend to have resilient life forms mentioned in Chapter 2 and can out-complete less resistant native species.[23, 221]

Spatial extent. Most unwanted species appear to stay relatively close to trails, but some shade-thriving species such as garlic mustard (*Alliaria peiolata*) encroach well into undisturbed habitat, with habitat-altering consequences.[60, 216, 222] Invasive species are associated with reductions of and changes in native plant cover and species across many geographies and habitats.[105] Various studies found that most weed species extended in the range of 2-20 m from trails,[95, 121, 189, 216, 222, 223] although many studies fail to account for a potential time lag from dispersal to germination and spread of seeds.[224] At the higher end, 20 meters on each side of the trail would create a 40-meter trail corridor zone of influence, plus the width of the trail itself.

However, smaller areas of influence are more common. For example, a local study documented that the strongest invasive species impacts occurred within the first meter on each side of unauthorized, and within two meters on each side of formal trails in the City of Portland's Forest Park.[121] The researcher mapped approximately 9.4 km of unauthorized trails branching from formal trails; the park has 129 km of formal trails. Assuming 4-m total widths for formal (2 m on each side of trail centerline) and 2-m widths for unauthorized trails to represent trailside invasive species encroachment, formal and unauthorized trails plus adjacent areas of invasive species cover at least 53.5 ha, or about 2.6 percent of the Forest Park's total area.

Despite studies documenting that most invasive species' effects fall within a few meters of trails, it only takes one destructive species such as garlic mustard, ivy (*Hedera* species), old man's beard (*Clematis vitalba*) or reed canarygrass (*Phalaris arundinacea*) to significantly degrade habitat. It is not unusual for non-native plant species to exist in low numbers for a decade or more before becoming invasive,[224] therefore short-term studies of one to three years are unlikely to document the full effects of invasive species due to trails.

Hikers. Hikers carry seeds on their clothes, shoes and shoelaces, and may carry seeds far into and between natural areas.[23] Mount and Pickering's review documented that at least 139 plant species can attach to clothing, of which 134 occur in major weed databases.[225] Another study found that although most seeds on hikers' shoes fell off within 5 m, seeds still remained after 5 km; modeling suggested that shoes were more effective at dispersing seeds over long distances than wind.[226]

As mentioned above, dog-walkers and their dogs may be particularly effective at spreading invasive weed seeds. A South African study found the greatest amount of invasive species along dog walking trails compared to hiking and cycling trails.[185] Of the three groups, all carried invasive seeds but dog walkers' shoes carried the highest seed load.

An experimental study found that walking in trousers distributed 17 percent fewer seeds than walking in shorts because shorts allowed uncovered socks and bootlaces to collect more seeds.[225] The average number of seeds collected per 100-m roadside walk included:

- Per boot: 66 seeds
- Per uncovered sock (shorts): 157 seeds vs. 10 per covered sock (trousers)
- Per uncovered bootlace: 66 seeds vs. 30 per covered bootlace
- Per trouser leg: 156 seeds

The study demonstrated that the type of clothing worn by a hiker can influence seed attachment and subsequent distribution. In further detail, normal socks collected more seeds and from a greater range of species, both native and non-native, than hiking socks.[225] Longer hikes resulted in more accumulated, and presumably more distributed, weed seeds.

Trail users can also spread pathogens that harm or kill trees. Researchers studying California hiking trails found strong associations between human recreational trail use and the spread of the pathogen causing Sudden Oak Death (*Phytophthora ramorum*), a fungus-like water mold.[183] While the pathogen does not appear to affect Oregon white oak (*Quercus garryana*) and has not yet reached northwestern Oregon's natural areas, it does have the potential to affect other species including Douglas fir (*Psueotsuga menziesii*) and Pacific madrone (*Arbutus menziesii*).[227] In California the costs to treat, remove and replace trees damaged from Sudden Oak Death are expected to be $7.5 million from 2010 to 2020, with a $135 million loss in residential property values.[218] Several researchers developed a prototype bike tire scrubber to reduce the spread of Sudden Oak Death that could be used as a best practice to reduce threats from these and other invasive species.[228] Trail use in protected areas have also been documented to spread the root-rotting fungus *Phytophthora cinnamomi*.[23]

Mountain bikers. Although the potential for mountain bikers to disperse weed seeds is commonly mentioned in the literature, we found few experimental studies examining this potential threat. With the emerging importance of mountain bikers as a user group, this is a relatively new topic of study. Hikers and equestrians have been regular trail users for much longer, thus there are more studies on these two user groups.

In Australia, Pickering et al. compared weed seed attachment in dry conditions on horses versus mountain bikes.[229] The researchers established 20 transects through which a horse or a mountain biker was led for 100 m. Seeds were meticulously collected after each transect crossing. Horses carried more weed species' seeds and the species composition differed between the two, but horses and bikes carried similar numbers of seeds. The authors recommended best practices similar to those for hikers – that is, seed and dirt removal devices near trailheads – and suggested enhanced efforts in areas of high ecological importance.

In an urban forest in Germany, Weiss et al. experimentally exposed mountain bikes to five species of seeds and subsequently rode them at a series of distances ranging from 1 to 500 m, in both damp and wet conditions.[46] The seed species were selected to represent different traits; depending on the species, up to 40 percent of seeds attached to bike tires. Although seed dispersal was relatively low in dry conditions, seeds stayed attached for up to 500 m in damp, and up to 100 m in wet conditions. Over half of all seeds detached within the first five meters. In contrast, seeds attached to the bike frame showed no significant decline at these distances. Seed traits were an important factor in persistence of attachment.

In contrast, a South Africa study examined mountain bike tires and associated riders' shoes for seeds found no seeds on tires, although seeds were present on two of the cyclists' shoes.[185] However, the brevity of the study (three days, of which two were dry) and small sample size (10 mountain bikers) may underestimate potential effects. In addition, the seeds were collected when riders first entered the natural area, without controlling for factors such as initial versus post-seed exposure on bikes and bikers.

Horses. We found numerous studies and literature reviews documenting weed issues due to horses.[7, 14, 20, 22, 112, 187-189, 222, 223, 230-233] Horses may be especially impactful because their pastures and hay tend to include seeds from weedy species.[14] In addition, nutrient enrichment from horse dung and urine may enhance growing conditions for weedy species, and horses churn soil which can facilitate germination.[20, 61, 79, 105, 187, 234]

Horses can carry these seeds long distances on their hooves, coats and in manure, and have long digestive periods capable of retaining seeds over significant distances.[23, 182, 188, 223] Adult horses can produce 17-26 kg of dung per day;[105] globally at least 244 weed species' seeds have been found in horse manure.[187] The highest risk for seeds sprouting from manure is in disturbed, damp sites and when riders go off-trail,[14] which suggests that placing horse trails or indeed, any type of trails in floodplains and near streams and wetlands increases the risk of invasive species introductions.

> Any recreational use can introduce invasive species seeds. Multi-use trails tend to harbor more invasives than single use trails.

The seed species that germinate along equestrian trails tend to be resilient to trampling. Ansong et al. reviewed 15 studies on seed germination from horse dung.[182] Nearly two-thirds of problem species were forbs, a third were graminoids, most were perennials, and nearly half were invasive. Another review found weedy perennial graminoids and herbs particularly prevalent along equestrian trails compared to other types of trails.[23] Manure along a trail in western Colorado yielded 20 species and 564 seedlings: 12 species were graminoids, six were forbs, and one each shrub and tree.[232] These findings concur with the resilient species' life forms discussed in Section 2.2 (vegetation effects); the most abundant and successful non-native species along equestrian trails tend to be those that can survive in diminished conditions and withstand ongoing trampling.

Several studies found that while many seeds were present in horse dung or germinated from dung in the lab, relatively few germinated from manure experimentally placed along equestrian trails.[222, 223, 230] However, these short-term studies do not account for multiple horses defecating over time, providing ongoing opportunities for weed establishment; they also fail to account for potential lag times between when seeds are first introduced to a natural area and when they spread to the point of becoming invasive.[224] In addition, some seeds require specific conditions such as a low temperature cycle to germinate, which may not occur every year while seeds lie dormant in the seed bank.[233] For instance, Australian researchers identified weeds being dispersed in trailside horse manure, and also which weed species were already established along equestrian trails.[189] Substantial percentages (from 20-55 percent) of horse manure weeds also grew along equestrian trails in their three study sites, although some vehicles also used these fairly wide, hardened trails.

Horses can also carry seeds in their coats and hooves.[19, 22, 223] A review of tourist seed dispersal found that 42 weed species transferred from horse coats between nature reserves. In Belgium, scientists collected and germinated seeds from the coats of large herbivores (cattle, donkey and horses).[233] Seeds from 75 plant species germinated in the lab and there was evidence of seed transfer within and between sites. The authors considered herbivore seed dispersal to be a potentially important restoration mechanism; this may be the case in undisturbed settings but in recreational settings, any restoration benefits may be offset by weed invasions.

Numerous studies found more non-native species and cover along equestrian trails compared to controls, or compared to other trail types.[110, 188, 230, 231] For example in Illinois, 23 exotic species germinated from dung in the lab but only one of those species was found in the field; however, more exotic species were found along horse than non-horse trails.[230] In Missouri, more species and a higher proportion of non-native species were documented along equestrian trails compared to old roads and intact communities.[231] In Queensland, Australia researchers examining diversity and distribution patterns of non-native plant species adjacent to equestrian trails found 39 non-native plant species within 20 m of trail, 30 of which were within 0-5 m of trails.[222]

One U.S. study found little evidence that horses are significant distributors of non-native seeds.[223] The researcher collected horse hay, manure, and hoof debris samples at five endurance rides in five states. He sowed sub-samples in pots and placed them on trails, and conducted plant surveys along 50-m transects perpendicular to equestrian and hiker-only trails at three sites. Some seeds germinated in pots, but few seeds germinated along trails; they concluded that hay and manure contain non-native plant seeds but that they rarely become established on equestrian trails due to harsh environmental conditions. However, this was a one-year study and the author acknowledged that several years' study would be necessary to better quantify the likelihood of the non-native invasive species to become established and out-compete native species. The preponderance of evidence in other studies suggests that horses do disperse non-native seeds along trails over space and time and overall, and that horses may be a stronger non-native seed vector per user than hikers and mountain bikers.

Multi-use trails and amount of use. Multi-use trails may have more invasive species cover than single-use trails; this is logical given that the findings above indicate that each type of user can distribute weed seeds in different ways. A study in California's Santa Monica Mountains compared single- versus multi-use trails in two sites with different shrubby habitat types.[204] Multi-use trails had higher proportions of exotic species and cover. The magnitude of these effects differed between the two different habitat types. These findings led the researcher to suggest that multi-use trails should be concentrated in (a) small areas, and (b) in the site less prone to exotic species invasion. Higher trail use is also correlated with increased non-native species and cover.[23, 189]

CHAPTER 5 SUMMARY – Effects on ecological processes and habitats

Ecological processes

- Trails and trail use change ecological processes through altered vegetation communities, soil impacts, distorted food webs and altered wildlife communities.

Riparian habitat and water quality

- Improperly sited or designed trails can alter the patterns of surface water drainage, creating excessive runoff that can alter hydrology and carry excess sediments to streams.
- Defoliation and trampling near stream crossings can compact soils, damage riparian vegetation and streambanks, and increase sediment inputs.
- Trails near and across streams without appropriate crossing structures can impair water quality through sedimentation and increased turbidity, potentially harming sensitive aquatic wildlife.
- Instream macroinvertebrate communities, which are indicators of water quality, have been found to be degraded immediately below stream culverts and fords. Similar studies were not found for stream crossings that use bridges.

Habitat loss, fragmentation and edge effects

- Trails do not typically fragment habitats in the traditional sense – that is, by physically separating habitat patches – but they do cause edge effects including invasive species and altered vegetative structure.
- Trails cause edge effects by introducing invasive species, altering habitat structure and composition, and changing microclimates. Physical edge effects are typically fairly limited in extent.
- Several studies offer methods of calculating physical edge effects due to trails.
- Trails – informal or formal – can collectively cause significant habitat loss.
- Disturbance from a trail is typically limited to a fairly narrow corridor, and trails do not usually create new barriers within a habitat patch that would physically prevent most wildlife movement.
- However, trail use can act as a fragmenting agent for wildlife by creating "zones of avoidance" that may extend much further than physical edge effects.
- Certain wildlife species such as large carnivores and area-sensitive birds may be reduced in or absent from sites that are fragmented by trails and recreational activity.

Invasive species

- Unaware trail users can carry non-native species far into and between natural areas.
- For hikers, the type of clothing worn can influence seed attachment.
- Horse dung, fur and hooves can carry many invasive species' seeds and between into natural areas. Hikers and even more so, dog walkers can also be significant vectors. Less is known about mountain bikes and their riders although they are capable of collecting and distributing weed seeds.
- Grasses, herbs and perennial weed species are the most common invaders but trail users can also spread pathogens such as Sudden Oak Death and root-rotting fungus.
- Multi-use trails tend to have more invasive species than single-use trails.

6. OVERVIEW OF EFFECTS ON WILDLIFE

Trails may degrade or fragment wildlife habitat and can also alter the activities of nearby animals, causing avoidance behavior in some and food-related attraction behavior in others. Although habitat effects from trails tend to be limited to a relatively narrow corridor, wildlife disturbance can extend considerably further into natural landscapes (Appendix 3). Species-specific responses to the same sources of disturbance can vary considerably and are discussed in Chapter 7.

The reality is that most of the time land managers lack site-specific formal wildlife surveys to inform their work before (baseline data), or after a site is opened for recreational access. Most wildlife studies are conducted after a site is opened for recreation, when disturbance may already have altered wildlife communities. This does not mean studies at disturbed sites are meaningless, because there will still be a range of sensitivity across wildlife species at the site to inform land management. However, care should be taken in interpreting results at disturbed sites without pre-disturbance data or undisturbed controls, because wildlife communities will already be altered from natural conditions. Another drawback to determining the true costs of recreation on wildlife is the need for statistical significance to validate results: animals that are already rare will be excluded from the findings due to small sample sizes.[235] These issues suggest a conservative approach to estimating effects of recreation on wildlife.

When research is conducted in areas that are already disturbed, the most sensitive wildlife species at the site – those that do not readily habituate to human disturbance (Section 6.2) – may experience reduced fitness, impaired reproductive success (potential reproductive "habitat sink"), or have already disappeared. If animals have already vacated a disturbed site when a study is initiated, the results are certain to underestimate disturbance effects on wildlife.

6.1 DISTURBANCE AND THE ANTIPREDATOR RESPONSE

Studies have documented that animals exhibit physiological responses – the so-called stress response – before anything is visible to researchers.[236, 237] Stress response is the functional response of an animal to an external stressor, such as seasonal changes in temperature and food availability or sudden disturbance.[238] Specific stress hormones are released to enable the animal to physically respond to the stressor, and the heart rate increases.[237-242] Acute stress response, when an animal reacts to an immediate situation, can benefit the animal by triggering it to respond appropriately to a threat. However, chronic stress such as repeated disturbances over time may reduce wildlife health, reproduction and growth, impair animals' immune system and increase vulnerability to parasites and diseases.[239, 243, 244] Long-term wildlife stress studies are scarce because they can be expensive, complex and may negatively impact the animals under study.

Wildlife subjected to human disturbance exhibit stress reactions termed the "antipredator response" in an attempt to avoid or minimize perceived threats.[19, 245, 246] Behavioral responses may include increased alertness to potential threats (vigilance), fleeing, habitat selection or avoidance, and altered feeding or breeding behavior.[246-248] Variability in behavioral responses essentially derives from a cost-benefit analysis: Does it cost more energetically or in terms of risk to hide, flee from or ignore the perceived threat?[249] Animals may be alert and experience stress response long before they initiate antipredator responses. By the time an animal flees, it has already spent energy being vigilant at the expense of normal activities.

In their seminal paper discussing the tradeoffs ("economics") of fleeing from predators, Ydenberg and Dill[249] asserted that the decision for an animal to flee may be deferred through economic costs. Under the economics model, FID should increase with increasing risk of predation and decrease with increasing cost of flight. For example, an animal may allow a person to approach more closely (shorter FID) in an area of abundant food, because the energy gained through extra feeding time compensates for the increased predation risk.[251] Similarly, if good cover is nearby a deer may wait longer to flee due to decreased risk of capture, or a bird with young in the nest may let a person approach more closely because biologically, it costs more to flee and abandon significant parental investment. In isolated habitats or where there is no suitable alternative for foraging nearby, wildlife may not flee at all because there is nowhere else to go.[246, 252]

Typical wildlife disturbance studies measure antipredator response through variables including stress hormone levels (e.g., measuring hormones in wildlife scat near trails versus controls, or through blood samples), indicators of reproductive output such as nest success, alert distance, FID, displacement distance, travel time, or time to resume normal behavior. There is a confusing array of potential disturbance behavior terms in the literature, and we found some variability in how these terms were used. Table 4 defines some of these terms to aid the discussion that follows.

Table 4. Definitions of terms used in wildlife studies to measure antipredator response, including tolerance to human disturbance.

Term	Alternative terms in the literature	Definition
Alert distance (AD)[250]	Vigilance distance Detectability period	The distance between an animal and an approaching human at which point the animal begins to exhibit alert behaviors to the human.[250]
Flight initiation distance (FID)[123, 253-257]	Flight distance Flight zone Escape flight distance Approach distance Flush distance Response distance	The distance from a person at which an animal first flees from perceived danger. The higher the FID, the lower the animals' tolerance to disturbance.
Displacement distance[258, 259]	Travel distance Distance moved Flush distance	The distance an animal moves away from the perceived threat, once flight has been initiated.
Travel time[260]		The amount of time a displaced animal spends moving away from a perceived threat (sometimes used when displacement distance cannot be easily measured).
Time to resume normal behavior[261]		The amount of time post-disturbance it takes an animal to discontinue antipredator response(s).
Detectability period[262]		The amount of time that a bird or other animal remains near its initial flush point. Shorter detectability period indicates lower tolerance to human intrusion.
Buffer distance[254, 263, 264]	Set-back distance Buffer zone Minimum approach distance	Typically used to establish guidelines to reduce wildlife disturbance.

The U.S. Forest Service researchers reviewed 238 articles on human disturbance effects on wildlife, including information on 395 wildlife species.[259] Of all types of interactions on non-motorized trails, their results indicated that displacement or avoidance affected the highest percentage of species, followed by disturbance such as alert distance. While the results may simply reflect the most popular or simple study topics – and underestimate the potential physiological effects of vigilance – the body of research does document the broad interest in and effects of human disturbance on wildlife.

In 2000 Jordan reviewed the literature pertaining to trails and wildlife, in which studies indicated several key points:[7]

- direct approaches cause greater wildlife disturbance than tangential approaches (Section 6.4)
- rapid movement by trail runners is more disturbing than slower hikers (Section 6.4)
- children and photographers[8] are especially disturbing to birds
- passing or stopping vehicles are less disturbing than people on foot

Disturbance can have a multitude of significant effects on wildlife. For example, studies document that disturbance reduces reproductive success for some wildlife species.[25, 194, 265, 266] Numerous scientists have found that female deer and elk, and deer and elk groups with young offspring, show greater alert and flight responses to human disturbances than other wildlife groups.[25] Stress hormones may cause male songbirds to reduce their territorial defense, females to reduce feeding of their young, nestlings to have reduced weight and poor immune systems, and adult birds to abandon nests.[244, 265-267]

Antipredator response can directly and indirectly affect individuals, communities and populations.[246, 268, 269] We found few studies documenting population-level effects from trails and disturbance, as summarized in the wildlife sections below. To be relevant, such studies need to be fairly large scale and conducted over several years – a complex and expensive approach.

Knight and Cole identified several key factors that influence wildlife response to disturbance:[270]

- type of disturbance (e.g., hikers, mountain bikers or equestrians)
- timing (e.g., during breeding season disturbance may affect productivity; during other seasons it may affect foraging/survival)
- location (e.g., animals avoiding areas where they can easily be seen)
- frequency (e.g., more visitors can reduce avian nest productivity; we would also include duration here)
- predictability (e.g., on-trail visitors are less disturbing than off-trail visitors)
- characteristics of wildlife (e.g., habituation or sensitization)

Pomerantz et al. developed a classification scheme to assess the effects of recreation on wildlife.[271] Their six categories are in Table 5 below. These types of effects are reviewed in Chapter 7.

Bennett et al. developed a spatially explicit model to explore spatiotemporal patterns of anthropogenic disturbances on wildlife for Yellow-headed Blackbirds, which could be adapted to other species if single-species management or more complex approaches to multi-species buffers were needed.[272] Using a simpler approach, FID and alert distances can provide some general guidance for minimizing disturbance to wildlife (Chapter 8). Weston et al. reviewed FID studies for Australian birds and called for standardized, widely available data to allow for greater application of these data to the management of disturbance.[273]

[8] The Audubon Society offers a guide to ethical wildlife photography: http://www.audubon.org/get-outside/audubons-guide-ethical-bird-photography

Table 5. Classification of recreational use effects on wildlife derived from interviews with refuge managers in the northeastern U.S. (From: [271])

Category of Effect	Description of Effect
Direct mortality	Immediate, on-site death of an animal.
Indirect mortality	Eventual, untimely death of an animal caused by an event or agent that predisposed an animal to death.
Lowered productivity	Reduced fecundity rate, nesting success, or reduced survival rate of young before dispersal from nest or birth site.
Reduced use of refuge	Wildlife not using refuge as frequently, or not using it in the manner they normally would in the absence of visitor activity.
Reduced use of preferred habitat on refuge	Wildlife use is relegated to less suitable habitat on the refuge due to visitor activity.
Aberrant behavior or stress	Wildlife demonstrating unusual behavior or signs of stress that are likely to result in reduced reproductive or survival rates.

Amount of use. In many cases, higher numbers of visitors cause more effects on wildlife including invertebrates, beetles, shorebirds, waterfowl, songbirds, herons, deer and elk, carnivores, and other species.[8, 19, 176, 178, 253, 274-283] As with trail and vegetation damage, in some cases there may be visitor number thresholds beyond which fewer animals or species use an area.

Some wildlife species can habituate to fairly high numbers of visitors without apparent harm, while others become increasingly sensitized to human disturbance (Section 6.2). For example, guanacos in Argentina appeared to have a threshold of approximately 250 visitors per day, beyond which the number of animals observed declined.[284] Other studies suggest visitor threshold effects for Sanderlings in Georgia (20 visitors per day)[285] and songbirds in the Netherlands, where eight out of 13 species showed thresholds ranging from 8-37 visitors per hectare.[235] Mexican Spotted Owls on the Colorado Plateau appeared to have a threshold around 50 hikers per day.[286] Regardless of any threshold effects, the majority of the research indicates that more visitors will cause more wildlife effects in general. The types of disturbance matter too, as discussed in the wildlife sections below.

Different wildlife species respond differentially to visual, auditory, olfactory and tactile stimuli. This variability is both difficult to study and critical to understanding the true effects of trail users on wildlife. The sections below describe and attempt to make sense of this variability to help inform our work.

A note about dogs. The research we reviewed strongly suggests that dogs are more alarming to wildlife than any non-motorized recreational user group without dogs. We previously reviewed the literature pertaining to the effects of dogs on wildlife (Appendix 1).[287] The evidence that dogs negatively affect wildlife is found repeatedly throughout the literature. People with dogs – on leash and even more so for off-leash dogs – appear to be more detrimental to wildlife than people without dogs. Land managers should consider prohibiting dogs at sites where conserving wildlife is a top priority.

6.2 HABITUATION, SENSITIZATION AND TOLERANCE

Evidence suggests that some wildlife species can become accustomed (habituate) to certain predictable, non-threatening disturbances such as people regularly walking on a trail in a natural area. Habituated animals (or those that appear to be habituated) still respond behaviorally and/or physiologically, but the amount of habitat affected via avoidance behavior or the magnitude of the disturbance response may diminish over time.[25, 173, 288, 289] Habituation is a gradient rather than a binary yes or no. Wildlife responses occur at different magnitudes in different contexts, and responses may vary by species and even by individual.[248, 282, 290, 291] There is evidence to support that the capacity to habituate is species-specific.[292-294]

The term "habituation" is often used inappropriately in the literature, and this can lead to misinterpreting or underestimating the effects of human disturbance on wildlife. Bejder et al. differentiate the following terms:[248]

> **Habituation:** the relative persistent waning of a response due to repeated stimulation, which is not followed by any kind of reinforcement - a process involving a reduction in response over time as individuals learn that there are neither adverse nor beneficial consequences of the occurrence of the stimulus.
>
> **Sensitization:** the opposite of habituation - increased behavioral responsiveness over time when animals learn that a repeated or ongoing stimulus has significant consequences for the animal.
>
> **Tolerance:** the type or intensity of disturbance that an individual tolerates without responding in a defined way; rather than a process, it is a state (for example, a threshold above which antipredator response occurs.)

Habituation and sensitization are appropriately studied by taking sequential measures of the same individuals over time, whereas tolerance is measured through instantaneous measures of many individuals at one time – for example, groups of elk being subjected to different types and levels of disturbance. Researchers often assume that tolerance equals habituation, when this may not in fact be the case. Bejder et al. suggest there are at least four potential explanatory mechanisms for habituation-like responses:[248]

1. Learning – some individuals become more tolerant (habituated) or less tolerant (sensitized) to disturbance through process of behavioral adaptation. This is the only mechanism that leads to true habituation or sensitization.
2. Displacement – individuals move out of an area. Displacement can be mistaken for habitation when most individuals move out of an area but the most bold or tolerant individuals remain behind. This could skew results towards tolerant individuals, which may not be advantageous to people or wildlife (for example, when a bolder cougar remains at a site whereas more human-averse cougar move away).
3. Physiology – for example, repeated or prolonged exposure to a stimulus such as loud noise impairs function such as hearing.
4. Ecology – there is some other variable in the habitat that prevents the individual from responding to the stimulus but physiological stress responses continue. For example, there may be no suitable adjacent habitat therefore an animal remains at the site, or wintering animals may prioritize obtaining food over moving away from human disturbance.

Habituation does not mean animals are unaffected by disturbance. What might appear to be habituation may actually be a choice of "lesser evils," such as an animal's decision to forage rather than taking flight during winter because the energetic cost of fleeing could mean starvation, or animals using disturbed habitats to avoid predators (next section). Many studies suggested some degree of habituation in various species depending on the circumstances,[67, 124, 248, 256, 270, 285, 295-298] although Bedjer et al. posit that some studies may be documenting tolerance rather than true habituation, and that conclusions about habituation or sensitization derived from behavioral responses can only be inferred, not proven.[248]

Less fit animals may be less likely to flee from human disturbance than healthy individuals. An English bird study demonstrates how easy it would be to mistake habituation for what is in fact an ecological response to changing conditions. Researchers conducted a 3-year winter disturbance study on oystercatchers foraging over mussel beds to assess whether the birds' response to human disturbance changed as food resources became more scarce.[299] Undisturbed controls were included in the study. As winter progressed, oystercatchers required more energy to endure harsh conditions while food became increasingly scarce. They had to spend more time feeding to survive, and their behavioral response to human disturbance steadily decreased in order to meet the most immediate need. The risk of starvation became more significant than the risk of predation.

The control group's behavioral response to human disturbance remained constant. Without controls in this study, the scientists could have assumed they were observing habituation, but in fact it was a strategy to survive. In the authors' words,

> "These results have implications for studies which assume that a larger behavioural response means that a species is more vulnerable to disturbance. The opposite may be true. To more fully understand the effect of disturbance, studies should measure both behavioural responses and the ease with which animals are meeting their requirements. Conservation effort should be directed towards species which need to spend a high proportion of their time feeding, but still have a large response to disturbance."

Scottish investigators also found that an animal's fitness can mediate antipredator response.[251] The researchers explored the link between a shorebird species' behavioral responses and individual fitness without directly measuring physiological attributes such as stress hormones. Using experimental and control treatments, birds at one site were fed mealworms every day for three days. On the fourth day the researchers recorded FID, flight length and alert distance for control and treatment birds. Birds whose condition was enhanced (fed mealworms) showed stronger anti-predator responses than unfed birds. Rather than habituating, the most vulnerable birds were more at risk of predation because their top priority was feeding rather than avoiding predation. The authors stated, "These findings suggest that our current management of the impact of human disturbance may be based on inaccurate assessments of vulnerability."

The predator shelter effect. In addition to differences in individual fitness, another phenomenon resembles but is not true habituation. The so-called "predator shelter effect" occurs when prey species spatially redistribute themselves to avoid predators.[172, 288, 300-305] For example, animals may seasonally avoid areas open to hunting by moving into areas with higher human disturbance but lower risk of predation, such as protected natural areas or suburban neighborhoods. This effect is especially well documented for elk (Section 7.4). The predator shelter effect does not represent true habituation; rather, it is a response to avoid the greater threat of being killed by hunters. In fact, elk in such circumstances tend to shift their activities more towards night-time, probably to reduce interactions with humans (Section 6.6).[173, 303]

The studies cited in this chapter suggest that there are species-specific responses to disturbance, including whether animals may become habituated or sensitized. True habituation is not easily measured, and what appears to be habituation is often not the case. Animals can experience significant stress without fleeing; when this is misconstrued as habituation, disturbance effects on wildlife are underestimated. Animals that do not appear to avoid recreational disturbance may still be experiencing stress or are unable to leave a site for some reason. Apparent habituation is not a true measure of whether people are disturbing wildlife.

6.3 SIZE MATTERS: INDIVIDUALS AND HERDS

Animal size. Larger sized animals tend to be more sensitive to human disturbance, although there is species-specific variability[247, 256]. We found one exception in a study of bison, mule deer and pronghorn,[113] but these are all large mammals therefore species-specific traits may have been more important than size. Numerous studies document larger alert and flight initiation distances (FIDs), and sometimes avoidance behavior in animals with higher body mass including birds[123, 247, 306, 307] and carnivores[168, 169] One likely reason is visibility, which correlates with detection distance: larger animals can see predators from further away than smaller animals[308], and animals that are more visible (such as larger animals or those in open habitats) are more nervous around potential threats because they perceive more risk.[306, 308, 309]

Stankowich and Blumstein's literature review and meta-analysis on the topic of animal size revealed that larger animals typically have longer FIDs, indicating increased sensitivity to potential predators.[247] The review also found that animals in good condition had longer FIDs than those in poor condition, which is logical given that the decision to take flight is a cost/benefit decision and fleeing is energetically expensive. Blumstein et al. reviewed studies on bird detection distance as a key factor explaining variability between species' response to human disturbance.[308] Larger birds tended to detect the presence of humans at a longer distance compared to smaller birds. Other bird studies on multiple continents support these results.[123, 250, 254, 256, 262, 306, 309, 310]

> Larger animals and larger groups of animals tend to be more disturbance-sensitive.

Flock or herd size. In addition to body size, studies on numerous wildlife species indicate that larger groups of terrestrial animals tend to be more sensitive to human disturbance.[113, 247, 254, 262, 270, 311-313] A major review and study of fear and risk assessment in animals found that in general, all taxa except fish tend to respond more quickly (larger FID) in groups than as one or a few individuals, although there were a few exceptions.[247]

Animals may also perceive a reduced risk of predation in a larger group ("safety in numbers").[249, 298, 313] Individual animals in a group do not need to be as vigilant because one or a few animals can serve as lookouts, leaving the remainder free to forage.[163, 268] However, if the lookout shows alarm it can cause the entire flock or herd to move away from the disturbance. This larger group sensitivity may also have to do with visibility, as other studies have shown that more visible animals tend to be more wary.[254, 306, 308, 309]

The tendency towards longer FIDs in larger groups may depend in part on group composition, particularly due to reproductive status. In a 5-year Yellowstone study examining elk vigilance due to natural predators, researchers found that adult males were less vigilant and fed more than females in any herd size. Female elk without young were more vigilant in small compared to large sized herds. However, females with young were more vigilant than other elk in any sized herd.[314] Herds with many mother elk were more vigilant than herds with few or no mothers. Section 6.6 includes additional information about this topic.

6.4 SPEED AND DIRECTNESS OF APPROACH

Whether an animal can see an approaching predator and has sufficient time to flee influence an animal's response to an approaching threat.[315] Consequently both predator and prey size, speed, and directness of approach modify antipredator responses.[247, 249] Humans are large compared to most other potential predators therefore a strong antipredator response can be expected based simply on size.

Faster approaches generally elicit a stronger antipredator response and cause longer flight distances compared to slower approaches.[6, 247, 249, 254, 316-318] In particular, joggers and mountain bikers can approach wildlife quickly and quietly and are sometimes more disturbing to wildlife than hikers,[297, 316, 317] although we did find one exception in the case of Bald Eagles in Idaho.[319] For example, slow-moving walkers such as photographers and wildlife watchers tend to actively seek out and approach wildlife, search for rare or unusual species, and stay in the vicinity for longer than typical hikers, therefore these activities may be particularly threatening to wildlife.[6, 97, 320]

Stankowich and Blumstein conducted a meta-analysis of 61 research papers that analyzed antipredator response in various wildlife species.[247] Results indicated that reptiles, even more than other animals, respond strongly to the speed of a potential predator's approach. Non-mammalian species showed a 60 percent increase in perceived risk when predators approached more quickly. The researchers did not have sufficient mammalian data for significant findings, although a later study by the same primary author found that deer in northern California showed longer FIDs when approached more quickly by a human.[318]

> Animals tend to flee more readily when approached quickly or directly.

Multiple studies indicate that prey species show more fear (longer alert distance and FID) when a predator directly approaches them compared to a trajectory that appears to pass them by.[247, 275, 318, 321] However, researchers evaluating potential buffer distances in Argentina grasslands studied five bird species' alert distance and FID responses to direct versus tangential approaches.[315] Four out of five species showed greater alert distance and FID with tangential rather than direct approaches. We suggest the possibility that grassland birds react differently to predators compared to forest-dwelling birds due to their visibility upon flushing in open structure habitats; in some cases it may be safer to hide than to flush. Miller et al.'s study in Colorado grasslands supports this theory; dogs consistently elicited the strongest anti-predator response (Appendix 1),[287] yet grassland birds had shorter FIDs when approached by a human with a dog or a dog alone, compared to a human without a dog.[322] The next section addresses relationships between vegetation cover and antipredator response in more detail.

6.5 HABITAT STRUCTURE AND NEST OR PERCH HEIGHT

Vegetation cover is known to be important to many wildlife species' reactions to human disturbance. Animals tend to be less responsive to disturbance in tall or complex habitat or in other situations where predators are less likely to see them.[25, 176, 268, 323] Mourning Dove nest success in Iowa depended in part on vegetation cover and nest concealment.[324] In Madrid, Spain birds that spent time foraging on the ground showed a higher disturbance tolerance when good cover was nearby.[250] In Utah, ground- and shrub-nesting and ground-foraging birds were more likely to be found in undisturbed areas than in campgrounds, attributed to differences in shrub and sapling density, litter depth, and amount of dead woody vegetation occurring between the two habitats.[323] In Finland, researchers found a strong decline in ground nesting bird abundance near trails compared to undisturbed areas, but no commensurate reductions in cavity or tree canopy nesters.[325] The best predictive variables for ground-dwelling birds related to number of recreationists, area of tourism infrastructure, and habitat characteristics. In Sri Lanka, bird species that used the understory were more susceptible to disturbance from hikers on a nature trail than away from trails.[178] These studies indicate that good vegetative cover can reduce birds' antipredator response in many situations. Perch height also affects bird antipredator response; birds perched higher up in trees tend to wait longer to flush.[123, 321, 326, 327]

Cervids show similar responses to enhanced cover. Deer and elk tend to wait longer to react to disturbance when forest or shrub habitat is nearby, presumably because they can quickly move to the safety of cover.[25, 268] In Scotland, red deer (elk are called red deer in Europe) during recreational seasons were more vigilant in meadows and shrublands compared to woodlands; most of the vigilant animals in disturbed heather and woodland habitats and in less disturbed habitats were standing, but in disturbed grasslands the main posture was lying down.[302] The researchers suggested that vigilant animals in grasslands lay down to be less conspicuous, while maintaining the ability to scan their surroundings. A review and meta-analysis indicated that elk that are further from cover have longer FIDs.[247] A study in central China found that ungulates' habitat use near trails depended on good vegetative cover.[176] These findings make sense, because vigilance and antipredator response are closely linked to perceived risk, and risk of predation is lower when animals can hide.

6.6 SEASON, REPRODUCTIVE STATUS AND TIME OF DAY

Reproductive status and season. Across multiple mammal species, research shows that pregnant females or those with young are especially sensitive to human disturbance.[124, 314, 328-330] For example, studies document stronger antipredator responses in pregnant elk or herds with young elk.[25, 331] Ciuti et al. studied mouflon, a type of wild sheep in Sardinia; groups with lambs fled at greater distances than male groups, and female groups without lambs.[329] In Canada, bison and herds with young were displaced further by human disturbance than herds without young.[328]

Birds may also be especially vulnerable to human disturbance during nesting season (see also Section 7.3). Endangered Belding's Savannah Sparrow became alert earlier and moved farther during the non-breeding season, possibly because they were non-territorial and in larger flocks in the non-breeding season.[332] Nestlings are unable to flee therefore for songbirds, protecting parental investment may outweigh the flight response up to a point. Female Ferruginous Hawks, a ground-nesting species, defended nests substantially more vigorously than male birds even though both parents participate in nesting.[333]

Some studies show seasonal differences in wildlife response to human disturbance, likely also pertaining to reproduction status. A study on desert bighorn sheep found that females fled further from human disturbance during spring lambing season, and males fled further during fall rut.[124] In the northeastern U.S., heron rookeries with a 50-meter buffer zone to prevent daily tourist visits showed no short-term reproductive losses.[8] However, people entering rookeries led to nest mortality rates of 15-28 percent depending on the heron species. This study and one on European pine marten suggest that in some cases, the increased number of recreationists with the coming of spring may be a confounding variable with actual reproductive status.[274] Nonetheless, there is ample evidence that pregnant animals or those with young – especially mammals – are particularly sensitive to human disturbance.

> Pregnant animals and those with young are especially nervous around human disturbance.

Time of day. Some animals alter the timing of movement and foraging to reduce conflicts with recreationists; this is particularly well documented in mammals.[173, 209, 334] In the San Francisco Bay area, certain mammal species altered the timing of their activities in areas where non-motorized recreation was allowed.[209, 335] Coyotes became more active at night and less active during the day; gray foxes were more active just before dawn and less active after dusk; and mule deer shifted peak activities towards earlier pre-dawn and later post-dusk periods, when recreationists were generally absent. Researchers in Colorado found that bull elk used residential areas more at night, when human encounters were at a minimum (Section 6.1).[173] Long-term data for eight species using wildlife over- and underpasses at Banff National Park, Canada indicated that four mammal species – black bear, deer, elk and wolves – shifted the time of day they used shared pedestrian/wildlife crossings in response to increased human activities.[336] In another study wolves in British Columbia shifted their activities to night in response to higher levels of recreational disturbance[172], and a study in southern France found similar results for wild sheep.[303]

> Some wildlife species shift to night-time activities to avoid human disturbance.

Changes in the timing of habitat use in response to disturbance is less well documented in birds, likely because they would be difficult to see at night and are less nocturnal than mammals. Mammals are generally larger and can be affixed with a GPS unit with relative ease compared to birds. However, we did find several relevant studies for shorebirds and waterbirds. Shorebirds in Florida fed more at night in response to human disturbance,[275] and waterfowl are known to forage more at night when under heavy hunting pressure.[337, 338] In India, storks that normally foraged during the day altered their behavior to night-time foraging due to the presence of fisherman.[339] Another Indian study showed similar results for pelicans.[340]

Human disturbance can alter foraging and other behavior for many species. Shifting to night-time foraging helps these species avoid risk of predation and can help make up for foraging time lost due to disturbance. It is unknown whether this type of compensatory behavior affects the fitness of these wildlife species. Night time can serve as a refuge for wildlife and may be the only time animals can avoid human activity, but human disturbance is not always limited to daylight hours. For example, mountain bikers sometimes ride at night in Portland's Forest Park.[341]

6.7 NOISE AND LIGHT POLLUTION

Noise pollution. Human-created noise can alter wildlife behavior including habitat selection, foraging patterns, and overall energy budgets.[331, 342-345] We found numerous studies documenting the effects of road noise on wildlife, including research showing that some animals change the pitch of their songs near loud roadways.[268, 342, 343, 346-354] Shannon et al.'s subject review documented reduced wildlife abundance in noisy habitats, increased vigilance, altered foraging patterns, impacts on individual fitness, and changes in the structure of wildlife communities.[345] Francis et al. reviewed the literature relating to how human-altered "soundscapes" influence both wildlife and people.[355] The review found that anthropogenic noise can alter behavior, physiology, reproductive success and distributions of wildlife. As a side note, the authors also found that natural soundscapes provide important, positive psychological benefits to people – for example, birdsong can facilitate more rapid stress recovery rates, and natural sounds can improve cognitive function.

We found several studies investigating noise effects directly due to non-motorized recreational users. The studies summarized below found that recreationists engaged in conversation elicit a stronger antipredator response compared to silent recreationists, and higher volume conversations tend to cause stronger wildlife responses.

Swaddle et al. proposed a research framework for investigating evolutionary responses to noise and light pollution.[356]

Researchers tested the response of a rain forest bird community to noise by playing a recorded conversation while conducting bird surveys.[357] Conversation noise of 50 decibels (approximately library speaking volume) caused 35 percent fewer bird detections and reduced detected species richness by 33 percent. They found similar but slightly stronger results at 60 decibel conversation noise, approximately the volume of an excited child. Bird vocalizations important to territory defense, breeding behavior and predator detection showed a 37 percent decline. Birds showed similar strong reactions both near an ecotourist lodge and in an intact reserve, suggesting a lack of habituation. Insectivorous birds were most sensitive. A New Zealand study also found that bird species with animal-based diets were more sensitive to noise than birds with plant-based diets.[358]

Noise has the potential to impair antipredator responses, potentially leading to increased wildlife mortality. A study conducted in California and Wyoming found that anthropogenic noise reduced the distance at which ground-foraging birds and one flycatcher (but not species within the tree canopy) flushed, suggesting that such noise either distracts these species from detecting potential threats as easily, noise masked the approach of the observer, or both.[359]

Other studies document the effects of anthropogenic noise on wildlife. Variation in feeding behavior for five species of waterbirds at a Florida refuge was largely explained by whether people were present, the number of people present, and the amount of noise made by the people.[278] In the Amazon, researchers approached Hoatzins (an at-risk bird species) by canoe playing recorded human conversations at different volumes.[360] The distance at which Hoatzins became agitated, as well as their FID correlated positively with noise volume. The birds apparently began to habituate to silent approaches by the end of the 10-week study period, but recorded conversations continued to cause the same antipredator responses over the full study period. The authors suggested that remaining silent would provide the most wildlife viewing opportunities. Another Hoatzin study found high stress responses and reduced chick survival in response to ecotourism.[236] These studies illustrate the species-specific nature of responses to different types of disturbance. Although reptile research is sparse, lizards have a particularly keen sense of hearing,[361] and may be easily disturbed by noise from recreationists.

> Even low levels of conversational noise can disturb wildlife.

We found two studies documenting negative effects of conversational noise on mammals. An Australian study testing wildlife response to various human disturbances found that people talking significantly lengthened FID of two kangaroo species compared to human approaches without conversation.[330] In an Arizona cave, bats in a *Myotis* maternity colony engaged in more takeoffs, landings and showed increased activity levels in response to tour groups engaged in conversation compared to silent tourists.[362]

A few studies show neutral or positive effects for certain species near busy roads.[350, 363] For example, elk in Grand Teton National Park did not react strongly to road noise, but they did react to pedestrians.[331] In a New Mexico study, researchers compared artificial nest depredation in natural gas fields with high levels of compressor noise with controls (gas fields with no compressors).[344] Nest depredation decreased with increasing noise; Western Scrub Jays depredated nests in controls, but not in noisy gas fields. However, there was insufficient information to determine whether jays were avoiding noisy areas, or whether some other factor was involved.

Although it can be difficult to tease out differential effects from noise and human presence, the studies summarized here suggest that simple conversational noise in natural areas can reduce habitat quality and affect productivity for some wildlife species, and can also reduce visitors' wildlife viewing opportunities. We surmise that the magnitude of the effect depends on the number of users; for example, on busy nature trails the daytime conversational noise might be fairly constant and the effect nearly continuous. This could cause more noise-sensitive species to avoid near-trail habitat completely – a displacement effect. In addition, additional road traffic or new roads associated with recreational access may adversely affect some wildlife species.

Artificial light pollution. Some trails have artificial lighting for night-time visibility or safety. Studies demonstrate that artificial light can affect wildlife behavior.[364] Nocturnal animals accustomed to navigating in darkness can become disoriented by artificial light; night lighting can temporarily blind and disorient certain species such as some frogs, nocturnal insects and migrating birds, making them vulnerable to predation or in the case of birds, window strikes.[364-366] Artificial night light can induce diurnal birds such as the American Robin to sing territorially at night or earlier in the morning, wasting valuable energy.[365, 367] Artificial lights on turbines, communication towers, power lines and buildings near trails can interfere with songbird migration and cause substantial wildlife mortality.[365, 368-370]

Nocturnal animals are most likely to show effects from ecological light pollution, and studies have shown effects on bat behavior including foraging, commuting, emergence, roosting and hibernation.[365, 371-374] For example, a researcher studied bats along a gradient of light intensity along an Ohio bicycle trail.[373] Three bat species occurred in lit areas and tended to be positively associated with the amount of light, but there appeared to be a light threshold beyond which bats did not use the trail area. A European study of house-dwelling bats found that juveniles were smaller in night-lit houses than in those that were not lit, suggesting that artificial light reduced these animals' fitness.[372] In Ontario, Canada researchers tested the effects of artificial light on two bat species using 11 lit buildings, with two unlit buildings – one for each species – as controls.[374] Compared to the initial population levels, bat populations in the experimental colonies decreased by 41 to 96 percent, whereas populations in the control buildings increased by 57 and 97 percent. These studies indicate that artificial lighting can harm bats.

> Nocturnal wildlife species such as bats are especially vulnerable to effects from artificial light.

Artificial light attracts some species and repels others, with implications for habitat connectivity. In a study conducted in Wilsonville, Oregon researchers installed artificial lights to explore animal usage of a bridge under-road crossing structure.[375] Different levels of light and an unlit control were established. Sand tracks recorded 23 wildlife species using the structures, of which 9 had sufficient data for analysis. Columbian black-tailed deer, deer mice, and Virginia opossums used the unlit bridge section less often when adjacent sections were lit. The authors concluded that artificial light may be interrupting connectivity for these species. Some large carnivores have also been shown to avoid artificial light.[210, 376]

Artificial light can alter feeding habitats for some species. Insects and other arthropods may be attracted or repelled by light, which can attract bats.[377, 378] Certain diurnal bird and reptile species will also forage under artificial light, potentially benefiting those species but not their prey.[11, 379] In a study of six wading bird species in Portugal, researchers found that the majority of species shifted more to night-time foraging in areas with artificial street lights.[379] A Florida study found that mice used fewer habitat patches and harvested fewer seeds near artificial light.[380] In New York, researchers discovered numerous migratory songbird species foraging around artificial stadium lights at night.[381] The consequences of such behavioral shifts are unknown.

If artificial lighting along trails is deemed necessary, wildlife effects can be partially mitigated, for example by following best practices that meet the Illuminating Engineering Society of North America's standards.[382] The Audubon Society of Portland produced a useful guide for bird-friendly building design.[383] Directing light downward or away from habitat, reducing glare and using lower wattage flat lens fixtures along trails reduces light pollution. Some urban areas are making strides toward reducing night lighting, such as the "Lights Out Portland [Oregon]" campaign.[384] This approach has the added benefit of reducing cost and energy use. To reduce wildlife effects from recreation, ideas could include limiting trail access from dusk to dawn or employing lighting standards or restrictions.

CHAPTER 6 SUMMARY – Overview of effects on wildlife

Disturbance and the antipredator response

- Wildlife species respond to human disturbance physiologically and by freezing, hiding or moving away.
- Higher disturbance levels generally cause stronger effects (although note habituation, below).
- Wildlife response to disturbance may vary substantially between species.
- Studies do not always reveal the strongest impacts because the most disturbance-sensitive species are naturally rare in number or are already gone from disturbed sites.

Habituation, sensitization and tolerance

- Some, but not all, species may become less reactive to human disturbance over time (habituation). On the other hand, some species react to continuing disturbance by becoming more sensitized.
- Some habituation-like responses are actually predator avoidance or occur because the need for resources such as food during winter outweighs the antipredator response.
- Animals have personalities; gregarious and adventurous individuals may habituate more readily, which is not always to their advantage.
- Wildlife does not appear to habituate to the presence of dogs; impacts linger after dogs are gone because the scent of dogs repels wildlife (see Appendix 1).

Size matters: Individuals and herds

- Larger animals and larger flocks/herds tend to flee more readily, possibly because they are more visible.

Speed and directness of approach

- Whether an animal is visible, can see an approaching predator and has sufficient time to flee influence wildlife response to an approaching threat.
- Faster and more direct approaches generally elicit stronger antipredator responses.
- Prey species show more fear when directly approached by predators or people.
- Animals know when a visitor is looking directly at them and will show increased antipredator response.

Habitat structure and perch height

- Animals in open areas or without nearby cover are more reactive to disturbance. If they can't see you or they think you can't see them, they tend to hide rather than flee.
- Grassland songbirds may be an exception and tend to wait until the last second to flush.
- Birds that nest or perch higher in trees react less to disturbance than those closer to the ground.

Season, reproductive status and time of day

- Animals may be displaced by space or time (e.g., switching to night-time foraging).
- Animals that are pregnant or have young, and groups with same, tend to flee more readily and are particularly vulnerable to disturbance.

Noise and ecological light pollution

- Conversational noise along trails can be very disturbing to wildlife.
- Artificial light can repel (or attract) wildlife, disrupt bat colonies and interfere with animals' navigation.

7. EFFECTS ON WILDLIFE BY SPECIES GROUP

7.1 SPECIES GROUP: INVERTEBRATES

We located few articles relating to the effects of recreation on invertebrate communities, although several issues related to trail use likely affect invertebrates (e.g., soil compaction, erosion, trampling and vegetation loss, artificial light). This group has not been widely studied in recreation ecology, and none of the studies we found differentiated recreational user group effects. In addition to invertebrates being intrinsically important as unique species, they are foundational food web components in many ecosystems.

Trails may influence invertebrates by reducing the amount of available habitat, particularly shrub cover.[103, 125] Hagar studied the relationship between bird abundance, availability of arthropod prey, and composition of understory vegetation in western Oregon forests.[385] Tall deciduous shrubs supported high abundances of arthropods – especially butterflies and moths – and aerial arthropods were positively related to deciduous shrub cover. Shrub cover also best explained the abundance and foraging patterns of several insectivorous Neotropical migratory songbirds. Most Neotropical migratory songbirds are insectivorous, and a reduction in shrub habitat near trails would reduce invertebrates and therefore negatively affect some bird species.

We found two studies investigating effects of stream crossings on in-stream invertebrate communities. In Zion National Park in Utah, densities of drifting aquatic invertebrates and organic matter in the water column increased with higher numbers of hikers crossing streams, with an apparent threshold effect around 500 hikers per day after which invertebrates and organic matter available to drift may have been depleted. Invertebrates appeared to readily recolonize affected reaches with no apparent long-term harm[197].

In contrast, a stream study in Yosemite National Park, California examined benthic macroinvertebrates (living in the stream bed and visible with the bare eye) above and immediately below two trail stream fords in spring and fall.[198] Benthic macroinvertebrates are known water quality indicators, unlike invertebrates found in the water column such as those collected in the Yosemite study. Downstream differences were evident below fords, with finer substrate, a thick periphyton layer, and higher pollution-tolerant but lower pollution-sensitive macroinvertebrate taxa. Differences in both spring, before hiking started, and fall suggested long-term effects. Trails were used by hikers and equestrians, thus it was not possible to disentangle user group-specific effects. Such studies suggest that while an occasional stream crossing may not cause widespread and lasting impacts, higher densities of crossings may cause impacts on aquatic invertebrates and water quality.

One study documented potential impacts to invertebrate on beaches. In Australia, trampling caused 5 percent to 55 percent reductions in invertebrate abundance and richness along the lower part of a beach where most of the tourists walked, compared to non-frequented areas.[386] On heavily used beaches this could have important implications for shorebirds, which rely on invertebrates for food, as well as on the invertebrate communities themselves. Although no studies were found, it is feasible that soil compaction associated with trail use would alter below-ground invertebrate communities; this would be an interesting topic of future studies in recreational ecology.

Researchers in California found that use of a natural area preserve by hikers and trail runners led to reduced butterfly diversity and local loss of some native species.[387] In an urban area in Russia, recreational effects changed the species composition, set of dominant species, degree of dominance and ratio between classes of carabid beetles. The heavier the recreation, the more significant was the decrease in beetle species diversity.[277]

A study in Poland compared spider communities on two lake islands, one which was isolated and the other frequently disturbed by tourists.[177] Tourism compacted soils, altered soil fertility and reduced organic matter; these changes led to more homogenous habitat on tourist islands. Species that were segregated on the undisturbed island were intermingled on the tourist island, with unknown consequences. The authors suggested that this "community disassembly" might be an early sign that tourism was having a negative effect on ecosystem functioning.

7.2 SPECIES GROUP: REPTILES AND AMPHIBIANS

We located several reptile and amphibian studies relating to recreation ecology. Although the research is sparse, it appears that reptiles are vulnerable to disturbance, while some trail effects on amphibians may relate more to habitat elements such as logs. Frogs, which are more mobile than salamanders, may be especially sensitive to recreational disturbance as described below.

For salamanders, the effects of trails may have more to do with habitat than disturbance. Researchers in Georgia studied terrestrial salamander distribution in paired plots near and away from trails.[388] Logs cut to create or maintain trails were often laid down alongside the trails, resulting in more logs near compared to away from trails. Salamander abundance increased with log abundance, thus there were more salamanders along trails. An Ohio study showed similar results.[389] However, salamander abundance in North Carolina was significantly lower on old, narrow abandoned logging roads in forests compared with adjacent upslope sites.[390] Salamander abundance was not correlated with invertebrate abundance or richness therefore it was not likely a food issue, but related to habitat alterations including structural simplification similar to the edge effects found adjacent to trails.

These studies illustrate an important point. For some species, maintaining vegetative structural diversity and retaining or adding specific habitat features such as dead wood may substantially reduce negative trail effects for some wildlife species, and could even improve habitat compared to conditions prior to recreational access. The alterations in microclimate associated with edge effects – especially dryer conditions – may pose a problem in some cases, but we located no such studies. One study documented that the internal condition of dead wood (e.g., moisture) is resistant to microclimate changes,[391] thus it is possible that installing sufficient dead wood would help offset this issue.

The studies mentioned above tested salamander abundance alongside versus away from trails, but their methods were not designed to test whether salamanders moved across trails. Trails may create barriers for some reptile and amphibian species. A study in Virginia examined salamander movement adjacent to unpaved hiking trails versus controls located away from trails.[392] The researcher used a fluorescent pigment powder applied to each individual that showed the animal's travel pathway. Salamander use near trails did not differ between gravel and dirt surface trails, but of 49 individuals located along hiking trails, only one salamander crossed a trail.

In a central Spain experimental study, researchers simulated human disturbance (walkers) on frogs using stream banks.[261] The more a given frog was disturbed, the longer it took to recover to pre-disturbance activities. This suggests sensitization, the opposite of habituation. Flight initiation distance did not differ between low and high disturbance levels, although FID was shorter where there was higher vegetative cover, possibly either because (a) the perceived risk of predation was less because they could hide, or (b) the frogs couldn't see the approaching person until he/she was close. Frog abundance was lower in areas closer to recreational areas, suggesting population-level disturbance effects.

Researchers in northern Italy collected data about human disturbance, environmental features such as leaf litter disturbance and tree size, and reptile, amphibian, and bird distribution within 44 wood patches in a large urban park.[44] They found strong species-specific and some wildlife group-specific differences in the response to the same source of disturbance. Reptiles were strongly, negatively associated with the amount of human use and somewhat so with reductions in leaf litter caused by trampling. Amphibian density was unaffected by human disturbance levels, but declined with declining leaf litter. Birds and mammals varied. This study demonstrates the substantial variability in wildlife responses to human disturbance and human-induced habitat changes.

Invasive species may be an issue for some amphibian species. A study in Gresham, Oregon examined amphibian community composition and occurrence patterns in relationship to various local and landscape attributes. Three out of five native amphibian species were negatively correlated with invasive species.[393] Trails are vectors for invasive species, and such introductions could reduce breeding habitat quality for some pond-breeding amphibian species.

We found no studies examining amphibian mortality due to recreational trails although amphibian deaths from road crossings are well documented, as is the success of amphibian undercrossings in reducing mortality.[394-396] This author has observed local seasonal mortalities of Northern red-legged frogs, rough-skinned newts, and garter snakes (*Thamnophis* species) on paved multi-use trails. Wildlife mortality on recreational trails would be a valuable topic for future studies, particularly studies comparing effects of different user groups, amount of use and type of trail.

Two Spanish lizard studies illustrate the importance of research methods in studying the effects of recreation. In the first study, researchers found evidence of habituation-like responses in tourist sites compared to controls, as indicated by shorter FIDs and flight distances.[397] In the second study, researchers found that lizards used the same antipredator escape strategies with tourists compared to other types of disturbance, with similar FIDs.[398] However, lizards in areas with high tourism levels had reduced fitness (more ticks, poorer body condition and dampened immune systems) compared to lizards in areas with fewer tourists. The authors stated that lizard body condition and health should be included in disturbance studies in order to accurately assess the real effects of tourism on lizard populations. Stankowich and Blumstein's review and meta-analysis found that reptiles are especially vulnerable to faster approaches.[247]

Turtles are vulnerable to recreational disturbance. Connecticut researchers monitored 133 wood turtles in two separated populations for 20 years, before and after human recreation (hiking and fishing) was introduced to the watershed.[399] After a 9-year pre-disturbance study period indicating population stability, once the sites were opened to recreation, both populations declined in tandem with the number of recreational permits issued. Mean turtle age increased while juveniles and females decreased; these are indicators of a population in decline. The last turtles were re-captured 1991, and none during the last two years of the study; the two turtle populations were stable prior to disturbance, but disappeared completely within 10 years of opening to recreational use.

A conservation assessment of western pond turtles in Oregon cited recreational disturbance as a key threat to this declining species, especially when basking or during nesting.[400] Although no specific studies were cited the document provided local examples of trails and recreational uses adjacent to aquatic habitats occupied by pond turtles including examples in Eugene and in Fern Ridge, Lookout, and Fall Creek reservoirs. A subsequent guidance document included a goal to "Manage recreation near turtle-use areas to reduce disturbance," including best practices to reduce effects when designing and constructing new recreational trails.[49]

A western pond turtle study in northern California found that recreational disturbance overall reduced basking time along a newly opened trail.[401] Runners, walkers, bicyclists and vehicles (mostly pickup trucks) all caused some basking turtles to flush underwater, but motorized vehicles exerted the strongest influence (2, 5, 6 and 45 percent of turtles flushed, respectively). However, observers were positioned within 20-30 meters of basking turtles, which may have been a compounding variable because non-motorized disturbance was already introduced by the observers. Nevertheless, turtles showed statistically significant differences between each of the four types of recreation use.

Amphibians and reptiles such as turtles are less mobile than other wildlife species. Specific habitat features such as dead wood and rock piles often provide both key habitat (cover, temperature refugia) and connectivity within and between habitat patches – for example, across clear-cuts. Strategically installing such features and ensuring appropriate vegetative cover will probably not prevent, but may help ameliorate the effects of recreation on this sensitive group of animals. Clearings on sunny south-facing slopes provide valuable reptile habitat. Special consideration should be given to avoid trail-induced mortality, such as considering crossing structures when placing trails between wetlands. It is also important to avoid disconnecting pond turtles with their upland nesting habitat. The Partners for Amphibian and Reptile Conservation (PARC) offers guidance to enhance habitat in the Pacific Northwest[402] and other geographic regions in the U.S. and parts of Canada.[9]

> Laying logs beside a trail can help reduce the impacts of recreation on salamanders.

7.3 SPECIES GROUP: BIRDS

Birds are the second-most studied terrestrial wildlife group in the recreation ecology literature, behind mammals.[192] Birds are relatively easy to locate by sight and sound, and the multitude of species provides ample comparative study opportunities. The literature reveals several patterns linked to migratory status and species guilds. We found evidence of differential effects based on both recreational user group and intensity of use.

All bird species will flush if approached too closely, but certain characteristics influence the distance at which birds flush from humans. Blumstein et al. conducted a literature review and meta-analysis involving 150 bird species, examining inter-specific variation in bird responses to human disturbance.[308] Larger birds flushed more readily than smaller birds because they could see people from greater distances (Section 6.3). Fitness[10] related responses such as the amount of food consumed are also important; for example, birds in winter may wait longer to flush because the need for food dampens the antipredator response (Chapter 6).[251]

Detection distance only explains part of birds' FID. In another Blumstein study, FID in birds depended in part on intruder starting distance for 64 of 68 Australian species; the further away a person began to approach a bird ("starting distance"), the earlier the bird flushed.[292] This relationship held true whether it was in open or

[9] http://separc.org/products/#/habitat-guidelines/

[10] Fitness refers to reproductive success and reflects how well an organism is adapted to its environment.

wooded habitats. The author suggested this could be explained by at least two factors: first, that animals detecting an approaching predator from further away may reduce the cost of flight by flying earlier, which could for example avoid the need to escape at maximum velocity. An alternative could be that it would energetically cost more for birds to remain if they needed to be vigilant for a long period. Several other studies also found positive correlations between starting distance and FID or alert distance.[254, 255, 403, 404]

Starting distance may explain some of the variability in FID between studies for the same species (Appendix 3). It could also have implications for wildlife near trails, because trail users may be detectable at least audibly for long distances, creating a longer disturbance period per visitor and therefore a shorter undisturbed period between trail users passing by. It also suggests that some birds may flush before a surveyor arrives to count birds, with less sensitive species or individuals remaining. If this is the case, it is likely that many studies underestimate the effects of recreation on birds and other wildlife.

Fernandez-Juricic et al. conducted a series of urban and disturbance related bird studies in habitat remnants in Spain and the Americas.[123, 250, 279, 280, 315, 405]. In addition to the classic habitat patch size and structural diversity correlations, they found:

- Higher pedestrian traffic reduced breeding bird species richness and abundance in urban parks.
- The amount of pedestrian traffic was the only factor significantly associated with inter-annual changes in species composition.
- Locally, human disturbance constrained the time and space of foraging and breeding opportunities, thus reducing fragment suitability.
- Regionally, high levels of disturbance increased extirpation and decreased colonization probabilities.
- Habitat structure influenced the flush distance of some ground-feeding bird species.
- Larger birds flushed more readily than smaller birds and landed further away from the disturbance.
- Alert distance provided a better, more conservative measure of bird disturbance than FID and may be useful to determining minimum approaching distances (buffers) to conserve birds in urban parks.

These findings are in keeping with many other studies we reviewed here.

Photographers, people with small children, bird watchers and those engaging in loud conversations may be especially detrimental to bird communities because they are unpredictable and generally alarming (Chapter 6).[6, 180, 320, 406, 407] Photographers and wildlife watchers tend to stop, look directly at wildlife and even follow them around, triggering stronger antipredator responses than when people are simply passing by; they also tend to seek out rare species and look for nests. Curious, excited children tend to run around and shout in an unpredictable fashion. These types of issues can be partially mitigated by providing wildlife viewing blinds, education and signage such as "Quiet please – sensitive nesting birds," or if necessary, seasonal trail closures in areas hosting particularly sensitive species such as nesting Bald Eagles or heron rookeries. As many national wildlife refuge visitors have learned to accept, the U.S. Fish and Wildlife Service routinely, seasonally closes portions of trails to protect breeding waterfowl and waterbird populations. The American Birding Association has a "Code of Birding Ethics" that includes best practices such as limiting the use of bird song recordings to attract birds, keeping well back from nests and colonies, and staying on trails.[408]

Although we found many bird studies measuring potential effects for single user groups or hikers versus motor vehicles, boats or aircraft, studies directly comparing the effects of our three user groups are less common.[26, 406] Such studies are difficult because (a) bird communities are complex and contain many species and guilds, (b) sites with more than one type of dedicated single-use trails are rare, and (c) bird surveyors cause disturbance which can confound results. In addition, it is more difficult to affix a GPS unit to birds than to large mammals, bird vocalizations can only be heard within a relatively short radius around the observer, and birds are smaller and less visible than many mammal species. However, birds comprise by far the largest group of terrestrial vertebrate wildlife species and are crucial to maintaining a site's biological diversity.

Generalists versus specialists. Some birds specialize on specific habitats or food resources, whereas others can succeed in a variety of circumstances. Studies show that habitat specialists are reduced, and generalists – which include most species that tend to tolerate or be associated with human use – increased near trails and in fragmented habitats.[193, 205, 357, 409-413]

In France, researchers used long-term Breeding Bird Survey data and associated landscape fragmentation metrics to assess whether habitat specialist bird species were more vulnerable to habitat fragmentation than generalist species.[412] Results fell on a gradient in which specialist bird species, but not generalists, declined with increasing fragmentation. European researchers found similar results for birds along a rural to urban gradient.[413] These large-scale studies support that habitat specialists are especially vulnerable to human disturbance.

This pattern of generalist/specialist species holds true for recreational disturbance as well. In Boulder, Colorado researchers compared near-trail bird communities and controls away from trails in grassland and woodland ecosystems.[410] In both ecosystem types, wildlife species composition differed between trail and control sites, with generalist species more abundant near trails and relatively fewer habitat specialists. This study identified a trail "zone of influence" of about 75 meters from the trail for most species.

> Migratory birds and those that require a specific habitat type may be more vulnerable to recreational disturbance.

Various studies have documented that some species are negatively associated with trails. In Colorado, Miller et al. found that the following species were negatively associated with trails: Vesper Sparrow, Western Meadowlark, Grasshopper Sparrow, Western Wood-pewee, Chipping Sparrow, Pygmy Nuthatch, Mountain Chickadee, Townsend's Solitaire and Solitary Vireo.[410] In Canada, the density of forest birds – especially those that forage or nest on the ground – were significantly reduced near trails.[175] Northern Parulas were more abundant in areas with fewer trails and edges, while other bird species' habitat use was not correlated with trails.[411]

Together these studies suggest that Neotropical migratory birds and habitat specialists such as grassland and oak-associated species tend to avoid trails and are adversely affected by habitat fragmentation. Because these types of species are declining more quickly than generalist species, they warrant special attention when considering trail alignment alternatives.

Altered breeding behavior and reproductive success. Trail use and human disturbance can lead to increased avian nest predation and reduced reproductive success[7, 181, 193, 410, 411, 414-416] In Hocken et al.'s literature review, 36 of 40 papers revealed that human disturbance reduced breeding success.[417] Several shorebird studies observed reduced or absent nesting on disturbed beaches.[8, 181] Numerous songbird studies found reduced nest success or reduced nesting frequency near trails and edges.[211, 212, 325, 410, 416, 418-420]

For example, researchers in Colorado studied the influence of trails on breeding birds in grasslands and forested habitats. Grassland, but not forest, birds nested more frequently near trails. Nest predation was greater near trails in both habitats.[410] A literature review and meta-analysis found that the nest success of many species of ground-nesting birds was reduced by disturbance of people on foot.[416] In Finland, Kangas et al. conducted bird surveys along forested hiking trails and undisturbed controls.[325] Although there was no change in species richness, the relative abundance and community composition did change. Open cup ground nesters were strongly negatively associated with trails, unlike shrub, tree or cavity nesters. Their results demonstrate that relatively low visitor pressure can have negative effects on specific bird guilds.

A study in Europe found differences in behavior and breeding success for a chickadee relative, the Blue Tit.[420] The researchers compared spring birds living in natural woodlands with those living in urban parks, considering whether thermal conditions affected breeding behavior. Nest success was positively associated with warmer temperatures in woodlands, but not in urban parks. In urban parks, lower temperatures and rainy days led to increased nest survival and productivity, apparently because there were fewer park visitors on days with poor weather.

Nest parasitism occurs when bird species such as Brown-headed Cowbirds and certain members of the cuckoo family lay their eggs in another "host" bird's nest, leaving any further parental investment to the host bird. Brown-headed Cowbirds do not even build nests. Cowbird chicks hatch quickly and have a flat spot on their rear ends that assists in pushing host species' eggs and young out of the nest. In addition, cowbird chicks are often much larger than host species' young and require more food. These factors significantly reduce reproductive output for host birds.

Cowbirds frequent habitat edges searching for open-cup nests in which to lay their eggs.[411, 420, 421] Trails create edges, and birds nesting near trails may be especially vulnerable to nest parasitism by Brown-headed Cowbirds. For example, cowbirds were more abundant near roads and trails in a large natural area in Colorado[418] and more abundant close to trails than away from trails in Illinois.[422] However, not all studies link cowbird parasitism with trails or trails use.[410]

Common nest predators such as corvids, raccoons and squirrels are attracted to recreational areas, trails and edge habitats, where they can more easily find nests and consume eggs or nestlings.[174, 245, 414, 422-425] Some nest predators may be attracted to both trails and humans.[425] A local study found that American Crows are more abundant near trails and revealed positive or negative associations with edge habitat for several avian species.[426] Marzluff et al. found that crows in North America tend to be most abundant and are increasing rapidly in urban areas,[427] thus birds nesting in urban and suburban natural areas may be increased at risk of nest depredation.

Common nest predators tend to be more abundant near trails.

Researchers in North Carolina found that mammalian nest predators were most common in edge-dominated forested corridor widths of 200 m or less, and were positively correlated with the number and width of trails.[174] Raccoons in Illinois tended to follow linear landscape features such as fencerows, forest edges and mowed trails during nocturnal foraging.[424] In Colorado, bird but not mammalian predators attacked more artificial nests near trails than away from trails.[414] However, artificial nest studies must be interpreted with caution, because they do not necessarily reflect reality.[428, 429]

The importance of good vegetative cover is elevated for birds nesting near trails. For example, Northern Cardinals tend to do well near humans, but have been shown to alter nest placement near trails. Cardinals in urban forested parks in Ohio did not experience reduced nest success in relation to trails, but nest sites closer to trails were surrounded by more small stems, placed at greater heights and were better concealed compared to nests away from trails.[321] Birds with higher nests were less likely to flush from trail users. Other studies showed similar results for different avian species in disturbed habitats; Burhans and Thompson found that higher-nesting birds' nests were more successful,[411] and in Finland open-cup nesters breeding higher in trees showed reduced disturbance responses compared to ground-nesters.[325]

Human disturbance can influence breeding bird behavior in more subtle ways, such as altering spring birds' singing patterns or aggression towards other bird species.[253, 286, 430] For example, pairs of Mexican Spotted Owls in the Colorado Plateau greatly increased vocalizations with nearby trail users.[286] In another study breeding male Western Bluebirds were more aggressive towards House Wrens and American Goldfinches when humans were present; females were more aggressive only towards House Wrens, which compete for nest cavities.[253] When people were near nest boxes, birds flushed and stayed away from the boxes for up to half an hour.

Habituation. Birds – primarily resident species – exhibit habituation or habituation-like responses.[241, 245, 255, 256, 281, 405] A researcher in England tested flush distance for birds on or low to the ground in suburban versus rural areas.[256] Urban birds allowed surveyors to approach more closely before flushing, and smaller birds allowed closer approach than larger birds. However, some migratory and specialist bird species found in significant numbers in rural areas did not occur in suburban areas, and may not tolerate disturbance well. Møller had similar findings in Europe.[431] Other studies have found an apparent lack of habituation or sensitization for some bird species, particularly in areas of high disturbance.[254, 285, 357] Storch's global review of grouse studies found modest habituation-type responses for some species, but the majority of studies documented negative associations with recreational use and other human disturbance, with some evidence of sensitization.[432]

Some studies simultaneously tested wildlife species' behavioral and physiological responses to disturbance. For example, two corvid species in Europe had fewer parasites but flushed more readily in tourist sites compared to non-tourist sites; it appeared that the physiological tradeoffs favored staying close to disturbance.[245] Although they flushed more readily in tourist areas, they did not fly as far compared to controls. Birds in tourist sites had lower stress hormones; the combination of dampened behavioral and physiological responses suggests true habituation.

Amount of Use. Despite evidence of habituation-like responses for some species, the body of literature we reviewed indicates that many bird species exhibit stronger antipredator responses with increased numbers of trail users or other types of human disturbance in a variety of circumstances.[181, 235, 261, 275, 278-280, 283, 285, 286, 297, 306, 333, 357, 409, 433, 434] This trend has been shown for shorebirds and waterbirds,[181, 275, 276, 283, 285] songbirds,[235, 279, 435] and raptors[286, 333, 409, 433]. In natural areas already open to the public, increasing recreational demand is likely to reduce biological diversity.

For example, in the San Francisco Bay Area the number of shorebirds decreased with increasing trail use.[283] Researchers in Spain found that 16 of 17 forest-dwelling bird species were negatively affected by increasing pedestrian rates in urban parks after accounting for the effects of fragment size and isolation.[279] In Colorado lowland riparian areas scientists studied habitat use by birds along an urban-to-rural gradient.[435] At sites with recreational trails (paved, multi-use), trail use intensity explained 60 percent of the variation in the occurrence of low-foraging species and nearly 90 percent of the variation in habitat use by ground-foraging species. In the Netherlands, eight of 13 bird species near urban areas showed significant negative correlations with increasing recreation intensities.[235] In Sri Lanka, the abundance of birds near trails declined significantly with increasing levels of trail users.[178]

The evidence is strong that increased numbers of trail users alter bird communities, particularly for species moving about on or near the ground. It is important to account for this effect when planning the placement and extent of trails: effects will be stronger in more heavily used sites.

LONG-DISTANCE MIGRATORY BIRDS

Many studies suggest that migratory birds are especially susceptible to habitat fragmentation and disturbance effects.[211, 212, 306, 419, 435-443] Specifically in the U.S., Neotropical migratory songbirds (NMBs) are well documented in this respect.[211, 212, 419, 435, 437, 438, 440, 443-445] Many NMB species need large habitat areas to maintain populations, wider travel corridors and high quality stopover habitat compared to residents or short-distance migrants[212, 439, 443-449] A local study[450] and studies done elsewhere indicate that NMBs are negatively associated with urbanization.[435, 447, 451, 452]

Why are Neotropical migrants more susceptible to human disturbance than many other bird species? Several factors may account for this trend. Most Neotropical migrants are insectivores, migrating north to take advantage of spring arthropod emergence.[212, 453] Many are area-sensitive; large habitats and wider corridors tend to have better three-dimensional habitat structure and more native shrubs than smaller patches and these characteristics are associated with increased insect abundance.[385, 438, 445, 454] Neotropical migrants require high quality habitat in their wintering grounds, migratory stopover habitat and breeding habitat; disruptions to any of those habitats may negatively affect these birds.[455-457] Because they are migratory, NMBs are probably not accustomed to the type of disturbances that may occur routinely within the home ranges of resident bird species.

Migratory birds in other countries, and non-songbird Neotropical migrants, show similar negative trends with disturbance and fragmentation. In India, migratory birds were less tolerant of the presence of people than were resident birds; migrants flushed sooner than residents and were more sensitive to the number of people approaching than residents.[306] Klein et al. found that most resident water bird species (e.g., herons and ducks) at a Florida refuge were less sensitive to disturbance than were migrants, especially early in the season when migrating ducks first arrived.[458]

> Migratory birds throughout the world tend to be more disturbance-sensitive than resident species.

Migration is energy intensive, and human disturbance may reduce time available for feeding, making birds less fit to migrate. A Tennessee researcher found that long-distance migrants, but not resident species, required areas of low disturbance to sufficiently acquire fat stores; she suggested that conservation measures for quality NMB stopover habitat should focus on reducing pedestrian activity.[457]

Several studies documented reduced nest success for Neotropical migrants in fragmented landscapes. Donovan et al. studied four Neotropical migratory songbirds in two Midwestern regions.[211] Nest failure was significantly higher in fragmented forests than in contiguous forests for all four species. Researchers in Colorado found reduced nest success for migratory birds nesting in the urban-rural interface compared to those nesting in more intact forests.[418] In a large-scale study covering nine Midwestern states, biologists found that NMB nest predation and cowbird parasitism increased with increasing forest fragmentation.[459]

7. EFFECTS ON WILDLIFE BY SPECIES GROUP

7.1 SPECIES GROUP: INVERTEBRATES

We located few articles relating to the effects of recreation on invertebrate communities, although several issues related to trail use likely affect invertebrates (e.g., soil compaction, erosion, trampling and vegetation loss, artificial light). This group has not been widely studied in recreation ecology, and none of the studies we found differentiated recreational user group effects. In addition to invertebrates being intrinsically important as unique species, they are foundational food web components in many ecosystems.

Trails may influence invertebrates by reducing the amount of available habitat, particularly shrub cover.[103, 125] Hagar studied the relationship between bird abundance, availability of arthropod prey, and composition of understory vegetation in western Oregon forests.[385] Tall deciduous shrubs supported high abundances of arthropods – especially butterflies and moths – and aerial arthropods were positively related to deciduous shrub cover. Shrub cover also best explained the abundance and foraging patterns of several insectivorous Neotropical migratory songbirds. Most Neotropical migratory songbirds are insectivorous, and a reduction in shrub habitat near trails would reduce invertebrates and therefore negatively affect some bird species.

We found two studies investigating effects of stream crossings on in-stream invertebrate communities. In Zion National Park in Utah, densities of drifting aquatic invertebrates and organic matter in the water column increased with higher numbers of hikers crossing streams, with an apparent threshold effect around 500 hikers per day after which invertebrates and organic matter available to drift may have been depleted. Invertebrates appeared to readily recolonize affected reaches with no apparent long-term harm[197].

In contrast, a stream study in Yosemite National Park, California examined benthic macroinvertebrates (living in the stream bed and visible with the bare eye) above and immediately below two trail stream fords in spring and fall.[198] Benthic macroinvertebrates are known water quality indicators, unlike invertebrates found in the water column such as those collected in the Yosemite study. Downstream differences were evident below fords, with finer substrate, a thick periphyton layer, and higher pollution-tolerant but lower pollution-sensitive macroinvertebrate taxa. Differences in both spring, before hiking started, and fall suggested long-term effects. Trails were used by hikers and equestrians, thus it was not possible to disentangle user group-specific effects. Such studies suggest that while an occasional stream crossing may not cause widespread and lasting impacts, higher densities of crossings may cause impacts on aquatic invertebrates and water quality.

One study documented potential impacts to invertebrate on beaches. In Australia, trampling caused 5 percent to 55 percent reductions in invertebrate abundance and richness along the lower part of a beach where most of the tourists walked, compared to non-frequented areas.[386] On heavily used beaches this could have important implications for shorebirds, which rely on invertebrates for food, as well as on the invertebrate communities themselves. Although no studies were found, it is feasible that soil compaction associated with trail use would alter below-ground invertebrate communities; this would be an interesting topic of future studies in recreational ecology.

Researchers in California found that use of a natural area preserve by hikers and trail runners led to reduced butterfly diversity and local loss of some native species.[387] In an urban area in Russia, recreational effects changed the species composition, set of dominant species, degree of dominance and ratio between classes of carabid beetles. The heavier the recreation, the more significant was the decrease in beetle species diversity.[277]

A study in Poland compared spider communities on two lake islands, one which was isolated and the other frequently disturbed by tourists.[177] Tourism compacted soils, altered soil fertility and reduced organic matter; these changes led to more homogenous habitat on tourist islands. Species that were segregated on the undisturbed island were intermingled on the tourist island, with unknown consequences. The authors suggested that this "community disassembly" might be an early sign that tourism was having a negative effect on ecosystem functioning.

7.2 SPECIES GROUP: REPTILES AND AMPHIBIANS

We located several reptile and amphibian studies relating to recreation ecology. Although the research is sparse, it appears that reptiles are vulnerable to disturbance, while some trail effects on amphibians may relate more to habitat elements such as logs. Frogs, which are more mobile than salamanders, may be especially sensitive to recreational disturbance as described below.

For salamanders, the effects of trails may have more to do with habitat than disturbance. Researchers in Georgia studied terrestrial salamander distribution in paired plots near and away from trails.[388] Logs cut to create or maintain trails were often laid down alongside the trails, resulting in more logs near compared to away from trails. Salamander abundance increased with log abundance, thus there were more salamanders along trails. An Ohio study showed similar results.[389] However, salamander abundance in North Carolina was significantly lower on old, narrow abandoned logging roads in forests compared with adjacent upslope sites.[390] Salamander abundance was not correlated with invertebrate abundance or richness therefore it was not likely a food issue, but related to habitat alterations including structural simplification similar to the edge effects found adjacent to trails.

These studies illustrate an important point. For some species, maintaining vegetative structural diversity and retaining or adding specific habitat features such as dead wood may substantially reduce negative trail effects for some wildlife species, and could even improve habitat compared to conditions prior to recreational access. The alterations in microclimate associated with edge effects – especially dryer conditions – may pose a problem in some cases, but we located no such studies. One study documented that the internal condition of dead wood (e.g., moisture) is resistant to microclimate changes,[391] thus it is possible that installing sufficient dead wood would help offset this issue.

The studies mentioned above tested salamander abundance alongside versus away from trails, but their methods were not designed to test whether salamanders moved across trails. Trails may create barriers for some reptile and amphibian species. A study in Virginia examined salamander movement adjacent to unpaved hiking trails versus controls located away from trails.[392] The researcher used a fluorescent pigment powder applied to each individual that showed the animal's travel pathway. Salamander use near trails did not differ between gravel and dirt surface trails, but of 49 individuals located along hiking trails, only one salamander crossed a trail.

In a central Spain experimental study, researchers simulated human disturbance (walkers) on frogs using stream banks.[261] The more a given frog was disturbed, the longer it took to recover to pre-disturbance activities. This suggests sensitization, the opposite of habituation. Flight initiation distance did not differ between low and high disturbance levels, although FID was shorter where there was higher vegetative cover, possibly either because (a) the perceived risk of predation was less because they could hide, or (b) the frogs couldn't see the approaching person until he/she was close. Frog abundance was lower in areas closer to recreational areas, suggesting population-level disturbance effects.

Researchers in northern Italy collected data about human disturbance, environmental features such as leaf litter disturbance and tree size, and reptile, amphibian, and bird distribution within 44 wood patches in a large urban park.[44] They found strong species-specific and some wildlife group-specific differences in the response to the same source of disturbance. Reptiles were strongly, negatively associated with the amount of human use and somewhat so with reductions in leaf litter caused by trampling. Amphibian density was unaffected by human disturbance levels, but declined with declining leaf litter. Birds and mammals varied. This study demonstrates the substantial variability in wildlife responses to human disturbance and human-induced habitat changes.

Invasive species may be an issue for some amphibian species. A study in Gresham, Oregon examined amphibian community composition and occurrence patterns in relationship to various local and landscape attributes. Three out of five native amphibian species were negatively correlated with invasive species.[393] Trails are vectors for invasive species, and such introductions could reduce breeding habitat quality for some pond-breeding amphibian species.

We found no studies examining amphibian mortality due to recreational trails although amphibian deaths from road crossings are well documented, as is the success of amphibian undercrossings in reducing mortality.[394-396] This author has observed local seasonal mortalities of Northern red-legged frogs, rough-skinned newts, and garter snakes (*Thamnophis* species) on paved multi-use trails. Wildlife mortality on recreational trails would be a valuable topic for future studies, particularly studies comparing effects of different user groups, amount of use and type of trail.

Two Spanish lizard studies illustrate the importance of research methods in studying the effects of recreation. In the first study, researchers found evidence of habituation-like responses in tourist sites compared to controls, as indicated by shorter FIDs and flight distances.[397] In the second study, researchers found that lizards used the same antipredator escape strategies with tourists compared to other types of disturbance, with similar FIDs.[398] However, lizards in areas with high tourism levels had reduced fitness (more ticks, poorer body condition and dampened immune systems) compared to lizards in areas with fewer tourists. The authors stated that lizard body condition and health should be included in disturbance studies in order to accurately assess the real effects of tourism on lizard populations. Stankowich and Blumstein's review and meta-analysis found that reptiles are especially vulnerable to faster approaches.[247]

Turtles are vulnerable to recreational disturbance. Connecticut researchers monitored 133 wood turtles in two separated populations for 20 years, before and after human recreation (hiking and fishing) was introduced to the watershed.[399] After a 9-year pre-disturbance study period indicating population stability, once the sites were opened to recreation, both populations declined in tandem with the number of recreational permits issued. Mean turtle age increased while juveniles and females decreased; these are indicators of a population in decline. The last turtles were re-captured 1991, and none during the last two years of the study; the two turtle populations were stable prior to disturbance, but disappeared completely within 10 years of opening to recreational use.

A conservation assessment of western pond turtles in Oregon cited recreational disturbance as a key threat to this declining species, especially when basking or during nesting.[400] Although no specific studies were cited the document provided local examples of trails and recreational uses adjacent to aquatic habitats occupied by pond turtles including examples in Eugene and in Fern Ridge, Lookout, and Fall Creek reservoirs. A subsequent guidance document included a goal to "Manage recreation near turtle-use areas to reduce disturbance," including best practices to reduce effects when designing and constructing new recreational trails.[49]

A western pond turtle study in northern California found that recreational disturbance overall reduced basking time along a newly opened trail.[401] Runners, walkers, bicyclists and vehicles (mostly pickup trucks) all caused some basking turtles to flush underwater, but motorized vehicles exerted the strongest influence (2, 5, 6 and 45 percent of turtles flushed, respectively). However, observers were positioned within 20-30 meters of basking turtles, which may have been a compounding variable because non-motorized disturbance was already introduced by the observers. Nevertheless, turtles showed statistically significant differences between each of the four types of recreation use.

Amphibians and reptiles such as turtles are less mobile than other wildlife species. Specific habitat features such as dead wood and rock piles often provide both key habitat (cover, temperature refugia) and connectivity within and between habitat patches – for example, across clear-cuts. Strategically installing such features and ensuring appropriate vegetative cover will probably not prevent, but may help ameliorate the effects of recreation on this sensitive group of animals. Clearings on sunny south-facing slopes provide valuable reptile habitat. Special consideration should be given to avoid trail-induced mortality, such as considering crossing structures when placing trails between wetlands. It is also important to avoid disconnecting pond turtles with their upland nesting habitat. The Partners for Amphibian and Reptile Conservation (PARC) offers guidance to enhance habitat in the Pacific Northwest[402] and other geographic regions in the U.S. and parts of Canada.[9]

> Laying logs beside a trail can help reduce the impacts of recreation on salamanders.

7.3 SPECIES GROUP: BIRDS

Birds are the second-most studied terrestrial wildlife group in the recreation ecology literature, behind mammals.[192] Birds are relatively easy to locate by sight and sound, and the multitude of species provides ample comparative study opportunities. The literature reveals several patterns linked to migratory status and species guilds. We found evidence of differential effects based on both recreational user group and intensity of use.

All bird species will flush if approached too closely, but certain characteristics influence the distance at which birds flush from humans. Blumstein et al. conducted a literature review and meta-analysis involving 150 bird species, examining inter-specific variation in bird responses to human disturbance.[308] Larger birds flushed more readily than smaller birds because they could see people from greater distances (Section 6.3). Fitness[10] related responses such as the amount of food consumed are also important; for example, birds in winter may wait longer to flush because the need for food dampens the antipredator response (Chapter 6).[251]

Detection distance only explains part of birds' FID. In another Blumstein study, FID in birds depended in part on intruder starting distance for 64 of 68 Australian species; the further away a person began to approach a bird ("starting distance"), the earlier the bird flushed.[292] This relationship held true whether it was in open or

[9] http://separc.org/products/#/habitat-guidelines/

[10] Fitness refers to reproductive success and reflects how well an organism is adapted to its environment.

wooded habitats. The author suggested this could be explained by at least two factors: first, that animals detecting an approaching predator from further away may reduce the cost of flight by flying earlier, which could for example avoid the need to escape at maximum velocity. An alternative could be that it would energetically cost more for birds to remain if they needed to be vigilant for a long period. Several other studies also found positive correlations between starting distance and FID or alert distance.[254, 255, 403, 404]

Starting distance may explain some of the variability in FID between studies for the same species (Appendix 3). It could also have implications for wildlife near trails, because trail users may be detectable at least audibly for long distances, creating a longer disturbance period per visitor and therefore a shorter undisturbed period between trail users passing by. It also suggests that some birds may flush before a surveyor arrives to count birds, with less sensitive species or individuals remaining. If this is the case, it is likely that many studies underestimate the effects of recreation on birds and other wildlife.

Fernandez-Juricic et al. conducted a series of urban and disturbance related bird studies in habitat remnants in Spain and the Americas.[123, 250, 279, 280, 315, 405]. In addition to the classic habitat patch size and structural diversity correlations, they found:

- Higher pedestrian traffic reduced breeding bird species richness and abundance in urban parks.
- The amount of pedestrian traffic was the only factor significantly associated with inter-annual changes in species composition.
- Locally, human disturbance constrained the time and space of foraging and breeding opportunities, thus reducing fragment suitability.
- Regionally, high levels of disturbance increased extirpation and decreased colonization probabilities.
- Habitat structure influenced the flush distance of some ground-feeding bird species.
- Larger birds flushed more readily than smaller birds and landed further away from the disturbance.
- Alert distance provided a better, more conservative measure of bird disturbance than FID and may be useful to determining minimum approaching distances (buffers) to conserve birds in urban parks.

These findings are in keeping with many other studies we reviewed here.

Photographers, people with small children, bird watchers and those engaging in loud conversations may be especially detrimental to bird communities because they are unpredictable and generally alarming (Chapter 6).[6, 180, 320, 406, 407] Photographers and wildlife watchers tend to stop, look directly at wildlife and even follow them around, triggering stronger antipredator responses than when people are simply passing by; they also tend to seek out rare species and look for nests. Curious, excited children tend to run around and shout in an unpredictable fashion. These types of issues can be partially mitigated by providing wildlife viewing blinds, education and signage such as "Quiet please – sensitive nesting birds," or if necessary, seasonal trail closures in areas hosting particularly sensitive species such as nesting Bald Eagles or heron rookeries. As many national wildlife refuge visitors have learned to accept, the U.S. Fish and Wildlife Service routinely, seasonally closes portions of trails to protect breeding waterfowl and waterbird populations. The American Birding Association has a "Code of Birding Ethics" that includes best practices such as limiting the use of bird song recordings to attract birds, keeping well back from nests and colonies, and staying on trails.[408]

Although we found many bird studies measuring potential effects for single user groups or hikers versus motor vehicles, boats or aircraft, studies directly comparing the effects of our three user groups are less common.[26, 406] Such studies are difficult because (a) bird communities are complex and contain many species and guilds, (b) sites with more than one type of dedicated single-use trails are rare, and (c) bird surveyors cause disturbance which can confound results. In addition, it is more difficult to affix a GPS unit to birds than to large mammals, bird vocalizations can only be heard within a relatively short radius around the observer, and birds are smaller and less visible than many mammal species. However, birds comprise by far the largest group of terrestrial vertebrate wildlife species and are crucial to maintaining a site's biological diversity.

Generalists versus specialists. Some birds specialize on specific habitats or food resources, whereas others can succeed in a variety of circumstances. Studies show that habitat specialists are reduced, and generalists – which include most species that tend to tolerate or be associated with human use – increased near trails and in fragmented habitats.[193, 205, 357, 409-413]

In France, researchers used long-term Breeding Bird Survey data and associated landscape fragmentation metrics to assess whether habitat specialist bird species were more vulnerable to habitat fragmentation than generalist species.[412] Results fell on a gradient in which specialist bird species, but not generalists, declined with increasing fragmentation. European researchers found similar results for birds along a rural to urban gradient.[413] These large-scale studies support that habitat specialists are especially vulnerable to human disturbance.

This pattern of generalist/specialist species holds true for recreational disturbance as well. In Boulder, Colorado researchers compared near-trail bird communities and controls away from trails in grassland and woodland ecosystems.[410] In both ecosystem types, wildlife species composition differed between trail and control sites, with generalist species more abundant near trails and relatively fewer habitat specialists. This study identified a trail "zone of influence" of about 75 meters from the trail for most species.

> Migratory birds and those that require a specific habitat type may be more vulnerable to recreational disturbance.

Various studies have documented that some species are negatively associated with trails. In Colorado, Miller et al. found that the following species were negatively associated with trails: Vesper Sparrow, Western Meadowlark, Grasshopper Sparrow, Western Wood-pewee, Chipping Sparrow, Pygmy Nuthatch, Mountain Chickadee, Townsend's Solitaire and Solitary Vireo.[410] In Canada, the density of forest birds – especially those that forage or nest on the ground – were significantly reduced near trails.[175] Northern Parulas were more abundant in areas with fewer trails and edges, while other bird species' habitat use was not correlated with trails.[411]

Together these studies suggest that Neotropical migratory birds and habitat specialists such as grassland and oak-associated species tend to avoid trails and are adversely affected by habitat fragmentation. Because these types of species are declining more quickly than generalist species, they warrant special attention when considering trail alignment alternatives.

Altered breeding behavior and reproductive success. Trail use and human disturbance can lead to increased avian nest predation and reduced reproductive success[7, 181, 193, 410, 411, 414-416] In Hocken et al.'s literature review, 36 of 40 papers revealed that human disturbance reduced breeding success.[417] Several shorebird studies observed reduced or absent nesting on disturbed beaches.[8, 181] Numerous songbird studies found reduced nest success or reduced nesting frequency near trails and edges.[211, 212, 325, 410, 416, 418-420]

For example, researchers in Colorado studied the influence of trails on breeding birds in grasslands and forested habitats. Grassland, but not forest, birds nested more frequently near trails. Nest predation was greater near trails in both habitats.[410] A literature review and meta-analysis found that the nest success of many species of ground-nesting birds was reduced by disturbance of people on foot.[416] In Finland, Kangas et al. conducted bird surveys along forested hiking trails and undisturbed controls.[325] Although there was no change in species richness, the relative abundance and community composition did change. Open cup ground nesters were strongly negatively associated with trails, unlike shrub, tree or cavity nesters. Their results demonstrate that relatively low visitor pressure can have negative effects on specific bird guilds.

A study in Europe found differences in behavior and breeding success for a chickadee relative, the Blue Tit.[420] The researchers compared spring birds living in natural woodlands with those living in urban parks, considering whether thermal conditions affected breeding behavior. Nest success was positively associated with warmer temperatures in woodlands, but not in urban parks. In urban parks, lower temperatures and rainy days led to increased nest survival and productivity, apparently because there were fewer park visitors on days with poor weather.

Nest parasitism occurs when bird species such as Brown-headed Cowbirds and certain members of the cuckoo family lay their eggs in another "host" bird's nest, leaving any further parental investment to the host bird. Brown-headed Cowbirds do not even build nests. Cowbird chicks hatch quickly and have a flat spot on their rear ends that assists in pushing host species' eggs and young out of the nest. In addition, cowbird chicks are often much larger than host species' young and require more food. These factors significantly reduce reproductive output for host birds.

Cowbirds frequent habitat edges searching for open-cup nests in which to lay their eggs.[411, 420, 421] Trails create edges, and birds nesting near trails may be especially vulnerable to nest parasitism by Brown-headed Cowbirds. For example, cowbirds were more abundant near roads and trails in a large natural area in Colorado[418] and more abundant close to trails than away from trails in Illinois.[422] However, not all studies link cowbird parasitism with trails or trails use.[410]

Common nest predators such as corvids, raccoons and squirrels are attracted to recreational areas, trails and edge habitats, where they can more easily find nests and consume eggs or nestlings.[174, 245, 414, 422-425] Some nest predators may be attracted to both trails and humans.[425] A local study found that American Crows are more abundant near trails and revealed positive or negative associations with edge habitat for several avian species.[426] Marzluff et al. found that crows in North America tend to be most abundant and are increasing rapidly in urban areas,[427] thus birds nesting in urban and suburban natural areas may be increased at risk of nest depredation.

Common nest predators tend to be more abundant near trails.

Researchers in North Carolina found that mammalian nest predators were most common in edge-dominated forested corridor widths of 200 m or less, and were positively correlated with the number and width of trails.[174] Raccoons in Illinois tended to follow linear landscape features such as fencerows, forest edges and mowed trails during nocturnal foraging.[424] In Colorado, bird but not mammalian predators attacked more artificial nests near trails than away from trails.[414] However, artificial nest studies must be interpreted with caution, because they do not necessarily reflect reality.[428, 429]

The importance of good vegetative cover is elevated for birds nesting near trails. For example, Northern Cardinals tend to do well near humans, but have been shown to alter nest placement near trails. Cardinals in urban forested parks in Ohio did not experience reduced nest success in relation to trails, but nest sites closer to trails were surrounded by more small stems, placed at greater heights and were better concealed compared to nests away from trails.[321] Birds with higher nests were less likely to flush from trail users. Other studies showed similar results for different avian species in disturbed habitats; Burhans and Thompson found that higher-nesting birds' nests were more successful,[411] and in Finland open-cup nesters breeding higher in trees showed reduced disturbance responses compared to ground-nesters.[325]

Human disturbance can influence breeding bird behavior in more subtle ways, such as altering spring birds' singing patterns or aggression towards other bird species.[253, 286, 430] For example, pairs of Mexican Spotted Owls in the Colorado Plateau greatly increased vocalizations with nearby trail users.[286] In another study breeding male Western Bluebirds were more aggressive towards House Wrens and American Goldfinches when humans were present; females were more aggressive only towards House Wrens, which compete for nest cavities.[253] When people were near nest boxes, birds flushed and stayed away from the boxes for up to half an hour.

Habituation. Birds – primarily resident species – exhibit habituation or habituation-like responses.[241, 245, 255, 256, 281, 405] A researcher in England tested flush distance for birds on or low to the ground in suburban versus rural areas.[256] Urban birds allowed surveyors to approach more closely before flushing, and smaller birds allowed closer approach than larger birds. However, some migratory and specialist bird species found in significant numbers in rural areas did not occur in suburban areas, and may not tolerate disturbance well. Møller had similar findings in Europe.[431] Other studies have found an apparent lack of habituation or sensitization for some bird species, particularly in areas of high disturbance.[254, 285, 357] Storch's global review of grouse studies found modest habituation-type responses for some species, but the majority of studies documented negative associations with recreational use and other human disturbance, with some evidence of sensitization.[432]

Some studies simultaneously tested wildlife species' behavioral and physiological responses to disturbance. For example, two corvid species in Europe had fewer parasites but flushed more readily in tourist sites compared to non-tourist sites; it appeared that the physiological tradeoffs favored staying close to disturbance.[245] Although they flushed more readily in tourist areas, they did not fly as far compared to controls. Birds in tourist sites had lower stress hormones; the combination of dampened behavioral and physiological responses suggests true habituation.

Amount of Use. Despite evidence of habituation-like responses for some species, the body of literature we reviewed indicates that many bird species exhibit stronger antipredator responses with increased numbers of trail users or other types of human disturbance in a variety of circumstances.[181, 235, 261, 275, 278-280, 283, 285, 286, 297, 306, 333, 357, 409, 433, 434] This trend has been shown for shorebirds and waterbirds,[181, 275, 276, 283, 285] songbirds,[235, 279, 435] and raptors[286, 333, 409, 433]. In natural areas already open to the public, increasing recreational demand is likely to reduce biological diversity.

For example, in the San Francisco Bay Area the number of shorebirds decreased with increasing trail use.[283] Researchers in Spain found that 16 of 17 forest-dwelling bird species were negatively affected by increasing pedestrian rates in urban parks after accounting for the effects of fragment size and isolation.[279] In Colorado lowland riparian areas scientists studied habitat use by birds along an urban-to-rural gradient.[435] At sites with recreational trails (paved, multi-use), trail use intensity explained 60 percent of the variation in the occurrence of low-foraging species and nearly 90 percent of the variation in habitat use by ground-foraging species. In the Netherlands, eight of 13 bird species near urban areas showed significant negative correlations with increasing recreation intensities.[235] In Sri Lanka, the abundance of birds near trails declined significantly with increasing levels of trail users.[178]

The evidence is strong that increased numbers of trail users alter bird communities, particularly for species moving about on or near the ground. It is important to account for this effect when planning the placement and extent of trails: effects will be stronger in more heavily used sites.

LONG-DISTANCE MIGRATORY BIRDS

Many studies suggest that migratory birds are especially susceptible to habitat fragmentation and disturbance effects.[211, 212, 306, 419, 435-443] Specifically in the U.S., Neotropical migratory songbirds (NMBs) are well documented in this respect.[211, 212, 419, 435, 437, 438, 440, 443-445] Many NMB species need large habitat areas to maintain populations, wider travel corridors and high quality stopover habitat compared to residents or short-distance migrants[212, 439, 443-449] A local study[450] and studies done elsewhere indicate that NMBs are negatively associated with urbanization.[435, 447, 451, 452]

Why are Neotropical migrants more susceptible to human disturbance than many other bird species? Several factors may account for this trend. Most Neotropical migrants are insectivores, migrating north to take advantage of spring arthropod emergence.[212, 453] Many are area-sensitive; large habitats and wider corridors tend to have better three-dimensional habitat structure and more native shrubs than smaller patches and these characteristics are associated with increased insect abundance.[385, 438, 445, 454] Neotropical migrants require high quality habitat in their wintering grounds, migratory stopover habitat and breeding habitat; disruptions to any of those habitats may negatively affect these birds.[455-457] Because they are migratory, NMBs are probably not accustomed to the type of disturbances that may occur routinely within the home ranges of resident bird species.

Migratory birds in other countries, and non-songbird Neotropical migrants, show similar negative trends with disturbance and fragmentation. In India, migratory birds were less tolerant of the presence of people than were resident birds; migrants flushed sooner than residents and were more sensitive to the number of people approaching than residents.[306] Klein et al. found that most resident water bird species (e.g., herons and ducks) at a Florida refuge were less sensitive to disturbance than were migrants, especially early in the season when migrating ducks first arrived.[458]

> Migratory birds throughout the world tend to be more disturbance-sensitive than resident species.

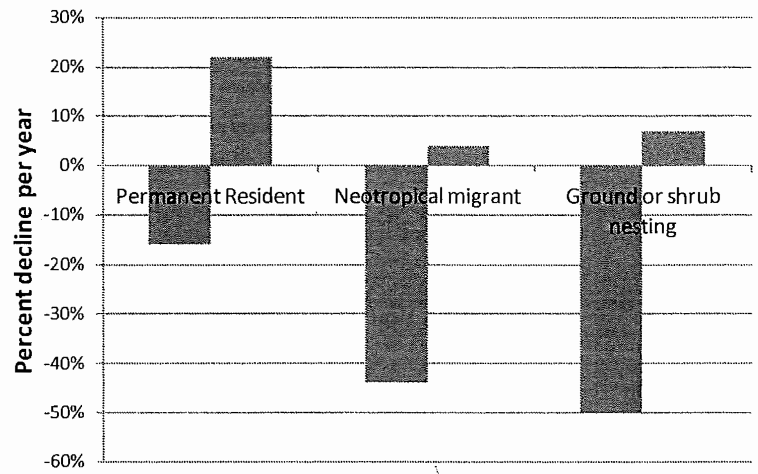
Migration is energy intensive, and human disturbance may reduce time available for feeding, making birds less fit to migrate. A Tennessee researcher found that long-distance migrants, but not resident species, required areas of low disturbance to sufficiently acquire fat stores; she suggested that conservation measures for quality NMB stopover habitat should focus on reducing pedestrian activity.[457]

Several studies documented reduced nest success for Neotropical migrants in fragmented landscapes. Donovan et al. studied four Neotropical migratory songbirds in two Midwestern regions.[211] Nest failure was significantly higher in fragmented forests than in contiguous forests for all four species. Researchers in Colorado found reduced nest success for migratory birds nesting in the urban-rural interface compared to those nesting in more intact forests.[418] In a large-scale study covering nine Midwestern states, biologists found that NMB nest predation and cowbird parasitism increased with increasing forest fragmentation.[459]

Recreational disturbance may cause some birds to increase the size of their breeding territories, effectively reducing the amount of available habitat to conspecifics. Male territories for an endangered songbird in Austin, Texas were five times as large along mountain biking trails compared to controls.[415] Nest success was 35 percent for biking sites versus 70 percent at controls, and nests at biking sites were abandoned three times more frequently than controls. The study did not consider other types of recreational use.

Long-term breeding bird survey data are available through the USGS' North American Breeding Bird Survey (BBS) website.[460] Figure 6 illustrates long-term trends for birds by specific guilds. Over the past 47 years permanent resident species increased nationwide, whereas Neotropical migrants and ground- or shrub-nesting birds decreased substantially. Doubtless a variety of factors led to these declines, but these trends suggest that particular attention should paid to these groups when considering the effects of trails in natural areas because both guilds seem to be more sensitive to human disturbance than other species.

Figure 6. Statistically significant trends for some Oregon breeding birds guilds, 1966-2013



SHOREBIRDS, WADING BIRDS AND WATERBIRDS

Considerable research has been conducted on this group of birds, possibly because they tend to be more visible than, for example, forest-dwelling songbirds. Many shorebird, wading bird and waterbird species are known to be sensitive to human disturbance.[8, 181, 254, 275, 276, 281, 283, 297, 320, 338, 403, 458, 461-465] These birds often avoid heavily disturbed areas and may spend more time feeding at night to avoid people or to make up for disturbance-induced nutritional deficits.[275, 338] Rather than habituating, some species may become sensitized to human disturbance.[285, 461, 463]

Carney and Sydeman reviewed the effects of human disturbance on nesting colonial waterbirds.[8] Most studies found significant negative effects from human disturbance including physiological parameters, behavior, reproductive success, changes in spatial distribution of nests, and reductions in breeding populations. The authors offered specific advice to limit effects on nesting herons including delaying visiting nests until one week before hatching, and limiting visitation to once every three days. Researchers in Florida studied disturbance effects on 16 species of waterbirds and suggested that a buffer of about 100 m should minimize disturbance to most species.[264] Such practices could help reduce recreational effects on wildlife.

Several studies suggest that some shorebird species are unable to habituate to human disturbance. At a migratory shorebird staging area in Massachusetts, four out of seven shorebird species' reaction to disturbance was stronger in more disturbed areas, suggesting sensitization to human disturbance.[461] In California, Snowy Plovers were less abundant near trail heads and at least over the short term, did not appear to habituate to human disturbance.[463] However, some species may habituate to human disturbance.[281]

Numerous studies show that higher levels of recreation reduce the abundance of shorebirds and waterbirds.[8, 275, 276, 283, 297, 461] For example, in Florida the number of people within 100 m altered Sanderling feeding timing (more at night) and birds moved to less crowded areas of the beach.[275] Sanderlings spent more time running/flying rather than foraging when more people were present. In the San Francisco Bay area, researchers studied shorebird metrics related to trail use at three study sites.[283] On lower (weekday) versus higher use (weekend) days, the number of shorebirds decreased with increasing trail use; higher trail-use days averaged 25 percent fewer birds. Argentinian water bird species' richness and abundance at heavily disturbed sites were higher on weekdays compared to weekends, when more visitors were present.[276]

Human encroachment into heron rookeries can cause nest failure.

Season may play an important role in how water-associated birds react to human disturbance.[8] For example, wintering snowy plovers on beaches near Santa Barbara, California reacted to human disturbance at half the distance (40 m) in winter compared to breeding season distances reported in the literature (80m), suggesting that the need for food partially over-rode human disturbance effects.[463] Timing within a single season can matter too; researchers in England found that Oystercatchers showed decreasing reactions to human disturbance as the winter progressed.[299] Disturbance events were at least two weeks apart, therefore the response was likely related to resource scarcity rather than habituation. Heron rookeries in Florida experienced a 15-28% nest mortality rate when humans entered the rookeries;[458] Appendix 3 includes references with recommended buffer distances to protect nesting colonies.

Other studies link changes in shorebird and waterbird feeding patterns with human disturbance.[281, 285, 320, 463] Sanderlings on a high-disturbance beach in Georgia had lower foraging success than those on a low-disturbance beach, with no evidence of habituation on high-disturbance sites.[285] Burger and Gochfeld's study showed similar results, plus a shift towards more night-time feeding in highly disturbed sites.[275] Feeding rates of Snowy Plovers were shown to decrease with increased human activities in California.[463] In a Florida wildlife refuge herons, egrets, pelicans, cormorants, grebes and Anhingas foraging or perching within 50 m of people walking by fled.[320] Sixty to 80 percent of herons either slowly moved away or fled from observers on foot, except for Green Herons, which waited until the observer got close. Green Herons rely on cryptic coloration to avoid predation and such species may wait longer before flushing. Photographers in this study were more disturbing than nature observers.

Waterfowl can also be sensitive to human disturbance.[320, 458, 466-471] Anglers, bird watchers and hikers along shorelines can displace waterfowl from feeding grounds, reduce breeding pairs and breeding success, and lower individual fitness.[469] A researcher in Germany found that a single angler can prevent ducks from establishing territories in areas of open water of less than 1 ha.[472] Mottled Ducks in Florida were sensitive to approach by humans on foot and moved away or fled in 95 percent of the trials.[320] In the same study, Pied-billed Grebes consistently moved or flew away from people approaching on foot and were more sensitive than most other waterbirds. A study of fish-eating waterbirds using Wisconsin lakes found that three species – Osprey, Common Merganser and Common Loon – did not occur in lakes with high levels of human disturbance.[470] This study illustrates why controls are important in disturbance studies; without undisturbed sites, the local extirpations of these species would have gone undetected.

In California's Sacramento Valley, the heart rates of wintering Greater White-fronted Geese increased as experimental observers approached, nearly tripling immediately before and after flushing.[467] In addition to interrupting normal feeding and resting behavior, this causes birds to burn extra calories that may be needed to survive the winter. There is also evidence that migratory waterfowl are more disturbance-sensitive than non-migratory species, as has been found for other taxa.[458]

To conserve the most disturbance sensitive water-associated bird, protecting specific areas at a site may be an effective solution for some species. In California, researchers erected barriers to protect roosting Snowy Plovers from disturbance; the barriers reduced the disturbance rates by more than 50 percent and abundance in the protected area increased throughout the season.[181] Once the barriers were in place, the shorebirds contracted their area of use to behind the barriers when humans were present. They began breeding behind the barriers when no nests were previously recorded at the beach, and bred in increasing numbers each year with high success. In another California study, wetland birds including several shorebird species were studied on both sides of a fence erected to eliminate human disturbance on one side.[403] On the protected side, birds reacted similarly to control sites. Heron rookeries in the northeastern U.S. showed no short-term reproductive losses when the rookery was buffered from disturbance by 50 m.[462]

We found numerous studies documenting alert distances and FIDs in recreational areas. Table 8 in Chapter 8 summarizes alert distances and FIDs from a variety of shorebird, wading and waterbird studies.

BIRDS OF PREY

Research concerning the effects of recreation on birds of prey is somewhat sparse. Bald Eagles may be the most studied raptor species in North America and it is clear that human disturbance is an issue for this species.[327, 433, 473-477]

Researchers in Washington conducted a 3-year study of wintering Bald Eagle-human interactions in the Skagit River Bald Eagle Natural Area.[433] Eagle abundance was negatively correlated with recreation intensity, which peaked on the weekends, and feeding was disrupted by an estimated 35 percent. Hikers were most disturbing, but motorboats disturbed a larger area and therefore more eagles. There appeared to be a threshold of about 20 daily recreational events after which eagles were slow to resume feeding and after 40 events, feeding was uncommon. Eagles did not resume eating for four hours after foot traffic disturbance, compared to 36 minutes following boat traffic. Sub-adults were less disturbance tolerant than adult eagles. The researchers recommended prohibiting recreation until after 11:00 a.m. and within 400 m of eagles. Public education was deemed important to reduce effects.

Anthony et al. reviewed the literature on Bald Eagles and found that recreation can exert both short- and long-term effects on behavior.[473] Long-term effects can include reductions in survival, particularly during winter and especially for juveniles. In an Arizona study, Bald Eagles flushed more often from perches than nests in spring; pedestrians, especially hikers, caused the most disturbance (compared to aquatic users, vehicles, noise from gunshots/sonic booms and aircraft), ranking highest in response frequency and duration.[474] Pedestrians within 275 meters caused a 79 percent eagle response rate. The researchers suggested a minimum disturbance buffer of 600 meters around breeding eagles, beyond which response frequency dropped below 30 percent.

> Bald Eagles and other large raptors are sensitive to recreational disturbance.

Guinn proposed a hypothesis under which a "generational habituation" occurs. Under this theory, eaglets hatched in nests near human disturbance imprint on such areas and select human-associated areas for their own nests as adults.[478] However, this theory remains to be proven, and other studies show the potential for long term impacts. Bald Eagles nesting in suburban and rural landscapes in Florida showed no difference in the number of chicks fledged or survival rates, but suburban fledglings initiated northward migration later and had only 65-72 percent longer term survival compared to 89 percent of rural fledglings.[479]

Research exploring links between other species of raptors and human disturbance are less common. In New Mexico, adult Ferruginous Hawks increased nest-defense intensity with repeated human visits to the nest; the authors recommended a 650-m buffer to prevent nest-attending hawks from flushing.[333] In Argentinian mountains, carnivorous bird densities were lower near recreational trails.[409] The frequency of visitation negatively affected two raptor species, a buteo and a falcon. Hikers near forested Mexican Spotted Owl nests caused altered feeding and grooming behavior for females and significantly increased vocalization for both males and females.[286] In a winter grassland raptor study American Kestrels, Merlin, Rough-legged Hawks, Ferruginous Hawks, and Golden Eagles were more likely to flush when approached by a walker than a vehicle.[257] Overall, 97 percent of raptors approached by walkers flushed with a mean flush distance of 118 m, whereas only 38 percent of raptors approached by car flushed with a mean flush distance of 75m.

The raptor studies we located suggest that:

1. Large raptor species tend to be disturbance-sensitive, as indicated by longer alert distances and FIDs.
2. People on foot tend to be more disturbing than boats, vehicles and aircraft.
3. There is scant evidence of habituation to hikers, and such research is generally lacking for mountain bikers and equestrians.
4. Both breeding and wintering birds are sensitive to disturbance, although FIDs and similar measures may differ.

7.4 SPECIES GROUP: MAMMALS

Mammals, especially members of the deer family, are the most studied group in the field of recreation ecology.[192] Studies have been conducted on deer, elk, pronghorn, wild sheep and a few smaller mammal species. We also found numerous studies on large carnivores. Mammalian disturbance studies may compare effects between recreational user groups, mammal species, or some combination of both.

UNGULATES (HOOVED MAMMALS)

Cervids are ungulates in the deer family including deer, elk and moose; other non-cervid ungulates include sheep and pronghorn. Large carnivores such as cougar prey on ungulates, and altering the balance of prey species and their predators can have significant consequences to food webs.[168, 171, 172, 313, 480, 481] However, human influences on vegetation, as measured by land use change, exert an even more powerful effect than predator-prey relationships;[482] habitat loss leaves less room for animals and is closely linked with fragmentation.[483]

Numerous studies measured alert or flight distances for ungulates in a variety of human disturbance scenarios. In the studies we reviewed, deer and elk had especially long antipredator responses, with distances ranging from 74-400 meters depending on setting and user intensity. Table 8, Figure 9 and Appendix 3 summarize this information.

Topics discussed in previous sections also apply to cervids. For example, the predator shelter effect is well documented for elk (Section 6.2),[25, 172, 268, 288, 301, 302, 305] and several cervid studies document that antipredator responses increase in tandem with the number of visitors.[124, 282, 284, 484, 485] Larger deer and elk herds are typically more sensitive to disturbance.[113, 247, 268, 311, 331]

Deer and elk may avoid human recreation by switching to more nocturnal activities or periods of reduced disturbance.[173, 303, 335, 336] For example, the probability of detecting deer during the day in a California urban nature reserve was lower with increasing levels of human recreation.[282] In northeastern Oregon, radio-collared elk reduced their movements late in the day, after experimental disturbances were ceased.[486]

Some cervid studies attempt to tease out relationships between recreational users and impacts from busy roadways.[268, 331, 487] Brown et al. investigated the potential effects of human disturbance on elk and pronghorn along a transportation corridor in Grand Teton National Park, with a focus on road noise.[331] The ungulates demonstrated reduced antipredator responses with increasing levels of vehicular traffic. In contrast, they showed significant antipredator responses to the presence of pedestrians and to passing motorcycles, the latter which are noisier than most other motor vehicles. The authors surmised that the wildlife either did not necessarily associate noise with risk of predation, or that it cost too much energy to continuously respond to the most frequent and predictable human disturbances. However, a study in a Canadian provincial park documented reduced ungulate use of habitat areas within sight of roads with heavier traffic, but groups of three cervid species were three times more abundant on weekdays compared to weekends, when more recreationists used the site.[487] Thus, although cervid species' responses to traffic may vary, their general avoidance of recreationists appears to be consistent.

Pregnant elk or groups with young do not appear to habituate to recreational disturbance. Recreation can directly, negatively affect elk reproductive success, with potential population-scale effects. A 5-year disturbance study on elk reproductive success in Colorado found that undisturbed control sites' calf/cow proportions were similar throughout the study period.[194] In treatment sites (1 pre-disturbance year, 2 disturbance, 2 post-disturbance), productivity rebounded following release from disturbance and recovered by the second post-disturbance year, but there was no increase in productivity to make up for losses. This study demonstrates the potential for significant population effects over time in recreational areas and makes a strong argument for leaving some areas undisturbed. Studies showing stronger ungulate responses for females during spring or females with young support this finding.[8, 25, 124, 314, 328-332] A study in Yellowstone National Park compared individual and group vigilance for adult elk females with and without calves, in small and large herds.[314] Females without calves increased scanning and decreased foraging in high natural predator risk situations in small but not large herds. Females with calves behaved similarly, except they did not decrease vigilance regardless of herd size; group vigilance depended in part on herd size and composition.

> Recreational disturbance may cause population-level impacts for elk.

Recreation can also influence cervid diet. For example, researchers in Scotland found that reducing disturbance near open grasslands, which are important food sources but lack adequate cover, would provide nutritional benefits to deer.[302] In another Scottish study examining elk pellets in disturbed versus undisturbed sites, elk shifted spring and winter diets in disturbed compared to undisturbed sites.[488]

A study in Utah examined pronghorn response to disturbance before (1 year) and after (2 years) the study area was opened to recreation.[312] In the two years after opening, groups of pronghorn stayed significantly farther from trails. Smaller groups stayed further from trails than larger groups, in contrast with studies on deer and elk.[308, 314] There was no evidence of habituation during the study period. Although not statistically significant, groups with fawns appeared to be more sensitive to disturbance. Unlike deer and elk, pronghorn prefer large open habitats and their visibility may alter antipredator responses.

Researchers in Argentina found that guanacos, a member of the camel family native to South America, developed a tolerance to vehicles and pedestrians in tourist areas that extended approximately 500 m around recreational areas.[284] However, field surveyors saw substantially fewer guanacos on days with higher numbers of visitors, with an apparent threshold effect of 247 visitors per day. Different methodologies yielded different results: flight distance analysis showed no response, but sighting frequency analysis revealed a fairly strong effect.

Two recreational disturbance studies on mouflon, a species of wild sheep native to old-world regions, demonstrated antipredator behavior in response to recreational pressures. In southern France, researchers contrasted days with high or low hunting or tourism pressures to assess responses of 66 GPS-collared Mediterranean mouflon.[303] In areas with intense tourism animals shifted to more nocturnal activity, compensating for foraging time lost due to tourist disturbance during the day. In another study, researchers in Sardinia found that female groups with lambs had longer FIDs compared to male groups or female groups without lambs.[329]

These studies reveal that ungulates as a group are vulnerable to recreational disturbance; herd size and composition influence antipredator response; some ungulates shift to nocturnal activities to avoid human disturbance; and recreational pressure can reduce or alter the types and amounts of food available to wildlife.

LARGE CARNIVORES

Apex predators are those at the top of the food web, upon which virtually no other wildlife species prey.[169] Large carnivores such as cougar and wolves are apex predators in the U.S. Humans have a long history of removing large carnivores from the landscape, partly because of safety fears but also due to competition for prey species such as deer and elk. Most large carnivores have already been lost from more than 95–99 percent of the contiguous United States and Mexico.[489] The range reductions and disappearance of large carnivores across many landscapes have important implications for food webs;[168-171] habitat fragmentation and human disturbance have played key roles in carnivore reductions.[169]

Mesopredator release. The disappearance of large predators in an ecosystem causes a "mesopredator release" in which medium- and smaller sized predators such as foxes, skunks, raccoons and domestic cats become much more prevalent in the absence of larger carnivores,[168, 170] a common issue in urban areas.[423] Oregon State University researchers studying North American range shifts over the past 200 years showed that 60 percent of mesopredators' ranges have expanded, but all large predator ranges have contracted.[168] Reductions in large carnivores and the resultant release of mesopredators such as domestic cats, raccoons and opossums near urban and disturbed areas lead to increased predation on prey species such as small mammals, reptiles, birds and bird nests.[174, 321]

Coyotes fall on the low end of the large carnivore group. Crooks and Soulé studied interactions between coyotes, other mesopredators and scrub-breeding birds in 28 urban habitat fragments in California.[170] There were twice as many mesopredators in patches with no coyotes. Patches with higher mesopredator abundance had fewer species and fewer birds, even after accounting for area effects and time since isolation [longer isolation leads to fewer species[202, 490-493]]. The researchers postulated that "the interactions between coyotes, cats and birds probably have the strongest effect on the decline and extinction of scrub-breeding birds." Coyotes were documented to predate cats in the study, thereby reducing cat predation on birds.

"Reverse" predator shelter. The previous large mammal discussion documented deer and elk using more disturbed areas as predator shelters, and the reverse effect can be seen for large carnivores, in which they avoid recreational and hunting areas. In Alberta, Canada researchers set up cameras along trails and roads to examine spatial relationships between people, prey (elk, moose and deer) and large predator species including wolves, bear, cougar and coyotes.[305] Human activity of more than 18 humans/day on trails and roads displaced predators but not prey species; cervids were three times more abundant on roads and trails with more than 32 humans/day, a good example of the predator shelter effect. Another example of this phenomenon was documented in the Yellowstone ecosystem, where pregnant moose shifted towards roads to give birth; brown bears, which commonly predate moose, avoided roads.[300] Another study in three Canadian national parks used GPS units to observe spatial distributions of elk and wolves in recreational areas.[172] Both wolves and elk avoided trails and roads within the first 50 m. However, wolves avoided areas 50-400 m from roads and trails, whereas elk appeared to use these areas as a predator shelter.

Habitat fragmentation and human disturbance. Our review indicates that large carnivores are sensitive to both habitat fragmentation and human disturbance,[169, 170, 209, 282, 293, 300, 494-497] and several studies specifically document large carnivore avoidance of trails and recreational areas.[170, 172, 209, 282, 305, 494, 498]

For example, a researcher in southern California conducted track surveys for nine native and two exotic carnivore species in 29 suburban habitat fragments and 10 control sites.[169] Cougar and other large carnivores were more sensitive to habitat fragmentation and occurred less frequently in suburban areas, but not control sites, compared to medium and small sized carnivores. Also in southern California, cougar were negatively associated with bicycle, but not equestrian use.[295] In Canada's Banff National Park, researchers studied large carnivore use of wildlife undercrossings that were also used by recreationists.[495] Cougar and black bear preferentially used underpasses with less recreational activity and that were further from town.

The boldness of individual carnivores appears to influence habitat use in recreational areas. Researchers radio-collared 10 cougar at a state park in California to examine whether recreationists influences the animals use of space and time.[496] Some cougars tended to avoid areas with human activities, but other individuals did not. There were no cougar-human conflicts despite increasing numbers of recreationists in the park. Other studies suggest that individual animal's temperaments can influence habituation-like responses.[124, 291]

Scientists in northern California surveyed mammalian carnivore scat in 28 protected areas including paired sites with and without recreation.[494] Scat was collected to enable DNA verification of species. The researchers found that dispersed, non-motorized recreation led to a five-fold decline in native carnivore density, and recreational sites revealed a substantial shift in carnivore composition towards non-native species; the authors stated that there is a "pressing need for new approaches to the designation and management of protected areas."

Several U.S. studies indicate that bobcats and coyotes are negatively associated with disturbance and recreational use,[170, 209, 282, 494, 497] although coyotes do not necessarily avoid urban areas. Coyotes in southern California were positively associated with certain levels of urbanization, but the researchers did not test effects of recreation; the study also found negative associations with urbanization for bobcats, gray foxes and mountain lions.[293] Gehrt et al. found that while coyotes in Chicago readily used urban areas, they used urban land cover within their territories less than expected.[499]

A southern California study found that deer, bobcats and coyotes became less active during the day in recreational areas, and effects were stronger in areas with heavy recreation.[282] Another southern California study found that adult female bobcats avoided human use areas more than adult male and young female bobcats.[294] The latter two had larger territories in human-dominated areas, suggesting reduced habitat suitability. Both bobcats and coyotes shifted more to night-time foraging activities near urban areas. Ordenata et al. found that bobcats, gray foxes and mountain lions were found less frequently near southern Californian urban areas compared to non-urban areas.[293]

The literature revealed differences between some carnivores' use of recreational trails. For example, red fox seem somewhat amenable to using recreational trails and disturbed areas,[13, 293, 497, 498, 500, 501] whereas gray fox seem to avoid them or switch their activities to night-time.[209, 498] In a study along the Appalachian Trail, red fox (but not gray fox, which were also present) were associated with, and black bears tended to avoid high use trail segments.[498]

Very large national parks in Canada are of course different from the Portland-Vancouver urban region, but the relationship between disturbance and large carnivores does not change: trails and recreational areas tend to repel large carnivores resulting in mesopredator release, with real potential to disrupt entire ecosystems and ecosystem processes by altering food webs, habitat and wildlife community dynamics. Recreational disturbance also substantially reduces the amount of habitat available to large carnivores.

> Larger carnivores are sensitive to habitat fragmentation and tend to avoid recreational areas.

Smaller carnivores may also be vulnerable to human disturbance and fragmentation. For example, researchers in Spain studied how fecal hormones in native wildcats (*Felix sylvestris*, ancestor of domestic cats) change seasonally and with different levels of disturbance.[502] Stress hormones were higher in park areas with more visitors, and were more elevated during spring and fall (reproductive seasons). The researchers recommended maintaining some areas of the park free of visitors, and controlling the number of users during wildcat gestation in recreational areas. In Portland, Oregon shorttail weasel were only found in remnant habitat patches larger than 10ha, likely due to home range requirements, sensitivity to disturbance or both.[503] A California study found evidence of area sensitivity for long-tailed weasels.[169]

Domestic dogs. The presence of dogs – a domesticated subspecies of wolves – appears to repel many wildlife species. A Colorado study showed reduced deer activity within 50 meters of trails where dogs were prohibited, but the distance doubled to at least 100 m for trails that allowed dogs, with similar effects on a variety of small mammals including squirrels, rabbits, chipmunks, mice, and prairie dog burrow locations.[497] The study was done using pellet surveys and other methods, and did not differentiate between day and night. Our previous review on the effects of dogs on wildlife revealed a pattern in which humans with dogs were more disturbing to wildlife than humans without dogs (Appendix 1).[287]

SMALLER MAMMALS

We found only a few trail-related studies on smaller non-carnivorous mammals. In Wyoming, the abundance of red squirrels subjected to low levels of disturbance (1-5 human disturbance events per week) did not differ from controls, although higher disturbance levels may have revealed effects.[504] However, small mammals endemic to California chaparral habitat were less diverse and abundant in disturbed sites, with the opposite patterns for disturbance-associated species; this related to changes in vegetation associated with trails and roads rather than directly linked to specific disturbance or level of use, the latter which were not studied.[126] In Colorado, prairie dogs were more wary of humans with dogs than humans alone, although they showed antipredator responses in both situations.[149]

Eastern chipmunks in Quebec, Canada were distributed non-randomly according to their temperament across a gradient of human disturbance.[291] More docile and more explorative individuals tended to have territories in more disturbed areas, although it is unclear whether this related to habituation. Stress hormones (cortisol) measured in the animals' hair was related to temperament rather than level of disturbance, therefore it was not possible to disentangle disturbance from temperament variables. Nonetheless, stress levels were higher in summer during tourist season.

Three marmot studies in Washington's Olympic Mountains[505] and the Swiss Alps[506, 507] suggest some habituation to hiker disturbance but increased wariness. However, habituation did not seem to be the case when dogs were present.[505] Marmots at high-use sites in the Olympics showed reduced responses to hikers compared to low use sites, but they were warier and looked up more when foraging. Despite these behavioral changes, marmots at high versus low use sites showed no difference in reproductive and survival rates, and they were in similar body condition. It appears that marmots' strategies in high-use sites effectively avoided the strongest disturbance effects. In the Swiss Alps, marmots were less disturbed by on-trail than by off-trail hikers, suggesting some degree of habituation.[507] The second Swiss Alps study showed similar habituation-like results, with a late summer increase in magnitude of antipredator response in both recreational areas and remote areas, but to a much larger extent in remote areas.

Except for issues with artificial light (Section 6.7) and the potential for cave visitors' conversational noise to be disturbing to bats,[362] we found little information directly examining effects of recreation and trails on bats. One study used mist nets to examine differences between an urban park and rural riparian bat communities.[508] Species diversity and evenness were lower in cities, and the most common bat – big brown bat, *Eptesicus fuscus*, were even more common in city parks. Several other bat species showed the opposite pattern. However, the study did not directly address recreationists or habitat variables.

USER GROUP COMPARISONS

In the studies we reviewed some found hikers more disturbing, but more studies found mountain bikers more disturbing to wildlife. People with dogs are clearly more disturbing than other visitors (Appendix 1). Equestrians appear to be least disturbing to wildlife.[209, 260, 268, 282, 290, 296, 486]

Animals are more alarmed when visitors behave in unpredictable ways, therefore faster approaches generally elicit a stronger antipredator response and cause longer flight distances compared to slower approaches.[19, 247, 254, 316-318] For example, several studies found that mountain bikers[260, 296, 316, 486] and joggers or trail runners[297, 316, 317] caused a greater antipredator response than hikers or equestrians. Shorebirds, herons and ducks on the Atlantic Coast[317] and on New England beaches [297] flushed more readily from joggers than from people walking. European scientists showed that male alpine chamois fled further from joggers and mountain bikers than from hikers.[316]

We found two exceptions to the "speed of approach" rule. In one study, a smaller proportion of joggers on the beach disturbed wintering Snowy Plovers than did walkers.[463] Another study showed that Bald Eagles flushed more readily from walkers than from bicyclists; however, the birds moved further away from bicyclists.[319]

Several elk studies compared the effects of different forms of recreation on wildlife. A researcher in northeastern Oregon radio-collared elk to explore responses of four types of recreational disturbances: ATVs, mountain biking, hiking and equestrian use (two publications on the same study).[296, 486] All four activities elicited antipredator responses. Time spent traveling increased in response to, and was significantly different between types of disturbances. Response to ATVs was most severe followed by mountain bikers, hikers, and equestrians in that order. Morning disturbance response was strongest. In this two-year study, some habituation appeared to occur but disturbance was still evident. Comparing results between visual observation and radio-collars, collars showed stronger effects, suggesting that studies based on visual estimates alone may underestimate recreational effects on wildlife. A companion study of 13 radio-collared female elk found similar results: mountain biking and hiking were less impactful than ATVs, but mountain bikers caused a stronger response than hikers.[260]

In studies where hikers were most disturbing to wildlife, hikers often went off-trail thereby reducing the predictability of their behavior.[113, 124, 268] Hikers in Utah caused the strongest responses in desert bighorn sheep (animals fled in 61 percent of encounters), followed by vehicles (17 percent fled) and mountain bikers (6 percent fled); hikers were more likely to go off trail and often directly approached sheep.[124] Ciuti et al.'s study in Canada found that ATVs were more disturbing to elk than hikers, mountain bikers or equestrians.[268] Bikers and equestrians mostly stayed on roads and showed little effect on elk, but hikers frequently went off-trail. In Utah, Taylor and Knight studied bison, mule deer and pronghorn responses to hikers and mountain bikers.[113] There was a 70 percent probability of individuals from any species flushing within 100m of visitors on trails. When people went off-trail, mule deer showed a 96 percent probability of flushing within 100 m of the visitors; their probability of flushing did not drop to 70 percent until visitors were 390 meters away. These studies make it clear that people venturing off of established trails are especially disturbing to wildlife.

> People with dogs appear to be most disturbing, and equestrians least disturbing to wildlife. Hikers and mountain bikers fall somewhere in between.

An Austrian researcher studied physiological and behavioral reactions of elk born and kept in large pens, using direct observation and implanted heart rate transmitters.[290] As with several other studies,[296, 486] elk were most reactive to disturbance during the morning hours, and antipredator responses varied by season. Elk were disturbed for at least 10 minutes after gunshots or walkers passed by, but less so for equestrians. The researcher did not test responses to bicyclists.

Scientists compared the effects of non-motorized recreation types on mammals in a large-scale northern California study to ascertain whether recreationists reduced wildlife use and whether there was a safe distance from trails that could inform appropriate trail placement within vegetated corridors.[209] Mountain lions and mule deer were negatively associated with the amount of hiking; raccoons were negatively associated with the amount of mountain biking; striped skunks were less abundant in the presence of hikers with dogs. The researcher also found that gray fox and coyote became more active at night in response to any level of human recreation. Mule deer were sensitive to any level of human recreation. The study illustrates the difficulties in making generalizations about wildlife responses to recreationists.

Taken together, these studies suggest that:

- People with dogs may be more disturbing to wildlife than any other non-motorized recreational use.
- When visitors stay on trails, mountain bikers and joggers/trail runners tend to be more alarming to wildlife than hikers because they move faster and wildlife encounters can be sudden and unpredictable.
- Off-trail hikers and perhaps any off-trail users (we did not find off-trail research for other user groups) are most alarming to wildlife, because animals do not expect to encounter people there and these users' movements are therefore unpredictable.
- Among non-motorized recreational uses, equestrians appear to have the least effect on wildlife.

CHAPTER 7 SUMMARY – Effects on wildlife by species group

Invertebrates

- Trails in forests can reduce shrub and canopy cover, which provide key invertebrate habitat. Invertebrates are important food resources for songbirds, especially during the breeding season. However trail construction does not always require tree or shrub removal.
- Stream crossings, especially fords, can impair instream macroinvertebrate communities.
- Trail users may compact soils and damage below-ground invertebrate habitat.
- Recreational use has been shown to alter beetle, butterfly and spider communities.

Reptiles and amphibians

- Less mobile animals such as salamanders and turtles on land cannot escape quickly.
- For salamanders, habitat variables such as logs and leaf litter near trails may be more important than trail use.
- Trail use may create movement barriers for some amphibian species, especially when trails intersect mass breeding migrations.
- Frogs can be easily disturbed and may become sensitized to recreationists near streams.
- Lizards may be especially vulnerable to recreational disturbance. Less is known about other reptiles.

Birds

- Generalist species tend to do well near trails, whereas migratory species of songbirds and waterfowl do not.
- Some year-round resident species show evidence of habituation-like responses.
- Larger bird species tend to flush more readily than smaller species.
- Species that nest and perch higher up in trees are less vulnerable to recreational disturbance.
- Higher recreational traffic leads to fewer bird species and altered nest success.
- Common nest predators such as jays, crows, Brown-headed Cowbirds and squirrels are attracted to edge habitats, recreational areas and trails.
- Shorebirds, waterbirds and wading birds are vulnerable to disturbance, especially at high levels of use.
- Bald Eagles and other (especially ground-nesting) raptors are very sensitive to people on foot, and to a lesser degree for other disturbance types such as boats, vehicles and aircraft.

Mammals

- Any visible or audible human presence can negatively affect ungulates, carnivores and probably small mammals.
- Human disturbance can reduce elk reproductive success.
- The predator shelter effect, in which animals move to non-hunted areas during hunting season, is well documented for elk. In such cases elk tend to shift towards night-time activities to avoid humans.
- Higher levels of recreational use cause higher levels of disturbance for ungulates.
- Large carnivores are fragmentation-sensitive, are even more sensitive to human disturbance than ungulates, and tend to avoid recreational areas rather than habituating (except red fox).
- Reduction in large carnivores can lead to increases in medium-sized carnivores (the so-called "mesopredator release" effect), thereby altering food webs and disproportionately affecting birds and small mammals.

User group comparisons

- People who go off-trail or stop to view or photograph wildlife elicit higher stress response than users passing by on trails or roads.
- Horses appear to be least disturbing of our three user groups. Fast-moving recreationists such as mountain bikes and trail runners tend to be more disturbing than hikers.
- People with dogs are more disturbing to wildlife than people without dogs.

8. TOOLS TO HELP MANAGE NEGATIVE EFFECTS

Conflicting goals can arise when a natural area is managed to preserve or enhance habitat while also providing recreational access. When the decision is made to provide recreational access to a site there are many available tools, frameworks and approaches designed to mitigate a variety of potential environmental effects from trail construction and use.

This chapter summarizes some of the more commonly used trail design and construction guidance documents currently available. Resources to reduce negative effects on wildlife are less common, therefore in this chapter we also consolidate information from a substantial body of literature to help consider how to reduce such effects. The information provided here is not meant to be prescriptive; rather, it holds promise to spur collaborative approaches to develop standards or best practices.

8.1 TRAIL DESIGN AND CONSTRUCTION RESOURCES

With proper site selection and trail alignment planning, impacts to natural resources can be reduced. As a simple example, consider siting new trails on sites or portions of sites that already have a history of public use rather than undisturbed sites. Vegetation removed or damaged during trail construction can be replanted to enhance recovery and provide a screen for wildlife.

When planning a park or trail it is important to consult land managers, conservation scientists and local experts to identify the most sensitive areas. Seeking win-win situations can further conservation goals while introducing or formalizing recreational access. Examples include thinning trees in order to diversify forests while also opening up view opportunities for people, or replacing culverts with bridges to facilitate both trail crossings and fish and wildlife movement.[509] Such dual purpose approaches may also expand project funding opportunities.

Several guidebooks offer best practices for trail design and construction (Table 6). Some guidebooks focus on single user groups – hikers, mountain bikers or equestrians – while others are non-specific or cover several user groups. For mountain biking, several agencies have adopted the International Mountain Bicycling Association's basic guidelines[510] for trail design and construction for sustainable non-motorized trails.[87, 341, 510]

IMBA's 2007 guidance document offers 11 essential elements of sustainable trails:

1. Trail location: Sidehill trails are best. Water tends to collect in flatter trail settings, causing trail widening over time.
2. Sustainable trail alignment: Avoid the fall line by gently traversing the slope, rather than traveling directly up or down it.
3. Half rule: A trail's grade should never exceed half the grade of the sidehill upon which it is located. Trail grade is calculated by dividing total elevation gain by total length of the uphill section times 100 to obtain percent.
4. Sustainable trail grade: Follow the ten percent average guideline.
5. Maximum sustainable trail grade: Typically the maximum sustainable trail grade is approximately 15 percent for a short distance, but is site-specific and may be substantially lower or occasionally higher.

6. Grade reversals: Frequent drainage features, including grade reversals and outslopes, are essential. A grade reversal is a spot at which a trail briefly changes elevation, dropping subtly before rising again. This forces water to drain at the lowest point before it can gain volume and momentum.
7. Outslope: The downhill side of trails crossing hillsides should tilt slightly down and away from the high side to ensure proper drainage.
8. Adapt trail design to soil texture [here we would add plant communities and life form].
9. Minimize user-caused soil displacement: Abrupt turns and sharp hills are locations most susceptible to user-caused soil movement.
10. Prevent user-created trails: The document provides a section on avoiding and managing unauthorized trails.
11. Maintenance: The fundamental goal is to get water off of the trail and keep users on it. IMBA's *Trail Solutions* guidebook includes details on this topic.[87]

Table 6 summarizes some of the trail design and construction guidance documents currently available. The list is not comprehensive and is not meant to be an endorsement of any particular guidance document. Note that only three of the documents include any significant guidance for minimizing the effects of trails and recreation on wildlife; these are noted in the table. Sections 8.7 and 8.8 provide more information that may be useful in developing wildlife-related best practices.

Table 6. A sampling of available trail design and construction guidance documents.

Guidance document	Primary user group focus	Comments
A human dimensions review of human-wildlife disturbance: A literature review of impacts, frameworks, and management solutions[97]	Various user groups	USGS research review and best practices report focused on identifying and reducing the negative effects of trails and recreation on wildlife. Includes information on social carrying capacity and other human dimensions. This reference has the most valuable and complete set of potential management solutions for wildlife of all the references we reviewed. ***Extensive wildlife guidance information.***
Complete guide to trail building and maintenance, fourth edition[511]	Various	Book published by the Appalachian Mountain Club. Includes chapters on trails on private land, cost estimates. *Lacks wildlife guidance.*
Environmentally sustainable trail management[40]	Various	Book chapter that includes key elements of a potential trail plan, trail placement, construction and maintenance guidance, techniques for wet soils, tread hardening and more. *Lacks wildlife guidance.*
Equestrian design guidebook for trails, trailheads, and campgrounds[51]	Horses	Designed more for backcountry and campgrounds, but includes extensive guidance that can be useful for equestrian trails in many settings. Chapter 13 provides information on reducing environmental and health concerns. *Lacks wildlife guidance except for "dangerous creatures."*
Green trails: Best practices for environmentally friendly trails[43]	Hiking	Guidance for planning and building environmentally friendly "green" trails. Includes recommendations to complement existing standards and guidelines adopted by local parks and watershed groups in the Portland, Oregon area. ***Substantial wildlife guidance information.***
Guidelines and best practices for the design, construction and maintenance of sustainable trails for all Ontarians[36]	Various	Trail construction and maintenance best practices. *Limited wildlife guidance.*

Guidance document	Primary user group focus	Comments
Guidelines for managing and restoring natural plant communities along trails and waterways[512]	Various	Detailed information on native plant restoration and management, including good information on riparian environments and controlling exotic species. *Lacks wildlife guidance.*
IMBA's Trailbuilding basics[513]	Mountain bikes	Designed to train land managers, mountain bike club leaders and other trail users on trail construction and maintenance techniques. *Lacks wildlife guidance.*
Informal trails and the spread of invasive species in urban natural areas: Spatial analysis of informal trails and their effects on understory plant communities in Forest Park, Portland, Oregon[121]	Various	Thesis of local research regarding unauthorized trails. Includes a "Management implications" section that outlines ways to minimize negative effects of unauthorized trails. *Lacks wildlife guidance.*
Leave no trace in the outdoors[514]	Various	Well known guidance document and website (LNT.org) to reduce the human footprint on the recreational landscape. Discusses concepts such as dispersed vs. concentrated use. *Lacks wildlife guidance.*
Lightly on the land: The SCA trail building and maintenance manual[515]	Various	Guidance on designing and building trails with environmental health in mind. *Limited wildlife guidance.*
Managing mountain biking - IMBA's guide to providing great riding[510]	Mountain biking	*Managing Mountain Biking* is a companion to IMBA's trail building how-to book *Trail Solutions: IMBA's Guide to Building Sweet Singletrack*.[87] Includes guidance on overcoming user conflicts, minimizing environmental impacts, managing risk, and providing technically challenging riding. While *Trail Solutions* covers trail construction, *Managing Mountain Biking* focuses on solving mountain biking issues through innovative trail design, effective partnerships, and visitor management strategies. *Lacks wildlife guidance.*
Managing visitor impacts in parks: A multi-method study of the effectiveness of alternative management practices[93]	Various	Research and exploration of best practices to keep visitors on trails. *Lacks wildlife guidance.*
Natural surface trails by design: Physical and human essentials of sustainable, enjoyable trails[516]	Various	Includes 11 concepts to explain, relate, and predict what actually happens on all natural surface trails in terms of their basic forces and relationships, both physical and human. Focuses on the reasons for issues and potential solutions. *Lacks wildlife guidance.*
Planning & managing environmentally friendly mountain bike trails: Ecological impacts, managing for future generations, resources[58]	Mountain biking	Extensive research based in the southwestern U.S. Describes ecological impacts, compares with other user groups and provides best practices for sustainable trails. Provides specific recommendations for resource managers. *Limited wildlife guidance.*
Planning trails with wildlife in mind. A handbook for trails planners[37]	Various	Colorado State Parks' guidance document to minimize negative effects on wildlife. Includes numerous case studies and best practices. ***Key wildlife guidance document.***

Guidance document	Primary user group focus	Comments
Research for the development of Best Management Practices to minimize horse trail impacts on the Hoosier National Forest[29]	Horses	Research investigates horse trail impacts to identify relationships between various levels of horse use, management alternatives, and factors that are most easily manipulated by managers to avoid/minimize horse trail impacts – e.g., gravel thickness of >3.5 inches combined with periodic grading can effectively minimize soil erosion on horse trails. Provides best management practices based on the research. *Limited wildlife guidance.*
Ten factors that affect the severity of environmental impacts of visitors in protected areas[100]	Various	Guidance for managing environmental impacts in terms of a site's conservation value, resistance and resilience of ecosystem and vegetation types, susceptibility to erosion, severity of direct and indirect impacts, likely amount of use, social and ecological aspects of timing of use, and total area likely to be affected. *Lacks wildlife guidance.*
The influence of use, environmental and managerial factors on the width of recreational trails[41]	Hiking trails	Research to evaluate the relative influences of use, managerial and environmental factors on trail width from a survey of all formal trails in Acadia National Park, Maine, USA. Study found differences in trail width based on trail surface type (class), and the presence or absence of trail borders. Potential guidance for trail design and implementation. *Lacks wildlife guidance.*
Trail construction and maintenance notebook[28]	Various	General Technical Report developed by the U.S. Forest service and transportation agencies. Includes information on trail design and building basics. Slightly out of date (for example, includes water bar recommendations). Substantial information on building trails in wet areas and crossing streams and rivers. *Lacks wildlife guidance.*
Trail design guidelines for Portland's park system[53]	Various	Includes specifications for a variety of trail types. *Limited wildlife guidance.*
Trail fundamentals and trail management objectives[517]	Various user groups	U.S. Forest Service's training reference package for trail design and construction. Standard soft surface trails, snow and water trails. *Excludes significant wildlife guidance.*
Trail planning, design, and development guidelines[518]	Various	Minnesota Department of Natural Resources guidance document. Fairly comprehensive how-to and best practices guidebook for developing all types of recreational trails. Some information is out of date (e.g., water bars). *Excludes significant wildlife guidance.*
Trail solutions: IMBA's guide to building sweet singletrack[87]	Mountain biking, but generally applicable to many user groups	Information-rich trail construction guidance document with sections on planning and designing trails, environmental considerations including water resources, managing user conflicts, partnerships, mountain bike patrols, signage, and more. *Incomplete wildlife review and limited guidance.*
Trails guidelines and best practices manual[89]	Various	Thorough guidance document including trail system planning, development, management, maintenance and monitory information. *Limited wildlife guidance.*

8.2 RECREATIONAL CARRYING CAPACITY AND VISITOR USE FRAMEWORKS

As human population and recreational demand increased during the 1960s through the 1980s, issues with over-crowding and environmental damage arose. Land managers began applying the concept of population carrying capacity – a line of inquiry more typical to wildlife studies – to humans in recreational settings.[519]

Recreational carrying capacity refers to the amount of recreational use a trail or site can support beyond which excessive environmental/biological damage, social and managerial issues, or decreased visitor experience may occur.[520] The idea is to identify social (recreationist) or ecological thresholds based on a predetermined set of standards which when exceeded, trigger specific management actions to reduce impacts.[17, 97, 98, 521]

> "Parks are to be used for outdoor recreation, but the impacts of use must not degrade park resources or experiences to the point that they cannot be enjoyed by future generations. The sustainability of parks for outdoor recreation must recognize these inherent limits (carrying capacities), and these limits are explicitly addressed in management-by-objectives frameworks in the form of standards for park resources and the visitor experience." (Manning et al. 2011)[1]

Watson et al. outlined the more technical components of a good sampling strategy for estimating visitor use.[522] D'Antonio et al.'s research paper presented techniques for estimating recreation use levels and outlined a socio-ecological approach that can be used by managers of smaller, local natural areas to balance dual missions of natural resource protection and managing for recreation use.[120]

However, the application of carrying capacity metrics used in either social or ecological approaches can be complex for several reasons.[520, 523] Sometimes the true carrying capacity limit is not recognized until it is been reached or exceeded.[96] Identifying the upper limits of carrying capacity can also be subjective because it depends on the goals of the land managers and their opinions on acceptable levels of impacts. In addition, there are many variables that can influence the environment (such as sensitivity of habitat, bad weather and landslides) or make recreational users feel crowded or infringed upon (such as adding a new user group when a site has traditionally only allowed hikers, or when a few disrespectful users create perceived conflicts at a site).

Due to these and other drawbacks, federal land managers identified the need for new frameworks that could address visitor use issues in more practical ways.[97] Recreational visitor use frameworks provide a common approach to planning for and managing visitor use at a recreational site. Rather than identifying specific numbers of allowable trail users, these frameworks generally place the primary emphasis on desired conditions at the site. For example, crowding and congestion along trails can lead to trail widening and vegetation loss when people step off trail to avoid other users; when these effects exceed a pre-defined standard, management actions may be triggered. The downside to such frameworks is that they usually fail to factor in wildlife disturbance issues (Table 6), thereby substantially underestimating visitor impacts.

We found numerous references describing, reviewing or evaluating carrying capacity or visitor use framework approaches.[1, 33, 47, 66, 93, 96, 115, 118, 519-521, 524-532] In 2007, Cline et al. reviewed management frameworks that address recreational carrying capacity.[97] All have the same primary components including a definition of recreation, associated indicators and standards of quality, monitoring indicator variables, and specific management actions to address issues identified through monitoring. Each framework also maintains environmental, social and managerial dimensions, although they generally do not provide specific guidance on wildlife. Examples of some of these frameworks include:

- Protected Area Visitor Impact Management Framework (VIM or PAVIM)[520, 528]
- Limits of Acceptable Change (LAC) developed by the U.S. Forest Service[33, 530]
- Visitor Experience and Resource Protection (VERP) developed by the U.S. Park Service [527, 529]
- Quality Upgrading and Learning (QUAL)[531]
- The new interagency Visitor Use Management Framework (see below)[528]

Table 3 in Cline's review summarizes the steps involved in three of the most commonly used methods - the VIM, LAC and VERP frameworks.[97] Farrell and Marion suggest that the PAVIM approach may be preferable to Limits of Acceptable Change and similar frameworks if managers lack sufficient funds and staff to collect and analyze data and the more intensive monitoring recommended under other frameworks.[520]

In 2016 a new *Visitor Use Management Framework,* co-published by six U.S. federal agencies, provides a detailed methodology that incorporates a "sliding scale" of effort to ensure that investment of time, funds and other resources aligns with project complexity and consequences of management decisions.[11][528] Under this approach, identifying carrying capacities is not always necessary. The document lays out specific steps to address four key elements: (1) building the foundation for the framework; (2) defining visitor use management direction; (3) identifying management strategies; and (4) implementing, monitoring, evaluating and adjusting management actions. Two companion guidance documents - the *Visitor Capacity Guidebook* and an *Indicators, Thresholds and Monitoring Guidebook* – were scheduled for release in 2016 but were not yet available at the time of this writing.

Any of these frameworks, possibly in simplified form for smaller sites or when low visitor use is anticipated, could be valuable to assist in managing recreational access, provided the framework contains site-specific management objectives, associated indicators, and specific thresholds (standards) that trigger specific management actions.[97] The common element is that indicators are measured and compared to established standards; if conditions do not meet the standards, management actions may be triggered in order to meet management objectives.

8.3 MONITORING APPROACHES

A strong monitoring and management framework can essentially increase a trail's or a site's carrying capacity by identifying and managing effects before they degrade the resource or jeopardize the visitor experience. On the other hand, such a framework may result in recommendations to reduce use, such as seasonal closures on specific trails or limiting trails and specific trail user groups to areas with less steep slopes. This section provides information on monitoring approaches that can be used to help guide site management.

Monitoring is the systematic collection of information to inform whether goals are being met. Monitoring goals, indicators and specific "not to exceed" thresholds (also known as targets or standards) are necessary to determine whether management actions are needed to stay below acceptable damage thresholds. An effective monitoring program can help identify issues before they become difficult or expensive to correct.

Visitor use frameworks include monitoring strategies (Section 8.2). Monitoring guidance is available for various user groups including hiking/general use,[42, 52, 56, 94] mountain biking[58, 86] and equestrian trails.[29, 94, 148] Houston reviewed monitoring approaches for Oregon State Parks and Recreation in 2012 and with an advisory group, developed a Rapid Trail Condition Assessment[533].

---

[11] See https://visitorusemanagement.nps.gov/VUM/Framework

When developing projects, monitoring frameworks typically recommend building in funds and staff time for monitoring and maintenance.[98, 527, 528, 534] One way to reduce the cost of monitoring is to engage partner organizations for studies and monitoring, as well as vegetation management.[534] Engaging residents as site stewards and "community [citizen] scientists" can be an excellent way to leverage limited resources and engage the public.[535]

Marion and others identified three general types of trail surveys to assist in managing trail systems:[56]

- Trail attribute inventory – use GPS units to map accurate GIS-based trail system characteristics. Can be used to map unauthorized and formal trails or other attributes such as views, use, etc. Assists mapping, planning, analytical and decision-making functions.
- Trail condition assessment – documents trail conditions and impact levels. Data can be compared against quantitative Limits of Acceptable Change/VERP type standards of quality or to determine where and how much trail conditions are changing over time. Typically uses point sampling and transect survey methods.
- Trail prescriptive management assessment – used to evaluate and document maintenance needs, sustainability attributes, use-type capabilities, and relocation options. Prescriptive maintenance work logs document the condition of or work needed on existing trail features, or the need for new features, including gates/barriers, bridges, signs, and tread drainage features such as grade dips and grade reversals.

Indicators and thresholds. Indicators are measurable, manageable variables that are proxies for management objectives. Common trail condition indicators include tread width, tread muddiness, erosion and incision. Thresholds, also known as standards or targets, define the minimum acceptable condition of indicators.[1] Thresholds are predetermined levels of the indicators which if exceeded, may trigger management actions. Thresholds should be set at or below acceptable, predetermined levels of visitor use effects, and should be responsive to trends in changing conditions as identified by monitoring.[528]

Selecting indicators and specific thresholds need not be overly complicated; it is most efficient to use as few indicators as possible to sufficiently inform management actions. The National Park Service (NPS) described eight characteristics of good indicators,[527] stating that they should:

- be specific – for example, instead of using "water quality," use "bacteria per volume of water"
- be objective rather than subjective
- be reliable and repeatable
- relate to visitor use – for example, levels of use, types of use, or behavior of visitor
- be sensitive to visitor use over a relatively short time period
- be responsive to, and help determine the effectiveness of, management action
- directly inform specific conditions related to management objectives
- not result in destructive resource impacts that would significantly detract from the quality of the visitor experience
- address prominent issues and management concerns, such as visitor impacts that could affect a natural area's purpose or significance

The National Park Service also suggests selecting indicators that are easy to measure, easy to train for monitoring, cost-effective, have minimal natural variability, show a gradient of conditions, have a large sampling time window, and can be compared to any past monitoring efforts' data.[527] Table 2 in Wimpey and Marion's monitoring protocols also provides a good summary of criteria for selecting indicators of resource condition.[98]

Table 7 provides some examples to aid in the thought process behind establishing indicators and thresholds. Thresholds and triggers should reflect site-specific "actionable items" in terms of trail management.

Table 7. Examples of indicators and thresholds to assess and address visitor effects.

Type of effect	Indicator example	Threshold example	Reference
Area of trail disturbance	The mean trail width times the trail length	Area of disturbance should not exceed (predetermined value) per unit of trail section	[536]
Cold-water fish	Population sampling of salmonids in stream during and following project implementation. (Comparing up- and downstream spawning conditions is also an option.)	No downward trend for more than 3 consecutive years.	[528]
Compaction and erosion	Percent of exposed soil	Percentage of exposed trail per predefined trail length should not exceed (predetermined value) %	[536]
Erosion	Hazard rating for soil erosion into stream at marked sections along the entire trail.	Soil erosion hazard rating will not exceed "low" in 80% of the water influence zone.	[528]
Excessive muddiness	Sections of trail with wet, muddy soils	Trail sections $\geq$ 10 feet that show imbedded foot or hoof prints $\geq$ 0.5 inches deep	[537]
Informal trails	Length per unit area, % of formal trail length, # per unit length on formal trails	Informal trails should not exceed (predetermined value)% percent of all trail lengths	[536]
Landscape fragmentation	Largest patch index; GIS-measured trail and site attributes.	Largest Patches Index Five (LPI5) of no more than 92.8%. Decreasing percentages will indicate an increased degree of fragmentation.	[94, 524]
Landscape fragmentation	Mean patch size; GIS-measured trail and site attributes.	Mean patch size should not fall below [select appropriate threshold for a given site][12]	[94]
Landscape fragmentation	Mean perimeter-area ratio; GIS-measured trail and site attributes.	Mean ratio should not fall below [select appropriate threshold for a given site][7]	[94]
Noise	"Soundscapes" as measured by the change in sound levels from natural ambient in areas more than 100 feet from roads or trails, and (2) the amount of time above speech interference thresholds in areas more than 100 feet from roads.[13]	Hourly change in sound levels not to exceed 3 dB.	[524]
Riparian effects	River bank erosion. Combination of vegetative cover condition and substrate erosion condition characteristics.	1. Channel morphology: <10% increase in cross-sectional area due to bank scour in 80% of sites. 2. Vegetation condition: <10% cover of bare ground in 80% of sites [or trail reaches].	[524]
Trail widening	Cross sectional area; maximum value, value/unit length, running average/unit length	Hiking trails at site should not exceed (predetermined value) feet in width	[536]

[12] Could be used for planning purposes to determine potential fragmenting effects from different trail alignments.

[13] The researchers proposed this method for impacts of road noise on ability for trail users to converse/hear each other, but this could also be used to gauge potential noise impacts from trail users on wildlife.

Type of effect	Indicator example	Threshold example	Reference
Water quality	Instream water quality based on official water quality standards	Water quality will not come within 5% of the listed State Department of Public Health and Environment and forest plan water quality standards.[14]	[528]
Water quality	Benthic invertebrates – sensitive taxa or Index of Biotic Integrity (IBI) above and below stream crossings, bridges or culverts.[15]	Reduction in below-crossing IBI values of a pre-determined percent, or in # sensitive taxa, or sensitive/non-sensitive taxa ratio.	[196]
Water-related effects	Unauthorized trail stream crossings.	Of the existing unauthorized trails, none leads to stream crossings in the lower third of the drainage/creek where salmon spawn.	[528]

8.4 ADDRESSING UNAUTHORIZED TRAILS

Monitoring and managing unauthorized trails is important because effects at a given site can be severe and widespread (Chapter 3). The literature we reviewed suggests several approaches to avoid or reduce possible negative environmental effects due to the creation and use of unauthorized trails. These include determining why the trails were created, monitoring the site for unauthorized trails, prioritizing their removal, and avoiding future creation (or re-creation) of such trails.

Understanding the circumstances for unauthorized trail creation can help guide effective management actions and reduce the likelihood of such trails in the future.[133] Unauthorized trails are created for a variety of purposes (Chapter 3), including valid reasons such as safety or to avoid overly challenging or muddy areas.[29, 57, 66, 77] In other cases unauthorized trails are created to access special features such as views, streams and wetlands. Indistinct trails can lead to accidental trail proliferation, particularly in rocky areas.[57] Good trail design can help alleviate some of these more predictable issues. However, some effects such as bathroom stops and trails from peoples' back yards are less predictable.

Trail designs can avoid some of these issues through trail placement or by providing limited formal access to sensitive areas where people tend to want to go anyway. For example, designing trails along side slopes rather than in the floodplain, or installing sufficient depths and types of gravel, can reduce the need for people to step off trails to avoid mud.[29, 57] Strategically including short spur trails to access sensitive habitat areas or view points in the initial trail design can reduce or eliminate the need for damaging unauthorized trails in these areas[37, 93, 533] Signage for views such as "photo point" can draw users to these formal spur trails.[93, 538]

When prioritizing which unauthorized trails to address first, consider focusing on the most sensitive habitat or wildlife areas first.[133] Once located, there are two options for addressing an unauthorized trail. The first is to close it using physical barriers (e.g., brush piles or logs) and restoration, with signage and education as needed.[133] The second option is to recognize that in some situations, an unauthorized trail is in an appropriate area or is likely to be re-created. In such cases land managers can incorporate the unauthorized trail into the formal trail system and take measures to ensure the trail design and surface are sustainable.

[14] Continuous or ongoing (e.g., weekly) monitoring will provide more accurate measures of change than grab samples.

[15] IBIs based on "reference conditions" in pristine areas may not be sensitive enough to detect site-level changes in disturbed areas; in some cases measures such as sensitive/non-sensitive taxa ratios may better reflect local condition changes.

Collaborative management approaches. One way to reduce unauthorized trails is to partner with user groups in collaborative-based recreation management to monitor and "self-police" inappropriate trail creation or use.[133, 534] Volunteer site stewards can also help identify emerging problems with unauthorized trails.[524] For example, in Oregon's Black Rock Forest the Oregon Department of Forestry partnered with the Black Rock Mountain Biking Association to address ongoing issues at the site.[534] The approach improved communication; it also provided opportunities to pool resources to protect sensitive areas and create improved recreational opportunities at reduced costs to the land manager. The collaborative group identified the following key processes and practices that influence the ability to improve environmental outcomes:

- Leave fundamental value differences out of the decision-making process.
- Strive to create an inclusive atmosphere.
- Write specific agreements and plan for ongoing communication while maintaining open communication.
- Hold formal annual meetings.
- Provide quality leadership.
- Meet onsite to review past and present projects.

Under this collaborative management approach, the Black Rock Mountain Biking Association's daily visits to the site have virtually eliminated the construction of unauthorized trails.

Monitoring for unauthorized trails. Without a monitoring approach in place, unauthorized trails can proliferate unbeknownst to land managers. Assessments of unauthorized trails can provide managers with spatial data to assist in identifying, prioritizing and managing these unwanted features. The City of Boulder report[57] and other references [52, 56, 98, 137, 539] include information on locating and correcting unauthorized trails, and Table 7 includes some examples of indicators and thresholds related to unauthorized trails and habitat fragmentation. Methodologies typically include GIS-assisted field work to map trails, field work to assess the condition of these trails such as where soil erosion is beginning or prevalent, and prioritizing removal based on habitat sensitivity, condition class or fragmentation metrics. Table 4 in Marion and Leung's *Indicators and protocols for monitoring impacts of formal and informal trails in protected areas* used the following metrics for both formal and unauthorized trails, both in the same table for comparison: aggregate length of trail, disturbance area, disturbance density, number of patches and mean patch size. The latter two are fragmentation metrics.

Practices to deter future creation (or re-creation) of unauthorized trails. The literature we reviewed included several approaches to avoid unauthorized trail creation at a site. For example, trail users are less likely to go off trail in heavily vegetated areas,[540] therefore planting shrubs and trees in problematic areas may be an effective deterrent, and would also improve wildlife habitat. Park et al. suggested using an integrated suite of direct (e.g., closing trails; uniformed rangers for enforcement) and indirect (e.g., educational) management practices to control unauthorized trail creation and use.[93] Employing signage and educational information specifically at natural area points of entry and at the head of unauthorized trails can help reduce impacts (Section 8.9). In very problematic areas such as key sensitive species locations, it may be effective to install cameras and post "under video surveillance" type signs to make clear that users are being monitored.[541]

8.5 PROTECTING RIPARIAN HABITAT AND WATER QUALITY

Trails in riparian areas or that cross streams can damage habitat and impair water quality. Practices to reduce effects on these sensitive resources are available in the literature.[28, 29, 40, 53, 90, 509, 542, 543] Some of the practices in Metro's *Green Trails* guidebook[43] include the following general suggestions (additional references are included for more detailed information):

- Rather than placing a trail along a stream, consider routing the trail outside of the riparian area and creating a spur trail(s) to the stream.[37]
- Minimize the number of stream crossings.[37] The U.S. Forest Service trail construction guidance document includes best practices for stream and river crossings.[28]
- Use fish-[509, 542] and wildlife-friendly[543] culvert designs.
- A raised trail in a wet area, such as a boardwalk, will keep people on the trail.[18, 88, 97]

The literature revealed other potentially useful recommendations to protect streams and riparian areas. For example, Colorado State Parks recommends avoiding crossings at or near stream confluences,[37] which are particularly ecologically sensitive. Marion and Wimpey suggest scouting streams carefully for the most resistant location such as rocky banks, and designing water crossings so the trail descends into and climbs out of the stream crossing, preventing stream water from flowing down the trail.[18] The City of Portland's trail design guidelines recommends installing dense shrub plantings, brush piles, or carefully designed fencing where trails intersect waterways to deter trail users from denuding streambanks and eroding soil, and states that bridges are preferable to culverts for stream crossings.[53, 88] Aust and others suggest designing water drainage from trails in riparian areas in a thin sheet flow that, prior to reaching water resources, travels through >15 horizontal feet of organic litter and vegetation to settle out or filter soil particles.[29]

When stream crossing structures are required, the City of Portland's *Trail Design Guidelines* offers guidance including design schematics for boardwalks, bridges and culverts as well as methods to avoid soil loss in riparian areas.[53] Blinn et al. provide forestry-based ideas for temporary stream and wetland crossings using some innovative approaches,[544] and Neese et al.'s publication includes guidance on floating trail bridges and docks.[545] We aren't necessarily endorsing these approaches; each site is different. The primary considerations for any stream or wetland crossing design should be to protect riparian vegetation, streambanks and shorelines, maintain or improve water quality, and provide appropriate wildlife passage. The Forest Services' TRACS assessment provides guidance on monitoring the conditions of various stream crossing structures over time.[52]

Sometimes trail construction can help improve wildlife passage. For example, the Lakeside underpass in Portland, Oregon was designed to accommodate a future trail.[543] Collaboration between scientists, transportation and trails planners resulted in relatively inexpensive modifications to improve wildlife passage including natural substrate, rock shelves to provide passage during high water flow, and elevated sidewalks. Metro's *Wildlife crossings: Providing safe passage for urban wildlife*[543] and wildlife corridors literature review[445] provide additional information on wildlife crossing structures and connectivity.

Climate change is expected to alter hydrology in some areas, including more intense rain storms in the Pacific Northwest.[546] Sizing culverts, bridges and crossings with this in mind can help preserve valuable infrastructure. More intense storms can also lead to additional trail damage; taking extra measures to avoid future erosion, such as adding deeper gravel in some areas than suggested in design specifications, may reduce future trail maintenance needs. The potential for larger floods – where standing water is likely to remain for some time due to sheer water volume – also argues for keeping trails out of floodplains, because trails are likely to be underwater more frequently as our climate changes.

8.6 MINIMIZING FRAGMENTATION AND EDGE EFFECTS

As described in Section 5.2, trails and trail use can cause habitat fragmentation and edge effects. Building any trail is likely to cause some environmental effects[58] therefore if recreation is to be introduced to a site, the most direct way to reduce these types of environmental effects is to keep the total lengths of trails in a natural area to the minimum needed to meet recreational demand and provide a quality visitor experience. This would have the added value of reducing unauthorized trails, which are frequently associated with formal trails (Chapter 3).

Figure 7. The Lakeside pedestrian and wildlife undercrossing in Portland, Oregon.

The majority of the guidance documents in Table 6 lack substantive recommendations on how to protect sensitive habitat areas, wildlife, and ways to reduce habitat fragmentation and edge effects. Such guidance documents are written from the perspective of trail planners and recreational site managers and naturally focus on trail construction, maintenance and the visitor experience. Similarly, wildlife biologists and natural resource staff would be expected to focus on protecting natural resources. The keys to achieving the goals of both groups are communication and informed compromise.

In 2004 Metro published *Green trails: Guidelines for environmentally friendly trails*.[43] Along with other natural resource related guidance the document includes the following general principles to use, as much as is feasible, for planning trails to preserve sensitive natural resources and minimize habitat fragmentation:

- Keep trails to a minimum
- Use existing disturbance corridors[16]
- Locate trails at habitat edges rather than through the middle of a habitat patch
- Keep trails out of core[17] habitat areas
- Maintain habitat connectivity and avoid placing trails in small patches of high-quality connector habitat
- Avoid habitat for threatened, endangered and sensitive species

How much habitat is enough? When routing trails through a natural area, leaving some larger undisturbed core habitat areas can benefit a variety of area-sensitive wildlife species. Figure 8 provides examples of typical area requirements for some wildlife species, derived from Metro's 2010 *Wildlife corridors and permeability* literature review.[445] Although not reflected in Figure 8, large carnivores are generally disturbance-sensitive and require large habitat patches, as discussed in Section 7.4.

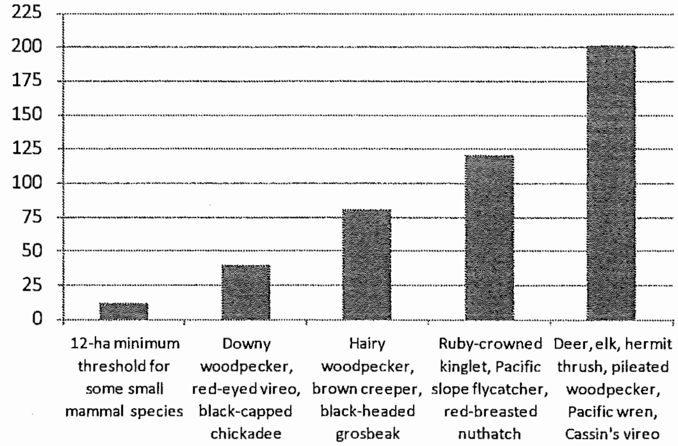
---

[16] Disturbance corridors include existing or abandoned rail lines, powerline corridors, old farm or forest roads, unauthorized trails when appropriate, right of way corridors, swaths adjacent to roadways, construction routes over buried utilities, utility maintenance access routes, and routes to quarries.

[17] Examples of core habitats include areas containing state- or federally-listed sensitive, threatened or endangered plant or animal species, exemplary natural communities, or exceptional native diversity. Large habitat patches are often considered core habitat because they can support more species and tend to have better habitat conditions compared to small patches.

Minimizing invasive species. Issues with invasive species associated with trail building and trail use are discussed in Section 5.3. Preventing the introduction of invasive species is critical because once introduced, it can be expensive to treat them [18] and they cannot always be fully eradicated, thereby raising the risk of distributing seeds to other sites via visitors, wildlife, wind or water. There is often a time lag between when seeds are first transported to a natural area and serious invasive species infestations,[224] thus regular monitoring and treatment for problem species and areas can help lower the severity of the problem.

Figure 8. Typical habitat size requirements for selected wildlife species (hectares)



Best practices to decrease invasive species seed loads include ensuring that natural area management staff and contractors follow best practices including cleaning boots, equipment and machinery;[30, 216] practicing Early Detection-Rapid Response (EDRR) before, during and after building trails, which can significantly reduce weed management costs;[30] minimizing soil disturbance;[30] using an Integrated Pest Management Plan (IPM), which can also reduce the need for pesticides;[30] and retaining tree and shrub cover to shade out invasives.[98] Another way to prevent establishment of invasive species is to educate visitors to be aware of their ability to carry non-native plant seeds on their bikes or clothing, and encourage them to remove seeds by washing mud from bikes, tires, shoes, and clothing.[30, 157] The latter may include installing trailhead educational signage (Section 8.9) and "clean your boots" and "clean your tires" stations.[30, 74, 228]

Cal-IPC's invasive species prevention manual provides a wealth of invasive species management information.[30] This guidebook states the following overall principles for preventing invasions:

- **Take time to plan.** Proper planning can reduce future maintenance costs by reducing the potential for invasive plant introduction and spread. A good first step is to conduct a pre-activity assessment of the work area to determine which activities could spread weeds and which best practices are applicable.
- **Stop movement of invasive plant materials and seeds.** The movement of workers, materials and equipment can carry weeds within and between sites. The CAL_IPC manual identifies potential vectors of spread and how to eliminate them or reduce their effects.
- **Reduce soil and vegetation disturbance.** Disturbance can allow invasive plants to colonize a new area. When disturbance is unavoidable, managers should conduct follow-up monitoring to ensure early detection of any invasive plants that may have been introduced.
- **Maintain desired plant communities.** A healthy plant community with native and desirable species provides resistance to invasive plant establishment.

8.2 RECREATIONAL CARRYING CAPACITY AND VISITOR USE FRAMEWORKS

As human population and recreational demand increased during the 1960s through the 1980s, issues with over-crowding and environmental damage arose. Land managers began applying the concept of population carrying capacity – a line of inquiry more typical to wildlife studies – to humans in recreational settings.[519]

Recreational carrying capacity refers to the amount of recreational use a trail or site can support beyond which excessive environmental/biological damage, social and managerial issues, or decreased visitor experience may occur.[520] The idea is to identify social (recreationist) or ecological thresholds based on a predetermined set of standards which when exceeded, trigger specific management actions to reduce impacts.[17, 97, 98, 521]

> "Parks are to be used for outdoor recreation, but the impacts of use must not degrade park resources or experiences to the point that they cannot be enjoyed by future generations. The sustainability of parks for outdoor recreation must recognize these inherent limits (carrying capacities), and these limits are explicitly addressed in management-by-objectives frameworks in the form of standards for park resources and the visitor experience." (Manning et al. 2011)[1]

Watson et al. outlined the more technical components of a good sampling strategy for estimating visitor use.[522] D'Antonio et al.'s research paper presented techniques for estimating recreation use levels and outlined a socio-ecological approach that can be used by managers of smaller, local natural areas to balance dual missions of natural resource protection and managing for recreation use.[120]

However, the application of carrying capacity metrics used in either social or ecological approaches can be complex for several reasons.[520, 523] Sometimes the true carrying capacity limit is not recognized until it is been reached or exceeded.[96] Identifying the upper limits of carrying capacity can also be subjective because it depends on the goals of the land managers and their opinions on acceptable levels of impacts. In addition, there are many variables that can influence the environment (such as sensitivity of habitat, bad weather and landslides) or make recreational users feel crowded or infringed upon (such as adding a new user group when a site has traditionally only allowed hikers, or when a few disrespectful users create perceived conflicts at a site).

Due to these and other drawbacks, federal land managers identified the need for new frameworks that could address visitor use issues in more practical ways.[97] Recreational visitor use frameworks provide a common approach to planning for and managing visitor use at a recreational site. Rather than identifying specific numbers of allowable trail users, these frameworks generally place the primary emphasis on desired conditions at the site. For example, crowding and congestion along trails can lead to trail widening and vegetation loss when people step off trail to avoid other users; when these effects exceed a pre-defined standard, management actions may be triggered. The downside to such frameworks is that they usually fail to factor in wildlife disturbance issues (Table 6), thereby substantially underestimating visitor impacts.

We found numerous references describing, reviewing or evaluating carrying capacity or visitor use framework approaches.[1, 33, 47, 66, 93, 96, 115, 118, 519-521, 524-532] In 2007, Cline et al. reviewed management frameworks that address recreational carrying capacity.[97] All have the same primary components including a definition of recreation, associated indicators and standards of quality, monitoring indicator variables, and specific management actions to address issues identified through monitoring. Each framework also maintains environmental, social and managerial dimensions, although they generally do not provide specific guidance on wildlife. Examples of some of these frameworks include:

- Protected Area Visitor Impact Management Framework (VIM or PAVIM)[520, 528]
- Limits of Acceptable Change (LAC) developed by the U.S. Forest Service[33, 530]
- Visitor Experience and Resource Protection (VERP) developed by the U.S. Park Service [527, 529]
- Quality Upgrading and Learning (QUAL)[531]
- The new interagency Visitor Use Management Framework (see below)[528]

Table 3 in Cline's review summarizes the steps involved in three of the most commonly used methods - the VIM, LAC and VERP frameworks.[97] Farrell and Marion suggest that the PAVIM approach may be preferable to Limits of Acceptable Change and similar frameworks if managers lack sufficient funds and staff to collect and analyze data and the more intensive monitoring recommended under other frameworks.[520]

In 2016 a new *Visitor Use Management Framework*, co-published by six U.S. federal agencies, provides a detailed methodology that incorporates a "sliding scale" of effort to ensure that investment of time, funds and other resources aligns with project complexity and consequences of management decisions.[11][528] Under this approach, identifying carrying capacities is not always necessary. The document lays out specific steps to address four key elements: (1) building the foundation for the framework; (2) defining visitor use management direction; (3) identifying management strategies; and (4) implementing, monitoring, evaluating and adjusting management actions. Two companion guidance documents - the *Visitor Capacity Guidebook* and an *Indicators, Thresholds and Monitoring Guidebook* – were scheduled for release in 2016 but were not yet available at the time of this writing.

Any of these frameworks, possibly in simplified form for smaller sites or when low visitor use is anticipated, could be valuable to assist in managing recreational access, provided the framework contains site-specific management objectives, associated indicators, and specific thresholds (standards) that trigger specific management actions.[97] The common element is that indicators are measured and compared to established standards; if conditions do not meet the standards, management actions may be triggered in order to meet management objectives.

8.3 MONITORING APPROACHES

A strong monitoring and management framework can essentially increase a trail's or a site's carrying capacity by identifying and managing effects before they degrade the resource or jeopardize the visitor experience. On the other hand, such a framework may result in recommendations to reduce use, such as seasonal closures on specific trails or limiting trails and specific trail user groups to areas with less steep slopes. This section provides information on monitoring approaches that can be used to help guide site management.

Monitoring is the systematic collection of information to inform whether goals are being met. Monitoring goals, indicators and specific "not to exceed" thresholds (also known as targets or standards) are necessary to determine whether management actions are needed to stay below acceptable damage thresholds. An effective monitoring program can help identify issues before they become difficult or expensive to correct.

Visitor use frameworks include monitoring strategies (Section 8.2). Monitoring guidance is available for various user groups including hiking/general use,[42, 52, 56, 94] mountain biking[58, 86] and equestrian trails.[29, 94, 148] Houston reviewed monitoring approaches for Oregon State Parks and Recreation in 2012 and with an advisory group, developed a Rapid Trail Condition Assessment[533].

[11] See https://visitorusemanagement.nps.gov/VUM/Framework

When developing projects, monitoring frameworks typically recommend building in funds and staff time for monitoring and maintenance.[98, 527, 528, 534] One way to reduce the cost of monitoring is to engage partner organizations for studies and monitoring, as well as vegetation management.[534] Engaging residents as site stewards and "community [citizen] scientists" can be an excellent way to leverage limited resources and engage the public.[535]

Marion and others identified three general types of trail surveys to assist in managing trail systems:[56]

- Trail attribute inventory – use GPS units to map accurate GIS-based trail system characteristics. Can be used to map unauthorized and formal trails or other attributes such as views, use, etc. Assists mapping, planning, analytical and decision-making functions.
- Trail condition assessment – documents trail conditions and impact levels. Data can be compared against quantitative Limits of Acceptable Change/VERP type standards of quality or to determine where and how much trail conditions are changing over time. Typically uses point sampling and transect survey methods.
- Trail prescriptive management assessment – used to evaluate and document maintenance needs, sustainability attributes, use-type capabilities, and relocation options. Prescriptive maintenance work logs document the condition of or work needed on existing trail features, or the need for new features, including gates/barriers, bridges, signs, and tread drainage features such as grade dips and grade reversals.

Indicators and thresholds. Indicators are measurable, manageable variables that are proxies for management objectives. Common trail condition indicators include tread width, tread muddiness, erosion and incision. Thresholds, also known as standards or targets, define the minimum acceptable condition of indicators.[1] Thresholds are predetermined levels of the indicators which if exceeded, may trigger management actions. Thresholds should be set at or below acceptable, predetermined levels of visitor use effects, and should be responsive to trends in changing conditions as identified by monitoring.[528]

Selecting indicators and specific thresholds need not be overly complicated; it is most efficient to use as few indicators as possible to sufficiently inform management actions. The National Park Service (NPS) described eight characteristics of good indicators,[527] stating that they should:

- be specific – for example, instead of using "water quality," use "bacteria per volume of water"
- be objective rather than subjective
- be reliable and repeatable
- relate to visitor use – for example, levels of use, types of use, or behavior of visitor
- be sensitive to visitor use over a relatively short time period
- be responsive to, and help determine the effectiveness of, management action
- directly inform specific conditions related to management objectives
- not result in destructive resource impacts that would significantly detract from the quality of the visitor experience
- address prominent issues and management concerns, such as visitor impacts that could affect a natural area's purpose or significance

The National Park Service also suggests selecting indicators that are easy to measure, easy to train for monitoring, cost-effective, have minimal natural variability, show a gradient of conditions, have a large sampling time window, and can be compared to any past monitoring efforts' data.[527] Table 2 in Wimpey and Marion's monitoring protocols also provides a good summary of criteria for selecting indicators of resource condition.[98]

Table 7 provides some examples to aid in the thought process behind establishing indicators and thresholds. Thresholds and triggers should reflect site-specific "actionable items" in terms of trail management.

Table 7. Examples of indicators and thresholds to assess and address visitor effects.

Type of effect	Indicator example	Threshold example	Reference
Area of trail disturbance	The mean trail width times the trail length	Area of disturbance should not exceed (predetermined value) per unit of trail section	[536]
Cold-water fish	Population sampling of salmonids in stream during and following project implementation. (Comparing up- and downstream spawning conditions is also an option.)	No downward trend for more than 3 consecutive years.	[528]
Compaction and erosion	Percent of exposed soil	Percentage of exposed trail per predefined trail length should not exceed (predetermined value) %	[536]
Erosion	Hazard rating for soil erosion into stream at marked sections along the entire trail.	Soil erosion hazard rating will not exceed "low" in 80% of the water influence zone.	[528]
Excessive muddiness	Sections of trail with wet, muddy soils	Trail sections $\geq$ 10 feet that show imbedded foot or hoof prints $\geq$ 0.5 inches deep	[537]
Informal trails	Length per unit area, % of formal trail length, # per unit length on formal trails	Informal trails should not exceed (predetermined value)% percent of all trail lengths	[536]
Landscape fragmentation	Largest patch index; GIS-measured trail and site attributes.	Largest Patches Index Five (LPI5) of no more than 92.8%. Decreasing percentages will indicate an increased degree of fragmentation.	[94, 524]
Landscape fragmentation	Mean patch size; GIS-measured trail and site attributes.	Mean patch size should not fall below [select appropriate threshold for a given site][12]	[94]
Landscape fragmentation	Mean perimeter-area ratio; GIS-measured trail and site attributes.	Mean ratio should not fall below [select appropriate threshold for a given site][7]	[94]
Noise	"Soundscapes" as measured by the change in sound levels from natural ambient in areas more than 100 feet from roads or trails, and (2) the amount of time above speech interference thresholds in areas more than 100 feet from roads.[13]	Hourly change in sound levels not to exceed 3 dB.	[524]
Riparian effects	River bank erosion. Combination of vegetative cover condition and substrate erosion condition characteristics.	1. Channel morphology: <10% increase in cross-sectional area due to bank scour in 80% of sites. 2. Vegetation condition: <10% cover of bare ground in 80% of sites [or trail reaches].	[524]
Trail widening	Cross sectional area; maximum value, value/unit length, running average/unit length	Hiking trails at site should not exceed (predetermined value) feet in width	[536]

[12] Could be used for planning purposes to determine potential fragmenting effects from different trail alignments.

[13] The researchers proposed this method for impacts of road noise on ability for trail users to converse/hear each other, but this could also be used to gauge potential noise impacts from trail users on wildlife.

Type of effect	Indicator example	Threshold example	Reference
Water quality	Instream water quality based on official water quality standards	Water quality will not come within 5% of the listed State Department of Public Health and Environment and forest plan water quality standards.[14]	[528]
Water quality	Benthic invertebrates – sensitive taxa or Index of Biotic Integrity (IBI) above and below stream crossings, bridges or culverts.[15]	Reduction in below-crossing IBI values of a pre-determined percent, or in # sensitive taxa, or sensitive/non-sensitive taxa ratio.	[196]
Water-related effects	Unauthorized trail stream crossings.	Of the existing unauthorized trails, none leads to stream crossings in the lower third of the drainage/creek where salmon spawn.	[528]

8.4 ADDRESSING UNAUTHORIZED TRAILS

Monitoring and managing unauthorized trails is important because effects at a given site can be severe and widespread (Chapter 3). The literature we reviewed suggests several approaches to avoid or reduce possible negative environmental effects due to the creation and use of unauthorized trails. These include determining why the trails were created, monitoring the site for unauthorized trails, prioritizing their removal, and avoiding future creation (or re-creation) of such trails.

Understanding the circumstances for unauthorized trail creation can help guide effective management actions and reduce the likelihood of such trails in the future.[133] Unauthorized trails are created for a variety of purposes (Chapter 3), including valid reasons such as safety or to avoid overly challenging or muddy areas.[29, 57, 66, 77] In other cases unauthorized trails are created to access special features such as views, streams and wetlands. Indistinct trails can lead to accidental trail proliferation, particularly in rocky areas.[57] Good trail design can help alleviate some of these more predictable issues. However, some effects such as bathroom stops and trails from peoples' back yards are less predictable.

Trail designs can avoid some of these issues through trail placement or by providing limited formal access to sensitive areas where people tend to want to go anyway. For example, designing trails along side slopes rather than in the floodplain, or installing sufficient depths and types of gravel, can reduce the need for people to step off trails to avoid mud.[29, 57] Strategically including short spur trails to access sensitive habitat areas or view points in the initial trail design can reduce or eliminate the need for damaging unauthorized trails in these areas[37, 93, 533] Signage for views such as "photo point" can draw users to these formal spur trails.[93, 538]

When prioritizing which unauthorized trails to address first, consider focusing on the most sensitive habitat or wildlife areas first.[133] Once located, there are two options for addressing an unauthorized trail. The first is to close it using physical barriers (e.g., brush piles or logs) and restoration, with signage and education as needed.[133] The second option is to recognize that in some situations, an unauthorized trail is in an appropriate area or is likely to be re-created. In such cases land managers can incorporate the unauthorized trail into the formal trail system and take measures to ensure the trail design and surface are sustainable.

[14] Continuous or ongoing (e.g., weekly) monitoring will provide more accurate measures of change than grab samples.

[15] IBIs based on "reference conditions" in pristine areas may not be sensitive enough to detect site-level changes in disturbed areas; in some cases measures such as sensitive/non-sensitive taxa ratios may better reflect local condition changes.

Collaborative management approaches. One way to reduce unauthorized trails is to partner with user groups in collaborative-based recreation management to monitor and "self-police" inappropriate trail creation or use.[133, 534] Volunteer site stewards can also help identify emerging problems with unauthorized trails.[524] For example, in Oregon's Black Rock Forest the Oregon Department of Forestry partnered with the Black Rock Mountain Biking Association to address ongoing issues at the site.[534] The approach improved communication; it also provided opportunities to pool resources to protect sensitive areas and create improved recreational opportunities at reduced costs to the land manager. The collaborative group identified the following key processes and practices that influence the ability to improve environmental outcomes:

- Leave fundamental value differences out of the decision-making process.
- Strive to create an inclusive atmosphere.
- Write specific agreements and plan for ongoing communication while maintaining open communication.
- Hold formal annual meetings.
- Provide quality leadership.
- Meet onsite to review past and present projects.

Under this collaborative management approach, the Black Rock Mountain Biking Association's daily visits to the site have virtually eliminated the construction of unauthorized trails.

Monitoring for unauthorized trails. Without a monitoring approach in place, unauthorized trails can proliferate unbeknownst to land managers. Assessments of unauthorized trails can provide managers with spatial data to assist in identifying, prioritizing and managing these unwanted features. The City of Boulder report[57] and other references [52, 56, 98, 137, 539] include information on locating and correcting unauthorized trails, and Table 7 includes some examples of indicators and thresholds related to unauthorized trails and habitat fragmentation. Methodologies typically include GIS-assisted field work to map trails, field work to assess the condition of these trails such as where soil erosion is beginning or prevalent, and prioritizing removal based on habitat sensitivity, condition class or fragmentation metrics. Table 4 in Marion and Leung's *Indicators and protocols for monitoring impacts of formal and informal trails in protected areas* used the following metrics for both formal and unauthorized trails, both in the same table for comparison: aggregate length of trail, disturbance area, disturbance density, number of patches and mean patch size. The latter two are fragmentation metrics.

Practices to deter future creation (or re-creation) of unauthorized trails. The literature we reviewed included several approaches to avoid unauthorized trail creation at a site. For example, trail users are less likely to go off trail in heavily vegetated areas,[540] therefore planting shrubs and trees in problematic areas may be an effective deterrent, and would also improve wildlife habitat. Park et al. suggested using an integrated suite of direct (e.g., closing trails; uniformed rangers for enforcement) and indirect (e.g., educational) management practices to control unauthorized trail creation and use.[93] Employing signage and educational information specifically at natural area points of entry and at the head of unauthorized trails can help reduce impacts (Section 8.9). In very problematic areas such as key sensitive species locations, it may be effective to install cameras and post "under video surveillance" type signs to make clear that users are being monitored.[541]

8.5 PROTECTING RIPARIAN HABITAT AND WATER QUALITY

Trails in riparian areas or that cross streams can damage habitat and impair water quality. Practices to reduce effects on these sensitive resources are available in the literature.[28, 29, 40, 53, 90, 509, 542, 543] Some of the practices in Metro's *Green Trails* guidebook[43] include the following general suggestions (additional references are included for more detailed information):

- Rather than placing a trail along a stream, consider routing the trail outside of the riparian area and creating a spur trail(s) to the stream.[37]
- Minimize the number of stream crossings.[37] The U.S. Forest Service trail construction guidance document includes best practices for stream and river crossings.[28]
- Use fish-[509, 542] and wildlife-friendly[543] culvert designs.
- A raised trail in a wet area, such as a boardwalk, will keep people on the trail.[18, 88, 97]

The literature revealed other potentially useful recommendations to protect streams and riparian areas. For example, Colorado State Parks recommends avoiding crossings at or near stream confluences,[37] which are particularly ecologically sensitive. Marion and Wimpey suggest scouting streams carefully for the most resistant location such as rocky banks, and designing water crossings so the trail descends into and climbs out of the stream crossing, preventing stream water from flowing down the trail.[18] The City of Portland's trail design guidelines recommends installing dense shrub plantings, brush piles, or carefully designed fencing where trails intersect waterways to deter trail users from denuding streambanks and eroding soil, and states that bridges are preferable to culverts for stream crossings.[53, 88] Aust and others suggest designing water drainage from trails in riparian areas in a thin sheet flow that, prior to reaching water resources, travels through >15 horizontal feet of organic litter and vegetation to settle out or filter soil particles.[29]

When stream crossing structures are required, the City of Portland's *Trail Design Guidelines* offers guidance including design schematics for boardwalks, bridges and culverts as well as methods to avoid soil loss in riparian areas.[53] Blinn et al. provide forestry-based ideas for temporary stream and wetland crossings using some innovative approaches,[544] and Neese et al.'s publication includes guidance on floating trail bridges and docks.[545] We aren't necessarily endorsing these approaches; each site is different. The primary considerations for any stream or wetland crossing design should be to protect riparian vegetation, streambanks and shorelines, maintain or improve water quality, and provide appropriate wildlife passage. The Forest Services' TRACS assessment provides guidance on monitoring the conditions of various stream crossing structures over time.[52]

Sometimes trail construction can help improve wildlife passage. For example, the Lakeside underpass in Portland, Oregon was designed to accommodate a future trail.[543] Collaboration between scientists, transportation and trails planners resulted in relatively inexpensive modifications to improve wildlife passage including natural substrate, rock shelves to provide passage during high water flow, and elevated sidewalks. Metro's *Wildlife crossings: Providing safe passage for urban wildlife*[543] and wildlife corridors literature review[445] provide additional information on wildlife crossing structures and connectivity.

Climate change is expected to alter hydrology in some areas, including more intense rain storms in the Pacific Northwest.[546] Sizing culverts, bridges and crossings with this in mind can help preserve valuable infrastructure. More intense storms can also lead to additional trail damage; taking extra measures to avoid future erosion, such as adding deeper gravel in some areas than suggested in design specifications, may reduce future trail maintenance needs. The potential for larger floods – where standing water is likely to remain for some time due to sheer water volume – also argues for keeping trails out of floodplains, because trails are likely to be underwater more frequently as our climate changes.

8.6 MINIMIZING FRAGMENTATION AND EDGE EFFECTS

As described in Section 5.2, trails and trail use can cause habitat fragmentation and edge effects. Building any trail is likely to cause some environmental effects[58] therefore if recreation is to be introduced to a site, the most direct way to reduce these types of environmental effects is to keep the total lengths of trails in a natural area to the minimum needed to meet recreational demand and provide a quality visitor experience. This would have the added value of reducing unauthorized trails, which are frequently associated with formal trails (Chapter 3).

Figure 7. The Lakeside pedestrian and wildlife undercrossing in Portland, Oregon.

The majority of the guidance documents in Table 6 lack substantive recommendations on how to protect sensitive habitat areas, wildlife, and ways to reduce habitat fragmentation and edge effects. Such guidance documents are written from the perspective of trail planners and recreational site managers and naturally focus on trail construction, maintenance and the visitor experience. Similarly, wildlife biologists and natural resource staff would be expected to focus on protecting natural resources. The keys to achieving the goals of both groups are communication and informed compromise.

In 2004 Metro published *Green trails: Guidelines for environmentally friendly trails*.[43] Along with other natural resource related guidance the document includes the following general principles to use, as much as is feasible, for planning trails to preserve sensitive natural resources and minimize habitat fragmentation:

- Keep trails to a minimum
- Use existing disturbance corridors[16]
- Locate trails at habitat edges rather than through the middle of a habitat patch
- Keep trails out of core[17] habitat areas
- Maintain habitat connectivity and avoid placing trails in small patches of high-quality connector habitat
- Avoid habitat for threatened, endangered and sensitive species

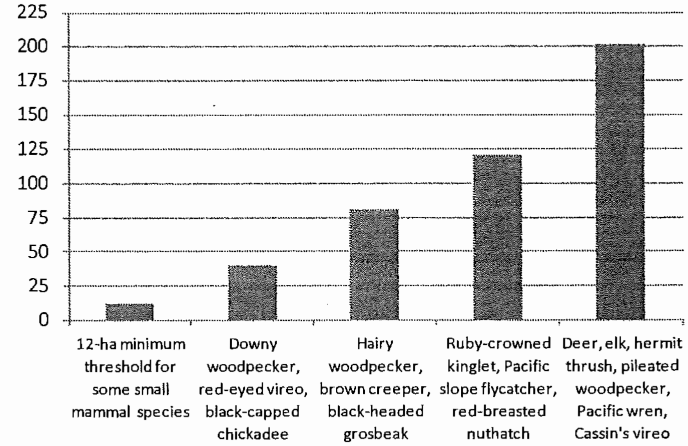
How much habitat is enough? When routing trails through a natural area, leaving some larger undisturbed core habitat areas can benefit a variety of area-sensitive wildlife species. Figure 8 provides examples of typical area requirements for some wildlife species, derived from Metro's 2010 *Wildlife corridors and permeability* literature review.[445] Although not reflected in Figure 8, large carnivores are generally disturbance-sensitive and require large habitat patches, as discussed in Section 7.4.

[16] Disturbance corridors include existing or abandoned rail lines, powerline corridors, old farm or forest roads, unauthorized trails when appropriate, right of way corridors, swaths adjacent to roadways, construction routes over buried utilities, utility maintenance access routes, and routes to quarries.

[17] Examples of core habitats include areas containing state- or federally-listed sensitive, threatened or endangered plant or animal species, exemplary natural communities, or exceptional native diversity. Large habitat patches are often considered core habitat because they can support more species and tend to have better habitat conditions compared to small patches.

Minimizing invasive species. Issues with invasive species associated with trail building and trail use are discussed in Section 5.3. Preventing the introduction of invasive species is critical because once introduced, it can be expensive to treat them [18] and they cannot always be fully eradicated, thereby raising the risk of distributing seeds to other sites via visitors, wildlife, wind or water. There is often a time lag between when seeds are first transported to a natural area and serious invasive species infestations,[224] thus regular monitoring and treatment for problem species and areas can help lower the severity of the problem.

Figure 8. Typical habitat size requirements for selected wildlife species (hectares)



Best practices to decrease invasive species seed loads include ensuring that natural area management staff and contractors follow best practices including cleaning boots, equipment and machinery;[30, 216] practicing Early Detection-Rapid Response (EDRR) before, during and after building trails, which can significantly reduce weed management costs;[30] minimizing soil disturbance;[30] using an Integrated Pest Management Plan (IPM), which can also reduce the need for pesticides;[30] and retaining tree and shrub cover to shade out invasives.[98] Another way to prevent establishment of invasive species is to educate visitors to be aware of their ability to carry non-native plant seeds on their bikes or clothing, and encourage them to remove seeds by washing mud from bikes, tires, shoes, and clothing.[30, 157] The latter may include installing trailhead educational signage (Section 8.9) and "clean your boots" and "clean your tires" stations.[30, 74, 228]

Cal-IPC's invasive species prevention manual provides a wealth of invasive species management information.[30] This guidebook states the following overall principles for preventing invasions:

- **Take time to plan.** Proper planning can reduce future maintenance costs by reducing the potential for invasive plant introduction and spread. A good first step is to conduct a pre-activity assessment of the work area to determine which activities could spread weeds and which best practices are applicable.
- **Stop movement of invasive plant materials and seeds**. The movement of workers, materials and equipment can carry weeds within and between sites. The CAL_IPC manual identifies potential vectors of spread and how to eliminate them or reduce their effects.
- **Reduce soil and vegetation disturbance.** Disturbance can allow invasive plants to colonize a new area. When disturbance is unavoidable, managers should conduct follow-up monitoring to ensure early detection of any invasive plants that may have been introduced.
- **Maintain desired plant communities.** A healthy plant community with native and desirable species provides resistance to invasive plant establishment.

- **Practice early detection and rapid response (EDRR).** Early detection and eradication of small populations helps prevent the spread of invasive plants and significantly reduces potential for future management time and expenses

Cal-IPC's list of best practices is described in detail in the text, and includes best practices for planning, project materials, travel, tool, equipment and vehicle cleaning, clothing, boots and gear cleaning, and waste disposal.

The Minnesota Department of Natural Resources' *Guidelines for managing and restoring natural plant communities along trails and waterways* manual includes a chapter on controlling invasive species.[512] The document states that invasive species control can be achieved by understanding the origin and biological behavior of invasive species [Davis and Sheley offer a framework for this issue[547]]; identifying and ranking the extent of exotic plant invasion; focusing control efforts on those plant communities that still have high ecological diversity to encourage natural regeneration of native plants; and monitoring treated sites regularly and thoroughly to keep invasive species under control.

Prioritizing treatment of invasive species. Cal-IPC suggests prioritizing treatment of invasive species as follows:[30]

- Species known or suspected to be invasive but still in small numbers (e.g., EDRR species)
- Species that can alter ecosystem processes
- Species with the potential to alter fire regimes
- Species that occur in areas of high conservation value
- Species with the potential to require high management costs
- Species that are likely to be controlled successfully
- Species determined to be of concern as identified through regional partnerships

Finding information about invasive species. Several resources are available to help identify and treat invasive species. Local Soil and Water Conservation Districts typically have weed identification and control programs. Some invasive species control guidance documents are habitat-specific; for example, Stanley et al. produced a report on controlling invasive species in Pacific Northwest native prairie habitats.[548].

Several resources are specific to the greater Portland area or the state of Oregon. The greater Portland-Vancouver region has a 4-county Cooperative Weed Management Area (https://4countycwma.org/). Soil and Water Conservation Districts (SWCDs) have weed identification and control programs and often have dedicated invasive species staff. Local jurisdictions and agencies (e.g., the City of Portland Bureau of Environmental Services invasive species program; Clean Water Services in the Tualatin watershed) are good resources. iMapInvasives (https://sites.google.com/site/orimapresources/) is an excellent resource to map or find weed locations.

Methods to estimate edge effects. Several methods to estimate edge effects from planned or existing trails are provided in Table 3. These methods can be particularly useful for comparing relative effects from different potential trail alignments or estimating effects from unauthorized trails, the latter which can provide guidance on where to prioritize removing such trails.

8.7 MINIMIZING EFFECTS OF RECREATIONAL USE ON WILDLIFE

Several references offer potentially valuable ideas and suggestions to help reduce negative recreational effects on wildlife.[37, 43, 97, 263] For example, Colorado State Parks' *Planning trails with wildlife in mind* handbook offers the following "rules of thumb" when considering effects of trails on wildlife:[37]

1. Lack of wildlife knowledge: Because there isn't much detailed knowledge about the effects of human disturbance on wildlife, be cautious in planning a trail, carefully weighing the alternatives.
2. Make do: Use the best wildlife information available, even if it is scarce. Solicit the advice of a biologist.
3. Considerable differences: Not only do different species respond differently to trails, different populations of the same species may respond differently, based on previous encounters with people.
4. Concentrated use: Generally, it is better to concentrate recreational use rather than disperse it. If social trails have developed in an area, it is probably better to consolidate them into one or a few trails.
5. Type of trail use: Some animals are more alarmed by hikers than by people who stay in their vehicles, especially if the vehicles don't stop.
6. Dog controls: If dogs are to be allowed on a trail where there are sensitive wildlife species, the dogs should be leashed or excluded seasonally to reduce conflicts. [When wildlife is one of a site's highest priorities, prohibiting dogs is preferable – see Appendix 1.]
7. Screening: The natural visual screening of a trail in a wooded area frequently makes most wildlife tolerate greater human disturbance than they would in open terrain. In some areas, it may be possible to plant a vegetative screen or build a screening fence to accomplish similar effects. [Our literature review indicates that vegetative cover may be as important as the number of visitors.[62]]
8. Impacts vs. benefits: Some wildlife effects cannot be resolved through management. Clear assessment of effects may lead to trail realignment.
9. Breeding areas or other special locations: Either avoid key wildlife breeding areas or close trails through them at the times such wildlife are most sensitive to human disturbance.
10. Enforcing closures: If there won't be sufficient resources to enforce a trail closure during wildlife-sensitive seasons, consider rerouting the trail through another area.

Chapter 6.7 reviewed the effects of noise and light pollution. Potential solutions could include limiting the extent of trails to minimize wildlife effects and providing education or signage to reduce conversation or conversation volume. Physical sound barriers could be useful where especially noisy roads negatively affect important wildlife areas. Minimizing trail lighting and ensuring that light does not encroach into habitat can help reduce lighting effects.

Formally incorporating wildlife considerations into the trail planning process right at the beginning is essential to reducing negative effects from recreational use. If trail planning is already well underway, it may be too late to gather sufficient wildlife information to inform trail alignments. However, collecting new wildlife information can help inform future management of existing trail systems.

GATHERING LOCAL WILDLIFE INFORMATION

Sometimes land managers do not have the expertise or the means to conduct formal or informal wildlife surveys. Timing can also be an issue; some wildlife species vary seasonally in their habitat use, such as Neotropical migratory songbirds or deer and elk moving between winter and summer grounds. There are several ways to help overcome such obstacles. Consulting a biologist early in the process can help guide the process of wildlife data collection.

Habitat maps and species-habitat associations. Maps delineating general habitat types such as mixed forest, oak savanna, riparian forest and wetlands are a first step to understanding what wildlife may be using a site. A logical next step is to ascertain what species live in the area and what habitats they use. Sometimes this information is readily available. For example, Johnson and O'Neil's *Wildlife-Habitat Relationships in Oregon and Washington* provides a wealth of species-specific information including range maps, habitat associations and special habitat elements required by some species (e.g., snags for birds or rock piles for lizards).

Collecting local wildlife information from other sources. Some sources of wildlife information can be collected in the office. Examples include information from local biologists at state and federal fish and wildlife agencies; governmental agencies with nearby natural land holdings; parks departments; online resources such as NatureServe (www.natureserve.org), i-Naturalist (www.inaturalist.corg), E-bird (www.ebird.org) and Breeding Bird Survey (www.pwrc.usgs.gov/bbs/) data; and nature-oriented nonprofits such as The Audubon Society, The Nature Conservancy and the Wildlife Conservation Society.

Residents adjacent to a site are often familiar with the wildlife on their lands, such as locations of amphibian breeding ponds, native turtles, eagle nests and whether cougar, bear or elk move through. They may also be willing to collect information in certain instances. For example, a Portland area resident adjacent to the region's largest natural area organized her neighbors to map elk sightings, which aided conservation planning. Open houses during the trail planning process can provide an opportunity for numerous residents to document wildlife they see in the neighborhood, as well as engage them more intimately with the project. Field staff members conducting restoration, maintenance or other activities often detect wildlife or wildlife sign, and such observations (including spatially explicit information) can be compiled into a wildlife list for the site.

Collecting wildlife information in the field. Several options are available for collecting field data, depending on the amount of time and resources available. Volunteers such as wildlife trackers or skilled amateur birdwatchers can be asked to survey a site. Community science projects and "bioblitzes" can yield relatively rich, site-specific wildlife information.[535] Wildlife cameras set in strategic locations, for example along wildlife trails or near water sources, can produce accurate, although incomplete, wildlife information. This approach is especially useful because some wildlife species are naturally nocturnal or switch to night-time activities in order to avoid human disturbance (Section 6.6), and daytime surveys may not detect such species.

Professional wildlife biologists can be hired to collect preliminary or longer term wildlife data in a natural area. Different types of animals require different survey methods. Some examples include:

- Amphibians: egg mass surveys and local area searches; track plates for some species; fluorescent dye; other methods [549-551]
- Reptiles: area searches, sometimes including placing boards or other hiding places at a site to check later; capture-mark-recapture studies to assess movement patterns; pit traps (regularly checked to avoid mortality); other methods[549-551]

- Birds: point counts, area searches, transects, mist-netting or nest surveys; multi-season studies are useful to ascertain how sites are used during migration or in the winter; area searches may be more effective in winter[551-553]
- Mammals: non-lethal trap arrays or pit traps (regularly checked to avoid mortality) for small mammals; for larger mammals, visual observations, tracking surveys, wildlife cameras or radio-collar studies to assess presence or movement patterns[551, 554]
- Habitat: Comprehensive guidance in *Inventory and monitoring of wildlife habitat*[551]

Several publications describe a variety of wildlife monitoring techniques.[551, 555-557] The U.S. Forest Services' habitat monitoring book includes a chapter on monitoring human disturbances for management of wildlife species and their habitats.[558] When considering wildlife monitoring techniques at the site level, methods to estimate wildlife populations may not be necessary; the most important things to know for trail planning are what species are using the site, where, and when. Steidl and Powell provide information on wildlife monitoring methods and how to choose an appropriate wildlife response measure for assessing the effects of human activity on wildlife.[559]

WILDLIFE FLIGHT INITIATION AND ALERT DISTANCES

Even with high quality wildlife data, estimating the potential effects of trails and recreation on wildlife can be difficult. The sheer number of wildlife species adds a great deal of complexity. Wildlife use of a site can change with variables such as location, restoration efforts, nearby land use changes, vegetation density, topography, wildlife species, season, reproductive status, habituation-type responses and chance. In addition, different species can react differently to the types and amount of trail use at a site. Due to these complexities, specific guidance on estimating or measuring potential wildlife effects is sparse.

However, a substantial body of literature documents wildlife responses to human disturbance. During the course of this literature review we compiled flight initiation distance (FID) and when available, alert distance information for various species that occur in the U.S. species (Appendix 3). Species were clustered into groups in Table 8 and Figure 9; the mean, median and range of disturbance response distances for species groups are provided.

Bird FIDs are typically 30 percent shorter on average than the alert distance.[163] Because most studies only consider FID, the median distances in Table 8 underestimate the distance at which wildlife become disturbed by humans. On the other hand, it is unknown the extent to where, when and which species habituate, therefore some studies in wildlands may overestimate the distances needed by species that can habituate to regularly disturbed landscapes such as suburban and urban areas. Also, FIDs and particularly alert distances for small animals and shy songbirds such as Neotropical migrants are difficult to measure because they are hard to see or tend to avoid disturbance altogether.

In the absence of higher quality wildlife information, land managers who want to roughly estimate wildlife response distances at a given site could select studies from Table 8 that are relevant to their geographic area or site, or use species groups' median, to consider potential effects from existing recreational uses or compare potential effects between different proposed trail alignments. Due to considerable uncertainties in how closely these data mirror local wildlife community responses, such an approach should not be viewed as prescriptive.

Figure 9 illustrates the flight initiation or alert distances from Table 8 and the more detailed study-specific information in Appendix 3. Figure 10 shows an example of how such data could be used to consider the potential impacts of recreation on wildlife.

Figure 9. Flight Initiation or alert distances for various wildlife species.
See Appendix Table 3 for underlying data.

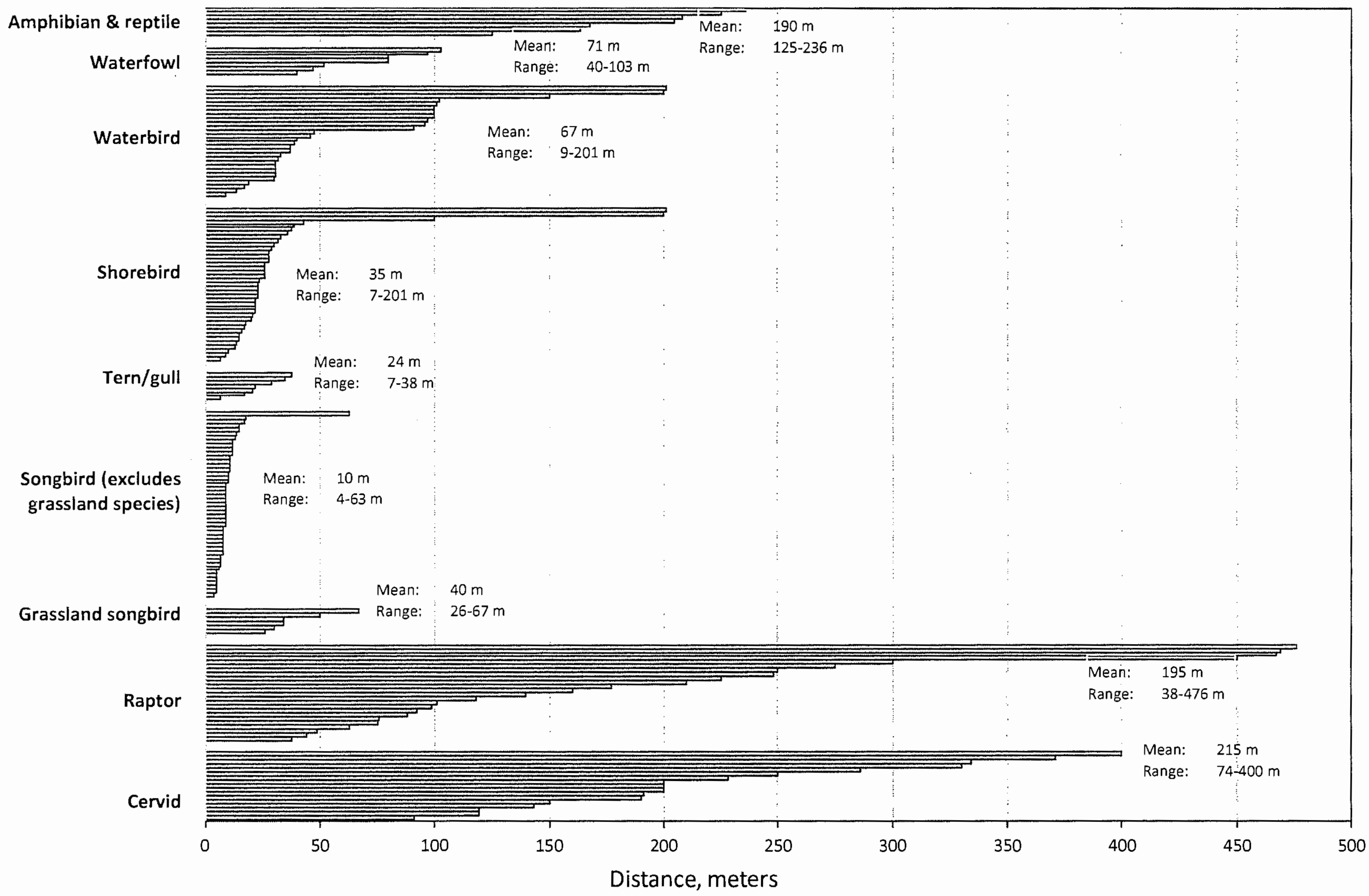


Table 8. Summary statistics for species groups' Flight Initiation Distances or Alert Distances from the scientific literature. We excluded species groups with fewer than three data points from Figure 9 (**hummingbirds**, corvids, doves/pigeons, **woodpeckers** and bovids) although data for these species groups are in this table and Appendix 3. Flight Initiation Distance = FID; Alert Distance = AD. Amphibians and reptiles are based on life history requirements rather than FID or AD.

Species group	# of studies	Mean (meters)	Median (meters)	Range (meters)	Notes
Amphibians (amphibians & reptiles combined in Figure 9)	5	194	168	125-287	Rather than FID or AD, these distances documented several amphibian species' terrestrial migration distances from aquatic breeding sites to upland habitat. Trails routed through this general zone could cause issues for amphibians. Buffering wetlands by these distances can help identify potential migration areas. *Additional information:* Boardwalks or wildlife undercrossings can enhance connectivity for these species. Migration typically occurs during certain seasons (typically spring).
Reptiles	3	216	208	205-236	Species group includes studies on reptiles as a group, snakes and turtles, for which numbers were generally similar. *Additional information:* Reptiles such as snakes and lizards benefit from sunny forest openings on south-facing slopes. Pond turtles require uplands with specific soil characteristics for nesting.
Waterfowl	7	71	80	40-103	This average is for both migratory and resident ducks. Migratory ducks generally flush more readily than resident species. *Additional information:* Installing viewing blinds or vegetation screens between trails and wetlands may decrease effects.
Waterbirds	28	67	40	9-201	This group consists of herons, egrets and cormorants. *Additional information:* Several researchers suggested avoiding placing trails, or seasonally closing trails, within 100m of heron rookeries to avoid nest abandonment or failure.
Raptors	24	195	150	38-476	Raptors' FIDs are generally high; kestrels are on the lower end and eagles on the higher end. People on foot tend to be more disturbing than other uses such as boating, and ground-nesting species tend to have longer FIDs. *Additional information on Bald Eagles:* Known Bald Eagle nests and high-use feeding areas may need special consideration due to low abundance and sensitivity to disturbance. Vegetative screens can reduce FID for eagles.
Shorebirds	39	35	23	7-201	Some shorebirds can adapt somewhat to human presence while others, particularly migratory species, are more sensitive. Migrating/nesting species tend to be more disturbance-sensitive. Exclusionary fencing can be effective.
Terns/gulls	7	24	22	7-38	Information on this species group was limited.
Doves/pigeons	2	16	N/A	15-16	Information on this species group was limited.
Hummingbirds	1	6	N/A	6	Rufous hummingbird (single study).
Woodpeckers	2	18	N/A	17-19	We only found two woodpecker FIDs but they were very similar (17 and 19 m). Distances could be used to create a trail avoidance buffer around large snags or areas with multiple snags; larger areas may be needed for more sensitive species.
Corvids	2	50	N/A	24-76	Information on this species group was limited.

Species group	# of studies	Mean (meters)	Median (meters)	Range (meters)	Notes
Songbirds (excludes grassland songbirds)	47	10	9	4-63	Most non-grassland songbirds had relatively short FIDs; however, it is difficult to detect birds in well vegetated areas, therefore forest-dwelling species may be under-represented in the literature. *Additional information:* Neotropical migratory birds are known to be especially disturbance-sensitive. Many migratory songbirds rely on fruiting shrubs during migration. In forest and shrub habitats, restoring vertical vegetation structure along trails to provide a visual screen and including fruiting shrubs for food and cover could help reduce effects of recreation on these species.
Grassland songbirds	6	40	34	26-67	Although grassland species are sometimes slow to flush, the median FID was substantially higher than other songbirds. If meadows and grasslands must be crossed, consider aligning trails on the outer edge of the habitat. Avoid placing trails through small meadows or grasslands to make such habitats available to nesting birds.
Deer/elk	18	215	200	74-400	Deer are sensitive to disturbance but their range of sensitivity is smaller than that of elk. Several variables mitigate the ability of elk to habituate to human disturbance. If elk are a priority at the site, consider these suggestions: • Add vegetation in a 50-100 m buffer between trails and known elk foraging areas (typically meadows and shrub habitat) to provide a visual screen. Ensure prompt closure of unauthorized trails in the buffer area. • Seasonal (spring) closures on trails within 200 m of high-use elk areas to protect pregnant elk or elk with young. • Seasonal closures of high-use elk areas during fall if any problematic encounters between people and rutting elk occur. These numbers may be on the low end but assume some habituation in recreational areas. See large carnivores for suggestions on protecting connectivity.
Bighorn sheep	3	104	165	46-200	Our area of interest excludes bighorn sheep, but we included this information in case land managers from other areas are interested in buffering trails from disturbing this species. Pregnant sheep/sheep with young/rutting males are most sensitive (spring and fall).
Large carnivores and general connectivity	Outside the scope of this report	N/A	N/A	N/A	The most important actions to conserve large carnivores are to: • Limit the total length of trails in a site. • When possible, leave large patches of habitat undisturbed. • Identify potential constrictions in connectivity and avoid trailheads in those areas. • Survey for and close unauthorized trails.

Figure 10. Example of a simple way to use the data presented in Table 8 to consider potential effects of human disturbance on waterfowl from a planned wildlife viewing blind adjacent to a large wetland. The median FID value for waterfowl (80 m) is drawn in orange. If migratory waterfowl are of particular concern, the higher end of the FID range (103 m) could be used.

8.8 REDUCING CONFLICTS BETWEEN USER GROUPS

The literature was rich with information on the types, reasons, and potential solutions for conflicts between user groups (Chapter 4). Several references emphasized that user groups that start out using trails together experience less perceived conflict; expectations are set at the beginning and no users are displaced. Some of the practices to reduce or avoid such recreational user group conflicts are described below.

Moore's review and synthesis of conflicts on multiple-use trails provides a clear, concise set of recommendations to reduce user conflicts on a variety of trail surfaces:[116]

1. Recognize conflict as the perception of a visitor interfering with another visitor's reasons for visiting the natural area.
2. Identify potential user groups and involve them as early as possible.
3. Actively and vigorously promote trail etiquette; target the audience, get the information into users' hands as quickly as possible, and present in simple, interesting, understandable and sometimes lighthearted/humorous ways.
4. Understand the needs of present and likely future users of each trail. This is critical for anticipating and managing conflicts and requires patience, effort, and sincere active listening.
5. Identify actual sources of conflicts – get beyond emotions and stereotypes as quickly as possible and get to the root of any problems that exist.
6. Minimize the number of conflicts in problem areas – for example, in congested areas and at trailheads. Disperse use and provide separate trails when necessary and after careful consideration of environmental effects.
7. Work with affected users (all parties involved) to reach mutually agreeable solutions. Users who are not involved as part of the solution are likely to be part of the problem now and in the future.
8. Encourage positive interaction among trail users; their values are likely more similar than different. Positive interactions both on and off the trail can break down barriers and stereotypes and build understanding, good will and cooperation. One example is to bring the different types of visitors together for joint trail building or maintenance projects.
9. Use the most "light-handed" management approaches possible that will still achieve the objectives. This is essential to providing the freedom of choice and natural environments that are so important to trail-based recreation.
10. Plan and act locally – whenever possible, address issues regarding multiple use trails at the local level. This allows greater sensitivity to local needs and provides better flexibility for addressing difficult issues on a case-by-case basis. This also facilitates involvement of the people most affected by any decisions, and most able to assist in their successful implementation.
11. Monitor the ongoing effectiveness of the decisions made and programs implemented. It is essential to evaluate the effectiveness of the actions designed to minimize conflicts; provide for safe, high-quality trail experiences; and protect natural resources. Conscious, deliberate monitoring is the only way to determine if conflicts are indeed being reduced and what changes in programs might be needed. This is only possible within the context of clearly understood and agreed-upon objectives for each trail area.

The literature indicates that hikers view mountain bikers and equestrians more negatively than the reverse (Chapter 4). Employing a two-pronged approach in which (1) hikers receive educational information about shared values with other groups, and (2) mountain bikers and equestrians are particularly encouraged to follow appropriate codes of conduct may be effective in reducing conflicts.

Preventing and reducing user conflicts does not necessarily follow the messaging outlined in Section 8.9. In the case of conflict, more positive messages may be more effective. Educational signage such as "share the trail" types of messages, including indicating which users have right-of-way priority, can reduce conflicts. Messages that emphasize shared values that user groups hold in common such as "we all care" can be effective.[88] However, signage may also be viewed as a visual impact on the landscape therefore a strategic approach such as placing signs at trail entries and problem areas may improve the user experience.

Engaging trail user groups can be an effective approach to enforcing codes of conduct through peer pressure. Creating a trail ambassador program with all user groups to provide etiquette guidance and monitoring is one way to reduce management and enforcement needed at a site. For more information about this type of approach see "collaborative management approaches" in Section 8.4.

We found several examples of codes of conduct, including for hikers,[560, 561] mountain bikers[58, 562] and equestrians.[14, 20, 146, 563] Note that most codes of conduct address user conflicts rather than environmental issues; incorporating environmental values into these rules and responsibilities could help decrease negative effects from trail users. Canada's Trent University has a website with links to many codes of conduct.[18] Numerous other references provide codes of conduct or additional guidance for minimizing user group conflicts.[96, 116, 144-146, 150, 564]

8.9 NOTES ABOUT SIGNAGE AND EDUCATIONAL MESSAGING

Messages conveyed in a variety of ways can be effective at changing some peoples' undesirable behaviors.[564] The body of research we reviewed suggests several approaches for effective visitor education through signage.

Several studies or reviews investigated the effectiveness of different approaches to visitor education. In a study conducted in Maine, Turner found that signage is least effective on people engaged in illegal, malicious, and unavoidable activities, and is most effective on uninformed and unskilled actions.[538] Marion and Reed reviewed the literature on education programs to address user-related damage to natural resources, social conditions and neighboring communities; they concluded that "...there is adequate evidence that most of the visitor education methods evaluated did affect visitor knowledge, attitudes, behaviour, and/or resource conditions in the intended direction."[564] Most of the papers they reviewed identified the content and delivery of messages, audience characteristics, and theoretical underpinnings as important to the effectiveness of such messaging.

Technical language information. Messages may present the "ought" (injunctive) or the "is" (descriptive) of behavior and may be stated positively (prescriptive) or negatively (proscriptive).[141, 564] Winter's experiments in Sequoia National Park directly tested the effectiveness of different types of messages used in signage.[141]

Evidence suggests that injunctive-proscriptive messages are often the most effective route in gaining desired behavior, and that negative messaging ("do not") appear to work best. For example:

- Most effective: To protect sensitive habitat, please do not go off the trail. (injunctive-proscriptive; these types of messages may be the most memorable)
- Less effective: Many visitors in the past have stayed on trails, helping to protect vegetation. (descriptive-prescriptive; states the desired behavior as the norm, encourages desirable behavior)
- Less effective: Please stay on paths to protect natural vegetation.(injunctive-prescriptive, basically saying "stay on the trail")
- NO: Many visitors in the past have left the established trail, changing the natural vegetation in this park. (descriptive-proscriptive; presents the undesirable behavior as the norm)

[18] http://www.trentu.ca/academic/trailstudies/moreethics.html

There is some evidence that people behave better when they think other visitors might see them doing something wrong. In the Petrified Wood National Park, researchers used a 2 x 2 factorial design (type of normative information – injunctive versus descriptive; and normative focus – strong negatively worded versus weak positively worded) to test whether positively or negatively phrased normative messages were most effective at deterring theft of petrified wood.[565] The investigators experimentally placed marked pieces of petrified wood along trails, then counted theft of marked wood along trails with different types of signage. The signs read:

1. "Please leave petrified wood in the park" accompanied by a picture of a visitor admiring and photographing a piece of wood.
2. "Many past visitors have removed the petrified wood from the park, changing the state of the Petrified Forest" accompanied by pictures of three visitors taking wood.
3. "The vast majority of past visitors have left the petrified wood in the park, preserving the natural state of the Petrified Forest," accompanied by pictures of three visitors admiring and photographing a piece of wood.
4. "Please don't remove the petrified wood from the park" accompanied by a picture of a visitor stealing a piece of wood, with a red circle-and-bar symbol superimposed on the hand.

All four messages essentially said the same thing, but the last message, which strongly focused recipients on injunctive normative information, was much more effective. In fact, the second message actually increased theft whereas the fourth message reduced it. The theory is that observers focus more on the negative message, which increases the sign's effectiveness. In addition, clearly pointing out the undesirable behavior as forbidden may deter undesirable behavior because visitors might worry about what other people would think.

The "Leave No Trace" environmental education approach is widely regarded as an effective tool to reducing user effects.[514] In sites or areas with significant impact issues, one approach is to strategically place staff or volunteers to provide personal educational contact with visitors; this type of personal contact can be quite effective.[564] Messages delivered via multiple methods (e.g., personal contacts, posters and brochures at trailheads, signs along trails) are most effective.[92] Multi-lingual signs that reflect the diversity of surrounding communities and expected visitors can help ensure that everyone gets the message.[141] Current best practices include using minimal text and relying on clear graphics that are universally comprehendible. Graphics also work for the segment of the population that use different languages or cannot read. Several articles provide more in-depth information about signage and messaging at a site.[141, 564-566]

LITERATURE CITED

1. Manning, R., et al., *Defining, measuring, monitoring, and managing the sustainability of parks for outdoor recreation.* Journal of Park and Recreation Administration. 2011. 29(3): p. 24-37.

2. Maller, C.J., et al., *Healthy nature healthy people: 'Contact with nature' as an upstream health promotion intervention for populations.* Health Promotion International. 2006. 21(1): p. 45-54.

3. Beil, K., *Health in nature: A summary of the contribution of urban green spaces to human health and its implications for urban planning.* 2009. Metro: Portland, OR.

4. Buckley, R.C. and P. Brough, *Economic value of parks via human health: An analytical framework.* Frontiers in Ecology and Evolution. 2017. 5(Article 16): p. 1-9.

5. Winter, C., *The intrinsic, instrumental and spiritual values of natural area visitors and the general public: A comparative study.* Journal of Sustainable Tourism. 2007. 15(6): p. 599-614.

6. Boyle, S.A. and F.B. Samson, *Effects of nonconsumptive recreation on wildlife: A review.* Wildlife Society Bulletin. 1985. 13: p. 110-116.

7. Jordan, M., *Ecological impacts of recreational use of trails: A literature review.* 2000. Cold Springs Harbor, NY. p. 1-6.

8. Carney, K.M. and W.J. Sydeman, *A review of human disturbance effects on nesting colonial waterbirds.* Waterbirds: The International Journal of Waterbird Biology. 1999. 22(1): p. 68-79.

9. Cessford, G.R., *Off-road impacts of mountain bikes. A review and discussion.* 1995. Wellington, New Zealand.

10. Green, R.J. and K. Higginbottom, *The effects of non-consumptive wildlife tourism on free-ranging wildlife: A review.* Pacific Conservation Biology. 2010. 6(3): p. 183-197.

11. Hill, D., *The impact of noise and artificial light on waterfowl behaviour: A review and synthesis of available literature.* 1992: Tring, U.K.

12. Kuss, F.R., *A review of major factors influencing plant responses to recreation impacts.* Environmental Management. 1986. 10(5): p. 637-650.

13. Joslin, G. and H. Youmans, *Effects of recreation on Rocky Mountain wildlife: A review for Montana*, Committee on Effects of Recreation on Wildlife, Montana Chapter of The Wildlife Society. 1999.

14. Landsberg, J., B. Logan, and D. Shorthouse, *Horse riding in urban conservation areas: Reviewing scientific evidence to guide management.* Ecological Management & Restoration. 2001. 2(1): p. 36-46.

15. Lathrop, J., *Ecological impacts of mountain biking: A critical literature review.* 2003.

16. Leung, Y.-F. and J.L. Marion, *Trail degradation as influenced by environmental factors: A State of the Knowledge review.* Journal of Soil and Water Conservation. 1996. 51(2): p. 130-136.

17. Leung, Y.-F. and J.L. Marion. *Recreation impacts and management in wilderness: A state-of-knowledge review.* 1999. U.S.D.A. Forest Service.

18. Marion, J. and J. Wimpey, *Environmental impacts of mountain biking: Science review and best practices*, in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding*. 2007, International Mountain Bicycling Association: Boulder, CO.

19. Marzano, M. and N. Dandy, *Recreational use of forests and disturbance of wildlife. A literature review.* 2012. Edinburgh, U.K.: Forestry Commission. 1-40.

20. Newsome, D., A. Smith, and S.A. Moore, *Horse riding in protected areas: A critical review and implications for research and management.* Current Issues in Tourism. 2008. 11(2): p. 144-166.

21. Pescott, O.L. and G.B. Stewart, *Assessing the impact of human trampling on vegetation: A systematic review and meta-analysis of experimental evidence.* PeerJ. 2014. 2:e360(https://doi.org/10.7717/peerj.360).

22. Pickering, C., *Literature review of horse riding impacts on protected areas and a guide to the development of an assessment program*. 2008. Environmental Protection Agency: Brisbane, Australia.

23. Pickering, C.M. and A.M. Mount, *Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses.* Journal of Sustainable Tourism. 2010. 18(2): p. 239-256.

24. Quinn, M. and G. Chernoff, *Mountain biking: A review of the ecological effects. A literature review for Parks Canada - National Office (Visitor Experience Branch)*. 2010. Calgary, AB.

25. Stankowich, T., *Ungulate flight response to human disturbance: A review and meta-analysis.* Biological Conservation. 2008. 141(9): p. 2159-2173.

26. Steven, R., C. Pickering, and J.G. Castley, *A review of the impacts of nature based recreation on birds.* Journal of Environmental Management. 2011. 92: p. 2287-2294.

27. U.S. Forest Service, *User created trail impacts - literature review*. 2014. USFS Red Rock District.

28. Hesselbarth, W., B. Bachowski, and M.A. Davises, *Trail construction and maintenance notebook*. 2007. U.S.D.A. Forest Service, Missoula Technology & Development Center: Missoula, MT.

29. Aust, M.W., J.L. Marion, and K. Kyle, *Research for the development of Best Management Practices to minimize horse trail impacts on the Hoosier National Forest*. 2015. Blacksburg, VA.

30. Cal-IPC, *Preventing the spread of invasive plants: Best management practices for land managers*. 2012. California Invasive Plant Council: Berkeley, CA.

31. Monz, C.A., C.M. Pickering, and W.L. Hadwen, *Recent advances in recreation ecology and the implications of different relationships between recreation use and ecological impacts.* Frontiers in Ecology and the Environment. 2013. 11(8): p. 441-446.

32. Ballantyne, M., O. Gudes, and C.M. Pickering, *Recreational trails are an important cause of fragmentation in endangered urban forests: A case-study from Australia.* Landscape and Urban Planning. 2014. 130: p. 112-124.

33. Hof, M. and D.W. Lime, *Visitor Experience and Resource Protection Framework in the National Park System–Rationale, current status, and future direction* in *Proceedings: Limits of Acceptable Change and Related Planning Processes – Progress and Future Change and Related Planning Processes, Progress and Future Directions*. 1997. U.S.D.A. Forest Service, Intermountain Research Station: Ogden, UT.

34. Oregon Parks & Recreation Department, *Statewide Comprehensive Outdoor Recreation Plan*. 2017. State of Oregon, Oregon Parks and Recreation Department: Washington, D.C.

35. The Outdoor Foundation, *Outdoor recreation participation*. 2016. The Outdoor Foundation: Washington, D.C. p. 458-465.

36. Trails for All Ontarians Collaborative, *Guidelines and best practices for the design, construction and maintenance of sustainable trails for all Ontarians*. 2006. Ontario, Canada.

37. Colorado State Parks, Trails and Wildlife Task Force, *Planning trails with wildlife in mind. A handbook for trails planners*. 1998.

38. Leung, Y.-F., et al., *Developing a monitoring protocol for visitor-created informal trails in Yosemite National Park, USA.* Environmental Management. 2011. 47(1): p. 93-106.

39. Burde, J.H. and J.R. Renfro. *Use impacts of the Appalachian Trail.* in *Proceedings, National Wilderness Research Conference: Issues, state-of-knowledge, future directions*. 1986. U.S.D.A. Forest Service.

40. Marion, J.L. and Y.-F. Leung, *Environmentally sustainable trail management*, in *Environmental Impacts of Ecotourism*, R. Buckley, Editor. 2004. CABI Publishers: Wallingford, Oxfordshire, U.K.

41. Wimpey, J.F. and J.L. Marion, *The influence of use, environmental and managerial factors on the width of recreational trails.* Journal of Environmental Management. 2010. 91: p. 2028-2037.

42. Marion, J.L. and Y.-F. Leung, *Trail resource impacts and an examination of alternative assessment techniques.* Journal of Park and Recreation Administration. 2001. 19(3): p. 17-37.

43. Metro, *Green Trails. Guidelines for environmentally friendly trails*. 2004. Metro: Portland, OR.

44. Focetola, G.F., et al., *Vertebrates respond differently to human disturbance: Implications for the use of a focal species approach.* Acta Oecologica. 2007. 31(1): p. 109-118.

45. Yan, X., W. Bao, and X. Pang, *Indirect effects of hiking trails on the community structure and diversity of trunk-epiphytic bryophytes in an old-growth fir forest.* Journal of Bryology. 2014. 36(1): p. 44-55.

46. Weiss, F., T.J. Brummer, and G. Pufal, *Mountain bikes as seed dispersers and their potential socio-ecological consequences.* Journal of Environmental Management. 2016. 181(1): p. 326-332.

47. Cater, C., et al., *High impact activities in parks. Best management practice and future research*, K. Van Asperen, Editor. 2008. Cooperative Research Centre for Sustainable Tourism Pty Ltd: Gold Coast, Queensland, Australia.

48. Miller, A.B., *Impacts of trail building on wildlife: A before-after control-impact experimental study using camera traps*, in *Parks, Recreaion and Tourism Management*. 2016. North Carolina State University: Raleigh, NC.

49. Oregon Department of Fish and Wildlife, *Guidance for conserving Oregon's native turtles including best management practices.* 2015. Salem, OR. p. 1-99.

50. Cole, D.N. and R.L. Knight, *Impacts of recreation on biodiversity in wilderness.* Natural Resources and Environmental Issues. 1990. 0(Article 6).

51. Hancock, J., et al., *Equestrian design guidebook for trails, trailheads, and campgrounds*. 2007. U.S.D.A. Forest Service, Missoula Technology and Development Center: Missoula, MT.

52. U.S.D.A. Forest Service, *TRACS Trail Assessment and Condition Surveys*. 2009. U.S.D.A. Department of Agriculture, Forest Service: Washington, D.C.

53. City of Portland, Oregon Parks & Recreation Department, *Trail design guidelines for Portland's park system*. 2009. City of Portland: Portland, OR.

54. Bratton, S.P., M.G. Hickler, and J.H. Graves, *Trail erosion patterns in Great Smoky Mountains National Park.* Environmental Management. 1979. 3(5): p. 431-445.

55. Bio-West, Inc., *Northern Bonneville Shoreline Trail Master Plan*. 2002. Bear River Association of Governments: Logan, UT.

56. Marion, J.L. and Y.-F. Leung, *Indicators and protocols for monitoring impacts of formal and informal trails in protected areas.* Journal of Tourism and Leisure Studies. 2011. 17(2): p. 216-236.

57. City of Boulder, Colorado, *System-wide undesignated trail mapping on open space and mountain park lands*. 2012. City of Boulder, CO: Boulder, CO.

Table 8. Summary statistics for species groups' Flight Initiation Distances or Alert Distances from the scientific literature. We excluded species groups with fewer than three data points from Figure 9 (**hummingbirds**, corvids, doves/pigeons, **woodpeckers** and bovids) although data for these species groups are in this table and Appendix 3. Flight Initiation Distance = FID; Alert Distance = AD. Amphibians and reptiles are based on life history requirements rather than FID or AD.

Species group	# of studies	Mean (meters)	Median (meters)	Range (meters)	Notes
Amphibians (amphibians & reptiles combined in Figure 9)	5	194	168	125-287	Rather than FID or AD, these distances documented several amphibian species' terrestrial migration distances from aquatic breeding sites to upland habitat. Trails routed through this general zone could cause issues for amphibians. Buffering wetlands by these distances can help identify potential migration areas. *Additional information:* Boardwalks or wildlife undercrossings can enhance connectivity for these species. Migration typically occurs during certain seasons (typically spring).
Reptiles	3	216	208	205-236	Species group includes studies on reptiles as a group, snakes and turtles, for which numbers were generally similar. *Additional information:* Reptiles such as snakes and lizards benefit from sunny forest openings on south-facing slopes. Pond turtles require uplands with specific soil characteristics for nesting.
Waterfowl	7	71	80	40-103	This average is for both migratory and resident ducks. Migratory ducks generally flush more readily than resident species. *Additional information:* Installing viewing blinds or vegetation screens between trails and wetlands may decrease effects.
Waterbirds	28	67	40	9-201	This group consists of herons, egrets and cormorants. *Additional information:* Several researchers suggested avoiding placing trails, or seasonally closing trails, within 100m of heron rookeries to avoid nest abandonment or failure.
Raptors	24	195	150	38-476	Raptors' FIDs are generally high; kestrels are on the lower end and eagles on the higher end. People on foot tend to be more disturbing than other uses such as boating, and ground-nesting species tend to have longer FIDs. *Additional information on Bald Eagles:* Known Bald Eagle nests and high-use feeding areas may need special consideration due to low abundance and sensitivity to disturbance. Vegetative screens can reduce FID for eagles.
Shorebirds	39	35	23	7-201	Some shorebirds can adapt somewhat to human presence while others, particularly migratory species, are more sensitive. Migrating/nesting species tend to be more disturbance-sensitive. Exclusionary fencing can be effective.
Terns/gulls	7	24	22	7-38	Information on this species group was limited.
Doves/pigeons	2	16	N/A	15-16	Information on this species group was limited.
Hummingbirds	1	6	N/A	6	Rufous hummingbird (single study).
Woodpeckers	2	18	N/A	17-19	We only found two woodpecker FIDs but they were very similar (17 and 19 m). Distances could be used to create a trail avoidance buffer around large snags or areas with multiple snags; larger areas may be needed for more sensitive species.
Corvids	2	50	N/A	24-76	Information on this species group was limited.

Species group	# of studies	Mean (meters)	Median (meters)	Range (meters)	Notes
Songbirds (excludes grassland songbirds)	47	10	9	4-63	Most non-grassland songbirds had relatively short FIDs; however, it is difficult to detect birds in well vegetated areas, therefore forest-dwelling species may be under-represented in the literature. *Additional information:* Neotropical migratory birds are known to be especially disturbance-sensitive. Many migratory songbirds rely on fruiting shrubs during migration. In forest and shrub habitats, restoring vertical vegetation structure along trails to provide a visual screen and including fruiting shrubs for food and cover could help reduce effects of recreation on these species.
Grassland songbirds	6	40	34	26-67	Although grassland species are sometimes slow to flush, the median FID was substantially higher than other songbirds. If meadows and grasslands must be crossed, consider aligning trails on the outer edge of the habitat. Avoid placing trails through small meadows or grasslands to make such habitats available to nesting birds.
Deer/elk	18	215	200	74-400	Deer are sensitive to disturbance but their range of sensitivity is smaller than that of elk. Several variables mitigate the ability of elk to habituate to human disturbance. If elk are a priority at the site, consider these suggestions: • Add vegetation in a 50-100 m buffer between trails and known elk foraging areas (typically meadows and shrub habitat) to provide a visual screen. Ensure prompt closure of unauthorized trails in the buffer area. • Seasonal (spring) closures on trails within 200 m of high-use elk areas to protect pregnant elk or elk with young. • Seasonal closures of high-use elk areas during fall if any problematic encounters between people and rutting elk occur. These numbers may be on the low end but assume some habituation in recreational areas. See large carnivores for suggestions on protecting connectivity.
Bighorn sheep	3	104	165	46-200	Our area of interest excludes bighorn sheep, but we included this information in case land managers from other areas are interested in buffering trails from disturbing this species. Pregnant sheep/sheep with young/rutting males are most sensitive (spring and fall).
Large carnivores and general connectivity	Outside the scope of this report	N/A	N/A	N/A	The most important actions to conserve large carnivores are to: • Limit the total length of trails in a site. • When possible, leave large patches of habitat undisturbed. • Identify potential constrictions in connectivity and avoid trailheads in those areas. • Survey for and close unauthorized trails.

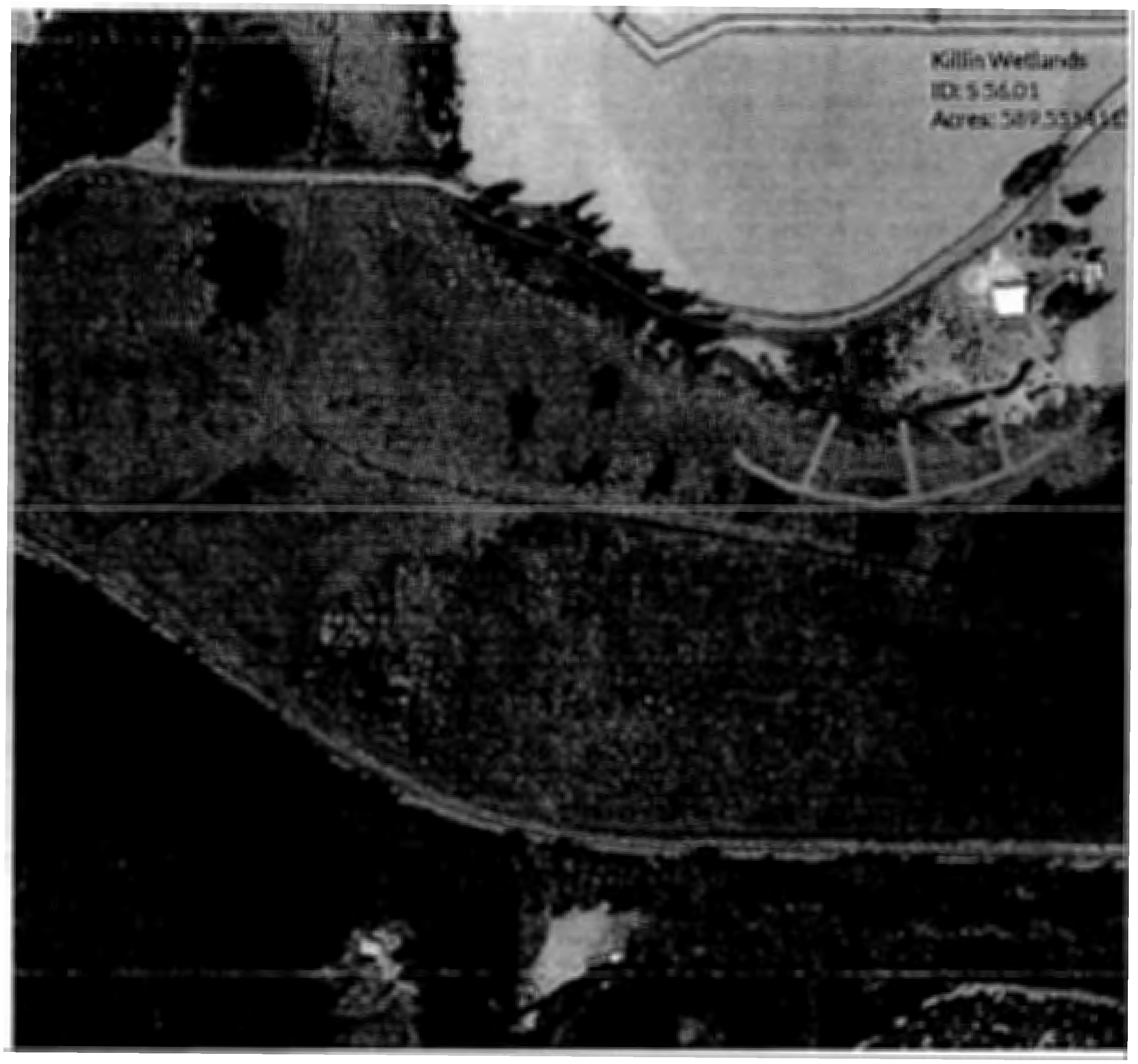


Figure 10. Example of a simple way to use the data presented in Table 8 to consider potential effects of human disturbance on waterfowl from a planned wildlife viewing blind adjacent to a large wetland. The median FID value for waterfowl (80 m) is drawn in orange. If migratory waterfowl are of particular concern, the higher end of the FID range (103 m) could be used.

8.8 REDUCING CONFLICTS BETWEEN USER GROUPS

The literature was rich with information on the types, reasons, and potential solutions for conflicts between user groups (Chapter 4). Several references emphasized that user groups that start out using trails together experience less perceived conflict; expectations are set at the beginning and no users are displaced. Some of the practices to reduce or avoid such recreational user group conflicts are described below.

Moore's review and synthesis of conflicts on multiple-use trails provides a clear, concise set of recommendations to reduce user conflicts on a variety of trail surfaces:[116]

1. Recognize conflict as the perception of a visitor interfering with another visitor's reasons for visiting the natural area.
2. Identify potential user groups and involve them as early as possible.
3. Actively and vigorously promote trail etiquette; target the audience, get the information into users' hands as quickly as possible, and present in simple, interesting, understandable and sometimes lighthearted/humorous ways.
4. Understand the needs of present and likely future users of each trail. This is critical for anticipating and managing conflicts and requires patience, effort, and sincere active listening.
5. Identify actual sources of conflicts – get beyond emotions and stereotypes as quickly as possible and get to the root of any problems that exist.
6. Minimize the number of conflicts in problem areas – for example, in congested areas and at trailheads. Disperse use and provide separate trails when necessary and after careful consideration of environmental effects.
7. Work with affected users (all parties involved) to reach mutually agreeable solutions. Users who are not involved as part of the solution are likely to be part of the problem now and in the future.
8. Encourage positive interaction among trail users; their values are likely more similar than different. Positive interactions both on and off the trail can break down barriers and stereotypes and build understanding, good will and cooperation. One example is to bring the different types of visitors together for joint trail building or maintenance projects.
9. Use the most "light-handed" management approaches possible that will still achieve the objectives. This is essential to providing the freedom of choice and natural environments that are so important to trail-based recreation.
10. Plan and act locally – whenever possible, address issues regarding multiple use trails at the local level. This allows greater sensitivity to local needs and provides better flexibility for addressing difficult issues on a case-by-case basis. This also facilitates involvement of the people most affected by any decisions, and most able to assist in their successful implementation.
11. Monitor the ongoing effectiveness of the decisions made and programs implemented. It is essential to evaluate the effectiveness of the actions designed to minimize conflicts; provide for safe, high-quality trail experiences; and protect natural resources. Conscious, deliberate monitoring is the only way to determine if conflicts are indeed being reduced and what changes in programs might be needed. This is only possible within the context of clearly understood and agreed-upon objectives for each trail area.

The literature indicates that hikers view mountain bikers and equestrians more negatively than the reverse (Chapter 4). Employing a two-pronged approach in which (1) hikers receive educational information about shared values with other groups, and (2) mountain bikers and equestrians are particularly encouraged to follow appropriate codes of conduct may be effective in reducing conflicts.

Preventing and reducing user conflicts does not necessarily follow the messaging outlined in Section 8.9. In the case of conflict, more positive messages may be more effective. Educational signage such as "share the trail" types of messages, including indicating which users have right-of-way priority, can reduce conflicts. Messages that emphasize shared values that user groups hold in common such as "we all care" can be effective.[88] However, signage may also be viewed as a visual impact on the landscape therefore a strategic approach such as placing signs at trail entries and problem areas may improve the user experience.

Engaging trail user groups can be an effective approach to enforcing codes of conduct through peer pressure. Creating a trail ambassador program with all user groups to provide etiquette guidance and monitoring is one way to reduce management and enforcement needed at a site. For more information about this type of approach see "collaborative management approaches" in Section 8.4.

We found several examples of codes of conduct, including for hikers,[560, 561] mountain bikers[58, 562] and equestrians.[14, 20, 146, 563] Note that most codes of conduct address user conflicts rather than environmental issues; incorporating environmental values into these rules and responsibilities could help decrease negative effects from trail users. Canada's Trent University has a website with links to many codes of conduct.[18] Numerous other references provide codes of conduct or additional guidance for minimizing user group conflicts.[96, 116, 144-146, 150, 564]

8.9 NOTES ABOUT SIGNAGE AND EDUCATIONAL MESSAGING

Messages conveyed in a variety of ways can be effective at changing some peoples' undesirable behaviors.[564] The body of research we reviewed suggests several approaches for effective visitor education through signage.

Several studies or reviews investigated the effectiveness of different approaches to visitor education. In a study conducted in Maine, Turner found that signage is least effective on people engaged in illegal, malicious, and unavoidable activities, and is most effective on uninformed and unskilled actions.[538] Marion and Reed reviewed the literature on education programs to address user-related damage to natural resources, social conditions and neighboring communities; they concluded that "...there is adequate evidence that most of the visitor education methods evaluated did affect visitor knowledge, attitudes, behaviour, and/or resource conditions in the intended direction."[564] Most of the papers they reviewed identified the content and delivery of messages, audience characteristics, and theoretical underpinnings as important to the effectiveness of such messaging.

Technical language information. Messages may present the "ought" (injunctive) or the "is" (descriptive) of behavior and may be stated positively (prescriptive) or negatively (proscriptive).[141, 564] Winter's experiments in Sequoia National Park directly tested the effectiveness of different types of messages used in signage.[141]

Evidence suggests that injunctive-proscriptive messages are often the most effective route in gaining desired behavior, and that negative messaging ("do not") appear to work best. For example:

- Most effective: To protect sensitive habitat, please do not go off the trail. (injunctive-proscriptive; these types of messages may be the most memorable)
- Less effective: Many visitors in the past have stayed on trails, helping to protect vegetation. (descriptive-prescriptive; states the desired behavior as the norm, encourages desirable behavior)
- Less effective: Please stay on paths to protect natural vegetation.(injunctive-prescriptive, basically saying "stay on the trail")
- NO: Many visitors in the past have left the established trail, changing the natural vegetation in this park. (descriptive-proscriptive; presents the undesirable behavior as the norm)

[18] http://www.trentu.ca/academic/trailstudies/moreethics.html

There is some evidence that people behave better when they think other visitors might see them doing something wrong. In the Petrified Wood National Park, researchers used a 2 x 2 factorial design (type of normative information – injunctive versus descriptive; and normative focus – strong negatively worded versus weak positively worded) to test whether positively or negatively phrased normative messages were most effective at deterring theft of petrified wood.[565] The investigators experimentally placed marked pieces of petrified wood along trails, then counted theft of marked wood along trails with different types of signage. The signs read:

1. "Please leave petrified wood in the park" accompanied by a picture of a visitor admiring and photographing a piece of wood.
2. "Many past visitors have removed the petrified wood from the park, changing the state of the Petrified Forest" accompanied by pictures of three visitors taking wood.
3. "The vast majority of past visitors have left the petrified wood in the park, preserving the natural state of the Petrified Forest," accompanied by pictures of three visitors admiring and photographing a piece of wood.
4. "Please don't remove the petrified wood from the park" accompanied by a picture of a visitor stealing a piece of wood, with a red circle-and-bar symbol superimposed on the hand.

All four messages essentially said the same thing, but the last message, which strongly focused recipients on injunctive normative information, was much more effective. In fact, the second message actually increased theft whereas the fourth message reduced it. The theory is that observers focus more on the negative message, which increases the sign's effectiveness. In addition, clearly pointing out the undesirable behavior as forbidden may deter undesirable behavior because visitors might worry about what other people would think.

The "Leave No Trace" environmental education approach is widely regarded as an effective tool to reducing user effects.[514] In sites or areas with significant impact issues, one approach is to strategically place staff or volunteers to provide personal educational contact with visitors; this type of personal contact can be quite effective.[564] Messages delivered via multiple methods (e.g., personal contacts, posters and brochures at trailheads, signs along trails) are most effective.[92] Multi-lingual signs that reflect the diversity of surrounding communities and expected visitors can help ensure that everyone gets the message.[141] Current best practices include using minimal text and relying on clear graphics that are universally comprehendible. Graphics also work for the segment of the population that use different languages or cannot read. Several articles provide more in-depth information about signage and messaging at a site.[141, 564-566]

LITERATURE CITED

1. Manning, R., et al., *Defining, measuring, monitoring, and managing the sustainability of parks for outdoor recreation.* Journal of Park and Recreation Administration. 2011. 29(3): p. 24-37.
2. Maller, C.J., et al., *Healthy nature healthy people: 'Contact with nature' as an upstream health promotion intervention for populations.* Health Promotion International. 2006. 21(1): p. 45-54.
3. Beil, K., *Health in nature: A summary of the contribution of urban green spaces to human health and its implications for urban planning.* 2009. Metro: Portland, OR.
4. Buckley, R.C. and P. Brough, *Economic value of parks via human health: An analytical framework.* Frontiers in Ecology and Evolution. 2017. 5(Article 16): p. 1-9.
5. Winter, C., *The intrinsic, instrumental and spiritual values of natural area visitors and the general public: A comparative study.* Journal of Sustainable Tourism. 2007. 15(6): p. 599-614.
6. Boyle, S.A. and F.B. Samson, *Effects of nonconsumptive recreation on wildlife: A review.* Wildlife Society Bulletin. 1985. 13: p. 110-116.
7. Jordan, M., *Ecological impacts of recreational use of trails: A literature review.* 2000. Cold Springs Harbor, NY. p. 1-6.
8. Carney, K.M. and W.J. Sydeman, *A review of human disturbance effects on nesting colonial waterbirds.* Waterbirds: The International Journal of Waterbird Biology. 1999. 22(1): p. 68-79.
9. Cessford, G.R., *Off-road impacts of mountain bikes. A review and discussion.* 1995. Wellington, New Zealand.
10. Green, R.J. and K. Higginbottom, *The effects of non-consumptive wildlife tourism on free-ranging wildlife: A review.* Pacific Conservation Biology. 2010. 6(3): p. 183-197.
11. Hill, D., *The impact of noise and artificial light on waterfowl behaviour: A review and synthesis of available literature.* 1992: Tring, U.K.
12. Kuss, F.R., *A review of major factors influencing plant responses to recreation impacts.* Environmental Management. 1986. 10(5): p. 637-650.
13. Joslin, G. and H. Youmans, *Effects of recreation on Rocky Mountain wildlife: A review for Montana*, Committee on Effects of Recreation on Wildlife, Montana Chapter of The Wildlife Society. 1999.
14. Landsberg, J., B. Logan, and D. Shorthouse, *Horse riding in urban conservation areas: Reviewing scientific evidence to guide management.* Ecological Management & Restoration. 2001. 2(1): p. 36-46.
15. Lathrop, J., *Ecological impacts of mountain biking: A critical literature review.* 2003.
16. Leung, Y.-F. and J.L. Marion, *Trail degradation as influenced by environmental factors: A State of the Knowledge review.* Journal of Soil and Water Conservation. 1996. 51(2): p. 130-136.
17. Leung, Y.-F. and J.L. Marion. *Recreation impacts and management in wilderness: A state-of-knowledge review.* 1999. U.S.D.A. Forest Service.
18. Marion, J. and J. Wimpey, *Environmental impacts of mountain biking: Science review and best practices*, in *Managing Mountain Biking: IMBA's Guide to Providing Great Riding.* 2007, International Mountain Bicycling Association: Boulder, CO.
19. Marzano, M. and N. Dandy, *Recreational use of forests and disturbance of wildlife. A literature review.* 2012. Edinburgh, U.K.: Forestry Commission. 1-40.

20. Newsome, D., A. Smith, and S.A. Moore, *Horse riding in protected areas: A critical review and implications for research and management.* Current Issues in Tourism. 2008. 11(2): p. 144-166.

21. Pescott, O.L. and G.B. Stewart, *Assessing the impact of human trampling on vegetation: A systematic review and meta-analysis of experimental evidence.* PeerJ. 2014. 2:e360(https://doi.org/10.7717/peerj.360).

22. Pickering, C., *Literature review of horse riding impacts on protected areas and a guide to the development of an assessment program*. 2008. Environmental Protection Agency: Brisbane, Australia.

23. Pickering, C.M. and A.M. Mount, *Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses.* Journal of Sustainable Tourism. 2010. 18(2): p. 239-256.

24. Quinn, M. and G. Chernoff, *Mountain biking: A review of the ecological effects. A literature review for Parks Canada - National Office (Visitor Experience Branch)*. 2010. Calgary, AB.

25. Stankowich, T., *Ungulate flight response to human disturbance: A review and meta-analysis.* Biological Conservation. 2008. 141(9): p. 2159-2173.

26. Steven, R., C. Pickering, and J.G. Castley, *A review of the impacts of nature based recreation on birds.* Journal of Environmental Management. 2011. 92: p. 2287-2294.

27. U.S. Forest Service, *User created trail impacts - literature review*. 2014. USFS Red Rock District.

28. Hesselbarth, W., B. Bachowski, and M.A. Davises, *Trail construction and maintenance notebook*. 2007. U.S.D.A. Forest Service, Missoula Technology & Development Center: Missoula, MT.

29. Aust, M.W., J.L. Marion, and K. Kyle, *Research for the development of Best Management Practices to minimize horse trail impacts on the Hoosier National Forest*. 2015. Blacksburg, VA.

30. Cal-IPC, *Preventing the spread of invasive plants: Best management practices for land managers*. 2012. California Invasive Plant Council: Berkeley, CA.

31. Monz, C.A., C.M. Pickering, and W.L. Hadwen, *Recent advances in recreation ecology and the implications of different relationships between recreation use and ecological impacts.* Frontiers in Ecology and the Environment. 2013. 11(8): p. 441-446.

32. Ballantyne, M., O. Gudes, and C.M. Pickering, *Recreational trails are an important cause of fragmentation in endangered urban forests: A case-study from Australia.* Landscape and Urban Planning. 2014. 130: p. 112-124.

33. Hof, M. and D.W. Lime, *Visitor Experience and Resource Protection Framework in the National Park System–Rationale, current status, and future direction* in *Proceedings: Limits of Acceptable Change and Related Planning Processes – Progress and Future Change and Related Planning Processes, Progress and Future Directions*. 1997. U.S.D.A. Forest Service, Intermountain Research Station: Ogden, UT.

34. Oregon Parks & Recreation Department, *Statewide Comprehensive Outdoor Recreation Plan*. 2017. State of Oregon, Oregon Parks and Recreation Department: Washington, D.C.

35. The Outdoor Foundation, *Outdoor recreation participation*. 2016. The Outdoor Foundation: Washington, D.C. p. 458-465.

36. Trails for All Ontarians Collaborative, *Guidelines and best practices for the design, construction and maintenance of sustainable trails for all Ontarians*. 2006. Ontario, Canada.

37. Colorado State Parks, Trails and Wildlife Task Force, *Planning trails with wildlife in mind. A handbook for trails planners*. 1998.

38. Leung, Y.-F., et al., *Developing a monitoring protocol for visitor-created informal trails in Yosemite National Park, USA.* Environmental Management. 2011. 47(1): p. 93-106.

39. Burde, J.H. and J.R. Renfro. *Use impacts of the Appalachian Trail.* in *Proceedings, National Wilderness Research Conference: Issues, state-of-knowledge, future directions*. 1986. U.S.D.A. Forest Service.

40. Marion, J.L. and Y.-F. Leung, *Environmentally sustainable trail management*, in *Environmental Impacts of Ecotourism*, R. Buckley, Editor. 2004. CABI Publishers: Wallingford, Oxfordshire, U.K.

41. Wimpey, J.F. and J.L. Marion, *The influence of use, environmental and managerial factors on the width of recreational trails.* Journal of Environmental Management. 2010. 91: p. 2028-2037.

42. Marion, J.L. and Y.-F. Leung, *Trail resource impacts and an examination of alternative assessment techniques.* Journal of Park and Recreation Administration. 2001. 19(3): p. 17-37.

43. Metro, *Green Trails. Guidelines for environmentally friendly trails*. 2004. Metro: Portland, OR.

44. Focetola, G.F., et al., *Vertebrates respond differently to human disturbance: Implications for the use of a focal species approach.* Acta Oecologica. 2007. 31(1): p. 109-118.

45. Yan, X., W. Bao, and X. Pang, *Indirect effects of hiking trails on the community structure and diversity of trunk-epiphytic bryophytes in an old-growth fir forest.* Journal of Bryology. 2014. 36(1): p. 44-55.

46. Weiss, F., T.J. Brummer, and G. Pufal, *Mountain bikes as seed dispersers and their potential socio-ecological consequences.* Journal of Environmental Management. 2016. 181(1): p. 326-332.

47. Cater, C., et al., *High impact activities in parks. Best management practice and future research*, K. Van Asperen, Editor. 2008. Cooperative Research Centre for Sustainable Tourism Pty Ltd: Gold Coast, Queensland, Australia.

48. Miller, A.B., *Impacts of trail building on wildlife: A before-after control-impact experimental study using camera traps*, in *Parks, Recreaion and Tourism Management*. 2016. North Carolina State University: Raleigh, NC.

49. Oregon Department of Fish and Wildlife, *Guidance for conserving Oregon's native turtles including best management practices.* 2015. Salem, OR. p. 1-99.

50. Cole, D.N. and R.L. Knight, *Impacts of recreation on biodiversity in wilderness.* Natural Resources and Environmental Issues. 1990. 0(Article 6).

51. Hancock, J., et al., *Equestrian design guidebook for trails, trailheads, and campgrounds*. 2007. U.S.D.A. Forest Service, Missoula Technology and Development Center: Missoula, MT.

52. U.S.D.A. Forest Service, *TRACS Trail Assessment and Condition Surveys*. 2009. U.S.D.A. Department of Agriculture, Forest Service: Washington, D.C.

53. City of Portland, Oregon Parks & Recreation Department, *Trail design guidelines for Portland's park system.* 2009. City of Portland: Portland, OR.

54. Bratton, S.P., M.G. Hickler, and J.H. Graves, *Trail erosion patterns in Great Smoky Mountains National Park.* Environmental Management. 1979. 3(5): p. 431-445.

55. Bio-West, Inc., *Northern Bonneville Shoreline Trail Master Plan*. 2002. Bear River Association of Governments: Logan, UT.

56. Marion, J.L. and Y.-F. Leung, *Indicators and protocols for monitoring impacts of formal and informal trails in protected areas.* Journal of Tourism and Leisure Studies. 2011. 17(2): p. 216-236.

57. City of Boulder, Colorado, *System-wide undesignated trail mapping on open space and mountain park lands*. 2012. City of Boulder, CO: Boulder, CO.

58. Foti, P., et al., *Planning & managing environmentally friendly mountain bike trails: Ecological impacts, managing for future generations, resources*. 2006.

59. Harper, K.A., et al., *Edge influences on forest structure and composition in fragmented landscapes.* Conservation Biology. 2005. 19(3): p. 768-782.

60. Nuzzo, V., *Invasion pattern of herb garlic mustard (Alliaria petiolata) in high quality forests.* Biological Invasions. 1999. 1(2): p. 169-179.

61. Hobbs, R.J. and L. Atkins, *Effect of disturbance and nutrient addition on native and introduced annuals in plant communities in the Western Australia wheatbelt.* Australian Journal of Botany. 1998. 13: p. 171-179.

62. Wolf, I.D., G. Hagenloh, and D.B. Croft, *Vegetation moderates impacts of tourism usage on bird communities along roads and hiking trails.* Journal of Environmental Management. 2013. 129: p. 224-234.

63. Cole, D.N., *Experimental trampling of vegetation. II. Predictors of resistance and resilience.* Journal of Applied Ecology. 1995. 32: p. 215-224.

64. Hill, R. and C. Pickering, *Differences in resistance of three subtropical vegetation types to experimental trampling.* Journal of Environmental Management. 2009. 90: p. 1305-1312.

65. Smith, W.G., *Raunkiaer's life-forms and statistical methods.* Journal of Ecology. 1913. 1(1): p. 16-26.

66. Marion, J.L., et al., *A review and synthesis of recreation ecology research findings on visitor impacts to wilderness and protected areas.* Journal of Forestry. 2016. 114(3): p. 352-362.

67. Cole, D.N., *Recreational trampling effects on six habitat types in western Montana*. 1985. Ogden, UT.

68. Weaver, T. and D. Dale, *Trampling effects of hikers, motorcycles and horses in meadows and forests.* Journal of Applied Ecology. 1978. 15(2): p. 451-457.

69. Mason, S., et al., *Recreational trampling negatively impacts vegetation structure of an Australian biodiversity hotspot.* Biodiversity Conservation. 2015. 24(11): p. 2685-2707.

70. Cole, D.N. and S.J. Trull, *Quantifying vegetation response to recreational disturbance in the North Cascades, Washington.* Northwest Science. 1992. 66(4): p. 229-236.

71. Yorks, T.P., et al., *Toleration of traffic by vegetation: Life form conclusions and summary extracts from a comprehensive data base.* Environmental Management. 1997. 21(1): p. 121-131.

72. Olive, N.D. and J.L. Marion, *The influence of use-related, environmental, and managerial factors on soil loss from recreational trails.* Journal of Environmental Management. 2009. 90(3): p. 1483-1493.

73. Wilson, J.P. and J.P. Seney, *Erosional impact of hikers, horses, motorcycles, and off-road bicycles on mountain trails in Montana.* Mountain Research and Development. 1994. 14(1): p. 77-88.

74. Randall, M. and D. Newsome, *Assessment, evaluation and a comparison of planned and unplanned walk trails in coastal south-western Australia.* Conservation Science in Western Australia. 2008. 7(1): p. 19-34.

75. White, D.D., et al., *A comparative study of impacts to mountain bike trails in five common ecological regions of the southwestern U.S.* Journal of Park and Recreation Administration. 2006. 24(2): p. 21-41.

76. Godwin, I.C.P., *Physiographic components of trail erosion*. 2000. Montana State University: Bozeman, MT.

77. Marion, J.L. and N. Olive, *Assessing and understanding trail degradation: Results from Big South Fork National River and Recreation Area*. 2006.

78. Chiu, L. and L. Kriwoken, *Managing recreational mountain biking in Wellington Park, Tasmania, Australia.* Annals of Leisure Research. 2003. 6(4): p. 339-361.

79. Deluca, T.H., et al., *Influence of llamas, horses, and hikers on soil erosion from established recreation trails in western Montana, USA.* Environmental Management. 1998. 22(2): p. 255-262.

80. Tempel, D., et al., *Linking wilderness research and management - Volume 5. Understanding and managing backcountry recreation impacts on terrestrial wildlife; an annotated reading list*. 2008. Fort Collins, CO. p. 1-70.

81. Williamson, J.R. and W.A. Neilsen, *The influence of forest site on rate and extent of soil compaction and profile disturbance of skid trails during ground-based harvesting.* Canadian Journal of Forest Research. 2000. 30(8): p. 1196-1205.

82. Australian Natural Heritage Trust, *Bulk density - measuring*, soilquality.org.au, Editor. Undated. Accessed online July 2017.

83. Stewart, D.P.C. and K.C. Cameron, *Effect of trampling on the soils of the St James Walkway, New Zealand.* Soil Use and Management. 1992. 8(1): p. 30-35.

84. Patterson IV, W.A., *Influence of llama, horse, and foot traffic on soil erosion from established recreation trails in western Montana*. 1996. University of Montana: Missoula, MT.

85. Liddle, M., *Recreation Ecology*. 1997. London, England: Chapman and Hall. 639.

86. Goeft, U. and J. Alder, *Sustainable mountain biking: A case study from the southwest of western Australia.* Journal of Sustainable Tourism. 2001. 9(3): p. 193-211.

87. Felton, V., *Trail solutions: IMBA's guide to building sweet singletrack*. 2004. International Mountain Bicycling Association: Boulder, CO.

88. City of Portland, Oregon, *River View Natural Area management plan*. 2015.

89. Recreation, M.D.o.C.a., *Trails guidelines and best practices manual*. 2014. State of Massachusetts: Boston, MA.

90. Marion, J.L. and J. Wimpey, *Assessing the influence of sustainable trail design and maintenance on soil loss.* Journal of Environmental Management. 2017. 189: p. 46-57.

91. Brant, C.J., *The size distribution of throughfall drops under vegetation canopies.* Catena. 1989. 16(4-5): p. 507-524.

92. Hockett, K., et al., *Deterring off-trail hiking in protected natural areas: Evaluating options with surveys and unobtrusive observation*. 2010. Department of Forest Resources & Environmental Conservation, Virginia Polytechnic Institute and State University: Blacksburg, VA.

93. Park, L.O., et al., *Managing visitor impacts in parks: A multi-method study of the effectiveness of alternative management practices.* Journal of Park and Recreation Administration. 2008. 26(1): p. 97-121.

94. Wimpey, J. and J.L. Marion, *A spatial exploration of informal trail networks within the Great Falls Park, VA.* Journal of Environmental Management. 2011. 92: p. 1012-1022.

95. Dale, D. and T. Weaver, *Trampling effects on vegetation of the trail corridors of north Rocky Mountain forests.* Journal of Applied Ecology. 1974. 11(2): p. 767-772.

96. Beeton, S., *Sustainable tourism in practice: Trails and tourism. Critical management issues of multi-use trails.* Tourism and Hospitality Planning & Development. 2006. 3(1): p. 47-64.

97. Cline, R., N. Sexton, and S.C. Stewart, *A human dimensions review of human-wildlife disturbance: A literature review of impacts, frameworks, and management solutions*. 2007, U.S. Geological Survey. p. 88.

98. Wimpey, J. and J.L. Marion, *Formal and informal trail monitoring protocols and baseline conditions: Great Falls Park and Potomac Gorge*. 2011. Virginia Tech / Department of Forest Resources & Environmental Conservation: Blacksburg, VA.

99. Pickering, C.M., S. Rossi, and A. Barros, *Assessing the impacts of mountain biking and hiking on subalpine grasslands using an experimental protocol.* Journal of Environmental Management. 2011. 92: p. 3049-3057.

100. Pickering, C.M., *Ten factors that affect the severity of environmental impacts of visitors in protected areas.* AMBIO. 2010. 39: p. 70-77.

101. Barlow, C., *Public access and recreation in the countryside and their impacts on biodiversity: An interdisciplinary analysis*. 2010. University of Warwick.

102. Thurston, E. and R.J. Reader, *Impacts of experimentally applied mountain biking and hiking on vegetation and soil of a deciduous forest.* Journal of Environmental Management. 2001. 27(3): p. 397-409.

103. Cole, D.N. and D.R. Spildie, *Hiker, horse and llama trampling effects on native vegetation in Montana, USA.* Journal of Environmental Management. 1998. 53: p. 61-71.

104. Whinam, J. and N.M. Chilcott, *Impacts after four years of experimental trampling on alpine/sub-alpine environments in western Tasmania.* Journal of Environmental Management. 2003. 67: p. 339-351.

105. Pickering, C.M., et al., *Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America.* Journal of Environmental Management. 2010. 91(551): p. 562.

106. Barros, A., J.M. Gonnet, and C. Pickering, *Impacts of informal trails on vegetation and soils in the highest protected area in the Southern Hemisphere.* Journal of Environmental Management. 2013. 127C: p. 50-60.

107. Kling, K.G., S. Wall-Reinius, and P. Fredman, *The multi-functional trail. An international literature review and the case of trails in southern Jämtland Mountains, Sweden*. 2017. Mid Sweden University: Östersund, Sweden.

108. Pickering, C. and A. Barros. *Assessing the relative impacts on plant composition and functional composition from mountain biking and hiking*. in *The 7th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas (MMV). Local community and outdoor recreation*. 2014.

109. Törn, A., et al., *Comparing the impacts of hiking, skiing and horse riding on trail and vegetation in different types of forest.* Journal of Environmental Management. 2009. 90(3): p. 1427-1434.

110. Phillips, N. and D. Newsome, *Understanding the impacts of recreation in Australian protected areas: Quantifying damage caused by horse riding in D'Entrecasteaux National Park, Western Australia.* Pacific Conservation Biology. 2001. 7(4): p. 256-273.

111. Whittaker, P.L., *Comparison of surface impact by hiking and horseback riding in the Great Smoky Mountains National Park*. 1978. Department of the Interior, National Park Service, Southeast Region: Gatlinburg, TN.

112. Newsome, D., et al., *Effects of horse riding on national parks and other natural ecosystems in Australia: Implications for management.* Journal of Ecotourism. 2002. 1(1): p. 52-74.

113. Taylor, A.R. and R.L. Knight, *Wildlife responses to recreation and associated visitor perceptions.* Ecological Applications. 2003. 13(4): p. 951-963.

114. Leung, Y.-F., et al. *Assessing technical trail features for mountain biking: Examples from four countries*. 2013. 7th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas: Local community and outdoor recreation.

115. Watson, A.E., M.J. Niccolucci, and D.R. Williams, *Hikers and recreational stock users: Predicting and managing recreation conflicts in three wildernesses*. 1993. Ogden, UT. p. 1-35.

116. Moore, R.L., *Conflicts on multiple-use trails: Synthesis of the literature and state of the practice*. 1994. North Carolina State University, Dept. of Parks, Recreation, & Tourism Management.

117. McClaran, M.P. and D.N. Cole, *Packstock in wilderness: Use, impacts, monitoring and management*. 1993. Ogden, UT. p. 33 pages.

118. Monz, C.A., et al., *Sustaining visitor use in protected areas: Future opportunities in recreation ecology research based on the USA experience.* Envrironmental Management. 2009. Published online 17 December 2009.

119. Leung, Y.-F., C. Pickering, and D.N. Cole. *Informal trails and fragmentation effects: A conceptual and research overview*. in *Proceedings of the 6th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas: Outdoor Recreation in Change – Current Knowledge and Future Challenges*. 2012.

120. D'Antonio, A., et al., *An application of recreation resource assessment techniques to inform management action in an urban-proximate natural area.* Journal of Outdoor Recreation and Tourism. 2016. 14: p. 12-21.

121. Van Winkle, J., *Informal trails and the spread of invasive species in urban natural areas: Spatial analysis of informal trails and their effects on understory plan communities in Forest Park, Portland, Oregon*. 2014. Portland State University: Portland, OR.

122. Ballantyne, M. and C.M. Pickering, *Differences in the impacts of formal and informal recreational trails on urban forest loss and tree structure.* Journal of Environmental Management. 2015. 159: p. 94-105.

123. Fernández-Juricic, E., R. Vaca, and N. Schroeder, *Spatial and temporal responses of forest birds to human approaches in a protected area and implications for two management strategies.* Biological Conservation. 2004. 117: p. 407-416.

124. Papouchis, C.M., F.J. Singer, and W.B. Sloan, *Responses of desert bighorn sheep to increased human recreation.* Journal of Wildlife Management. 2001. 65: p. 573-582.

125. Ballantyne, M., C. Pickering, and O. Gudes, *How formal and informal mountain biking trails result in the reduction, degradation and fragmentation of endangered urban forest remnants.* in *The 7th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas (MMV). Local community and outdoor recreation*. 2014.

126. Sauvajot, R.M., et al., *Patterns of human disturbance and response by small mammals and birds in chaparral near urban development.* Urban Ecosystems. 1998. 2(4): p. 279.

127. Johnson, C., *Socio-economic and environmental impact of homelessness in Olympia, Washington*. 2016. Environmental Health and Social Justice: Olympia, WA.

128. Chamard, S., *Homeless encampments*. 2009. U.S. Department of Justice, Office of Community Oriented Policing Services: Washington, D.C.

129. Mulrooney, D., *Geocaching in Ontario's protected areas*. in *Parks and Protected Areas Research in Ontario (PRFO), Waterloo, Ontario, Canada*. 2003. University of Western Ontario: Parks Research Forum of Ontario.

130. Metro, *Metro geocaching and letterboxing guidelines*. 2011. Metro: Portland, OR.

131. Reams, V. and S. West, *Agency-sponsored treasure hunts: Providing alternatives to traditional geocaching.* in *Rethinking Protected Areas in a Changing World: Proceedings of the 2007 GWS Biennial Conference on Parks, Protected Areas, and Cultural Sites*. 2008. Hancock, MI: The George Wright Society.

132. Reed, S.E., et al., *Wildlife response to human recreation on NCCP reserves in San Diego County*. 2014. Bozeman, MT.

133. Newsome, D. and C.H. Davies, *A case study in estimating the area of informal trail development and associated impacts caused by mountain bike activity in John Forrest National Park, western Australia.* Journal of Ecotourism. 2009. 8(3): p. 237-253.

134. Maus, J., *Unauthorized bike trail damages "pristine habitat" in Forest Park - UPDATED*, in *BikePortland*. 2010. BikePortland.Org: Portland, OR.

135. Tory, S., *Illegal bike trails and a Forest Service crackdown divide a town*, in *High Country News*. 2015. Paonia, CO.

136. Burns, J., *Outdoor enthusiasts join wildlife officials to tackle "renegade trails"*. EarthFix. 2015. Published online February 18, 2015.

137. Pickering, C., et al., *Environmental, safety and management issues of unauthorised trail technical features for mountain bicycling.* Landscape and Urban Planning. 2010. 97: p. 58-67.

138. Pickering, C. and Y.-F. Leung. *Current knowledge and future research directions. What's the latest research on mountain biking in protected areas? Results from the special issue of the Journal of Outdoor Recreation and Tourism,* in *8th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas*. 2016. Novi Sad, Serbia: Journal of Outdoor Recreation and Tourism.

139. Various, *Mountain biking in Forest Park*. Undated. Mazamas Conservation Committee, Northwest Trail Alliance, Forest Park Conservancy and the City of Portland Parks & Recreation: Portland, OR.

140. Bushman, M., *Peer review comments received 11-15-2016*, L. Hennings. 2016. Portland, OR.

141. Winter, P.L., *The impact of normative message types on off-trail hiking.* Journal of Interpretive Research. 2006. 11(1): p. 35-53.

142. Newsome, D., S.A. Moore, and R.K. Dowling, *Natural Area Tourism: Ecology, Impacts and Management*. Second ed. 2013. New York, NY: Channel View Publications.

143. International Mountain Biking Association, *Mt. Shasta Conceptual Trails Plan*. 2013. International Mountain Bicycling Association: Boulder, CO.

144. Carothers, P. and J.J. Vaske, *Social values versus interpersonal conflicts among hikers and mountain bikers.* Leisure Sciences. 2001. 23: p. 47-61.

145. Cessford, G. *Perception and reality of conflict: Walkers and mountain bikes on the Queen Charlotte Track in New Zealand*. 2002.

146. Beeton, S., *Hoofing it - on four or two feet? Managing multi-use trails and sites.* 1999.

147. Rossi, S.G., et al., *'Seeing red' in national parks: How visitors' values affect perceptions and park experiences.* Geoforum. 2015. 66: p. 41-52.

148. Abbott, E., D. Newsome, and S. Palmer, *A case study analysis of horse riding and its management in a peri-urban setting*. 2010. Sustainable Tourism Cooperative Research Centre: Gold Coast, Queensland, Australia.

149. Bekoff, M. and R.W. Ickes, *Behavioral interactions and conflict among domestic dogs, black-tailed prairie dogs, and people in Boulder, Colorado.* Anthrozoos. 1999. 12(2): p. 105-110.

150. Horn, C., *Conflict in recreation: The case of mountain-bikers and trampers*. 1994. Lincoln University: Lincoln, New Zealand.

151. Heer, C., H.-P. Rusterholz, and B. Baur, *Forest perception and knowledge of hikers and mountain bikers in two different areas in northwestern Switzerland.* Environmental Management. 2003. 31(6): p. 709-723.

152. Watson, A.E., D.R. Williams, and J.J. Daigle, *Sources of conflict between hikers and mountain bike riders.* Journal of Parks and Recreation Administration. 1991. 9(3): p. 59-71.

153. Watson, A.E., M.J. Niccolucci, and D.R. Williams, *The nature of conflict between hikers and recreational stock users in the John Muir Wilderness.* Journal of Leisure Research. 1994. 26(4): p. 372-385.

154. Pickering, C.M. and S. Rossi, *Mountain biking in peri-urban parks: Social factors influencing perceptions of conflicts in three popular national parks in Australia.* Journal of Outdoor Recreation and Tourism. 2016. 15: p. 71-81.

155. Ramthun, R., *Factors in user group conflict between hikers and mountain bikers.* Leisure Sciences. 1995. 17(3): p. 159-169.

156. Levêque, J., et al., *Forest visitor perceptions of recreational impacts on amphibian wildlife.* European Journal of Wildlife Research. 2015. 61(4): p. 505-515.

157. Ansong, M. and C. Pickering, *What's a weed? Knowledge, attitude and behavior of park visitors about weeds.* PLoS ONE. 2015. 10(8): p. e0135026, doi:10.1371/journal.pone.0135026.

158. Chavez, D.P., P.L. Winter, and J.M. Baas, *Recreational mountain biking: A management perspective.* Journal of Park and Recreation Administration. 1993. 11(3): p. 29-36.

159. Chavez, D.J., *Mountain biking: Issues and actions for USDA Forest Service Managers*. 1996. Albany, CA. p. 1-33.

160. Barnard, A., *Getting the facts – Dog walking and visitor number surveys at Burnham Beeches and their implications for the management process.* Countryside Recreation. 2003. 11(2): p. 16-19.

161. Sterl, P., C. Brandenburg, and A. Arnberger, *Visitors' awareness and assessment of recreational disturbance of wildlife in the Donau-Auen National Park.* Journal for Nature Conservation. 2008. 16: p. 135-145.

162. Vaske, J.J., M.D. Needham, and R.C. Cline, Jr., *Clarifying interpersonal and social values conflict among recreationists.* Journal of Leisure Research. 2007. 39(1): p. 182-195.

163. Blanc, R., et al., *Effects of non-consumptive leisure disturbance to wildlife.* Revue d'Ecologie (La Terre et la Vie). 2006. 61(2): p. 117-133.

164. Perry, D.A., *Forest Ecosystems*. 1994. Baltimore, MD: The Johns Hopkins University Press.

165. Didham, R.K. and R.M. Ewers, *Edge effects disrupt vertical stratification of microclimate in a temperate forest canopy.* Pacific Science. 2014. 68(4): p. 493.

166. Weaver, T., D. Dale, and E. Hartley. *The relationship of trail condition to use, vegetation, user, slope, season and time*. in *Recreational Impacts on Wildlife*. 1979. U.S.D.A. Forest Services, Pacific Northwest Region.

167. Marzluff, J.M., *Effects of urbanization and recreation on songbirds*, in *Songbird Ecology in Southwestern Ponderosa Pine Forests: A Literature Review. General Technical Report RM-GTR-292*, W.M.F. Block, D.M., Editor. 1997. U.S.D.A. Forest Service: Fort Collins, CO. p. 89-102.

168. Prugh, L.R., et al., *The rise of the mesopredator.* BioScience. 2009. 59(9): p. 779-791.

169. Crooks, K.R., *Relative sensitivities of mammalian carnivores to habitat fragmentation.* Conservation Biology. 2002. 16(2): p. 488-502.

170. Crooks, K.R. and M.E. Soulé, *Mesopredator release and avifaunal extinctions in a fragmented system.* Nature. 1999. 400: p. 563-566.

171. Beschta, R.L. and W.J. Ripple, *Large predators and trophic cascades in terrestrial ecosystems of the western United States.* Biological Conservation. 2009. 142: p. 2401-2415.

172. Rogola, J.K., et al., *Human activity differentially redistributes large mammals in the Canadian Rockies National Parks.* Ecology and Society. 2011. 16(3): p. 16.

173. Schultz, R.D. and J.A. Bailey, *Responses of national park elk to human activity.* Journal of Wildlife Management. 1978. 42(1): p. 91-100.

174. Sinclair, K.E., et al., *Mammalian nest predators respond to greenway width, landscape context and habitat structure.* Landscape and Urban Planning. 2005. 71(2-4): p. 277-293.

175. Thompson, B., *Recreational trails reduce the density of ground-dwelling birds in protected areas.* Environmental Management. 2015. 55(5): p. 1181-1190.

176. Zhou, Y., et al., *Balancing the benefits of ecotourism and development: The effects of visitor trail-use on mammals in a Protected Area in rapidly developing China.* Biological Conservation. 2013. 165: p. 18-24.

177. Ulrich, W., et al., *Tourism disassembles patterns of co-occurrence and weakens responses to environmental conditions of spider communities on small lake islands.* Community Ecology. 2010. 11: p. 5-12.

178. Alwis, N.S., P. Perera, and N.P. Dayawansa, *Response of tropical avifauna to visitor recreational disturbances: A case study from the Sinharaja Work Heritage Forest, Sri Lanka.* Avian Research. 2016. 7(15): p. 1-13.

179. Bartos Smith, S., et al., *Edges, trails, and reproductive performance of Spotted Towhees in urban greenspaces*, in *Urban Bird Ecology and Conservation*. 2012. University of California Press: Oakland, CA.

180. Burger, J. and M. Gochfeld, *Beach recreation and nesting birds*, in *Wildlife and Recreationists. Coexistence through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Press: Washington, D.C. p. 281-295.

181. Lafferty, K.D., D. Goodman, and C.P. Sandoval, *Restoration of breeding by Snowy Plovers following protection from disturbance.* Biodiversity and Conservation. 2006. 15: p. 2217-2230.

182. Ansong, M. and C. Pickering, *Long-distance dispersal of black spear grass (Heteropogon contortus) seed on socks and trouser legs by walkers in Kakadu National Park.* Ecological Management & Restoration. 2013. 14(1): p. 71-74.

183. Cushman, J.H. and R.K. Meentemeyer, *Multi-scale patterns of human activity and the incidence of an exotic forest pathogen.* Journal of Ecology. 2008. 96(4): p. 766-776.

184. Pickering, C.M., et al., *Estimating human-mediated dispersal of seeds within an Australian protected area.* Biological Invasions. 2011. 13: p. 1869-1880.

185. Bourchard, E.H., et al., *Undeclared baggage: Do tourists act as vectors for seed dispersal in fynbos protected areas?* Koedoe - African Protected Area Conservation and Science. 2015. 57(1): p. 1-9.

186. Turton, S.M., *Managing environmental impacts of recreation and tourism in rainforests of the wet tropics of Queensland World Heritage Area.* Geographical Research. 2005. 43(2): p. 140-151.

187. Ansong, M. and C. Pickering, *A global review of weeds that can germinate from horse dung.* Ecological Management and Restoration. 2013. 14(3): p. 216-223.

188. Magro, T.C. and F.S.A. de Andrade. *Horse riding in protected areas: And the dung?* in *The 6th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas*. 2012.

189. Weaver, V. and R. Adams. *Horses as vectors in the dispersal of weeds into native vegetation*. in *Proceedings of the 11th Australian Weeds Conference, Melbourne, Australia, 30 September - 3 October 1996.* 1996. Weed Science Society of Victoria, University of Melbourne.

190. Ballantyne, M. and C.M. Pickering, *Recreational trails as a source of negative impacts on the persistence of keystone species and facilitation.* Journal of Environmental Management. 2016. 159: p. 48-57.

191. Naeem, S., et al., *Biodiversity and ecosystem functioning: Maintaining natural life support processes.* Issues in Ecology. 1999. 4: p. 1-11.

192. Larson, C.L., et al., *Effects of recreation on animals revealed as widespread through a global systematic review.* PLoS One. 2016. 11(12): p. e0167259.

193. Mallord, J.W., et al., *Linking recreational disturbance to population size in a ground-nesting passerine.* Journal of Applied Ecology. 2007. 44(1): p. 185-195.

194. Shively, K.J., A.W. Alldredge, and G.E. Phillips, *Reproductive success of elk following disturbance by humans during calving season.* Journal of Wildlife Management. 2005. 69(3): p. 1073-1080.

195. Keller, K.J.D., *Mountain bikes on public lands: A manager's guide to the state of practice*. 1990. Bicycle Federation of America: Washington, D.C.

196. Kidd, K.R., W.M. Aust, and C.A. Copenheaver, *Recreational stream crossing effects on sediment delivery and macronvertebrates in southwestern Virginia, USA.* Environmental Management. 2014. 54: p. 505-516.

197. Caires, A.M., M.R. Vinson, and A.M.D. Brasher, *Impacts of hikers on aquatic invertebrates in the North Fork of the Virgin River, Utah.* Southwestern Naturalist. 2010. 55(4): p. 551-557.

198. Holmquist, J.G., J. Schmidt-Gengenbach, and J.W. Roche, *Stream macroinvertebrates and habitat below and above two wilderness fords used by mules, horses, and hikers in Yosemite National Park.* Western North American Naturalist. 2015. 75(3): p. 311-324.

199. Palmisano, J.F., R.H. Ellis, and V.W. Kaczynski, *The impact of environmental and management factors on Washington's wild anadromous salmon and trout*. 1993. Olympia, WA: Washington Forest Protection Association and The State of Washington Department of Natural Resources.

200. Donovan, T.M., et al., *Modeling the effects of habitat fragmentation on source and sink demography of neotropical migrant birds.* Conservation Biology. 1995. 9(6): p. 1396-1407.

201. Faaborg, J., et al., *Habitat fragmentation in the temperate zone: A perspective for managers*, D.M. Finch and P.W. Stangel, Editors. 1993. Fort Collins, CO. p. 331-338.

202. Soulé, M.E., et al., *Reconstructed dynamics of rapid extinctions of chaparral-requiring birds in urban habitat islands.* Conservation Biology. 1988. 2(1): p. 75-92.

203. Crooks, K.R., et al., *Extinction and colonization of birds on habitat islands.* Conservation Biology. 2001. 15(1): p. 159-172.

204. Esby, E.M.S., *Edge effects: Native and non-native plant distribution along single use and multi-use trails in the Santa Monica Mountains National Recreation Area, California.* 2011. Montana State University: Bozeman, MT.

205. Canada, E., *Area-sensitive forest birds in urban areas.* 2007. Ontario, Canada. p. 1-57.

206. Shipley, A.A., *Postfledging survival and habitat use of Spotted Towhees (Pipilo maculatus) in an urban park.* 2011. Portland State University: Portland, OR.

207. Haddad, N.M., et al., *Habitat fragmentation and its lasting impact on Earth's ecosystems.* Science Advances. 2015. 1(2): p. e1500052.

208. Hunter, R.D., R.N. Fisher, and K.R. Crooks, *Landscape-level connectivity in coastal Southern California, USA, as assessed through carnivore habitat suitability.* Natural Areas Journal. 2003. 23(4): p. 302-314.

209. Reilly, M., *Effects of non-motorized recreation on mid-size and large mammals in the San Francisco Bay area.* 2015. Northern Arizona University: Flagstaff, AZ.

210. Beier, P., *Dispersal of juvenile cougars in fragmented habitat.* Journal of Wildlife Management. 1995. 59: p. 228-237.

211. Donovan, T., et al., *Reproductive success of migratory birds in habitat sources and sinks.* Conservation Biology. 1995. 9(6): p. 1380-1395.

212. Lindell, C.A., et al., *Edge responses of tropical and temperate birds.* The Wilson Journal of Ornithology. 2007. 119(2): p. 205-220.

213. Maurer, B.A. and S.G. Heywood, *Geographic range fragmentation and abundance in neotropical migratory birds.* Conservation Biology. 1993. 7(3): p. 501-509.

214. Donovan, T.M. and C.H. Flather, *Relationships among North American songbird trends, habitat fragmentation, and landscape occupancy.* Ecological Applications. 2002. 12(2): p. 365-374.

215. Ballantyne, M., et al., *Comparing the impacts of different types of recreational trails on Grey Box grassy-woodland vegetation: Lessons for conservation and management* Australian Journal of Botany. 2016. 64: p. 246-259.

216. Barros, A. and C.M. Pickering, *Non-native plant invasion in relation to tourism use of Aconcagua Park, Argentina, the highest protected area in the Southern Hemisphere.* Mountain Research and Development. 2014. 31(1): p. 13-26.

217. Pickering, C., J.G. Castley, and K. Richardt. *Informal trails fragmenting endangered remnant vegetation in Australia.* 2012.

218. U.S. Fish and Wildlife Service, *The cost of invasive species.* 2012. U.S. Fish and Wildlife Service.

219. Pimentel, D.e., *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal and Microbe Species.* 2nd ed. 2011. CRC Press.

220. Davey, J., *The effects of invasive alien plants on cultural ecosystem services: Tourism and recreation*, in *Department of Environmental and Geographical Sciences.* 2011. University of Cape Town: Cape Town, South Africa.

221. Pickering, C.M. and W. Hill, *Impacts of recreation and tourism on plant biodiversity and vegetation in protected areas in Australia.* Journal of Environmental Management. 2007. 85: p. 791-800.

222. Ngugi, M.R., V.J. Neldner, and R. Dowling, *Non-native plant species richness adjacent to a horse trail network in seven National Parks in southeast Queensland, Australia.* Australasian Journal of Environmental Management. 2014. 21(4): p. 413-428.

223. Gower, S.T., *Are horses responsible for introducing non-native plants along forest trails in the eastern United States?* Forest Ecology and Management. 2008. 256: p. 997-1003.

224. Crooks, J.A., *Lag times and exotic species: The ecology and management of biological invasions in slow-motion.* Ecoscience. 2005. 12(3): p. 316-329.

225. Mount, A. and C.M. Pickering, *Testing the capacity of clothing to act as a vector for non-native seed in protected areas.* Journal of Environmental Management. 2009. 91: p. 168-179.

226. Wichmann, M.C., et al., *Human-mediated dispersal of seeds over long distances.* Proceedings of the Royal Society of Biological Sciences. 2009. 276(1656): p. 523-532.

227. U.S.D.A. Animal and Plant Health Inspection Service, *APHIS list of regulated hosts and plants proven or associated with Phytophthora ramorum*. 2013. Washington, D.C.

228. Thut, P., et al. *Sudden oak death bike tire scrubber*. in *Proceedings of the sudden oak death second science symposium: the state of our knowledge. PSW-GTR-196*. 2005. Monterey, CA: U.S.D.A. Forest Service, Pacific Southwest Research Station.

229. Pickering, C., M. Ansong, and E. Wallace, *Experimental assessment of weed seed attaching to a mountain bike and horse under dry conditions.* Journal of Outdoor Recreation and Tourism. 2016. 15: p. 66-70.

230. Campbell, J.E. and D.J. Gibson, *The effect of seeds of exotic species transported via horse dung on vegetation along trail corridors.* Plant Ecology. 2001. 157: p. 23-51.

231. Stroh, E.D. and M.A. Struckhoff, *Exotic plant species associations with horse trails, old roads, and intact native communities in the Missouri Ozarks.* Natural Areas Journal. 2009. 29(1): p. 50-56.

232. Wells, F.H. and W.K. Lauenroth, *The potential for horses to disperse alien plants along recreational trails.* Rangeland Ecology & Management. 2007. 60(6): p. 574-577.

233. Couvreur, M., et al., *Large herbivores as mobile links between isolated reserves through adhesive seed dispersal.* Applied Vegetation Science. 2004. 7(2): p. 229-236.

234. Wedin, D.A. and D. Tilman, *Influence of nitrogen loading and species composition on the carbon balance of grasslands.* Science. 1996. 274: p. 1720-1723.

235. Van der Zande, A.N., et al., *Impact of outdoor recreation on the density of a number of breeding bird species in woods adjacent to urban residential areas.* Biological Conservation. 1984. 30(1): p. 1-39.

236. Mullner, A., K.E. Linsenmair, and M. Wikelski, *Exposure to ecotourism reduces survival and affects stress response in hoatzin chicks (Opisthocomus hoazin).* Biological Conservation. 2004. 118: p. 549-558.

237. MacArthur, R.A., V. Geist, and R.H. Johnston, *Cardiac and behavioral responses of mountain sheep to human disturbance.* Journal of Wildlife Management. 1982. 46(2): p. 351-358.

238. Baker, M.R., K. Gobush, and C. Vynne, *Review of factors influencing stress hormones in fish and wildlife.* Journal for Nature Conservation. 2013. 21: p. 309-318.

239. Hing, S., et al., *The relationship between physiological stress and wildlife disease: Consequences for health and conservation.* Wildlife Research. 2016. 43(1): p. 51-60.

240. MacArthur, R.A., R.H. Johnston, and V. Geist, *Factors influencing heart rate in free-ranging bighorn sheep: A physiological approach to the study of wildlife harassment.* Canadian Journal of Zoology. 1979. 57(10): p. 2010-2021.

241. Bisson, I.-A., et al., *No energetic cost of anthropogenic disturbance in a songbird.* Proceedings of the Royal Society of Biological Sciences. 2009. 276(1658): p. 961-969.

242. Creel, S., J.A. Winnie, Jr., and D. Christianson, *Glucocorticoid stress hormones and the effect of predation risk on elk reproduction.* Proceedings of the National Academy of Sciences. 2009. 106(30): p. 12388-12393.

243. Cizauskas, C.A., et al., *Seasonal patterns of hormones, macroparasites, and microparasites in wild African ungulates: The interplay among stress, reproduction, and disease.* PLoS One. 2015. 10(4): p. e0120800.

244. Wingfield, J.C., et al., *Environmental stress, field endocrinology, and conservation biology*, in *Behavioral Approaches to Conservation in the Wild*, J.R. Clemons and R. Buchholz, Editors. 1997. Cambridge University Press: London, England. p. 95-131.

245. Jiménez, G., et al., *Dampened behavioral and physiological responses mediate birds' association with humans.* Biological Conservation. 2011. 144(5): p. 1702-1711.

246. Frid, A. and L.M. Dill, *Human-caused disturbance stimuli as a form of predation risk.* Conservation Ecology. 2002. 6(1): p. Article 11.

247. Stankowich, T. and D.T. Blumstein, *Fear in animals: A meta-analysis and review of risk assessment.* Proceedings of the Royal Society of Biological Sciences. 2005. 272(1581): p. 2627-2634.

248. Bejder, L., et al., *Impact assessment research: Use and misuse of habituation, sensitisation and tolerance in describing wildlife responses to anthropogenic stimuli.* Marine Ecology Progress Series. 2009. 395: p. 177-185.

249. Ydenberg, R.C. and L.M. Dill, *The economics of fleeing from predators.* Advances in the Study of Behavior. 1986. 16: p. 229-249.

250. Fernández-Juricic, E., M.D. Jimenez, and E. Lucas, *Alert distance as an alternative measure of bird tolerance to human disturbance: Implications for park design.* Environmental Conservation. 2001. 28(3): p. 263-269.

251. Beale, C.M. and P. Monaghan, *Behavioural responses to human disturbance: A matter of choice?* Animal Behaviour. 2004. 68(5): p. 1065-1069.

252. Gill, J.A., K. Norris, and W.J. Sutherland, *Why behavioural responses may not reflect the population consequences of human disturbance.* Biological Conservation. 2001. 97: p. 265-268.

253. Bhardwaj, M., C.A. Dale, and L.M. Ratcliffe, *Aggressive behavior by Western Bluebirds (Sialia mexicana) varies with anthropogenic disturbance to breeding habitat.* Wilson Journal of Ornithology. 2015. 127(3): p. 421-431.

254. Glover, H.K., et al., *Towards ecologically meaningful and socially acceptable buffers: Response distances of shorebirds in Victoria, Australia, to human disturbance.* Landscape and Urban Planning. 2011. 103(3-4): p. 326-334.

255. Rodriguez-Prieto, I., et al., *Antipredator behavior in blackbirds: Habituation complements risk allocation.* Behavioral Ecology. 2009. 20: p. 371-377.

256. Cooke, A.S., *Observations on how close certain passerine species will tolerate an approaching human in rural and suburban areas.* Biological Conservation. 1980. 18(2): p. 85-88.

257. Holmes, T.L., et al., *Responses of wintering grassland raptors to human disturbance.* Wildlife Society Bulletin. 1993. 21(461): p. 468.

258. Freddy, D.J., W.M. Bronaugh, and M.C. Fowler, *Responses of mule deer to disturbance by persons afoot and snowmobiles.* Wildlife Society Bulletin. 1986. 14(1): p. 63-68.

259. Gaines, W.L., P.H. Singleton, and R.C. Ross, *Assessing the cumulative effects of linear recreation routes on wildlife habitats on the Okanogan and Wenatchee National Forests.* 2003. Portland, OR. p. 1-79.

260. Naylor, L.M., M.J. Wisdom, and R.G. Anthony, *Behavioral responses of North American elk to recreational activity.* Journal of Wildlife Management. 2009. 73(3): p. 328-338.

261. Rodríguez-Prieto, I. and E. Fernández-Juricic, *Effects of direct human disturbance on the endemic Iberian frog Rana iberica at individual and population levels.* Biological Conservation. 2005. 123(1): p. 1-9.

262. Gutzwiller, K.J., et al., *Bird tolerance to human intrusion in Wyoming montane forests.* The Condor. 1998. 100: p. 519-527.

263. Bentrup, G., *Conservation buffers: Design guidelines for buffers, corridors, and greenways. General Technical Report SRS-109.* 2008. U.S.D.A. Forest Service, Southern Research Station: Ashville, NC.

264. Rodgers, J.A., Jr. and H.T. Smith, *Buffer zone distances to protect foraging and loafing waterbirds from human disturbance in Florida.* Wildlife Society Bulletin. 1997. 25(1): p. 139-145.

265. Love, O.P., et al., *Stress hormones: A link between maternal condition and sex-biased reproductive investment.* The American Naturalist. 2005. 166(6): p. 751-766.

266. Breuner, C.W., *Stress and reproduction in birds*, in *Hormones and Reproduction of Vertebrates, Volume 4 - Birds*, D.O. Norris and K.H. Lopez, Editors. 2011. Academic Press: Cambridge, MA. p. 129-151.

267. Love, O.P., et al., *Mediation of a corticosterone-induced reproductive conflict.* Hormones and Behavior. 2004. 46(59-65).

268. Ciuti, S., et al., *Effects of humans on behavior of wildlife exceed those of natural predators in a landscape of fear.* PLoS ONE. 2012. Published online November 28, 2012 http://dx.doi.org/10.1371/journal.pone.0050611.

269. Díaz, M., et al., *Interactive effects of fearfulness and geographical location on bird population trends.* Behavioral Ecology. 2015. 26(3): p. 716-721.

270. Knight, R.L. and D.N. Cole. *Effects of recreational activity on wildlife in wildlands*. 1992. In *Transactions of the 56th North American Wildlife and Natural Resources Conference.*

271. Pomerantz, G.A., et al., *Assessing impact of recreation on wildlife: A classification scheme.* Wildlife Society Bulletin. 1988. 16: p. 58-62.

272. Bennett, V.J., et al., *Understanding wildlife responses to human disturbance through simulation modelling: A management tool.* Ecological Complexity. 2009. 6: p. 113-134.

273. Weston, M.A., et al., *A review of flight-initiation distances and their application to managing disturbance in Australian birds.* Emu. 2012. 112: p. 269-286.

274. Barja, I., et al., *Stress physiological responses to tourist pressure in a wild population of European pine marten.* Journal of Steroid Biochemistry & Molecular Biology. 2007. 104: p. 136-142.

275. Burger, J. and M. Gochfeld, *Human activity influence and diurnal and nocturnal foraging of sanderlings (Calidris alba).* The Condor. 1991. 93: p. 259-265.

276. Cardoni, D.A., M. Favero, and J.P. Isacch, *Recreational activities affecting the habitat use by birds in Pampa's wetlands, Argentina: Implications for waterbird conservation.* Biological Conservation. 2008. 141(3): p. 797-806.

277. Halinouski, M.H. and A.M. Krytskaya, *Ecological and faunistic review of ground beetles (Coleoptera, Carabidae) in Gomel Urbocenosis (The Republic of Belarus).* Vestnik zoologii. 2008. 48(6): p. 521-532.

278. Burger, J. and M. Gochfeld, *Effects of ecotourists on bird behavior at Loxahatchee National Wildlife Refuge, Florida.* Environmental Conservation. 1998. 25(1): p. 13-21.

279. Fernández-Juricic, E., *Local and regional effects of pedestrians on forest birds in a fragmented landscape.* The Condor. 2000. 102(2): p. 247-255.

280. Fernández-Juricic, E., *Can human disturbance promote nestedness? A case study with breeding birds in urban habitat fragments.* Oecologia. 2002. 131: p. 269-278.

281. Fitzpatrick, S. and B. Bouchez, *Effects of recreational disturbance on the foraging behaviour of waters on a rocky beach.* Bird Study. 1998. 45(2): p. 157-171.

282. George, S.L. and K.R. Crooks, *Recreation and large mammal activity in an urban nature reserve.* Biological Conservation. 2006. 133(1): p. 107-117.

283. Trulio, L.A. and J. Sokale, *Foraging shorebird response to trail use around San Francisco Bay.* Journal of Wildlife Management. 2008. 72(8): p. 1775-1780.

284. Malo, J.E., P. Acebes, and J. Traba, *Measuring ungulate tolerance to human with flight distance: A reliable visitor management tool?* Biodiversity and Conservation. 2011. 20: p. 3477-3488.

285. Gray, A.C., *Impacts of human disturbance on the behavior of sanderlings on the Georgia Coast*. 2006. Georgia Southern University, Jack N. Averitt College of Graduate Studies: Statesboro, GA.

286. Swarthout, E.C.H. and R.J. Steidl, *Experimental effects of hiking on breeding Mexican Spotted Owls.* Conservation Biology. 2003. 17(1): p. 307-315.

287. Hennings, L.A., *Impacts of dogs on wildlife and water quality*. 2016. Metro Regional Government: Portland, OR.

288. Shannon, G., et al., *Behavioral responses associated with a human-mediated predator shelter.* PLoS ONE. 2014. 9(4): p. e94630.

289. Thompson, M.J. and R.E. Henderson, *Elk habituation as a credibility challenge for wildlife professionals.* Wildlife Society Bulletin. 1998. 26(3): p. 477-483.

290. Reimoser, S., *Influence of anthropogenic disturbances on activity, behavior and heart rate of roe deer (Capreolus capreolus) and red deer (Cervus elaphus), in context of their daily and yearly patterns*, in *Deer: Habitat, Behavior and Conservation*, A.A.M. Cahler, J.P., Editor. 2012. Nova Science Publishers, Inc.: Hauppauge, NY.

291. Martin, J.G.A. and D. Réale, *Animal temperament and human disturbance: Implications for the response of wildlife to tourism.* Behavioural Processes. 2008. 77(1): p. 66-72.

292. Blumstein, D.T., *Flight-initiation distance in birds is dependent on intruder starting distance.* Journal of Wildlife Management. 2003. 67(4): p. 852-857.

293. Ordenana, M.A., et al., *Effects of urbanization on carnivore species distribution and richness.* Journal of Mammology. 2010. 91(6): p. 1322-1331.

294. Riley, S., et al., *Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California.* Conservation Biology. 2003. 17(2): p. 566-576.

295. Markovchick-Nicholls, L., et al., *Relationships between human disturbance and wildlife land use in urban habitat fragments.* Conservation Biology. 2008. 22(1): p. 99-109.

296. Naylor, L.M., *Behavioral responses of Rocky Mountain elk (Cervus elaphus) to recreational disturbance*. 2006. Oregon State University: Corvallis, OR.

297. Mayo, T.W., P.W.C. Paton, and P.V. August, *Responses of birds to humans at a coastal barrier beach: Napatree Point, Rhode Island.* Northeastern Naturalist. 2015. 22(3): p. 501-512.

298. Knight, R.L. and D.N. Cole, *Factors that influence wildlife responses to recreationists*, in *Wildlife and Recreationists: Coexistence through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Press: Washington, D.C. p. 71-79.

299. Stillman, R.A. and J.D. Goss-Custard, *Seasonal changes in the reponse of oystercatchers Haematopus ostralegus to human disturbance.* Journal of Avian Biology. 2002. 33: p. 358-365.

300. Berger, J., *Fear, human shields and the redistribution of prey and predators in protected areas.* Biology Letters. 2007. 3(6): p. 620-623.

301. Cleveland, S.M., et al., *Linking elk movement and resource selection to hunting pressure in a heterogeneous landscape.* Wildlife Society Bulletin. 2012. 36(4): p. 658-668.

302. Jayakody, S., et al., *Red deer Cervus elephus vigilance behaviour differs with habitat and type of human disturbance.* Wildlife Biology. 2008. 14(1): p. 81-91.

303. Marchand, P., et al., *Impacts of tourism and hunting on a large herbivore's spatio-temporal behavior in and around a French protected area.* Biological Conservation. 2014. 177: p. 1-11.

304. Whittaker, D. and R.L. Knight, *Understanding wildlife responses to humans.* Wildlife Society Bulletin. 1999. 26(2): p. 312-317.

305. Muhly, T.B., et al., *Human activity helps prey win the predator-prey space race.* PLoS ONE. 2011. 6(3): p. e17050, doi:10.1371/journal.pone.0017050.

306. Burger, J. and M. Gochfeld, *Human distance and birds: Tolerance and response distances of residents and migrant species in India.* Environmental Conservation. 1991. 18(2): p. 158-165.

307. Møller, A.P., *Flight distance of urban birds, predation, and selection for urban life.* Behavioral Ecology and Sociobiology. 2008. 63(1): p. 63-75.

308. Blumstein, D.T., et al., *Inter-specific variation in avian responses to human disturbance.* Journal of Applied Ecology. 2005. 42(5): p. 943-953.

309. Blumstein, D.T., *Developing an evolutionary ecology of fear: How life history and natural history traits affect disturbance tolerance in birds.* Animal Behaviour. 2006. 71(2): p. 389-399.

310. Møller, A.P., et al., *American exceptionalism: Population trends and flight initiation distances in birds from three continents.* PLoS ONE. 2014. 9(e107883).

311. Czech, B., *Elk behavior in response to human disturbance at Mount St. Helens National Volcanic Monument.* Applied Animal Behaviour Science. 1991. 29(1-4): p. 269-277.

312. Fairbanks, W.S. and R. Tullous, *Distribution of pronghorn (Antilocapra americana Ord) on Antelope Island State Park, Utah, USA, before and after establishment of recreational trails.* Natural Areas Journal. 2002. 22: p. 277-282.

313. Knight, R.L. and D.N. Cole, *Wildlife responses to recreationists*, in *Wildlife and Recreationists: Coexistence through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Press: Washington, D.C. p. 51-70.

314. Childress, M.J. and M. Lung, *Predation risk, gender and the group size effect: Does elk vigilance depend on the behaviour of conspecifics?* Animal Behaviour. 2003. 66: p. 389-398.

315. Fernández-Juricic, E., et al., *Sensitivity of wildlife to spatial patterns of recreationist behavior: A critical assessment of minimum approaching distances and buffer areas for grassland birds.* Biological Conservation. 2005. 125(2): p. 225-235.

316. Gander, H. and P. Ingold, *Reactions of male alpine chamois (Rupicapra r. rupicapra) to hikers, joggers and mountainbikers.* Biological Conservation. 1997. 79(1): p. 107-109.

317. Burger, J., *The effect of human activity on birds at a coastal bay.* Biological Conservation. 1981. 21(3): p. 231-241.

318. Stankowich, T. and R.G. Coss, *Effects of predator behavior and proximity on risk assessment by Columbian black-tailed deer.* Behavioral Ecology. 2006. 17(2): p. 246-254.

319. Spahr, R., *Factors affecting distribution of Bald Eagles and effects of human activity on Bald Eagles wintering along the Boise River*, in *Biology*. 1990. Boise State University: Boise, ID.

320. Klein, M.L., *Waterbird behavioral responses to human disturbances.* Wildlife Society Bulletin. 1993. 21: p. 31-39.

321. Smith-Castro, J.R., *Impacts of recreational trails on breeding birds in forested urban parks*. 2008. Ohio State University: Columbus, OH.

322. Miller, S.G., R.L. Knight, and C.K. Miller, *Wildlife responses to pedestrians and dogs.* Wildlife Society Bulletin. 2001. 29: p. 124-132.

323. Blakesley, J.A. and K.P. Reese, *Avian use of campground and noncampground sites in riparian zones.* Journal of Wildlife Management. 1988. 52(3): p. 399-402.

324. Westmoreland, D. and L.B. Best, *The effect of disturbance on mourning dove nesting success.* The Auk. 1985. 102: p. 774.

325. Kangas, K., et al., *Recreation-induced changes in boreal bird communities in protected areas.* Ecological Applications. 2010. 20(6): p. 1775-1786.

326. Battle, K.E., S.L. Foltz, and I.T. Moore, *Predictors of flight behavior in rural and urban songbirds.* Wilson Journal of Ornithology. 2016. 128(3): p. 510-519.

327. McGarigal, K., R.G. Anthony, and F.B. Isaacs, *Interactions of humans and Bald Eagles on the Columbia River Estuary.* Wildlife Monographs. 1991. 115: p. 3-47.

328. Fortin, D. and M. Andruskiw, *Behavioral response of free-ranging bison to human disturbance.* Wildlife Society Bulletin. 2003. 31(3): p. 804-813.

329. Ciuti, S., et al., *The key role of lamb presence in affecting flight response in Sardinian mouflon (Ovis orientalis musimon).* Behavioural Processes. 2008. 77(3): p. 408-412.

330. Wolf, I.D. and D.B. Croft, *Minimizing disturbance to wildlife by tourists approaching on foot or in a car: A study of kangaroos in the Australian rangelands.* Applied Animal Behaviour Science. 2010. 126(1/2): p. 75-84.

331. Brown, C.L., et al., *The effect of human activities and their associated noise on ungulate behavior.* PLoS ONE. 2012. 7(7): p. e40505.

332. Fernández-Juricic, E., et al., *California's endangered Belding's Savannah Sparrow (Passerculus sandwichensis beldingi): Tolerance of pedestrian disturbance.* Avian Conservation and Ecology [online]. 2009. 4(2): p. Article 1.

333. Keeley, W.H. and M.J. Bechard, *Flushing distances of Ferruginous Hawks nesting in rural and exurban New Mexico.* Journal of Wildlife Management. 2011. 75: p. 1034-1039.

334. Hebblewhite, M. and E. Merrill, *Modelling wildlife–human relationships for social species with mixed-effects resource selection models.* Journal of Applied Ecology. 2008. 45(3): p. 834-844.

335. Reilly, M.L., et al., *Spatial and temporal response of wildlife to recreational activities in the San Francisco Bay ecoregion.* Biological Conservation. 2017. 207: p. 117-126.

336. Barrueto, M., A.T. Fort, and A.P. Clevenger, *Anthropogenic effects on activity patterns of wildlife at crossing structures.* Ecosphere. 2014. 5(3): p. 1-19.

337. Bélanger, L. and J. Bédard, *Hunting and waterfowl*, in *Wildlife and Recreationists. Coexistence through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Pres: Washington, D.C. p. 243-256.

338. McNeil, R., P. Drapeau, and J.D. Goss-Custard, *The occurrence and adaptive significance of nocturnal habits in waterfowl.* Biological Reviews. 1992. 67: p. 381-419.

339. Kannan, V. and R. Manadadan, *Nocturnal foraging by Painted Storks Mycteria leucocephala at Pulicat Lake, India.* Indian Birds. 2007. 3(1): p. 25-26.

340. Gokula, V., *Nocturnal foraging by Spot-billed Pelicans Pelecanus philippensis in Karaivetti Bird Sanctuary, Tamil Nadu, India.* Marine Ornithology. 2011. 39: p. 267-268.

341. Van Winkle, J., *E-mail correspondence from Jill Van Winkle to Lori Hennings dated October 20, 2016*, L. Hennings. 2016. Portland, OR.

342. Ortega, C.P., *Effects of noise pollution on birds: A brief review of our knowledge.* Ornithological Monographs. 2012. 74: p. 6-22.

343. Radle, A.L., *The effect of noise on wildlife: A literature review*. 2006. University of Oregon, Eugene, OR. p. 1-16.

344. Francis, C.D., et al., *Are nest predators absent from noisy areas or unable to locate nests?* Ornithological Monographs. 2012. 74: p. 101-110.

345. Shannon, G., et al., *A synthesis of two decades of research documenting the effects of noise on wildlife.* Biological Reviews. 2015. http://doi.org/10.1111/brv.12207

346. Dowling, J.L., D.A. Luther, and P.P. Marra, *Comparative effects of urban development and anthropogenic noise on bird songs.* Behavioural Ecology. 2012. 22(1): p. 201-209.

347. Eigenbrod, F., S.J. Hecnar, and L. Fahrig, *Quantifying the road-effect zone: Threshold effects of a motorway on anuran populations in Ontario, Canada.* Ecology and Society [online]. 2009. 14(1): Article 24.

348. Parris, K.M. and A. Schneider, *Impacts of traffic noise and traffic volume on birds of roadside habitats.* Ecology and Society [online]. 2009. 14(1): Article 29.

349. Parris, K.M., M. Velik-Lord, and J.M.A. North, *Frogs call at a higher pitch in traffic noise.* Ecology and Society [online]. 2009. 14(1): Article 25.

350. Slabbekoorn, H. and E.A. Ripmeester, *Birdsong and anthropogenic noise: Implications and applications for conservation.* Molecular Ecology. 2006(17): p. 72-83.

351. Wood, W.E. and S.M. Yezerinac, *Song sparrow (Melospiza melodia) song varies with urban noise.* The Auk. 2006. 123(3): p. 650-659.

352. Gough, D.C., D.J. Mennill, and E. No, *Singing seaside: Pacific Wrens (Troglodytes pacificus) change their songs in the presence of natural and anthropogenic noise.* The Wilson Journal of Ornithology. 2014. 126(2): p. 269-278.

353. Patricelli, G.L. and J.L. Blickley, *Avian communication in urban noise: Causes and consequences of vocal adjustment.* The Auk. 2006. 123(3): p. 639-649.

354. Slabbekoorn, H. and A. den Boer-Visser, *Cities change the songs of birds.* Current Biology. 2006. 16: p. 2326-2331.

355. Francis, C.D., et al., *Acoustic environments matter: Synergistic benefits to humans and ecological communities.* Journal of Environmental Management. 2017. 203: p. 245-254.

356. Swaddle, J.P., et al., *A framework to assess evolutionary responses to anthropogenic light and sound.* Trends in Ecology and Evolution. 2015. 30(9): p. 550-560.

357. Karp, D.S. and R. Guevara, *Conversational noise reduction as a win-win for ecotourists and rain forest birds in Peru.* Biotropica. 2011. 43: p. 122-130.

358. Francis, C.D., *Vocal traits and diet explain avian sensitivities to anthorpogenic noise.* Global Change Biology. 2015. 21(5): p. 1809-1820.

359. Petrelli, A.R.L., M.J.; Wardle, R.; Barber, J.R.; Francis, C.D., *First to flush: The effects of ambient noise on songbird flight initiation distances and implications for human experiences with nature.* Frontiers in Ecology and Evolution. 2017. 5: Article 67.

360. Karp, D.S. and T.L. Root, *Sound the stressor: How Hoatzins (Opisthocomus hoazin) react to ecotourist conversation.* Biodiversity and Conservation. 2009. 18: p. 3733-3742.

361. Bowles, A.E., *Responses of wildlife to noise*, in *Wildlife and Recreationists: Coexistence Through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Press: Washington, D.C. p. 109-156.

362. Mann, S.L., R.J. Steidl, and V.M. Dalton, *Effects of cave tours on breeding Myotis velifer.* Journal of Wildlife Management. 2002. 66(3): p. 618-624.

363. Francis, C.D., C.P. Ortega, and A. Cruz, *Noise pollution changes avian communities and species interactions.* Current Biology. 2009. 19: p. 1-5.

364. Beier, P., *Effects of artificial night lighting on terrestrial mammals*, in *Ecological Consequences of Artificial Night Lighting*, C. Rich and T. Longcore, Editors. 2006. Island Press: District of Columbia, U.S. p. 19-42.

365. Longcore, T. and C. Rich, *Ecological light pollution.* Frontiers in Ecology. 2004. 2(4): p. 191-198.

366. Frank, K.D., *Impact of outdoor lighting on moths.* Journal of the Lepidopterists' Society. 1988. 42: p. 63-93.

367. Miller, M.V., *Apparent effects of light pollution on singing behavior of American robins.* The Condor. 2006. 108: p. 130-139.

368. Manville, A.M.I., *Towers, turbines, power lines, and buildings - steps being taken by the U.S. Fish and Wildlife Service to avoid or minimize take of migratory birds at these structures*, in *Proceedings 4th International Partners in Flight Conference, February 2008*, C.J. Ralph and T.D. Rich, Editors. 2009. McAllen, TX.

369. Manville II, A., *Bird strikes and electrocutions at power lines, communication towers, and wind turbines: State of the art and state of the science – next steps toward mitigation*, in *Bird Conservation and Integration in the Americas*, C.J. Ralph and T.D. Rich, Editors. 2005. p. 1051-1064.

370. Longcore, T., C. Rich, and S.A. Gauthreaux, *Height, guy wires, and steady-burning lights increase hazard of communication towers to nocturnal migrants: A review and meta-analysis.* The Auk. 2008. 125(2): p. 485-492.

371. Stone, E.L., S. Harris, and G. Jones, *Impacts of artificial lighting on bats: A review of challenges and solutions.* Mammalian Biology. 2015. 80(3): p. 213-219.

372. Boldogh, S., D. Dobrosi, and P. Samu, *The effects of the illumination of buildings on house-dwelling bats and its conservation consequences.* Acta Chiropterologica. 2007. 9(2): p. 527-534.

373. Hudzik, S., *A case study of the spatial relationship between bat pass frequency and artificial light pollution along a bike trail in Portage County, Ohio*, in *Environmental Science Program*. 2015. Youngstown State University: Youngstown, OH.

374. Laidlaw, G.W.J. and M.B. Fenton, *Control of nursery colony populations of bats by artificial light.* Journal of Wildlife Management. 1971. 35(4): p. 843-.

375. Bliss-Ketchum, L., et al., *The effect of artificial light on wildlife use of passage structures.* Biological Conservation. 2016. 199(25-28).

376. Grigione, M.M. and R. Mrykalo, *Effects of artificial night lighting on endangered ocelots (Leopardus paradalis) and nocturnal prey along the United States-Mexico border: A literature review and hypotheses of potential impacts.* Urban Ecosystems. 2004. 7: p. 65-77.

377. Bruce-White, C. and M. Shardlow, *A review of the impact of artificial light on invertebrates*. 2011. Buglife - The Invertebrate Conservation Trust.

378. Rydell, J. and P.A. Racey. *Street lamps and the feeding ecology of insectivorous bats. Recent advances in bat biology*. in *Recent Advances in Bat Biology: Zoological Society of London Symposium abstracts*. 1993. Zoological Society of London.

379. Santos, C.D., et al., *Effects of artificial illumination on the nocturnal foraging of waders.* Acta Oecologica. 2010. 36: p. 166-172.

380. Bird, B.L., L.C. Branch, and D.L. Miller, *Effects of coastal lighting on foraging behavior of beach mice.* Conservation Biology. 2004. 18(5): p. 1435-1439.

381. Lebbin, D.J., et al., *Nocturnal migrants foraging at night by artificial light.* The Wilson Journal of Ornithology. 2007. 119(3): p. 506-508.

382. Jacobson, S.L., *Mitigation measures for highway-caused impacts to birds*. 2005. General Technical Report PSW-GTR-91. p. 1043-1050.

383. Audubon Society of Portland, et al., *Resource guide for bird-friendly building design*. 2012. Audubon Society of Portland: Portland, OR.

384. Audubon Society of Portland, *Portland Audubon's Birdsafe Portland: Lights Out Portland*. 2016. Portland, OR.

385. Hagar, J., *Functional relationships among songbirds, arthropods, and understory vegetation in Douglas-fir forests, western Oregon*. 2003. Oregon State University: Corvallis, OR.

386. Schlacher, T.A. and L. Thompson, *Beach recreation impacts benthic invertebrates on ocean-exposed sandy shores.* Biological Conservation. 2012. 147(1): p. 123-132.

387. Blair, R.B. and A.E. Launer, *Butterfly diversity and human land use: Species assemblages along an urban gradient.* Biological Conservation. 1997. 80: p. 113-125.

388. Davis, A.K., *Walking trails in a nature preserve alter terrestrial salamander distributions.* Natural Areas Journal. 2007. 27(4): p. 385-389.

389. Fleming, M.M., et al., *Effects of trails on eastern redback salamander (Plethodon cinereus Green).* Herpetology Notes. 2011. 4: p. 229-232.

390. Semlitsch, R.D., et al., *Salamander abundance along road edges and within abandoned logging roads in Appalachian forests.* Conservation Biology. 2007. 21(1): p. 159-167.

391. Kluber, M.R., D.H. Olson, and K.J. Puettmann, *Downed wood microclimates and their potential impact on plethodontid salamander habitat in the Oregon Coast Range.* Northwest Science. 2009. 83(1): p. 25-34.

392. Goff, C.B., *Effects of roads and trails on Peaks of Otter salamander (Plethodon hubrichti) and eastern red-backed salamander (Plethodon cinereus) movement behavior*. 2015. Marshall University: Huntington, WV.

393. Guderyahn, L.B., A.P. Smithers, and M.C. Mims, *Assessing habitat requirements of pond-breeding amphibians in a highly urbanized landscape: Implications for management.* Urban Ecosystems. 2016. May 2016(DOI: 10.1007/s11252-016-0569-6).

394. Wolz, H., J.P. Gibbs, and P.K. Ducey, *Road crossing structures for amphibians and reptiles: Informing design through behavioral analysis.* Biological Conservation. 2008. 141(11): p. 2745-2750.

395. Schmidt, B.R. and S. Zumbach, *Amphibian road mortality and how to prevent it: A review*, in *Urban Herpetology*, J.C. Mitchell, R.D. Jung Brown, and R. Bartolomew, Editors. 2008. Society for the Study of Amphibians and Reptiles: St. Louis, MO.

396. Jackson, S.D., *Underpass systems for amphibians*, in *Trends in Addressing Transportation Related Wildlife Mortality, Proceedings of the Transportation Related Wildlife Mortality Seminar*, G.L. Evink, et al., Editors. 1996. State of Florida Department of Transportation: Tallahassee, FL.

397. Diego-Rasilla, F.J., *Human influence on the tameness of wall lizard, Podarcis muralis.* Italian Journal of Zoology. 2003. 70: p. 225-228.

398. Amo, L., P. López, and J. Martin, *Nature-based tourism as a form of predation risk affects body condition and health state of Podarcis muralis lizards.* Biological Conservation. 2006. 131(3): p. 402-409.

399. Garber, S.D. and J. Burger, *A 20-year study documenting the relationship between turtle decline and human recreation.* Ecological Applications. 1995. 5(4): p. 1151-1162.

400. Rosenberg, D., et al., *Conservation assessment of the western pond turtle in Oregon (Actinemys marmorata).* 2009. Sponsored by U.S.D.I. Bureau of Land Management and Fish and Wildlife Service, U.S.D.A. Forest Service Region 6, Oregon Department of Fish and Wildlife, City of Portland, and Metro: Portland, OR.

401. Nyhof, P.E. and L. Trulio, *Basking western pond turtle response to recreational trail use in urban California.* Chelonian Conservation and Biology. 2015. 14(2): p. 182-184.

402. Pilliod, D.S. and E. Wind, *Habitat management guidelines for amphibians and reptiles of the northwestern United States and western Canada*. 2008. Partners in Amphibian and Reptile Conservation: Birmingham, AL.

403. Ikuta, L.A. and D.T. Blumstein, *Do fences protect birds from human disturbance?* Biological Conservation. 2003. 112(3): p. 447-452.

404. McLeod, E.M., et al., *Buses, cars, bicycles and walkers: The influence of the type of human transport on the flight responses of waterbirds.* PLoS One. 2013. 8(12): p. e82008.

405. Fernández-Juricic, E., M.D. Jimenez, and E. Lucas, *Bird tolerance to human disturbance in urban parks of Madrid (Spain): Management implications*, in *Avian Ecology and Conservation in an Urbanizing World*, J.M. Marzluff, R. Bowman, and R. Donnelly, Editors. 2001. Kluwer Academic Publishers: Norwell, MA. p. 259-273.

406. Marzano, M. and N. Dandy, *Recreationist behaviour in forests and the disturbance of wildlife.* Biodiversity and Conservation. 2012. 21(11): p. 2967-2986.

407. Bennett, K.A. and E.F. Zuelke, *The effects of recreation on birds: A literature review*. 1999. Delaware Natural Heritage Program: Smyrna, DE.

408. American Birding Association. *American Birding Association Code of Birding Ethics*. Undated.

409. Heil, L., et al., *Avian responses to tourism in the biogeographically isolated high Cordoba Mountains, Argentina.* Biodiversity and Conservation. 2006. 16: p. 1009-1026.

410. Miller, S.G., R.L. Knight, and C.K. Miller, *Influence of recreational trails on breeding bird communities.* Ecological Applications. 1998. 8(1): p. 162-169.

411. Burhans, D.E. and F.R. Thompson III, *Songbird abundance and parasitism differ between urban and rural shrublands.* Ecological Applications. 2006. 16(1): p. 394-405.

412. Devictor, V., R. Julliard, and F. Jiguet, *Distribution of specialist and generalist species along spatial gradients of habitat disturbance and fragmentation.* Oikos. 2008. 117: p. 507-514.

413. Morelli, F., et al., *Evidence of evolutionary homogenization of bird communities in urban environments across Europe.* Global Ecology and Biogeography. 2016. 25: p. 1284-1293.

414. Miller, J.R. and N.T. Hobbs, *Recreational trails, human activity, and nest predation in lowland riparian areas.* Landscape and Urban Planning. 2000. 50: p. 227-236.

415. Davis, C.A., et al., *Mountain biking trail use affects reproductive success of nesting Golden-cheeked Warbler.* Wilson Journal of Ornithology. 2010. 122(3): p. 465-474.

416. Showler, D.A., *What is the impact of public access on the breeding success of ground-nesting and cliff-nesting birds?* 2010. University of East Anglia, Norwich, UK.

417. Hocken, D., et al., *Examination of the effects of disturbance on birds with reference to its importance in ecological assessments.* Journal of Environmental Management. 1992. 36: p. 253-286.

418. Chace, J.F., et al., *Spatial and temporal activity patterns of the brood parasitic brown-headed cowbird at an urban/wildland interface.* Landscape and Urban Planning. 2002. 64(3): p. 179-190.

419. Lee, M., et al., *Importance of patch scale vs landscape scale on selected forest birds.* Oikos. 2002. 96(1): p. 110-118.

420. Glądalski, M., et al., *Effects of human-related disturbance on breeding success of urban and non-urban blue tits (Cyanistes caeruleus).* Urban Ecosystems. 2016. 19(3): p. 1325-1334.

421. Gates, J.E. and N.R. Giffen, *Neotropical migrant birds and edge effects at a forest-stream ecotone.* Wilson Bulletin. 1991. 103(2): p. 204-217.

422. Hickman, S., *The effects of nature trails on breeding birds*, in *Grayslake, IL.* 1985. College of Lake County, Biology Department.

423. Sorace, A., *High density of bird and pest species in urban habitats and the role of predator abundance.* Ornis Fennica. 2002. 79(2): p. 60-71.

424. Bardin, E.E. and T.A. Nelson, *Raccoons use habitat edges in northern Illinois.* The American Midland Naturalist. 2008. 159(2): p. 394-402.

425. Walker, L.E. and J.M. Marzluff, *Recreation changes the use of a wild landscape by corvids.* The Condor. 2015. 117(2): p. 262-283.

426. Hennings, L.A., *Avian communities in riparian reserves in an urban landscape*. 2001. Oregon State University, Corvallis, OR. p. 1-60.

427. Marzluff, J.M., et al., *Causes and consequences of expanding American Crow populations in urban environments*, in *Avian Ecology and Conservation in an Urbanizing World*, J.M. Marzluff, R. Bowman, and R. Donnelly, Editors. 2001. Kluwer Academic Press: Norwell. p. 331-363.

428. Wilson, G.R. and M.C. Brittingham, *How well do artificial nests estimate success of real nests?* The Condor. 1998. 100: p. 357-364.

429. Part, T. and J. Wretenberg, *Do artificial nests reveal relative nest predation risk for real nests?* Journal of Avian Biology. 2002. 33(1): p. 39-46.

430. Gutzwiller, K.J., et al., *Effects of human intrusion on song occurrence and singing consistency in subalpine birds.* The Auk. 1994. 111(1): p. 28-37.

431. Møller, A.P., *Urban areas as refuges from predators and flight distance of prey.* Behavioral Ecology. 2012. 23(5): p. 1030-1035.

432. Storch, I., *Human disturbance of grouse - why and when?* Wildlife Biology. 2013. 19(4): p. 390-403.

433. Stalmaster, M.V. and J.L. Kaiser, *Effects of recreational activity on wintering bald eagles.* Wildlife Monographs. 1998. 137: p. 3-46.

264. Rodgers, J.A., Jr. and H.T. Smith, *Buffer zone distances to protect foraging and loafing waterbirds from human disturbance in Florida.* Wildlife Society Bulletin. 1997. 25(1): p. 139-145.

265. Love, O.P., et al., *Stress hormones: A link between maternal condition and sex-biased reproductive investment.* The American Naturalist. 2005. 166(6): p. 751-766.

266. Breuner, C.W., *Stress and reproduction in birds*, in *Hormones and Reproduction of Vertebrates, Volume 4 - Birds*, D.O. Norris and K.H. Lopez, Editors. 2011. Academic Press: Cambridge, MA. p. 129-151.

267. Love, O.P., et al., *Mediation of a corticosterone-induced reproductive conflict.* Hormones and Behavior. 2004. 46(59-65).

268. Ciuti, S., et al., *Effects of humans on behavior of wildlife exceed those of natural predators in a landscape of fear.* PLoS ONE. 2012. Published online November 28, 2012 http://dx.doi.org/10.1371/journal.pone.0050611.

269. Díaz, M., et al., *Interactive effects of fearfulness and geographical location on bird population trends.* Behavioral Ecology. 2015. 26(3): p. 716-721.

270. Knight, R.L. and D.N. Cole. *Effects of recreational activity on wildlife in wildlands.* 1992. In *Transactions of the 56th North American Wildlife and Natural Resources Conference.*

271. Pomerantz, G.A., et al., *Assessing impact of recreation on wildlife: A classification scheme.* Wildlife Society Bulletin. 1988. 16: p. 58-62.

272. Bennett, V.J., et al., *Understanding wildlife responses to human disturbance through simulation modelling: A management tool.* Ecological Complexity. 2009. 6: p. 113-134.

273. Weston, M.A., et al., *A review of flight-initiation distances and their application to managing disturbance in Australian birds.* Emu. 2012. 112: p. 269-286.

274. Barja, I., et al., *Stress physiological responses to tourist pressure in a wild population of European pine marten.* Journal of Steroid Biochemistry & Molecular Biology. 2007. 104: p. 136-142.

275. Burger, J. and M. Gochfeld, *Human activity influence and diurnal and nocturnal foraging of sanderlings (Calidris alba).* The Condor. 1991. 93: p. 259-265.

276. Cardoni, D.A., M. Favero, and J.P. Isacch, *Recreational activities affecting the habitat use by birds in Pampa's wetlands, Argentina: Implications for waterbird conservation.* Biological Conservation. 2008. 141(3): p. 797-806.

277. Halinouski, M.H. and A.M. Krytskaya, *Ecological and faunistic review of ground beetles (Coleoptera, Carobidae) in Gomel Urbocenosis (The Republic of Belarus).* Vestnik zoologii. 2008. 48(6): p. 521-532.

278. Burger, J. and M. Gochfeld, *Effects of ecotourists on bird behavior at Loxahatchee National Wildlife Refuge, Florida.* Environmental Conservation. 1998. 25(1): p. 13-21.

279. Fernández-Juricic, E., *Local and regional effects of pedestrians on forest birds in a fragmented landscape.* The Condor. 2000. 102(2): p. 247-255.

280. Fernández-Juricic, E., *Can human disturbance promote nestedness? A case study with breeding birds in urban habitat fragments.* Oecologia. 2002. 131: p. 269-278.

281. Fitzpatrick, S. and B. Bouchez, *Effects of recreational disturbance on the foraging behaviour of waters on a rocky beach.* Bird Study. 1998. 45(2): p. 157-171.

282. George, S.L. and K.R. Crooks, *Recreation and large mammal activity in an urban nature reserve.* Biological Conservation. 2006. 133(1): p. 107-117.

283. Trulio, L.A. and J. Sokale, *Foraging shorebird response to trail use around San Francisco Bay.* Journal of Wildlife Management. 2008. 72(8): p. 1775-1780.

284. Malo, J.E., P. Acebes, and J. Traba, *Measuring ungulate tolerance to human with flight distance: A reliable visitor management tool?* Biodiversity and Conservation. 2011. 20: p. 3477-3488.

285. Gray, A.C., *Impacts of human disturbance on the behavior of sanderlings on the Georgia Coast*. 2006. Georgia Southern University, Jack N. Averitt College of Graduate Studies: Statesboro, GA.

286. Swarthout, E.C.H. and R.J. Steidl, *Experimental effects of hiking on breeding Mexican Spotted Owls.* Conservation Biology. 2003. 17(1): p. 307-315.

287. Hennings, L.A., *Impacts of dogs on wildlife and water quality*. 2016. Metro Regional Government: Portland, OR.

288. Shannon, G., et al., *Behavioral responses associated with a human-mediated predator shelter.* PLoS ONE. 2014. 9(4): p. e94630.

289. Thompson, M.J. and R.E. Henderson, *Elk habituation as a credibility challenge for wildlife professionals.* Wildlife Society Bulletin. 1998. 26(3): p. 477-483.

290. Reimoser, S., *Influence of anthropogenic disturbances on activity, behavior and heart rate of roe deer (Capreolus capreolus) and red deer (Cervus elaphus), in context of their daily and yearly patterns*, in *Deer: Habitat, Behavior and Conservation*, A.A.M. Cahler, J.P., Editor. 2012. Nova Science Publishers, Inc.: Hauppauge, NY.

291. Martin, J.G.A. and D. Réale, *Animal temperament and human disturbance: Implications for the response of wildlife to tourism.* Behavioural Processes. 2008. 77(1): p. 66-72.

292. Blumstein, D.T., *Flight-initiation distance in birds is dependent on intruder starting distance.* Journal of Wildlife Management. 2003. 67(4): p. 852-857.

293. Ordenana, M.A., et al., *Effects of urbanization on carnivore species distribution and richness.* Journal of Mammology. 2010. 91(6): p. 1322-1331.

294. Riley, S., et al., *Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California.* Conservation Biology. 2003. 17(2): p. 566-576.

295. Markovchick-Nicholls, L., et al., *Relationships between human disturbance and wildlife land use in urban habitat fragments.* Conservation Biology. 2008. 22(1): p. 99-109.

296. Naylor, L.M., *Behavioral responses of Rocky Mountain elk (Cervus elaphus) to recreational disturbance*. 2006. Oregon State University: Corvallis, OR.

297. Mayo, T.W., P.W.C. Paton, and P.V. August, *Responses of birds to humans at a coastal barrier beach: Napatree Point, Rhode Island.* Northeastern Naturalist. 2015. 22(3): p. 501-512.

298. Knight, R.L. and D.N. Cole, *Factors that influence wildlife responses to recreationists*, in *Wildlife and Recreationists: Coexistence through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Press: Washington, D.C. p. 71-79.

299. Stillman, R.A. and J.D. Goss-Custard, *Seasonal changes in the reponse of oystercatchers Haematopus ostralegus to human disturbance.* Journal of Avian Biology. 2002. 33: p. 358-365.

300. Berger, J., *Fear, human shields and the redistribution of prey and predators in protected areas.* Biology Letters. 2007. 3(6): p. 620-623.

301. Cleveland, S.M., et al., *Linking elk movement and resource selection to hunting pressure in a heterogeneous landscape.* Wildlife Society Bulletin. 2012. 36(4): p. 658-668.

302. Jayakody, S., et al., *Red deer Cervus elephus vigilance behaviour differs with habitat and type of human disturbance.* Wildlife Biology. 2008. 14(1): p. 81-91.

303. Marchand, P., et al., *Impacts of tourism and hunting on a large herbivore's spatio-temporal behavior in and around a French protected area.* Biological Conservation. 2014. 177: p. 1-11.

304. Whittaker, D. and R.L. Knight, *Understanding wildlife responses to humans.* Wildlife Society Bulletin. 1999. 26(2): p. 312-317.

305. Muhly, T.B., et al., *Human activity helps prey win the predator-prey space race.* PLoS ONE. 2011. 6(3): p. e17050, doi:10.1371/journal.pone.0017050.

306. Burger, J. and M. Gochfeld, *Human distance and birds: Tolerance and response distances of residents and migrant species in India.* Environmental Conservation. 1991. 18(2): p. 158-165.

307. Møller, A.P., *Flight distance of urban birds, predation, and selection for urban life.* Behavioral Ecology and Sociobiology. 2008. 63(1): p. 63-75.

308. Blumstein, D.T., et al., *Inter-specific variation in avian responses to human disturbance.* Journal of Applied Ecology. 2005. 42(5): p. 943-953.

309. Blumstein, D.T., *Developing an evolutionary ecology of fear: How life history and natural history traits affect disturbance tolerance in birds.* Animal Behaviour. 2006. 71(2): p. 389-399.

310. Møller, A.P., et al., *American exceptionalism: Population trends and flight initiation distances in birds from three continents.* PLoS ONE. 2014. 9(e107883).

311. Czech, B., *Elk behavior in response to human disturbance at Mount St. Helens National Volcanic Monument.* Applied Animal Behaviour Science. 1991. 29(1-4): p. 269-277.

312. Fairbanks, W.S. and R. Tullous, *Distribution of pronghorn (Antilocapra americana Ord) on Antelope Island State Park, Utah, USA, before and after establishment of recreational trails.* Natural Areas Journal. 2002. 22: p. 277-282.

313. Knight, R.L. and D.N. Cole, *Wildlife responses to recreationists*, in *Wildlife and Recreationists: Coexistence through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Press: Washington, D.C. p. 51-70.

314. Childress, M.J. and M. Lung, *Predation risk, gender and the group size effect: Does elk vigilance depend on the behaviour of conspecifics?* Animal Behaviour. 2003. 66: p. 389-398.

315. Fernández-Juricic, E., et al., *Sensitivity of wildlife to spatial patterns of recreationist behavior: A critical assessment of minimum approaching distances and buffer areas for grassland birds.* Biological Conservation. 2005. 125(2): p. 225-235.

316. Gander, H. and P. Ingold, *Reactions of male alpine chamois (Rupicapra r. rupicapra) to hikers, joggers and mountainbikers.* Biological Conservation. 1997. 79(1): p. 107-109.

317. Burger, J., *The effect of human activity on birds at a coastal bay.* Biological Conservation. 1981. 21(3): p. 231-241.

318. Stankowich, T. and R.G. Coss, *Effects of predator behavior and proximity on risk assessment by Columbian black-tailed deer.* Behavioral Ecology. 2006. 17(2): p. 246-254.

319. Spahr, R., *Factors affecting distribution of Bald Eagles and effects of human activity on Bald Eagles wintering along the Boise River*, in *Biology*. 1990. Boise State University: Boise, ID.

320. Klein, M.L., *Waterbird behavioral responses to human disturbances.* Wildlife Society Bulletin. 1993. 21: p. 31-39.

321. Smith-Castro, J.R., *Impacts of recreational trails on breeding birds in forested urban parks*. 2008. Ohio State University: Columbus, OH.

322. Miller, S.G., R.L. Knight, and C.K. Miller, *Wildlife responses to pedestrians and dogs.* Wildlife Society Bulletin. 2001. 29: p. 124-132.

323. Blakesley, J.A. and K.P. Reese, *Avian use of campground and noncampground sites in riparian zones.* Journal of Wildlife Management. 1988. 52(3): p. 399-402.

324. Westmoreland, D. and L.B. Best, *The effect of disturbance on mourning dove nesting success.* The Auk. 1985. 102: p. 774.

325. Kangas, K., et al., *Recreation-induced changes in boreal bird communities in protected areas.* Ecological Applications. 2010. 20(6): p. 1775-1786.

326. Battle, K.E., S.L. Foltz, and I.T. Moore, *Predictors of flight behavior in rural and urban songbirds.* Wilson Journal of Ornithology. 2016. 128(3): p. 510-519.

327. McGarigal, K., R.G. Anthony, and F.B. Isaacs, *Interactions of humans and Bald Eagles on the Columbia River Estuary.* Wildlife Monographs. 1991. 115: p. 3-47.

328. Fortin, D. and M. Andruskiw, *Behavioral response of free-ranging bison to human disturbance.* Wildlife Society Bulletin. 2003. 31(3): p. 804-813.

329. Ciuti, S., et al., *The key role of lamb presence in affecting flight response in Sardinian mouflon (Ovis orientalis musimon).* Behavioural Processes. 2008. 77(3): p. 408-412.

330. Wolf, I.D. and D.B. Croft, *Minimizing disturbance to wildlife by tourists approaching on foot or in a car: A study of kangaroos in the Australian rangelands.* Applied Animal Behaviour Science. 2010. 126(1/2): p. 75-84.

331. Brown, C.L., et al., *The effect of human activities and their associated noise on ungulate behavior.* PLoS ONE. 2012. 7(7): p. e40505.

332. Fernández-Juricic, E., et al., *California's endangered Belding's Savannah Sparrow (Passerculus sandwichensis beldingi): Tolerance of pedestrian disturbance.* Avian Conservation and Ecology [online]. 2009. 4(2): p. Article 1.

333. Keeley, W.H. and M.J. Bechard, *Flushing distances of Ferruginous Hawks nesting in rural and exurban New Mexico.* Journal of Wildlife Management. 2011. 75: p. 1034-1039.

334. Hebblewhite, M. and E. Merrill, *Modelling wildlife–human relationships for social species with mixed-effects resource selection models.* Journal of Applied Ecology. 2008. 45(3): p. 834-844.

335. Reilly, M.L., et al., *Spatial and temporal response of wildlife to recreational activities in the San Francisco Bay ecoregion.* Biological Conservation. 2017. 207: p. 117-126.

336. Barrueto, M., A.T. Fort, and A.P. Clevenger, *Anthropogenic effects on activity patterns of wildlife at crossing structures.* Ecosphere. 2014. 5(3): p. 1-19.

337. Bélanger, L. and J. Bédard, *Hunting and waterfowl*, in *Wildlife and Recreationists. Coexistence through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Pres: Washington, D.C. p. 243-256.

338. McNeil, R., P. Drapeau, and J.D. Goss-Custard, *The occurrence and adaptive significance of nocturnal habits in waterfowl.* Biological Reviews. 1992. 67: p. 381-419.

339. Kannan, V. and R. Manadadan, *Nocturnal foraging by Painted Storks Mycteria leucocephala at Pulicat Lake, India.* Indian Birds. 2007. 3(1): p. 25-26.

340. Gokula, V., *Nocturnal foraging by Spot-billed Pelicans Pelecanus philippensis in Karaivetti Bird Sanctuary, Tamil Nadu, India.* Marine Ornithology. 2011. 39: p. 267-268.

341. Van Winkle, J., *E-mail correspondence from Jill Van Winkle to Lori Hennings dated October 20, 2016*, L. Hennings. 2016. Portland, OR.

342. Ortega, C.P., *Effects of noise pollution on birds: A brief review of our knowledge.* Ornithological Monographs. 2012. 74: p. 6-22.

343. Radle, A.L., *The effect of noise on wildlife: A literature review*. 2006. University of Oregon, Eugene, OR. p. 1-16.

344. Francis, C.D., et al., *Are nest predators absent from noisy areas or unable to locate nests?* Ornithological Monographs. 2012. 74: p. 101-110.

345. Shannon, G., et al., *A synthesis of two decades of research documenting the effects of noise on wildlife.* Biological Reviews. 2015. http://doi.org/10.1111/brv.12207

346. Dowling, J.L., D.A. Luther, and P.P. Marra, *Comparative effects of urban development and anthropogenic noise on bird songs.* Behavioural Ecology. 2012. 22(1): p. 201-209.

347. Eigenbrod, F., S.J. Hecnar, and L. Fahrig, *Quantifying the road-effect zone: Threshold effects of a motorway on anuran populations in Ontario, Canada.* Ecology and Society [online]. 2009. 14(1): Article 24.

348. Parris, K.M. and A. Schneider, *Impacts of traffic noise and traffic volume on birds of roadside habitats.* Ecology and Society [online]. 2009. 14(1): Article 29.

349. Parris, K.M., M. Velik-Lord, and J.M.A. North, *Frogs call at a higher pitch in traffic noise.* Ecology and Society [online]. 2009. 14(1): Article 25.

350. Slabbekoorn, H. and E.A. Ripmeester, *Birdsong and anthropogenic noise: Implications and applications for conservation.* Molecular Ecology. 2006(17): p. 72-83.

351. Wood, W.E. and S.M. Yezerinac, *Song sparrow (Melospiza melodia) song varies with urban noise.* The Auk. 2006. 123(3): p. 650-659.

352. Gough, D.C., D.J. Mennill, and E. No, *Singing seaside: Pacific Wrens (Troglodytes pacificus) change their songs in the presence of natural and anthropogenic noise.* The Wilson Journal of Ornithology. 2014. 126(2): p. 269-278.

353. Patricelli, G.L. and J.L. Blickley, *Avian communication in urban noise: Causes and consequences of vocal adjustment.* The Auk. 2006. 123(3): p. 639-649.

354. Slabbekoorn, H. and A. den Boer-Visser, *Cities change the songs of birds.* Current Biology. 2006. 16: p. 2326-2331.

355. Francis, C.D., et al., *Acoustic environments matter: Synergistic benefits to humans and ecological communities.* Journal of Environmental Management. 2017. 203: p. 245-254.

356. Swaddle, J.P., et al., *A framework to assess evolutionary responses to anthropogenic light and sound.* Trends in Ecology and Evolution. 2015. 30(9): p. 550-560.

357. Karp, D.S. and R. Guevara, *Conversational noise reduction as a win-win for ecotourists and rain forest birds in Peru.* Biotropica. 2011. 43: p. 122-130.

358. Francis, C.D., *Vocal traits and diet explain avian sensitivities to anthorpogenic noise.* Global Change Biology. 2015. 21(5): p. 1809-1820.

359. Petrelli, A.R.L., M.J.; Wardle, R.; Barber, J.R.; Francis, C.D., *First to flush: The effects of ambient noise on songbird flight initiation distances and implications for human experiences with nature.* Frontiers in Ecology and Evolution. 2017. 5: Article 67.

360. Karp, D.S. and T.L. Root, *Sound the stressor: How Hoatzins (Opisthocomus hoazin) react to ecotourist conversation.* Biodiversity and Conservation. 2009. 18: p. 3733-3742.

361. Bowles, A.E., *Responses of wildlife to noise*, in *Wildlife and Recreationists: Coexistence Through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Press: Washington, D.C. p. 109-156.

362. Mann, S.L., R.J. Steidl, and V.M. Dalton, *Effects of cave tours on breeding Myotis velifer.* Journal of Wildlife Management. 2002. 66(3): p. 618-624.

363. Francis, C.D., C.P. Ortega, and A. Cruz, *Noise pollution changes avian communities and species interactions.* Current Biology. 2009. 19: p. 1-5.

364. Beier, P., *Effects of artificial night lighting on terrestrial mammals*, in *Ecological Consequences of Artificial Night Lighting*, C. Rich and T. Longcore, Editors. 2006. Island Press: District of Columbia, U.S. p. 19-42.

365. Longcore, T. and C. Rich, *Ecological light pollution.* Frontiers in Ecology. 2004. 2(4): p. 191-198.

366. Frank, K.D., *Impact of outdoor lighting on moths.* Journal of the Lepidopterists' Society. 1988. 42: p. 63-93.

367. Miller, M.V., *Apparent effects of light pollution on singing behavior of American robins.* The Condor. 2006. 108: p. 130-139.

368. Manville, A.M.I., *Towers, turbines, power lines, and buildings - steps being taken by the U.S. Fish and Wildlife Service to avoid or minimize take of migratory birds at these structures*, in *Proceedings 4th International Partners in Flight Conference, February 2008*, C.J. Ralph and T.D. Rich, Editors. 2009. McAllen, TX.

369. Manville II, A., *Bird strikes and electrocutions at power lines, communication towers, and wind turbines: State of the art and state of the science – next steps toward mitigation*, in *Bird Conservation and Integration in the Americas*, C.J. Ralph and T.D. Rich, Editors. 2005. p. 1051-1064.

370. Longcore, T., C. Rich, and S.A. Gauthreaux, *Height, guy wires, and steady-burning lights increase hazard of communication towers to nocturnal migrants: A review and meta-analysis.* The Auk. 2008. 125(2): p. 485-492.

371. Stone, E.L., S. Harris, and G. Jones, *Impacts of artificial lighting on bats: A review of challenges and solutions.* Mammalian Biology. 2015. 80(3): p. 213-219.

372. Boldogh, S., D. Dobrosi, and P. Samu, *The effects of the illumination of buildings on house-dwelling bats and its conservation consequences.* Acta Chiropterologica. 2007. 9(2): p. 527-534.

373. Hudzik, S., *A case study of the spatial relationship between bat pass frequency and artificial light pollution along a bike trail in Portage County, Ohio*, in *Environmental Science Program*. 2015. Youngstown State University: Youngstown, OH.

374. Laidlaw, G.W.J. and M.B. Fenton, *Control of nursery colony populations of bats by artificial light.* Journal of Wildlife Management. 1971. 35(4): p. 843-.

375. Bliss-Ketchum, L., et al., *The effect of artificial light on wildlife use of passage structures.* Biological Conservation. 2016. 199(25-28).

376. Grigione, M.M. and R. Mrykalo, *Effects of artificial night lighting on endangered ocelots (Leopardus paradalis) and nocturnal prey along the United States-Mexico border: A literature review and hypotheses of potential impacts.* Urban Ecosystems. 2004. 7: p. 65-77.

377. Bruce-White, C. and M. Shardlow, *A review of the impact of artificial light on invertebrates*. 2011. Buglife - The Invertebrate Conservation Trust.

378. Rydell, J. and P.A. Racey. *Street lamps and the feeding ecology of insectivorous bats. Recent advances in bat biology*. in *Recent Advances in Bat Biology: Zoological Society of London Symposium abstracts*. 1993. Zoological Society of London.

379. Santos, C.D., et al., *Effects of artificial illumination on the nocturnal foraging of waders.* Acta Oecologica. 2010. 36: p. 166-172.

380. Bird, B.L., L.C. Branch, and D.L. Miller, *Effects of coastal lighting on foraging behavior of beach mice.* Conservation Biology. 2004. 18(5): p. 1435-1439.

381. Lebbin, D.J., et al., *Nocturnal migrants foraging at night by artificial light.* The Wilson Journal of Ornithology. 2007. 119(3): p. 506-508.

382. Jacobson, S.L., *Mitigation measures for highway-caused impacts to birds*. 2005. General Technical Report PSW-GTR-91. p. 1043-1050.

383. Audubon Society of Portland, et al., *Resource guide for bird-friendly building design*. 2012. Audubon Society of Portland: Portland, OR.

384. Audubon Society of Portland, *Portland Audubon's Birdsafe Portland: Lights Out Portland*. 2016. Portland, OR.

385. Hagar, J., *Functional relationships among songbirds, arthropods, and understory vegetation in Douglas-fir forests, western Oregon*. 2003. Oregon State University: Corvallis, OR.

386. Schlacher, T.A. and L. Thompson, *Beach recreation impacts benthic invertebrates on ocean-exposed sandy shores.* Biological Conservation. 2012. 147(1): p. 123-132.

387. Blair, R.B. and A.E. Launer, *Butterfly diversity and human land use: Species assemblages along an urban gradient.* Biological Conservation. 1997. 80: p. 113-125.

388. Davis, A.K., *Walking trails in a nature preserve alter terrestrial salamander distributions.* Natural Areas Journal. 2007. 27(4): p. 385-389.

389. Fleming, M.M., et al., *Effects of trails on eastern redback salamander (Plethodon cinereus Green).* Herpetology Notes. 2011. 4: p. 229-232.

390. Semlitsch, R.D., et al., *Salamander abundance along road edges and within abandoned logging roads in Appalachian forests.* Conservation Biology. 2007. 21(1): p. 159-167.

391. Kluber, M.R., D.H. Olson, and K.J. Puettmann, *Downed wood microclimates and their potential impact on plethodontid salamander habitat in the Oregon Coast Range.* Northwest Science. 2009. 83(1): p. 25-34.

392. Goff, C.B., *Effects of roads and trails on Peaks of Otter salamander (Plethodon hubrichti) and eastern red-backed salamander (Plethodon cinereus) movement behavior*. 2015. Marshall University: Huntington, WV.

393. Guderyahn, L.B., A.P. Smithers, and M.C. Mims, *Assessing habitat requirements of pond-breeding amphibians in a highly urbanized landscape: Implications for management.* Urban Ecosystems. 2016. May 2016(DOI: 10.1007/s11252-016-0569-6).

394. Wolz, H., J.P. Gibbs, and P.K. Ducey, *Road crossing structures for amphibians and reptiles: Informing design through behavioral analysis.* Biological Conservation. 2008. 141(11): p. 2745-2750.

395. Schmidt, B.R. and S. Zumbach, *Amphibian road mortality and how to prevent it: A review*, in *Urban Herpetology*, J.C. Mitchell, R.D. Jung Brown, and R. Bartolomew, Editors. 2008. Society for the Study of Amphibians and Reptiles: St. Louis, MO.

396. Jackson, S.D., *Underpass systems for amphibians*, in *Trends in Addressing Transportation Related Wildlife Mortality, Proceedings of the Transportation Related Wildlife Mortality Seminar*, G.L. Evink, et al., Editors. 1996. State of Florida Department of Transportation: Tallahassee, FL.

397. Diego-Rasilla, F.J., *Human influence on the tameness of wall lizard, Podarcis muralis.* Italian Journal of Zoology. 2003. 70: p. 225-228.

398. Amo, L., P. López, and J. Martin, *Nature-based tourism as a form of predation risk affects body condition and health state of Padarcis muralis lizards.* Biological Conservation. 2006. 131(3): p. 402-409.

399. Garber, S.D. and J. Burger, *A 20-year study documenting the relationship between turtle decline and human recreation.* Ecological Applications. 1995. 5(4): p. 1151-1162.

400. Rosenberg, D., et al., *Conservation assessment of the western pond turtle in Oregon (Actinemys marmorata).* 2009. Sponsored by U.S.D.I. Bureau of Land Management and Fish and Wildlife Service, U.S.D.A. Forest Service Region 6, Oregon Department of Fish and Wildlife, City of Portland, and Metro: Portland, OR.

401. Nyhof, P.E. and L. Trulio, *Basking western pond turtle response to recreational trail use in urban California.* Chelonian Conservation and Biology. 2015. 14(2): p. 182-184.

402. Pilliod, D.S. and E. Wind, *Habitat management guidelines for amphibians and reptiles of the northwestern United States and western Canada*. 2008. Partners in Amphibian and Reptile Conservation: Birmingham, AL.

403. Ikuta, L.A. and D.T. Blumstein, *Do fences protect birds from human disturbance?* Biological Conservation. 2003. 112(3): p. 447-452.

404. McLeod, E.M., et al., *Buses, cars, bicycles and walkers: The influence of the type of human transport on the flight responses of waterbirds.* PLoS One. 2013. 8(12): p. e82008.

405. Fernández-Juricic, E., M.D. Jimenez, and E. Lucas, *Bird tolerance to human disturbance in urban parks of Madrid (Spain): Management implications*, in *Avian Ecology and Conservation in an Urbanizing World*, J.M. Marzluff, R. Bowman, and R. Donnelly, Editors. 2001. Kluwer Academic Publishers: Norwell, MA. p. 259-273.

406. Marzano, M. and N. Dandy, *Recreationist behaviour in forests and the disturbance of wildlife.* Biodiversity and Conservation. 2012. 21(11): p. 2967-2986.

407. Bennett, K.A. and E.F. Zuelke, *The effects of recreation on birds: A literature review*. 1999. Delaware Natural Heritage Program: Smyrna, DE.

408. American Birding Association. *American Birding Association Code of Birding Ethics*. Undated.

409. Heil, L., et al., *Avian responses to tourism in the biogeographically isolated high Cordoba Mountains, Argentina.* Biodiversity and Conservation. 2006. 16: p. 1009-1026.

410. Miller, S.G., R.L. Knight, and C.K. Miller, *Influence of recreational trails on breeding bird communities.* Ecological Applications. 1998. 8(1): p. 162-169.

411. Burhans, D.E. and F.R. Thompson III, *Songbird abundance and parasitism differ between urban and rural shrublands.* Ecological Applications. 2006. 16(1): p. 394-405.

412. Devictor, V., R. Julliard, and F. Jiguet, *Distribution of specialist and generalist species along spatial gradients of habitat disturbance and fragmentation.* Oikos. 2008. 117: p. 507-514.

413. Morelli, F., et al., *Evidence of evolutionary homogenization of bird communities in urban environments across Europe.* Global Ecology and Biogeography. 2016. 25: p. 1284-1293.

414. Miller, J.R. and N.T. Hobbs, *Recreational trails, human activity, and nest predation in lowland riparian areas.* Landscape and Urban Planning. 2000. 50: p. 227-236.

415. Davis, C.A., et al., *Mountain biking trail use affects reproductive success of nesting Golden-cheeked Warbler.* Wilson Journal of Ornithology. 2010. 122(3): p. 465-474.

416. Showler, D.A., *What is the impact of public access on the breeding success of ground-nesting and cliff-nesting birds?* 2010. University of East Anglia, Norwich, UK.

417. Hocken, D., et al., *Examination of the effects of disturbance on birds with reference to its importance in ecological assessments.* Journal of Environmental Management. 1992. 36: p. 253-286.

418. Chace, J.F., et al., *Spatial and temporal activity patterns of the brood parasitic brown-headed cowbird at an urban/wildland interface.* Landscape and Urban Planning. 2002. 64(3): p. 179-190.

419. Lee, M., et al., *Importance of patch scale vs landscape scale on selected forest birds.* Oikos. 2002. 96(1): p. 110-118.

420. Glądalski, M., et al., *Effects of human-related disturbance on breeding success of urban and non-urban blue tits (Cyanistes caeruleus).* Urban Ecosystems. 2016. 19(3): p. 1325-1334.

421. Gates, J.E. and N.R. Giffen, *Neotropical migrant birds and edge effects at a forest-stream ecotone.* Wilson Bulletin. 1991. 103(2): p. 204-217.

422. Hickman, S., *The effects of nature trails on breeding birds*, in *Grayslake, IL.* 1985. College of Lake County, Biology Department.

423. Sorace, A., *High density of bird and pest species in urban habitats and the role of predator abundance.* Ornis Fennica. 2002. 79(2): p. 60-71.

424. Bardin, E.E. and T.A. Nelson, *Raccoons use habitat edges in northern Illinois.* The American Midland Naturalist. 2008. 159(2): p. 394-402.

425. Walker, L.E. and J.M. Marzluff, *Recreation changes the use of a wild landscape by corvids.* The Condor. 2015. 117(2): p. 262-283.

426. Hennings, L.A., *Avian communities in riparian reserves in an urban landscape*. 2001. Oregon State University, Corvallis, OR. p. 1-60.

427. Marzluff, J.M., et al., *Causes and consequences of expanding American Crow populations in urban environments*, in *Avian Ecology and Conservation in an Urbanizing World*, J.M. Marzluff, R. Bowman, and R. Donnelly, Editors. 2001. Kluwer Academic Press: Norwell. p. 331-363.

428. Wilson, G.R. and M.C. Brittingham, *How well do artificial nests estimate success of real nests?* The Condor. 1998. 100: p. 357-364.

429. Part, T. and J. Wretenberg, *Do artificial nests reveal relative nest predation risk for real nests?* Journal of Avian Biology. 2002. 33(1): p. 39-46.

430. Gutzwiller, K.J., et al., *Effects of human intrusion on song occurrence and singing consistency in subalpine birds.* The Auk. 1994. 111(1): p. 28-37.

431. Møller, A.P., *Urban areas as refuges from predators and flight distance of prey.* Behavioral Ecology. 2012. 23(5): p. 1030-1035.

432. Storch, I., *Human disturbance of grouse - why and when?* Wildlife Biology. 2013. 19(4): p. 390-403.

433. Stalmaster, M.V. and J.L. Kaiser, *Effects of recreational activity on wintering bald eagles.* Wildlife Monographs. 1998. 137: p. 3-46.

434. Cole, D.N. and P.B. Landres, *Indirect effects of recreation on wildlife*, in *Wildlife and Recreationists - Coexistence Through Management and Research*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Press: Washington, D.C.

435. Miller, J.R., et al., *Effects of human settlement on bird communities in lowland riparian areas of Colorado (USA).* Ecological Applications. 2003. 13(4): p. 1041-1059.

436. Villard, M.-A., G. Merriam, and B.A. Maurer, *Dynamics in subdivided populations of Neotropical migratory birds in a fragmented temperate forest.* Ecology. 1995. 76(1): p. 27-40.

437. Various, *Ecology and Management of Neotropical Migratory Birds*. 1995. New York, NY: Oxford University Press.

438. Robinson, S.K., *Another threat posed by forest fragmentation: Reduced food supply.* The Auk. 1998. 115: p. 1-3.

439. Maurer, B.A., *Biological diversity, ecological integrity, and neotropical migrants: New perspectives for wildlife management*, D.M. Finch and P.W. Stangel, Editors. 1993. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. p. 24-31.

440. Mattsson, B.J. and G.J. Niemi, *Factors influencing predation on Ovenbird (Seiurus aurocapilla) nests in northern hardwoods: Interactions across spatial scales.* The Auk, 2006. 123(1): p. 82-96.

441. Rich, T.D., et al., *Partners in Flight North American Landbird Conservation Plan*. 2004. Partners in Flight, Ithaca, NY.

442. Robbins, C.S., J.R. Sauer, and B.G. Peterjohn, *Population trends and management opportunities for neotropical migrants*, in *Status and management of neotropical migratory birds*, D.M. Finch and P.W. Stangel, Editors. 2009. Fort Collins, CO. p. 17-23.

443. Croonquist, M. and R.P. Brooks, *Effects of habitat disturbance on bird communities in riparian corridors.* Journal of Soil and Water Conservation. 1993. 48(1): p. 65-70.

444. Hodges, M.F., Jr. and D.G. Krementz, *Neotropical migratory breeding bird communities in riparian forests of different widths along the Altamaha River, Georgia.* Wilson Bulletin. 1996. 108(3): p. 496-506.

445. Hennings, L.A. and J. Soll, *Wildlife corridors and permeability. A literature review*. 2010. Metro, Portland, OR.

446. Keller, C.M.E., C.S. Robbins, and J.S. Hatfield, *Avian communities in riparian forests of different widths in Maryland and Delaware.* Wetlands. 1993. 13(2): p. 137-144.

447. Pennington, D.N., J. Hansel, and R.B. Blair, *The conservation value of urban riparian areas for landbirds during spring migration: Land cover, scale, and vegetation effects.* Biological Conservation. 2008. 141(5): p. 1235-1248.

448. Thurmond, D.P., K.V. Miller, and T.G. Harris, *Effect of streamside management zone width on avifauna communities.* Southern Journal of Applied Forestry. 1995. 19(4): p. 166-169.

449. Burke, D.M. and E. Nol, *Influence of food abundance, nest-site habitat, and forest fragmentation on breeding Ovenbirds.* The Auk. 1998. 115: p. 96-104.

450. Hennings, L.A. and W.D. Edge, *Riparian bird community structure in Portland, Oregon: Habitat, urbanization, and spatial scale patterns.* The Condor. 2003. 105(2): p. 288-302.

451. Rodewald, A.D. and D.P. Shustack, *Urban flight: Understanding individual and population-level responses of Nearctic–Neotropical migratory birds to urbanization.* Journal of Animal Ecology, 2007. 77(1): p. 83-91.

452. Rodewald, P.G. and S.N. Matthews, *Landbird use of riparian and upland forest stopover habitats in an urban landscape.* The Condor, 2005. 107(2): p. 259-268.

453. Finch, D.M., *Population ecology, habitat requirements, and conservation of Neotropical migratory birds*. 1991: Fort Collins, CO. p. 1-26.

454. Murphy, M., *Demography of birds breeding in an urban environment: Identification of source and sink populations*. 2006. p. 1-18.

455. Wilcove, D.S., *Nest predation in forest tracts and the decline of migratory songbirds.* Ecology. 1985. 66: p. 1211-1214.

456. Weinberg, H.J. and R.R. Roth, *Forest area and habitat quality for nesting Wood Thrushes.* The Auk. 1998. 115(4): p. 879-889.

457. Marsh, L.K., *Relationship between human intrusion and avian body mass: Do recreationists hinder birds' abilities to acquire fat during migration?* 2015. University of Tennessee at Chattanooga: Chattanooga, TN.

458. Klein, M.L., S.R. Humphrey, and H.F. Percival, *Effects of ecotourism on distribution of waterbirds in a wildlife refuge.* Conservation Biology. 1995. 9(6): p. 1454-1465.

459. Robinson, S.K., et al., *Regional forest fragmentation and the nesting success of migratory birds.* Science. 1995. 267: p. 1987-1990.

460. Sauer, J.R., et al. *The North American Breeding Bird Survey, Results and Analysis 1966 - 2013. Version 01.30.2015* Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2014. USGS Patuxent Wildlife Research Center, Laurel, MD.

461. Pfister, C., B.A. Harrington, and M. Lavine, *The impact of human disturbance on shorebirds at a migration staging area.* Biological Conservation. 1992. 60(2): p. 115-126.

462. Burger, J., M. Gochfeld, and L.J. Niles, *Ecotourism and birds in coastal New Jersey: Contrasting responses of birds, tourists, and managers.* Environmental Conservation. 1995. 22(1): p. 56-65.

463. Lafferty, K.D., *Disturbance to wintering western Snowy Plovers.* Biological Conservation. 2004. 101(3): p. 315-325.

464. Thomas, K., R.G. Kvitek, and C. Bretz, *Effects of human activity on the foraging behavior of sanderlings Calidris alba.* Biological Conservation. 2003. 109(1): p. 67-71.

465. Pease, M.L., R.K. Rose, and M.J. Butler, *Effects of human disturbances on the behavior of wintering ducks.* Wildlife Society Bulletin. 2005. 33(1): p. 103-112.

466. Spencer, D.W. and J.M. Conard, *Impacts of human disturbance on migratory waterfowl*. 2014. Sterling College: Sterling, KS.

467. Ackerman, J.T., et al., *Using radiotelemetry to monitor cardiac response of free-living Tule Greater White-fronted Geese (Anser albifrons elgasi) to human disturbance.* Wilson Bulletin. 2004. 116(2): p. 146-151.

468. Trulio, L.A. and H.R. White, *Wintering waterfowl avoidance and tolerance of recreational trail use.* Waterbirds. 2017. 40(3): p. 252-262.

469. Korschgen, C.E. and R.B. Dahlgren, *Human disturbances of waterfowl: Causes, effects, and management*. 1992. U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, La Crosse Field Station: La Cross, WI.

470. Newbrey, J.L., M.A. Bozek, and N.D. Niemuth, *Effects of lake characteristics and human disturbance on the presence of piscivorous birds in northern Wisconsin, USA.* Waterbirds. 2005. 28(4): p. 478-486.

471. Mathers, R.G., et al., *A study of the impact of human disturbance on Wigeon Anas penelope and Brent geese Branta bernicla hrota on an Irish sea loch.* Wildfowl. 2000. 51: p. 67-81.

472. Reichholf, J., *The influence of recreational activities on waterfowl*, in *Proceedings of the International Conference on the Conservation of Wetlands and Waterfowl*, M. Smart, Editor. 1976. International Waterfowl Research Bureau: Simbridger, England.

473. Anthony, R.G., R.J. Steidl, and K. McGarigal, *Recreation and Bald Eagles in the Pacific Northwest*, in *Wildlife and Recreationists. Coexistence through Management*, R.L.G. Knight, Gutzwiller, K.J., Editors. 1995. Island Press: Washington, D.C. p. 223-242.

474. Grubb, T.G. and R.M. King, *Assessing human disturbance of breeding Bald Eagles with classification tree models.* Journal of Wildlife Management. 1991. 55(3): p. 500-511.

475. Steidl, R.J. and R.G. Anthony, *Experimental effects of human activity on breeding Bald Eagles.* Ecological Applications. 2000. 10(1): p. 258-268.

476. Berry, M.E., C.E. Bock, and S.L. Haire, *Abundance of diurnal raptors on open space grasslands in an urbanized landscape.* The Condor. 1998. 100(4): p. 601-608.

477. Skagen, S.K., R.L. Knight, and G.H. Orians, *Human disturbance of an avian scavenging guild.* Ecological Applications. 1991. 1(2): p. 215-225.

478. Guinn, J.E., *Generational habituation and current Bald Eagle populations.* Human-Wildlife Interactions. 2013. 7(1): p. 69-76.

479. Millsap, B., et al., *Comparative fecundity and survival of Bald Eagles fledged from suburban and rural natal areas in Florida.* Journal of Wildlife Management. 2004. 68(4): p. 1018-1031.

480. Ripple, W.J. and R.L. Beschta, *Trophic cascades in Yellowstone: The first 15 years after wolf reintroduction.* Biological Conservation. 2011. 145(1): p. 205-213.

481. Various, *Trophic cascades: Predators, prey, and the changing dynamics of nature*, ed. J.E. Terborgh, J.A. 2010. Washington, D.C.: Island Press.

482. Muhly, T.B., et al., *Humans strengthen bottom-up effects and weaken trophic cascades in a terrestrial food web.* PLoS ONE. 2013. 8(5): p. e64311.

483. Various, *Avian ecology and conservation in an urbanizing world*. 2001. Norwell, MA: Kluwer Academic Publishers.

484. Sibbald, A.M., et al., *Responses of red deer (Cervus elaphus) to regular disturbance by hill walkers.* European Journal of Wildlife Research. 2011. 57(4): p. 817-825.

485. Manor, R. and D. Saltz, *Effects of human disturbance on use of space and flight distance of mountain gazelles.* Journal of Wildlife Management. 2005. 69(4): p. 1683-1690.

486. Wisdom, M.J., et al. *Effects of off-road recreation on mule deer and elk*. in *Transactions of the 69th North American Wildlife and Natural Resources Conference*. 2004.

487. Pelletier, F., *Effects of tourist activities on ungulate behaviour in a mountain protected area.* Journal of Mountain Ecology. 2006. 8: p. 15-19.

488. Jayakody, S., et al., *Effects of human disturbance on the diet composition of wild red deer (Cervus elaphus).* European Journal of Wildlife Research. 2011. 57: p. 939-948.

489. Berger, J., et al., *A mammalian predator-prey imbalance: Grizzly bear and wolf extinction affect avian neotropical migrants.* Ecological Applications. 2001. 11: p. 947-960.

490. Cintra, R., W.E. Magnusson, and A. Albernaz, *Spatial and temporal changes in bird assemblages in forest fragments in an eastern Amazonian savannah.* Ecology and Evolution. 2013. Article first published online: 6 AUG 2013, DOI: 10.1002/ece3.700.

491. Saunders, D.A., R.J. Hobbs, and C.R. Margules, *Biological consequences of ecosystem fragmentation: A review.* Conservation Biology. 1991. 5(1): p. 18-32.

492. Laurance, W.F., S.G. Laurance, and D.W. Hilbert, *Long-term dynamics of a fragmented rainforest mammal assemblage.* Conservation Biology. 2008. 22(5): p. 1154-1164.

493. Fernández-Juricic, E., *Bird community composition patterns in urban parks of Madrid: The role of age, size and isolation.* Ecological Research. 2000. 15: p. 373-383.

494. Reed, S.E. and A.M. Merenlender, *Quiet, nonconsumptive recreation reduces protected area effectiveness.* Conservation Letters. 2008. 1(3): p. 146-154.

495. van der Ree, R. and E.A. van der Grift, *Recreational co-use of wildlife crossing structures*, in *Handbook of Road Ecology*, R. van der Ree, D.J. Smith, and C. Grilo, Editors. 2015. John Wiley & Sons, Ltd.: New York, NY.

496. Sweanor, L.L., et al., *Puma and human spatial and temporal use of a popular California state park.* Journal of Wildlife Management. 2008. 72(5): p. 1076-1084.

497. Lenth, B.E., R.L. Knight, and M.E. Brennan, *The effects of dogs on wildlife communities.* Natural Areas Journal. 2008. 28(3): p. 218-227.

498. Erb, P.L., W.J. McShea, and R.P. Guralnick, *Anthropogenic influences on macro-level mammal occupancy in the Appalachian Trail corridor.* PLoS ONE. 2013. 7(8): p. e42574.

499. Gehrt, S.D., C. Anchor, and L.A. White, *Home range and landscape use of coyotes in a metropolitan landscape: Conflict or coexistence?* Journal of Mammalogy. 2009. 90(5): p. 1045-1057.

500. Corlatti, L., K. Hackländer, and F. Frey-Roos, *Ability of wildlife overpasses to provide connectivity and prevent genetic isolation.* Conservation Biology. 2009. 23(3): p. 548-556.

501. Pouwels, R. and E.A. van der Grift. *The use of wildlife overpasses for outdoor recreation*. in *The 6th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas*. 2012.

502. Piñeiro, A., et al., *Effects of tourist pressure and reproduction on physiological stress response in wildcats: Management implications for species conservation.* Wildlife Research. 2012. 39(532): p. 539.

503. Murphy, M., *Determinants of vertebrate species richness in an urban landscape*. 2005. Portland State University, Portland, OR.

504. Gutzwiller, K.J. and S.K. Riffell, *Does repeated human instrusion alter use of wildland sites by red squirrels? Multiyear experimental evidence.* Journal of Mammalogy. 2008. 89(2): p. 374-380.

505. Griffin, S.C., et al., *Effects of tourists on behavior and demography of Olympic marmots.* Conservation Biology. 2007. 21: p. 1070-1081.

506. Mainini, B., P. Neuhaus, and P. Ingold, *Behaviour of marmots Marmota marmota under the influence of different hiking activities.* Biological Conservation. 1993. 64: p. 161-164.

507. Neuhaus, P. and B. Mainini, *Reactions and adjustment of adult and young alpine marmots Marmota marmota to intense hiking activities.* Wildlife Biology. 1998. 4(2): p. 119-123.

508. Kurta, A. and J.A. Teraminc, *Bat community structure in an urban park.* Ecography. 1992. 15(3): p. 257-261.

509. Barnard, R.J., et al., *Design of culverts for fish passage*. 2003. Washington Department of Fish and Wildlife: Olympia, WA.

510. Webber, P., *Managing mountain biking - IMBA's guide to providing great riding*. 2007. State of Minnesota, Department of Natural Resources, Trails and Waterways Division: Boulder, CO. p. 256.

511. Appalachian Mountain Club, *Complete guide to trail building and maintenance*. 2008. Boston, MA: Appalachian Mountain Club.

512. Minnesota Department of Natural Resources, Trails for All Ontarians Collaborative, *Guidelines for managing and restoring natural plant communities along trails and waterways*. 2004. Minnesota Department of Natural Resources.

513. Riter, J. and M. Riter, *Trailbuilding basics*. 2000. International Mountain Bicycling Association: Boulder, CO.

514. Marion, J., *Leave No Trace in the outdoors*. 2014. Mechanicsburg, PA: Stackpole Books.

515. Birkby, R.C., *Lightly on the land: The SCA trail building and maintenance manual*. 2006. The Mountaineers Books: Seattle, WA.

516. Parker, T.S., *Natural surface trails by design: Physical and human essentials of sustainable, enjoyable trails*. 2004. Boulder, CO: Natureshape.

517. U.S.D.A. Forest Service, *Trail fundamentals and trail management objectives*. 2011. State of Minnesota, Department of Natural Resources, Trails and Waterways Division: St. Paul, MN. p. 300.

518. Minnesota Department of Natural Resources, Trails and Parks Division, *Trail planning, design, and development guidelines*. 2007. Minnesota Department of Natural Resources: St. Paul, MN.

519. Marion, J.L., *A review and synthesis of recreation ecology research supporting carrying capacity and visitor use management decisionmaking.* Journal of Forestry. 2016. 114(3): p. 339-351.

520. Farrell, T.A. and J.L. Marion, *The Protected Area Visitor Impact Management (PAVIM) Framework: A simplified process for making management decisions.* Journal of Sustainable Tourism. 2002. 10(1): p. 31-51.

521. Graefe, A.R., J.J. Vaske, and F.R. Kuss, *Social carrying capacity: An integration and synthesis of twenty years of research.* Leisure Sciences. 1984. 6(4): p. 395.

522. Watson, A.E., et al., *Wilderness recreation use estimation: A handbook of methods and systems*. 2000. U.S.D.A. Forest Service, Rocky Mountain Research Station: Ogden, UT.

523. Lindberg, K., S.F. McCool, and G.H. Stankey, *Rethinking carrying capacity.* Annals of Tourism Research. 1997. 24(2): p. 461-465.

524. Yosemite National Park Division of Resources Management and Science and U.S.D.I. National Park Service, *Field monitoring guide visitor use and impact monitoring program*. 2009. U.S.D.I. National Park Service: Washington, D.C.

525. Shelby, B. and T.A. Heberlein, *Carrying capacity in recreation settings*. 1986. Corvallis, OR: Oregon State University Press.

526. Jim, C.Y., *Visitor management in recreation areas.* Environmental Conservation. 1989. 16(1): p. 19-40.

527. U.S. Department of the Interior, National Park Service, *The Visitor Experience and Resource Protection (VERP) framework: A handbook for planners and managers*. 1997. U.S.D.I. National Park Service: Denver, CO.

528. Interagency Visitor Use Management Council, *Visitor use management framework. A guide to providing sustainable outdoor recreation*. 2016. Bureau of Land Managment, U.S. Forest Service, National Oceanic and Atmospheric Administration, National Park Service, U.S. Army Corps of Engineers, and U.S. Fish and Wildlife Services: Washington, D.C.

529. Manning, R., *Visitor Experience and Resource Protection: A framework for managing the carrying capacity of national parks.* Journal of Park and Recreation Administration. 2001. 19(1): p. 93-108.

530. Stankey, G.H., et al., *The Limits of Acceptable Change (LAC) system for wilderness planning*. 1985. U.S.D.A. Forest Service, Intermountain Forest and Range Experiment Station: Ogden, UT.

531. Chilman, K., J. Ladley, and T. Wilke, *Refining existing recreational carrying capacity process – Recent refinements*, in *Managing America's Enduring Wilderness Resource*. 1989. Minnesota Agricultural Experiment Station: St. Paul, MN. p. 163-169.

532. Marion, J.L., J.F. Wimpey, and L.O. Park, *The science of trail surveys: Recreation Ecology provides new tools for managing wilderness trails.* Park Science. 2011. 28(3).

533. Houston, R., *Evaluation of trail impact assessments for use at Oregon Parks and Recreation Department*. 2012. Portland State University, Hatfield School of Government: Portland, OR.

534. Tomlinson, T., *Analyzing the impacts of collaborative-based recreation management in Oregon's Black Rock Forest*. 2009. University of Oregon: Eugene, OR.

535. Dickinson, J.L., et al., *The current state of citizen science as a tool for ecological research and public engagement.* Frontiers in Ecology and the Environment. 2012. 10(6): p. 291-297.

536. Marion, J.L. and C. Carr, *Backcountry recreation site and trail conditions: Haleakalā National Park*. 2009. U.S. Geological Survey, Virginia Tech Field Unit, College of Natural Resources & Environment: Blacksburg, VA.

537. Leung, Y.-F. and J.L. Marion, *The influence of sampling interval on the accuracy of trail impact assessment.* Landscape and Urban Planning. 1999. 43(4): p. 167-179.

538. Turner, R., *Visitor behaviors and resource impacts at Cadillac Mountain, Acadia National Park*. 1998. University of Maine: Orono, ME.

539. Barros, A. and C.M. Pickering, *How networks of informal trails cause landscape level damage to vegetation.* Environmental Management. 2017. DOI: 10.1007/s00267-017-0865-9 (early online publication).

540. Bright, J.A., *Hiker impact on herbaceous vegetation along trails in an evergreen woodland of Central Texas.* Biological Conservation. 1986. 36(1): p. 53-69.

541. Forys, E.A., et al., *Can video cameras decrease human intrusion into a closed natural area?* Natural Areas Journal. 2016. 36(2): p. 146-152.

542. National Marine Fisheries Service, *Anadromous salmonid passage facility design*. 2008. National Marine Fisheries Service: Portland, OR.

543. Metro, *Wildlife crossings. Providing safe passage for urban wildlife*. 2009. Metro: Portland, OR.

544. Blinn, C.R., et al., *Temporary stream and wetland crossing options for forest management*. 1998. North Central Research Station, U.S.D.A. Forest Service: St. Paul, MN.

545. Neese, J., M. Eriksson, and B. Vachowski, *Floating trail bridges and docks.* 2002. U.S.D.A. Forest Service, Missoula Technology and Development Center, Missoula, MT.

546. Cooley, A. and H. Chang, *Precipitation intensity trend detection using hourly and daily observations in Portland, Oregon.* 2017. Portland State University, Portland, OR.

547. Davies, K.W. and R.L. Sheley, *A conceptual framework for preventing the spatial dispersal of invasive plants.* Weed Science. 2007. 55: p. 178-184.

548. Stanley, A.G., T.N. Kaye, and P.W. Dunwiddie, *Regional strategies for restoring invaded prairies, final technical report*. 2010. Institute for Applied Ecology, Corvallis, OR and The Nature Conservancy, Seattle, WA: Corvallis, OR.

549. Partners in Amphibian and Reptile Conservation, *Inventory and monitoring: recommended techniques for reptiles and amphibians, with applications to the United States and Canada*. 2013. Savannah, GA: University of Georgia.

550. Hooper, J., R.V. Rea, and A. Loison, *The use of an orthotic casting foam as a track-plate medium for wildlife research and monitoring.* Wildlife Biology. 2009. 15(1): p. 106-112.

551. Various, *Inventory and monitoring of wildlife habitat*. 1986. Denver, CO: U.S.D.A. Bureau of Land Management.

552. Ralph, C.J., S. Droege, and J.R. Sauer, *Managing and monitoring birds using point counts: Standards and applications*. 1995. U.S.D.A. Forest Service: Pacific Southwest Research Station, Albany, CA.

553. Wilson, R.R., D.J. Twedt, and A.B. Elliott, *Comparison of line transects and point counts for monitoring of spring migration in forested wetlands.* Journal of Field Ornithology. 2000. 71(2): p. 345-355.

554. Various, *Monitoring wildlife (full issue).* Methods in Ecology and Evolution. 2015. (online virtual issue: http://www.methodsinecologyandevolution.org/view/0/virtualIssues/monitoringwildlife.html).

555. Morrison, M.L., *Wildlife restoration: Techniques for habitat analysis and animal monitoring*. 2002. Washington, D.C.: Island Press / Society for Ecological Restoration.

556. Cafferata Coe, F., *Techniques and tools for monitoring wildlife on small woodlands*. 2013. Woodland Fish and Wildlife Group: Hillsboro, OR.

557. Droege, S., *Monitoring Neotropical migrants on managed lands: When, where, why*, in *Status and management of neotropical migratory birds*, D.M. Finch and P.W. Stangel, Editors. 1993. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station: Fort Collins, CO. p. 189-191.

558. Various, *A technical guide for monitoring wildlife habitat*, M.M. Rowland and C.D. Vojta, Editors. 2013. U.S. Department of Agriculture, Forest Service: Washington, D.C.

559. Steidl, R.J. and B.F. Powell, *Assessing the effects of human activities on wildlife.* George Wright Forum. 2006. 23(2): p. 50-58.

560. Canada Trails. *Hiker's Code of Ethics*. Undated.

561. Footprint Hiking Club. *The Hikers Credo and hikers' responsibility and code of ethics*. Undated.

562. Association, I.M.B., *Rules of the trail*, in *https://www.imba.com/sites/default/files/Team_IMBA/RulesOfTheTrail.pdf*. 1996. Forest Stewardship Council.

563. Department of National Parks, S.a.R., *Code of conduct for recreational horse riding on designated multi-use trails in State forests, forest reserves and protected areas*. 2014. Department of National Parks, Sport and Racing: Queensland, Australia.

564. Marion, J.D. and S.E. Reid, *Minimising visitor impacts to protected areas: The efficacy of low impact education programmes.* Journal of Sustainable Tourism. 2007. 15(1): p. 5-27.

565. Cialdini, R.B., et al., *Managing social norms for persuasive impact.* Social Influence. 2006. 1(1): p. 3-15.

566. Cialdini, R.B., *Activating and aligning two kinds of norms in persuasive communications.* Journal of Interpretive Research. 1996. 1(1): p. 3-10.

567. Semlitsch, R.D. and J.R. Bodie, *Biological criteria for buffer zones oround wetlands and riparian habitats for amphibians and reptiles.* Conservation Biology. 2003. 17(5): p. 1219-1228.

568. Semlitsch, R.D., *Biological delineation of terrestrial buffer zones for pond-breeding salamanders.* Conservation Biology. 1998. 12(5): p. 1113-1119.

569. Carrete, M. and J.L. Tella, *Individual consistency in flight initiation distances in burrowing owls: A new hypothesis on disturbance-induced habitat selection.* Biology Letters. 2010. 6: p. 167-170.

570. U.S. Fish and Wildlife Service, *National Bald Eagle management guidelines*. 2007. Washington, D.C.

571. Fraser, J.D., L.D. Frenzel, and J.E. Mathisen, *The impact of human activities on breeding bald eagles in north-central Minnesota.* Journal of Wildlife Management. 1985. 49(3): p. 585-592.

572. Paton, D.C., et al., *Disturbance distances for water birds and the management of human recreation with special reference to the Coorong region of south Australia*. 2000. University of Adelaide: Adelaide, South Australia.

573. Stafl, N. and M.K. O'Connor, *American Pikas' (Ochotona princeps) foraging response to hikers and sensitivity to heat in an alpine environment.* Arctic, Antarctic, and Alpine Research. 2015. 47(3): p. 519-527.

574. Evans, J.P., K. Boudreau, and J. Hyman, *Behavioural syndromes in urban and rural populations of song sparrows.* Ethology. 2010. 116: p. 588-595.

575. Møller, A.P., *Life history, predation and flight initiation distance in a migratory bird.* Journal of Evolutionary Biology. 2014. 27: p. 1105-1113.

576. Rodgers, J.A., Jr. and H.T. Smith, *Set-back distances to protect nesting bird colonies from human disturbance in Florida.* Conservation Biology. 1995. 9(1): p. 89-99.

577. White, H.R., *Wintering duck response to trail use at former San Francisco Bay salt ponds*. 2009. San Jose State University: San Jose, CA.

Appendix 1: Literature review on the impacts of dogs on wildlife and water quality

The impacts of dogs on wildlife and water quality: A literature review

Compiled by Lori Hennings, Metro Parks and Nature, April 2016

SUMMARY

Metro periodically reviews the science literature behind its natural resource policies to ensure policies are based on the most current science. Recently staff reviewed the scientific literature regarding the impacts of dogs on wildlife to inform Metro Regulatory Code Title 10.01, which excludes pets from most Metro properties. The only exceptions are service dogs, leashed dogs on some regional trails, Broughton Beach, boat ramps and properties managed by others through intergovernmental agreements that are integrated into larger parks where leashed dogs are allowed (e.g., Forest Park).

Any human related activity can disturb wildlife. In order to meet Metro's dual goals of protecting natural resources and providing access to nature, Metro has tried to strategically locate trails in less sensitive habitat and to ensure that human activity is as non-disruptive as possible. Part of that strategy has been to allow public access, while limiting certain activities such as bringing dogs into natural areas.

The evidence that dogs negatively impact wildlife is overwhelming. It is clear that people with dogs – on leash or off – are much more detrimental to wildlife than people without dogs. Dogs (*Canis lupus familiaris*) are considered to be a subspecies of wolves (*Canis lupus*), and wildlife perceive dogs as predators.[30] Impacts include:

1. **Physical and temporal displacement** – The presence of dogs causes wildlife to move away, temporarily or permanently reducing the amount of available habitat in which to feed, breed and rest. Animals become less active during the day to avoid dog interactions. Furthermore, the scent of dogs repels wildlife and the effects remain after the dogs are gone.
2. **Disturbance and stress response** – Animals are alarmed and cease their routine activities. This increases the amount of energy they use, while simultaneously reducing their opportunities to feed. Repeated stress causes long-term impacts on wildlife including reduced reproduction and growth, suppressed immune system and increased vulnerability to disease and parasites.
3. **Indirect and direct mortality** – Dogs transmit diseases (such as canine distemper and rabies) to and from wildlife. Loose dogs kill wildlife.
4. **Human disease and water quality impacts** - Dog waste pollutes water and transmits harmful parasites and diseases to people.

INTRODUCTION

Metro owns 17,000 acres of parks and natural areas and does not allow dogs or other pets on the vast majority of these lands. Exceptions include service animals, leashed dogs on some regional trails, Broughton Beach, boat ramps and certain properties managed by others through intergovernmental agreements that are integrated into larger parks where leashed dogs are allowed (e.g., Forest Park). The policy that prohibits visitors from bringing pets to most of Metro's managed parks and natural areas was initiated by Multnomah County in the 1980s and continued in practice after Metro assumed management of those parks in the early 1990s. After a review of the scientific literature and meaningful public discourse, Metro formally adopted the pets policy into its code in 1997 (Metro Council Regulatory code Title 10.01 adopted in Ordinance 96-659A).

To ensure this decision reflects the most up-to-date information, Metro staff examined 54 peer-reviewed scientific journal articles and several research reports relating to the impacts of dogs in natural areas, including numerous literature reviews on the impacts of various types of recreation on wildlife and habitat.(10, 28, 42,54,61,63, 65,68,71,73,77) The results of our literature review are summarized below.

PHYSICAL AND TEMPORAL DISPLACEMENT

Displacement may be the most significant impact due to the amount of habitat affected. The presence of dogs causes most wildlife to move away from an area, which temporarily or permanently reduces the amount of functionally available habitat to wildlife. The research is clear that people with dogs disturb wildlife more than humans alone.(5,10,33,38,39,41,44,61,68,69) These effects reduce a natural area's carrying capacity for wildlife, and also reduces wildlife viewing experiences for visitors.

Studies on a variety of wildlife in many countries and settings demonstrate that dogs along trails and in natural areas significantly alter wildlife behavior.(9,33,39,41,49,53,58) A 2011 literature review found negative dog effects in all 11 papers that examined such effects.(65) Studies demonstrate dog-specific impacts on reptiles,(29,31,48) shorebirds and waterfowl,(24,32,51,69) songbirds,(5,9,10) small mammals,(33,39,56) deer, elk and bighorn sheep,(4,36,38,44,49,59,63) and carnivores.(22,33,52,58)

A study in France found that two hikers disturbed an area of 3.7 hectares walking near wild sheep, whereas two hikers with dogs disturbed 7.5 hectares around the sheep.(41) In Chicago, migratory songbirds were less abundant in yards with dogs.(9) Dog walking in Australian woodlands led to a 35% reduction in bird diversity and a 41% reduction in the overall number of birds.(5) The same study showed some disturbance of birds by humans, but typically less than half that induced by dogs.

Studies in California and Colorado showed that bobcats avoided areas where dogs were present, including spatial displacement(22,33,52) and temporal displacement in which bobcats switched to night time for most activities.(22) The Colorado study also demonstrated significantly lower deer activity near trails specifically in areas that allowed dogs, and this effect extended at least 100 meters off-trail.(33) This negative effect was also true for small mammals including squirrels, rabbits, chipmunks and mice, with the impact extending at least 50 meters off-trail.

Evidence suggests that some wildlife species can habituate to certain predictable, non-threatening disturbances such as people walking on a trail in a natural area; this effectively lowers the stress response. Part of this adaptation may be due to wildlife learning what is and isn't a threat, and also avoidance of hunters.[19,55,63,70] Habituated animals still react, but amount of habitat affected is not as large.[55,56,63,70] However, dogs – especially off-leash dogs – may prevent wildlife habituation because wildlife consistently see them as predators. Dog-specific disturbance has been studied for birds, with no evidence of habituation even with leashed dogs, even where dog-walking was frequent; this effect was much weaker for people without dogs.[5]

Even the scent of dog urine or feces can trigger wildlife to avoid an area. Therefore, the impacts of dog presence can linger long after the dog is gone, even days later. One literature review found that predator odors caused escape, avoidance, freezing, and altered behavior in a large suite of wildlife species including scores of amphibian, reptile, bird, and mammal species from other studies.[30] The scent of domestic dogs has been shown to repel American beaver (*Castor Canadensis*), mountain beaver (*Aplodontia rufa*), deer (*Odocoileus* species), elk (*Cerus elaphus*), and a wide variety of wildlife native to other countries.[20,30] Mountain beaver cause economic damage to young tree stands in the Pacific Northwest, and foresters are considering using dog urine as a repellant.[20] An experimental study demonstrated that dog feces are an effective repellent for sheep, with no habituation observed over seven successive days.[1]

One Colorado study showed mixed effects of dogs on wildlife.[44] The study compared effects of pedestrians alone, pedestrians with leashed dogs and unleashed dogs alone on grassland birds. Vesper Sparrows (*Pooecetes gramineus*) and Western Meadowlarks (*Sturnella neglecta*) waited until dogs were closest to flush – that is, they fly or run away. This could be an attempt to remain undetected against the greatest threat, but could also mean that these bird species perceive humans as a greater threat than dogs. However, the same study found strong dog-specific impacts on mule deer in woodlands. A literature review found that ungulates (deer, elk and sheep) had stronger flight responses in open habitats compared to forested habitats.[63] Unlike small ground-nesting songbirds, larger animals would have no cover and could easily be seen in open habitats.

The disturbance effects of off-leash dogs are stronger than on-leash and substantially expand the amount of wildlife habitat affected,[32,59,63,69] and the unpredictability of off-leash dogs may prevent wildlife habituation in large areas of habitat.[5,10,32,61,69] The negative effects are increased even further when dogs and people venture off-trail, probably because their behavior is less predictable.[44,67] Off-leash dogs are likely to reduce the number and types of wildlife in large areas of habitat.

A Colorado study found off-leash dogs ventured up to 85 meters from the trail, although this result was from 1 square meter plots covering a very small percentage of the area.[33] Remote cameras in another study documented the same dog 1.5 miles apart in the same day.[61] In Utah, mule deer showed a 96% probability of flushing within 100 meters of recreationists located off trails; their probability of flushing did not drop to 70% until the deer were 390 meters from the recreationists.[67] A California shorebird study found that off-leash dogs were a disproportionate source of disturbance, and that plovers did not habituate to disturbance; birds were disturbed once every 27 minutes on weekends.[32]

To illustrate the potential of dogs to displace wildlife we explored two well-known local park examples that allow dogs on leash. Forest Park is one of the largest urban parks in the U.S. and was always intended to connect urban dwellers with nature; people have been walking their dogs there since before the park's 1948 dedication. Forest Park covers 5,172 acres of forest, including approximately 80 miles of trails and service. Using a very conservative 25-meter buffer around mapped trails to represent the "human + dog on leash" area of disturbance and assuming 100% compliance with leash rules, the area affected would be 1,406 acres – that's 28% of the entire park. In 651-acre Tryon Creek Natural Area, 207 acres of land (32%) is within 25 meters of a trail.

DISTURBANCE AND STRESS RESPONSE

Stress response is the functional response of an animal to an external stressor, such as seasonal changes in temperature and food availability or sudden disturbance.(3) Specific stress hormones are released to enable the animal to physically respond to the stressor. Acute stress response, when an animal reacts to an immediate situation, can benefit an animal by triggering it to respond appropriately to a threat. However, chronic stress such as repeated disturbances over time may reduce wildlife health, reproduction, growth, impair the immune system and increase vulnerability to parasites and diseases.(16,27,75)

Dogs cause wildlife to be more alert, which reduces feeding, sleeping, grooming and breeding activities and wastes vital energy stores that may mean life or death when resources are low, such as during winter or reproduction.(8,32,40,41,69) Animals release stress hormones and their heart rates elevate in response.(3,27,37,38) When stress becomes too high, animals may flush, freeze, or hide.(26,30)

Several studies document that disturbance reduces reproductive success for some wildlife species.(11,35,40,50,63) Numerous studies found that female deer and elk, and deer and elk groups with young offspring, show greater flight responses to human disturbances than other groups.(63) Stress hormones may cause male songbirds to reduce their territorial defense, females to reduce feeding of their young, nestlings to have reduced weight and poor immune systems, and adult birds to abandon nests.(11,34,35,76) A Colorado study showed that elk repeatedly approached by humans had fewer young.(50) Although research is lacking on whether dogs specifically reduce the reproductive success of wildlife, the fact that humans with dogs create much stronger disturbance effects than without dogs (5,33,38,41,44,61,68,69) implies that these stress effects would be magnified if people had dogs with them.

INDIRECT AND DIRECT MORTALITY

Dogs chase and kill many wildlife species including reptiles, small mammals, deer and foxes.(12,13,29,31,48,58,62) A Canadian study found that domestic dogs were one of the top three predators that killed white-tailed deer fawns.(4) In northern Idaho winter deer grounds, an Idaho Fish and Game conservation officer witnessed or received reports of 39 incidents of dogs chasing deer, directly resulting in the deaths of at least 12 animals.(36) A study in southern Chile revealed that domestic dogs preyed on most of the mammal species present in the study area.[60] A 2014 literature review of dogs in parks identified 19 studies that investigated the effects of dogs preying on wildlife.[73] Of these, 13 reported observing or finding strong evidence of dog predation on wildlife. The Audubon Society of Portland's Wildlife Care Center took in 1,681 known "dog-caught" injured animals from 1987 through March 2016.[2]

Dogs transmit diseases to wildlife and vice versa including rabies, Giardia, distemper and parvovirus.[18,23,66,74] A Mexico City study concluded that feral dogs continually transmitted parvovirus, toxoplasmosis and rabies to wildlife including opossums, ringtails, skunks, weasels and squirrels.[66] Large carnivores such as cougars are especially vulnerable to domestic dog diseases including canine distemper.[74]

HUMAN DISEASE AND WATER QUALITY IMPACTS

Under the Oregon Department of Environmental Quality (DEQ), Metro is a Designated Management Agency to protect water quality in compliance with the federal Clean Water Act. Limiting dog access at most natural areas is one of Metro's commitments to DEQ, because dog feces pollute water. Feces are often delivered to waterways through stormwater.[57] The average dog produces ½ to ¾ pound of fecal matter each day – a hundred dogs can produce more than 500 pounds of waste per week.[45] The DEQ identifies pet waste as a significant contributor to one of the region's most ubiquitous and serious pollutants, *E. coli* bacteria. Contact with *E. coli*-polluted water can make people sick. Because dog waste can be a relatively simple source to reduce or eliminate exposure to *E. coli*, DEQ considers reducing or eliminating dog waste an important action item in jurisdictions' clean water implementation plans for the Willamette Basin watershed.[47]

Humans can catch parasites and diseases such as hookworms (causes rash), roundworms (may cause vision loss in small children, rash, fever, or cough) and salmonella (causes gastrointestinal illness) from dog waste.[7,57] Aside from potential illnesses, dog waste can negatively affect visitors' experience in a natural area. Dog waste left on the ground is a leading complaint in Portland parks, and violators may be fined up to $150 per incident.[14]

Several examples illustrate local dog impacts. A Clean Water Services DNA study found that dog waste alone accounts for an average of 13% of fecal bacteria in stream study sites in the Tualatin River Basin.[17] Off-leash dog walking is documented to cause erosion in Portland's Marshall Park, creating sediment problems in stream water.[15] In 2014 Portland school administrators expressed concern because playgrounds had become "a minefield for animal waste" from people using school grounds as after hours, off-leash dog parks, threatening the health of school children.[21] The City of Gresham found extremely high levels of *E. coli* bacteria in water quality samples of a very specific stretch of a stream, where dog feces were found along stream banks behind several yards with dogs.[1] The city sent letters to

---

[1] Personal communication with Katie Holzer, Watershed Scientist at the City of Gresham, Oregon, 4/11/2016.

residents in the neighborhood about the incident and how to properly dispose of dog feces; the levels have not been elevated in follow-up sampling.

BELIEF, BEHAVIOR AND REALITY

People do not always take responsibility for their impacts on wildlife. Several studies demonstrate that natural area visitors, including dog owners, often don't believe they are having much of an effect on wildlife, or assign blame to different user groups rather than accepting responsibility themselves.(6,64,67,68) Some natural area visitors assume that when they see wildlife, it means that they are not disturbing the animals – or worse, that because they didn't see any wildlife, they didn't disturb any.(64)

For example, in Utah, about half of recreational visitors surveyed did not believe that recreation was having a negative impact on wildlife; of those that did, each user group blamed other groups for the strongest impacts.(67) In Austria, 56% of people surveyed at a national park agreed that wildlife is in general disturbed by human activity.(64) However, only 12% believed that they had disturbed wildlife in their visit that day, and dog-walkers ranked their activities as less disturbing than other user groups' activities. When asking different user groups to rate the impacts of overall human disturbance on wildlife, dog-walkers rated the impacts the lowest, at 2.6 out of 5 possible impact points.

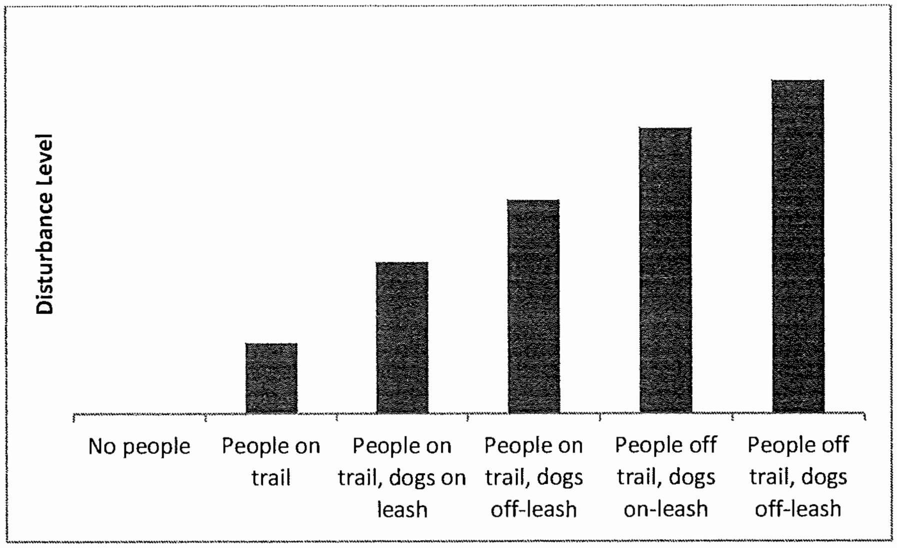
Surveys indicate that many dog owners desire fewer restrictions, while non-dog owners often feel the opposite.(72,73) However dog owners don't always follow the rules, and some dog owners allow their dogs to run free in leash-only natural areas.(32,52,73) In a Santa Barbara study, only 21% of dogs were leashed despite posted leash requirements.(32) And despite regulations and claims to the contrary, dog owners often don't pick up their dog's waste.(6,32) An English study revealed that although 95% of visitors claimed to pick up their dog's waste only 19-46% actually did so, depending on location within the park.(6)

DISCUSSION

In summary, people and their dogs disturb wildlife, and people are not always aware of or willing to acknowledge the significance of their own impacts. Wildlife perceive dogs as predators. Dogs subject wildlife to physical and temporal displacement from habitat, and dog scent repels wildlife with lingering impacts. Dogs disturb wildlife which can induce long-term stress, impact animals' immune system and reduce reproduction. Dogs spread disease to and outright kill wildlife. People with dogs are much more detrimental to wildlife than people alone; off-leash dogs are worse; and off-trail impacts are the highest (Figure 1).

Urban wildlife is subjected to many human-induced stressors including habitat loss, degraded and fragmented habitat, impacts from a variety of user groups, roads, trails, infrastructure, noise and light pollution.(26) These stressors will increase with population; from July 2014 to 2015 the Portland-Vancouver metropolitan region added 40,621 new residents.(43) Current population in the region stands at 2.4 million, with another 400,000 residents expected over the next 20 years.

Figure 1. Conceptual illustration of the relative impacts on wildlife due to people without and with dogs.



Among medium to high density cities, Portland currently ranks second in the total area covered by parks at nearly 18%, and also second in the number of park acres per resident.[25] Of 34 park providers in the Portland region, all but four allow dogs in most or all of their natural areas, typically on-leash; more than two-thirds also offer dog parks or off-leash dog areas (Table 1 at end of document).

Wildlife conservation is not the only valid reason to preserve natural areas. Park providers must weigh the trade-offs between wildlife, habitat, water quality and recreational values. But when considering different types of public access in a natural area, it is important to understand that the research is clear: people with dogs substantially increase the amount of wildlife habitat affected and are more detrimental to wildlife than people without dogs.

LITERATURE CITED

1. Arnould C, Signoret J-P. 1993. Sheep food repellents: Efficacy of various products, habituation, and social facilitation. Journal of Chemical Ecology 19:225-236.
2. Audubon Society of Portland. 2016. Wildlife Care Center intake summary, 1987-2015. Derived from Audubon Society of Portland's database by Joe Liebezeit on April 13, 2016. Audubon Society of Portland, Portland, OR.
3. Baker MR, Gobush K, Vynne C. 2013. Review of factors influencing stress hormones in fish and wildlife. Journal for Nature Conservation 21:309-318.
4. Ballard WB, Whitlaw HA, Young SJ, Jenkins RA, Forges GJ. 1999. Predation and survival of white-tailed deer fawns in northcentral New Brunswick. Journal of Wildlife Management 63:574-579.
5. Banks PB, Bryant JV. 2007. Four-legged friend or foe? Dog walking displaces native birds from natural areas. Biological Letters [online] doi:10.1098/rsbl.0374:1-4.
6. Barnard A. 2003. Getting the facts – Dog walking and visitor number surveys at Burnham Beeches and their implications for the management process. Countryside Recreation 11:16-19.
7. Becker, K. 2010. Top 5 diseases you can get from your pet. http://healthypets.mercola.com/sites/healthypets/archive/2010/08/24/top-5-diseases-you-can-get-from-your-pet.aspx. Healthy Pets with Dr. Karen Becker.
8. Bekoff M, Ickes RW. 1999. Behavioral interactions and conflict among domestic dogs, black-tailed prairie dogs, and people in Boulder, Colorado. Anthrozoos 12:105-110.
9. Belaire JA, Whelan CJ, Minor ES. 2014. Having our yards and sharing them too: The collective effects of yards on native bird species in an urban landscape. Ecological Applications 24:2132-2143.
10. Blanc R, Guillemain M, Mouronval J-B, Desmonts D, Fritz H. 2006. Effects of non-consumptive leisure disturbance to wildlife. Revue d'Ecologie (La Terre et la Vie) 61:117-133.
11. Breuner CW. 2011. Stress and reproduction in birds. In Norris DO, Lopez KH (eds): Hormones and Reproduction of Vertebrates, Volume 4 - Birds. Cambridge, MA, Academic Press, pp 129-151.
12. Butler JRA, Du Toit JT, Bingham J. 2004. Free-ranging domestic dogs (*Canis familiaris*) as predators and prey in rural Zimbabwe: Threats of competition and disease to large wild carnivores. Biological Conservation 115:369-378.
13. Campos CB, Esteves CF, Ferraz KMPMB, Crawshaw PG, Jr., Verdade LM. 2009. Diet of free-ranging cats and dogs in a suburban and rural environment, southeastern Brazil. Journal of Zoology 273:14-20.
14. City of Portland Bureau of Environmental Services and City of Portland Parks and Recreation. 2008. Dogs for the environment. Portland, OR, City of Portland.
15. City of Portland Bureau of Environmental Services. 2005. Fanno and Tryon Creeks watershed management plan. Portland, Oregon, City of Portland.
16. Cizauskas CA, Turner WC, Pittes N, Getz WM. 2015. Seasonal patterns of hormones, macroparasites, and microparasites in wild African ungulates: The interplay among stress, reproduction, and disease. PLoS ONE 10:e0120800.
17. Clean Water Services. 2005. DNA fingerprinting of bacteria sources in the Tualatin sub-basin. Hillsboro, OR, Clean Water Services.
18. Cleaveland S, Appel MGJ, Chalmers WSK, Chillingworth C, Kaare M, Dye C. 2000. Serological and demographic evidence for domestic dogs as a source of canine distemper virus infection for Serengeti wildlife. Veterinary Microbiology 72:217-227.

19. Cleveland SM, Hebblewhite M, Thompson M, Henderson R. 2012. Linking elk movement and resource selection to hunting pressure in a heterogeneous landscape. Wildlife Society Bulletin 36:658-668.
20. Epple G, Mason J, Nolte D, Campbell D. 1993. Effects of predator odors on feeding in the mountain beaver *Aplodontia rufa*. Journal of Mammalogy 74:715-722.
21. FOX 23 staff. Cracking down on doggie droppings at Portland schools. 2014. http://www.kptv.com/story/25197482/cracking-down-on-doggie-droppings-at-portland-schools. KPTV-KPDX Broadcasting Corporation.
22. George SL, Crooks KR. 2006. Recreation and large mammal activity in an urban nature reserve. Biological Conservation 133:107-117.
23. Gondim LFP, McAllister MM, Mateus-Pinilla NE, Pitt WC, Mech LD, Nelson ME. 2004. Transmission of *Neospora caninum* between wild and domestic animals. Journal of Parasitology 90:1361-1365.
24. Gray AC. 2006. Impacts of human disturbance on the behavior of sanderlings on the Georgia Coast. Thesis. Statesboro, GA, Georgia Southern University, Jack N. Averitt College of Graduate Studies.
25. Harnik P, Martin A, Barnhart K. 2015 City Park Facts. 2015. Washington, D.C., The Trust for Public Lands, Center for City Park Excellence.
26. Hennings L A, Soll J. 2010. Wildlife corridors and permeability. A literature review. Portland, OR, Metro.
27. Hing S, Narayan EJ, Thompson RCA, Godfrey SS. 2016. The relationship between physiological stress and wildlife disease: Consequences for health and conservation. Wildlife Research 43:51-60.
28. Hughes J, Macdonald DW. 2013. A review of the interactions between free-roaming domestic dogs and wildlife. Biological Conservation 157:341-351.
29. Iverson J. 1978. The impact of feral cats and dogs on populations of the West Indian rock iguana, *Cyclura carinata*. Biological Conservation 14:63-73.
30. Kats LB, Dill LM. 1998. The scent of death: Chemosensory assessment of predation risk by prey animals. EcoScience 5:361-394.
31. Koenig J, Shine R, Shea G. 2002. The dangers of life in the City: Patterns of activity, injury and mortality in suburban lizards (*Tiliqua scincoides*). Journal of Herpetology 36:62-68.
32. Lafferty KD. 2004. Disturbance to wintering western Snowy Plovers. Biological Conservation 101:315-325.
33. Lenth BE, Knight RL, Brennan ME. 2008. The effects of dogs on wildlife communities. Natural Areas Journal 28:218-227.
34. Love OP, Breuner CW, Vezina F, Williams TD. 2004. Mediation of a corticosterone-induced reproductive conflict. Hormones and Behavior 46:59-65.
35. Love OP, Chin EH, Wynne-Edwards KE, Williams TD. 2005. Stress hormones: A link between maternal condition and sex-biased reproductive investment. The American Naturalist 166:751-766.
36. Lowry DA, McArthur KL. 1978. Domestic dogs as predators on deer. Wildlife Society Bulletin 6:38-39.
37. MacArthur RA, Johnston RH, Geist V. 1979. Factors influencing heart rate in free-ranging bighorn sheep: a physiological approach to the study of wildlife harassment. Canadian Journal of Zoology 57:2010-2021.
38. MacArthur RA. 1982. Cardiac and behavioral responses of mountain sheep to human disturbance. Journal of Wildlife Management 46:351-358.
39. Mainini B, Neuhaus P, Ingold P. 1993. Behaviour of marmots *Marmota marmot* under the influence of different hiking activities. Biological Conservation 64:161-164.

40. Manor R, Saltz D. 2004. The impact of free-roaming dogs on gazelle kid / female ratio in a fragmented area. Biological Conservation 119:231-236.
41. Martinetto K, Cugnasse JM. 2001. Reaction distance in Mediterranean Mouflon (*Ovis gmelini* musimon x Ovis sp.) in the presence of hikers with a dog on the Caroux plateau (Herault, France). Revue d Ecologie-La Terre at La Vie 56:231-242.
42. Marzano M, Dandy N. 2015. Recreational use of forests and disturbance of wildlife. A literature review. Edinburgh, U.K., Forestry Commission.
43. Metro. 2015. 2014 Urban Growth Report. Portland, OR, Metro.
44. Miller SG, Knight RL, Miller CK. 2001. Wildlife responses to pedestrians and dogs. Wildlife Society Bulletin 29:124-132.
45. Natural Resources Conservation Service, Fairbanks Soil and Water Conservation District. 2005. Composting dog waste. Palmer, AK, U.S.D.A. Natural Resources Conservation Service, Fairbanks Soil and Water Conservation District.
46. Nickum, R. 2013. 17 best U.S. cities for dogs. http://blog.estately.com/2013/05/17-best-u-s-cities-for-dogs/.
47. Oregon Department of Environmental Quality. 2015. Reducing bacterial pollution in the Willamette Basin. 10-WQ-032, 1-2. Portland, OR, Oregon Department of Environmental Quality.
48. Oregon Department of Fish and Wildlife. 2015. Guidance for conserving Oregon's native turtles including best management practices. Salem, OR, Oregon Department of Fish and Wildlife.
49. Pelletier F. 2006. Effects of tourist activities on ungulate behaviour in a mountain protected area. Journal of Mountain Ecology 8:15-19.
50. Phillips GE, Alldredge AW. 2000. Reproductive success of elk following disturbance by humans during calving season. Journal of Wildlife Management 64:521-530.
51. Randler R. 2006. Disturbances by dog barking increases vigilance in coots *Fulica atra*. European Journal of Wildlife and Research 52:265-270.
52. Reed SE, Merenlender AM. 2011. Effects of management of domestic dogs and recreation on carnivores in protected areas in Northern California. Conservation Biology 25:504-513.
53. Reed SE, Merenlender AM. 2008. Quiet, nonconsumptive recreation reduces protected area effectiveness. Conservation Letters 1:146-154.
54. Reed SE, Larson CL, Crooks KR, Merenlender AM. 2014. Wildlife response to human recreation on NCCP reserves in San Diego County. Report number P1182112. Bozeman, MT, Wildlife Conservation Society.
55. Schultz RD, Bailey JA. 1978. Responses of national park elk to human activity. Journal of Wildlife Management 42:91-100.
56. Shannon G, Cordes LS, Hardy AR, Angeloni LM, Crooks KR. 2014. Behavioral responses associated with a human-mediated predator shelter. PLoS ONE 9:e94630.
57. Shueler T. 2000. Microbes and urban watersheds: Concentrations, sources, & pathways. Watershed Protection Techniques 3:1-12.
58. Silva-Rodriguez EA, Ortega-Solis GR, Jimenez JE. 2010. Conservation and ecological implications of the use of space by chilla foxes and free-ranging dogs in a human-dominated landscape in southern Chile. Austral Ecology 35:765-777.
59. Silva-Rodriguez EA, Sieving KE. 2012. Domestic dogs shape the landscape-scale distribution of a threatened forest ungulate. Biological Conservation 150:103-110.
60. Silva-Rodriguez EA, Sieving KE. 2011. Influence of care of domestic carnivores on their predation on vertebrates. Conservation Biology 25:808-815.
61. Sime CA. 1999. Domestic dogs in wildlife habitats: Effects of recreation on Rocky Mountain wildlife. A review for Montana. Montana Chapter of The Wildlife Society.

62. Spinks PQ, Pauly GB, Crayon JC, Shaffer HB. 2003. Survival of the western pond turtle (*Emys marmorata*) in an urban California environment. Biological Conservation 113:257-267.
63. Stankowich T. 2008. Ungulate flight response to human disturbance: A review and meta-analysis. Biological Conservation 141:2159-2173.
64. Sterl P, Brandenburg C, Arnberger A. 2008. Visitors' awareness and assessment of recreational disturbance of wildlife in the Donau-Auen National Park. Journal for Nature Conservation 16:135-145.
65. Steven R, Pickering C, Castley JG. 2011. A review of the impacts of nature based recreation on birds. Journal of Environmental Management 92:2287-2294.
66. Suzan G, Ceballos G. 2005. The role of feral mammals on wildlife infectious disease prevalence in two nature reserves within Mexico City limits. Journal of Zoo and Wildlife Medicine 36:479-484.
67. Taylor AR, Knight RL. 2003. Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13:951-963.
68. Taylor K, Taylor R, Anderson P, Longden K, Fisher P. 2005. Dogs, access and nature conservation. English Nature Research Report 649, 1-2.
69. Thomas K, Kvitek RG, Bretz C. 2003. Effects of human activity on the foraging behavior of sanderlings *Calidris alba*. Biological Conservation 109:67-71.
70. Thompson MJ, Henderson RE. 1998. Elk habituation as a credibility challenge for wildlife professionals. Wildlife Society Bulletin 26:477-483.
71. UK CEED. 2000. A review of the effects of recreational interactions within UK European marine sites. 1-264. Countryside Council for Wales (UK Marine SACs Project).
72. Webley P, Siviter C. 2006. Why do some owners allow their dogs to foul the pavement? The social psychology of a minor rule infraction. Journal of Applied Social Psychology 30:1371-1380.
73. Weston MA, Fitzsimons JA, Wescott G, Miller KK, Ekanayake KB, Schneider T. 2014. Bark in the park: A review of domestic dogs in parks. Environmental Management 54:373-382.
74. Whiteman CW, Matushima ER, Cavalcanti-Confalonieri UE, Palha MDDC, Da Silva ADSL, Monteiro VC. 2009. Human and domestic animal populations as a potential threat to wild carnivore conservation in a fragmented landscape from the Eastern Brazilian Amazon. Biological Conservation 138:290-296.
75. Wingfield JC, Hunt K, Breuner C, Dunlap K, Fowler GS, Freed L, Lepson J. 1997. Environmental stress, field endocrinology, and conservation biology; in Clemons JR, Buchholz R (eds). In: Behavioral Approaches to Conservation in the Wild. London, England, Cambridge University Press, pp 95-131.
76. Wingfield JC, Silverin B. 1986. Effects of corticosterone on territorial behavior of free-living male song sparrows *Melospiza melodia*. Hormones and Behavior 20:405-417.
77. Young JK, Olson KA, Reading RP, Amgalanbaatar S, Berger J. 2011. Is Wildlife Going to the Dogs? Impacts of Feral and Free-Roaming Dogs on Wildlife Populations. BioScience 61:125-132.

Table 1. Park providers' dog policies in the greater Portland, Oregon metropolitan area.

Parks provider	No dogs allowed	Some parks allow dogs	Dogs allowed	On-leash	Free to roam	Off-leash areas or dog park
Audubon Society of Portland	X					
City of Beaverton		X[2]		X		X
City of Cornelius			X	X[3]		
City of Durham			X	X		X
City of Fairview		X[4]		X		
City of Forest Grove			X	X		X
City of Gladstone			X	X		X
City of Gresham			X	X		X
City of Happy Valley			X	X[5]		X
City of Hillsboro			X	X		X
City of Lake Oswego			X	X		X
City of Milwaukie[6]			X	X		X
City of Oregon City			X	X		X[7]
City of Portland		X		X[8]		X[9]
City of Sherwood			X	X		X
City of Tigard			X	X		X
City of Troutdale		X[10]		X		X[11]
City of Tualatin			X	X		X
City of West Linn			X	X		X[12]
City of Wilsonville			X	X		X
City of Wood Village			X	X		
Clackamas County			X	X		X
Clean Water Services (Fernhill Wetlands)	X					

[2] All parks except fountain provided by Tualatin Hills Parks & Recreation District.
[3] Considering off-leash dog area at Water Park.
[4] Dogs on leash allowed at all parks except Salish Ponds (no dogs).
[5] Dogs on leash except prohibited in playgrounds.
[6] All city parks are operated by North Clackamas Parks and Recreation Department.
[7] The City of Oregon City is currently testing off-leash areas in three parks.
[8] Dogs on-leash except prohibited at Foster Floodplain Natural Area, Tanner Springs Park, Whitaker Ponds Nature Park, Riverview Natural Area, and the amphitheater at Mt Tabor Park.
[9] 33 off-leash dog areas.[46]
[10] Most parks: dogs not allowed. Exception: Sunrise Park and large Beaver Creek Greenway, leash only. Considering two more on-leash dogs allowed parks.
[11] Plans for an off-leash area at Sunrise Park.
[12] One off-leash dog area: field near parking lot at Mary S. Young Park. Off-leash dogs were identified as an issue by parks board.

Parks provider	No dogs allowed	Some parks allow dogs	Dogs allowed	On-leash	Free to roam	Off-leash areas or dog park
Federal / State (Sandy River Natural Area)			X[13]	X	X	X
Metro		X[14]				
N. Clackamas Parks & Recreation			X			X
OR Department of Fish and Wildlife			X	X[15]	X	X
OR Parks & Recreation Department			X	X		X
Port of Portland		X[16]		X		
The Nature Conservancy	X					
The Wetlands Conservancy			X[17]	X	X	
Tualatin Hills Park and Rec. District		X[18]		X		X
U.S. Fish & Wildlife Service	X					
U.S. Forest Service[19]			X	X	X	X

[13] Leashes required only on/near Confluence Trail and in parking area. Leash-off everywhere else. Region's largest off-leash area, and heavily used.
[14] Metro does not allow dogs except for service dogs, leashed dogs on regional trails, Broughton Beach, boat ramps and properties managed by others through intergovernmental agreements that are integrated into larger parks where leashed dogs are allowed (e.g., Forest Park).
[15] All dogs must be on leash, except while hunting during seasons authorized on Sauvie Island Wildlife Area, or pursuant to a valid "Competitive Hunting Dog Trial Permit" or "Sauvie Island Wildlife Area Individual Dog Training Permit."
[16] Includes Vanport Wetlands and mitigation sites. No dogs allowed except Government Island State Recreation Area (leased to Oregon Parks Department).
[17] No formal policy.
[18] Dogs allowed on-leash except Tualatin Hills Nature Park and Cooper Mountain Nature Park.
[19] Refers specifically to the Sandy River Delta, owned and administered by the National Forest Service, Columbia River Gorge National Scenic Area.

EN 1.16

MEMO

To: Olena Turula, Parks Planner, Parks & Nature Department, Metro
Rodney Wojtanik, Principal Parks Designer, Parks & Nature Department, Metro

From: Chris Bernhardt, Director of Consulting Services, IMBA

Date: 14 November 2015

Re: North Tualatin Mountains (Burlington site) Design Review

On 28 October 2015, staff from IMBA's Trail Solutions program visited the Burlington site for the purpose of reviewing the proposed trail design. The comments herein are derived from that site visit, a review of the plans, and conversations with the above-noted Metro staff.

1) Because of the lack of mountain bicycling trails in the Portland metropolitan area it is predicted that the site will see heavy year-round use by cyclists. Conversely, as hikers have a wide variety of opportunities, including varying degrees of difficulty and distance, it is predicted that most pedestrian use will come from neighbors.
2) The trail design should generally conform to the sustainable trail development guidelines developed by the International Mountain Bicycling Association. In particular, trails should follow a rolling contour alignment, be aligned to conform to the Half Rule, be excavated to mineral soil, contain clear sightlines, and have regular and frequent grade reversals.
3) Several drainages cut steeply through the site. Any bridges should be designed by a qualified engineering professional with the consultation of a professional trail builder/designer.
4) The main road is too steep to be reasonably used as an enjoyable part of the trail experience. Sustained grades in excess of 10% combined with a loose surface will make both ascending and descending alternately discouraging and terrifying for cyclists. Sustainable singletrack should be used to get users around the site.
5) Single-direction descending trails should be provided for cyclists. These trails provide a unique, high-quality experience, one that is currently not available in the metropolitan area. They are also a good risk-management strategy as they provide an outlet for a certain style of mountain bicycling in a manner that can be controlled.
6) Easier trails, particularly for children, could be placed in the lower area below the trailhead. This area contains generally flatter terrain, making it easier to construct wider trails for less-experience cyclists.

7) A return-leg trail should be located down along the lower portion of the property. This will allow riders to climb to the top from the trailhead, descend to the bottom, and then return to the trailhead. This trail can tie into, and allow progression from, the aforementioned beginner trails.

8) Hiking trails should be geared towards neighborhood use given the considerable amount of hiking-only trails in nearby open spaces.

9) It should be a priority to develop a connector route, preferably singletrack, from Newberry Road to the site. This will allow riders to avoid Highway 30 to the greatest extent possible thus encouraging more people to ride, not drive, to the site. This will also begin to approximate the longer-distance trail experiences that are currently available to hikers and equestrians.

10) The trail design should support the possible development of trail access from Highway 30 into southeast corner of site. This will improve access for people arriving on bicycles via Highway 30 and eliminate a steep and narrow climb up McNamee Road.

11) As parking may be constrained Metro is encouraged to partner with the Northwest Trails Alliance (NWTA) to consider innovative routes, particularly through Forest Park, that would allow people to "ride to their ride".

12) Given the predicted year-round use, wet conditions, and generally steep sideslopes and unstable soils it is recommended that much of the trail tread will need to be amended with crushed rock (1/2" minus). The rock should be added during construction and while the soil is moist so that it can be compacted into the tread, not just placed on top.

13) Given the steep sideslopes on much of the site the trails will likely approximate narrow, backcountry singletrack. Active tread width is expected to be 24" – 30" in most areas; constructed tread width will be slightly wider to provide a durable, sustainable surface. Tread widths for most trails should increase with sideslope grade (e.g., the steeper the sideslope, the wider the trail). Dual-direction trails on steeper sideslopes should have occasional "passing zones": temporarily wider portions of the tread that will allow users to pass with increased ease.

14) Given the difficult nature of trail construction in this venue (mixed canopy, steep sideslopes, frequent drainages, projected heavy use, wet conditions) volunteers should be discouraged from designing and constructing trails. A professional trail designer/builder should be retained to ensure the highest quality trail. Construction is estimated to cost $10/LF.

15) Recommended next steps include a refinement of the trail layout per the above comments. During this process areas with distinct canopy characteristics (older and/or coniferous) should be identified as preferred locations for trails.

PORTLAND PARKS & RECREATION

Healthy Parks, Healthy Portland

Trail Design Guidelines

for Portland's Park System

May 2009

Exhibit 17

Trail Design Guidelines
Regional Trails, Natural Areas and Developed Parks
April 2009

PP&R Trail Guidelines Coordination Team

Robin Grimwade, Manager, Corporate Strategy, Marketing & Business Development
Brett Horner, Strategic Projects Manager
Gregg S. Everhart, Senior Planner/Project Manager

Trail Design Guidelines **Contributors and Reviewers**

Bruce Barbarasch, THPRD
Lynn Barlow
Susan Barthel, BES
Janet Bebb, Metro
April Bertelsen, PBOT
Richard Bosch
Will Brozy
Shannon Buono, BOP
Tonia Burns, NCPRD
Mary Anne Cassin, Metro
Ric Catron, Gresham
Jonathan David, Gresham
Jennifer Devlin, BES
Sue Donaldson
Bob Downing
Kim Freeman, BDS
Patty Freeman
Peggy Glascock
Lisa Goorjian, Vancouver/ Clark County Parks
Nancy Gronowski
Greg Hawley
Gary Hill
Brett Horner
P.J. McGuire
Michelle Healy, NCPRD
Dawn Hottenroth, BES
Mart Hughes
Marie Johnson, BES
Deb Lev
George Lozovoy
Fred Nilsen
Claire Puchy, BES
Mike Reed, BES
Emily Roth
Alex Salazar
Jim Sjulin
Rod Wojtanik, Metro

Production/Editing
Joan Hallquist
Colleen Keyes

Portland Parks & Recreation
1120 SW Fifth Avenue, Suite 1302
Portland, Oregon 97204
(503) 823-PLAY
www.PortlandParks.org

Commissioner Nick Fish
Director Zari Santner

Contents

Introduction 1
Trails in *Parks 2020 Vision* Plan 1
Need for Trail Standards 2
Trail Design Guidelines 2
Trail Design Philosophy 4
Accessibility 5
Street Rights-of-Way 7
Trail Type Matrix Introduction 7
Accessibility Table 8
Trail Design, Construction, and Maintenance 9
Trail Type Matrix 11
Trail Type A - Hiking (high challenge) 13
Trail Type B - Hiking (moderate challenge) 15
Trail Type C - Hiking (accessible) 17
Trail Type D - Walking 18
Trail Type E - Exercise / Fitness (track) 21
Trail Type F - Biking 23
Trail Type G - Mountain Biking 25
Trail Type H - Cyclo Cross 27
Trail Type I - Equestrian 29
Trail Type J - Hiking and Mountain Biking 31
Trail Type K - Hiking and Equestrian 33
Trail Type L - Walking and Biking 35
Trail Type M - Walking, Biking, and Equestrian 37
Trail Type N - Fire and Maintenance 39

Trail Detail 01 - Cribbed Steps 41
Trail Detail 02 - Timber Steps 43
Trail Detail 03 - Boardwalk 45
Trail Detail 04 - Wood Bridge 47
Trail Detail 05 - Wood Bridge with Railing 49
Trail Detail 06 - Erosion Control at Bridge 51
Trail Detail 07 - Trail with Swale and Culvert 53
Trail Detail 08 - Causeway 55
Trail Detail 09 - Trail with Infiltration Trench 57
Trail Detail 10 - Trail on Levee 59
Trail Detail 11 - Soft-Surface Switchback on Levee 61
Trail Detail 12 - Porous Asphalt Trail 63
Trail Detail 13 - Signs 65
Trail Detail 14 - Alignment Tread Crests 67
Trail Detail 15 - Alignment Tread Dips 69
Trail Detail 16 - Removable Bollard 71
Trail Detail 17 - Cribbed Retaining Wall 73

Appendix A - References 75

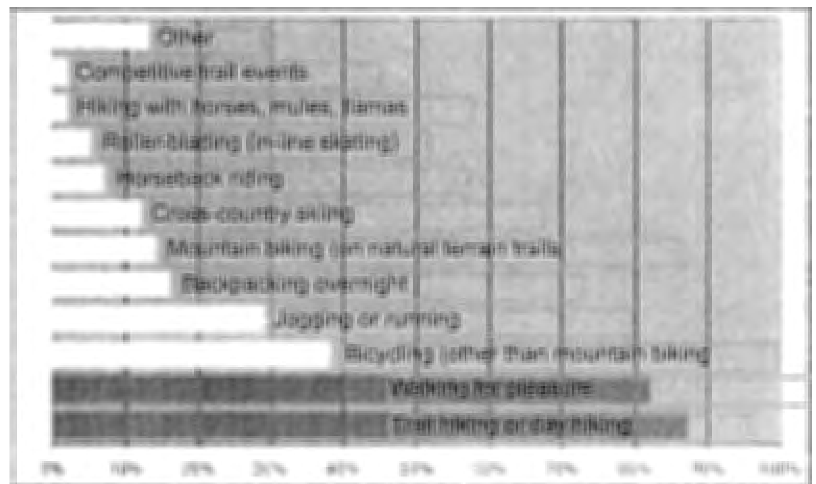
Introduction

Trails are an integral part of our park and recreation system. They are used by people of all ages and abilities to exercise, relax, socialize, view wildlife, and travel to destinations such as school and work. Portland Parks & Recreation (PP&R) is committed to providing trails throughout Portland in response to local, state, and national studies indicating high demand for walking and biking. PP&R interprets the term 'trail' broadly to include sidewalks around parks, park pathways, sidewalks, and enhanced paths on green streets, as well as unpaved pathways in natural resource areas and regional multi-modal trails.

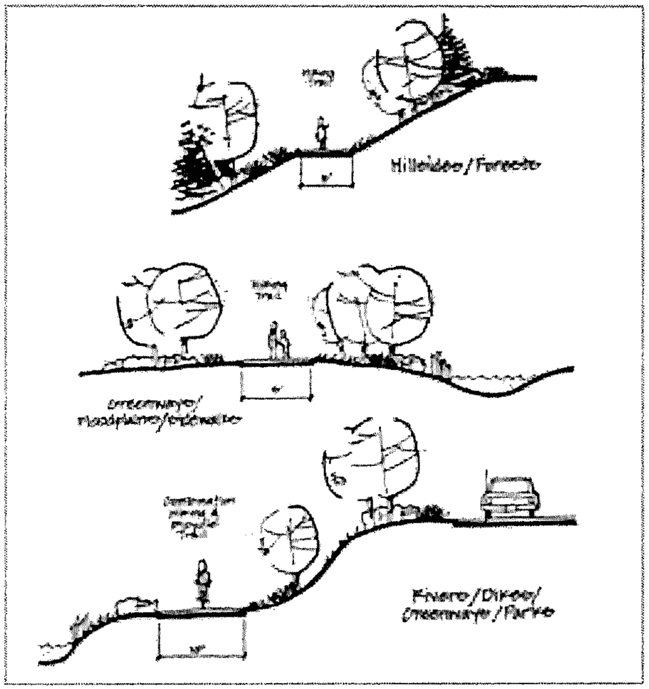
Trails in *Parks 2020 Vision* Plan

One of the goals of *Parks 2020 Vision* is to "create an interconnected regional and local system of paths and walks to make Portland 'The Walking City of the West.'" This would provide safe and convenient access between parks, natural areas, and recreation facilities and connect them with residential areas, civic institutions, and businesses. The *Vision* identified trails as PP&R's most heavily used resource. Completing specific regional trails, and adding more miles of soft-surface trails and other green connectors were key objectives.

The trails section in the appendix of *Parks 2020 Vision* noted that trails are places and connectors that traverse a variety of ownerships and environments, from remote forests to the Central City. It recognized multiple values: recreational, transportation, aesthetic, scenic, environmental, and economic. However, the trail system was acknowledged to have many gaps and lack of connectivity that limited its usability. Insufficient capacity, where older trail segments are too narrow for current, not to mention future, use was also identified as a problem.



Oregon Trails Usage
Oregon Statewide Comprehensive Outdoor Recreation Plan 2003-2007



Minimum Trail Widths in 1983 *40-Mile Loop Master Plan*

Need for Trail Standards

The *Parks 2020 Vision* plan identified "no trail standards" as an issue. It noted that trail standards are lacking for the many trail types, sizes, and materials needed in different settings. Impacts to sensitive habitat and stormwater quality and quantity must be considered. The specific recommendation "Develop trail standards for the different conditions and needs" recommended that PP&R:

- Develop standards for the different trail types in the 40-Mile Loop system and for non-Loop sites.
- Include other bureaus, agencies, and adjoining jurisdictions in developing trail standards. Encourage other agencies and jurisdictions to adopt similar standards and trail alignments.
- Rebuild trail sections to meet the revised standards as funding is available.
- Develop and implement a consistent, regional trail signage program to enable users to better utilize the system.

Trail Design Guidelines

Since the *Vision* was published in 2001, more trail segments have been constructed in a variety of settings for different users. The existing system and its gaps have been documented in PP&R's geographic information system (GIS), revealing a diverse range of widths and trail materials. Although some of the older trails are clearly 'substandard,' there are so many special settings and constraints that setting standards is too limiting. Instead, these 'design guidelines' establish a range of materials and widths so that trail designers can design trails more flexibly. This will guide PP&R staff in the design of trails and pathways in the entire parks system: regional trails, developed parks, and natural areas. It will also guide consultants, developers, and volunteer groups that build trails, whether designing a narrow footpath through a woodland, an exercise circuit in a lawn area or a waterfront promenade. Although not intended as a maintenance guide, it should also be useful for volunteer trail building projects.

Design Philosophy

Siting and design of every trail requires consideration of four main goals: safety, connectivity, response to location, and diversity of users.

1. **Safety** is the top concern. Ideally, cars and trucks alongside or crossing a trail should be minimized. If the trail parallels a roadway, separate bicycle and pedestrian space is preferred unless there are few vehicles and low travel speed. Higher speed and traffic volumes decrease users' perception of safety and tend to discourage less experienced users. Although parked cars sometimes slow traffic by making the street seem more narrow, there is danger of opening doors into bicyclists. Visibility is particularly important at intersections with roads and in natural areas, but design principles for crime prevention should be applied to all projects. Different trail users also travel at differing speeds, which can cause conflicts and accidents. In some sites, trail markers designate trails for use by hikers, bikers and/or equestrians; in others we urge everyone to 'share the path.' In corridors of high density (such as the Willamette Greenway in South Waterfront) a biking trail can be used in combination with a walking trail to form a dual trail to separate slower speed "feet" from higher speed "wheels." Additional education and enforcement are needed.

2. **Connectivity** is important because trail length makes longer trips possible, increasing usefulness for commuting and exercise. Trails also connect gaps in the on-street pedestrian network. Trails should have multiple access points from the surrounding system of sidewalks, other

FOUR MAIN GOALS FOR TRAIL DESIGN

1. SAFETY
   - 1st Choice - Separate trail from vehicles
   - 2nd Choice - Minimize vehicle crossings of trail
   - 3rd Choice - If trail co-exists with road then choose route with lower speed and volume
   - Design for visibility and crime prevention in all settings

2. CONNECTIVITY
   - Connected lengths of trails make longer trips possible, increasing usefulness for commuting and exercise
   - Provide trail access points and connect trails to bicycle and pedestrian network in City rights-of-way

3. CONTEXT
   - Trail changes to meet opportunities and constraints of its surroundings

4. DIVERSITY
   - Provide range of trails to meet needs of all ages and abilities so everyone benefits, including those with disabilities

Vera Katz Eastbank Esplanade - stairs near Riverwalk on Steel Bridge

Vera Katz Eastbank Esplanade - accessible ramp near Riverwalk on Steel Bridge

Marine Drive Trail - rollerblader

Springwater Corridor - scooters

Springwater Corridor - Hood-to-Coast runners

Vera Katz Eastbank Esplanade - near plaza just north of Firehouse

trails, and bikeways to make short trips and loops possible. However, these access points will be less frequent than in a typical street network in order to make fewer interruptions to flow of users along the trail.

3. **Response to location** means that trail design responds to opportunities, constraints, and character of the surroundings. In some locations, impacts to environmentally sensitive areas and wildlife can be avoided or minimized by relocating the trail or adjusting trail size and material to limit types of users. However, providing periodic views of water may avoid damaging user-made trails to reach the water. Metro's *Green Trails: Guidelines for environmentally friendly trails* discusses practices for minimizing natural resource impacts. Trail width, slope, and material of trails may also change to fit neighboring development, vegetation, drainage needs, vehicle circulation patterns, and so forth. Impacts to private property should be avoided or minimized. Although trails may be less consistent over their length, the adaptations enliven the overall trail experience and fit different neighborhoods and settings.

4. **Diversity of users** refers to activity, age, and ability. Although the overall recreational trail system includes challenging segments for the most fit and expert, the general aim is to provide challenge levels suitable for all ages and abilities. Trails provide potential health benefits for all, including those with disabilities and a growing number of seniors. Where possible, trail design should accommodate diverse modes and mobility devices – walkers and runners, bicyclists and rollerbladers, wheelchairs and baby strollers. However, in many locations, not all users may be accommodated. Although trail facilities can often be successfully shared, it is also important to have some locations where hikers need not fear being overtaken by mountain bikes, places where mountain bikers know there aren't supposed to be hikers, and trails where horses won't need to shy away from cyclists.

Accessibility

The Americans with Disabilities Act (ADA) is a comprehensive civil rights law which prohibits discrimination on the basis of disability. It requires, among other things, that newly constructed and altered "places of public accommodation" be readily accessible to and usable by individuals with disabilities. Accessibility guidelines are developed by the Architectural and Transportation Barriers Compliance Board (Access Board). Most accessibility standards (ADAAG, Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities) are not readily applicable to the natural environment. The most pertinent to trails is the *Recommendations for Accessibility Guidelines: Outdoor Developed Areas Final Report*. The United States Department of Agriculture Forest Service (USFS) has developed Forest Service Trail Accessibility Guidelines (FSTG) based on the guidelines on outdoor developed areas. Although the USFS trail design parameters do not apply to the range of trails provided by PP&R, the FSTG are helpful because they "provide guidance for maximizing accessibility of trails... while recognizing and protecting the unique characteristics of their natural setting."

Although there is a substantial amount of technical information regarding accessibility and trails, PP&R seeks to provide a range of challenge levels for outdoor facilities such as trails. These guidelines encourage design for increased accessibility but do not require unreasonable efforts to provide an accessible route in hiking trails in steep terrain without added surfacing. Where terrain allows accessible slopes, a range of surfacing choices from pavement to fine gravel to engineered wood fiber can create levels of accessibility that respond to the character and desired use of the trail. In an early review of some standard construction details for the *Trail Design Guidelines* by

Kelley Point Park - some of the 40-Mile Loop Trail at the confluence of the Willamette and Columbia Rivers was once inaccessible gravel road

Kelley Point Park - accessible asphalt replaces gravel and sand

Forest Park Ridge Trail

Oaks Bottom Connector - existing dirt road was paved, some slopes greater than 5%

Forest Park - accessible trail along Balch Creek in Lower Macleay

the Portland Citizens' Disability Advisory Committee (PCDAC), the committee noted that trail users, including the disabled community, value diversity of experience.

The PCDAC agreed that there should be varying levels of physical challenge. Everyone would be able to use the level esplanade next to a major river; fewer could make the steep scramble up a 'wilderness' site. Steep hillsides in the west hills and east buttes are particularly challenging because the long lengths of trail (at 5%, 1:20 accessible slope) and multiple switchbacks may destroy the natural character of the site. The most challenging constraints to providing accessibility are:

- Steep slopes and landslide potential
- Sensitive vegetation or wildlife species
- Wetlands and waterways
- Desired character of minimal development

Public process and PCDAC review help determine what type and amount of use is likely and appropriate to each site. Most trails are fully accessible, although there is little signage indicating accessibility status. Examples of fully accessible trails include Springwater Corridor, Kelley Point Park, and Terwilliger Parkway. Some sites have higher challenge or no accessible features, such as Forest Park Ridge Trail, Woods Memorial Natural Area, Oaks Bottom Connector, and OHSU Trails #13 (Connor Trail) and #24 (proposed). In some locations PP&R made more site impacts by providing accessible features at one site so that other similar sites could avoid those impacts. Examples include the Lower Macleay paved accessible path along lower portion of Balch Creek, Stephens Creek Nature Park's boardwalk across part of the creek that also serves as a detention basin, and Johnson Creek Park's porous pavement to confluence with Crystal Springs Creek. Other creeks and other portions of Balch, Stephens, and Johnson Creeks are not fully accessible. Unfortunately, nearly every trail in the PP&R system needs improvements in edge protection, wayfinding, and accessible signage.

The Technical Provisions for Access Routes, Outdoor Access Routes, and Accessible Trails table (page 8) gives the technical details of ADAAG and the Outdoor Developed Areas guidelines. 'Access routes' (ADAAG) relate to the built environment where all routes must meet accessibility requirements. 'Outdoor access routes' are in outdoor environments, e.g., parks where reasonable access is required, such as between a parking lot and a playground. 'Accessible trails' are those trails that meet the USFS guidelines. All refer to newly constructed or altered trails, not retroactively to existing trails. 'Alteration' differs from 'maintenance' by changing the trail from its original condition. Exceptions to the technical provisions can be made in certain situations.

Technical provisions for outdoor access routes and accessible trails may not apply if it cannot be provided because compliance would:

- cause substantial harm to cultural, historic, religious or significant natural features or characteristics;
- substantially alter the nature of the setting or purpose of the facility;
- require construction methods or materials that are prohibited by Federal, state or local regulations or statutes; or
- be infeasible due to terrain or prevailing construction practices

Street Rights-of-Way

The Portland Bureau of Transportation (PBOT) manages the public street right-of-way in Portland. Many park sidewalks and/or edges of parks and natural areas are within the right-of-way; PBOT should be consulted regarding design standards and permits for development in rights-of-way adjacent to PP&R property. The most current guidance regarding accessibility that pertains to public right-of-way (*Revised DRAFT Public Rights-of-Way Accessibility Guidelines* (*PROWAG*)) permits the grade of a pedestrian access route within a sidewalk to be as steep as the grade of the adjoining roadway. In some areas of steep terrain, this allows 'accessible' sidewalks to be steeper than accessible trails.

Trail Type Matrix Introduction

PP&R trail types (page 11 and 12) are based on trail user activity. The first section outlines trail types with single users. The second section outlines trail types shared by different types of trail users. Some basic design features (surface, width, longitudinal and cross-slope, accessibility) and notes are included. Individual sheets on each trail type provide a definition, describe users and materials, and show photograph(s) and typical detail. Some trail types can be built of several materials so other details are also referenced. Ranges of width or longitudinal and cross-slope allow flexibility to respond to site conditions and expected intensity of use.

Trail Design, Construction, and Maintenance

Descriptions, charts, photographs, and construction details cannot convey the complete reality of selecting, designing, and building a trail that is appropriate for a site and its intended users. Trained designers and experience are essential for success. The following information

TECHNICAL PROVISION FOR ACCESS ROUTES, OUTDOOR ACCESS ROUTES AND ACCESSIBLE TRAILS			
	Access Route (ADAAG)	**Outdoor Access Route**	**Accessible Trail**
Surface	stable, firm, and slip resistant	firm and stable	firm and stable (exception:*)
Maximum Running Slope	1:12 [8.33%]	1: 20 [5%] (for any distance) 1: 12 [8.33%] (for max. 50 ft) 1:10 [10%] (for max. 30 ft)	1: 20 [5%] (for any distance) 1: 12 [8.33] (for max. 50 ft) 1:10 [10%] (for max. 30 ft) 1: 8 [12.5%] (for max. 10 ft) (*Exception: 1: 7 [14.3%] for 5 ft maximum for open drainage structures or when * applies*)
Maximum Cross Slope	1:50 [2%]	1: 33 [3.03%] (Exception: 1: 20 [5%] for drainage purposes	1: 20 [5%] (Exception: 1: 10 [10%] at the bottom of an open drain where clear tread width is a minimum of 42 inches
Minimum Clear Tread Width	36 inches 32 inches for no more than 24 inches	36 inches (*Exception: 32 inches when * applies*)	36 inches (*Exception: 32 inches when * applies*)
Tread Obstacles	Changes in level: 1/4 inch with no beveled edge, 1/4 - 1/2 inch must have a beveled edge with a max slope of 1: 2 [50%] (over 1/2 inch = ramp)	1 inch high maximum *Exception: 2 inches high maximum where beveled with a slope no greater than 1: 2 [50%] and where * applies.*	2 inches high maximum Exception: 3 inches maximum where running and cross slopes are 1: 20 [5%] or less. (*Exception: **)
Passing Space	Every 200 feet where clear tread width is less than 60 inches, a minimum 60 x 60 inch space, or a T-shaped intersection of two walks or coridors with arms and stem extending minimum of 48 inches.	Every 200 feet where clear tread width is less than 60 inches, a minimum 60 x 60 inch space, or a T-shaped intersection of two walks or coridors with arms and stem extending minimum of 48 inches. (*Exception: Every 300 feet where * applies.*)	Every 1000 feet where clear tread width is less than 60 inches, a minimum 60 x 60 inch space, or a T-shaped intersection of two walks or coridors with arms and stem extending minimum of 48 inches. (*Exception: **)
Resting Intervals	Landings: 60 inch min length, minimum width as wide as the ramp run leading to it, if change in direction occcurs, must have 60 x 60 inch space	60 inches minimum length, width at least as wide as the widest portion of the trail segment leading to the resting interval and a max slope of 1: 33 [3.03%] (Exception: A max slope of 1: 20 [5%] is allowed for drainage purpose.)	60 inches minimum length, width at least as wide as the widest portion of the trail segment leading to the resting interval and a max slope of 1: 20 [5%] (*Exception: **)

* *The provision may not apply if it cannot be provided because compliance would cause substantial harm to cultural, historic, religious, or significant natural features or characteristics; substantially alter the nature of the setting or purpose of the facility; require construction methods or materials that are prohibited by Federal, state, or local regulations or statues; or be infeasible due to terrain or the prevailing construction practices.*

Based on table in *Trail Planning, Design, and Development Guidelines: Shared Use Paved Trails, Natural Surface Trails, Winter-Use Trails, Bikeways* by Minnesota Department of Natural Resources Trails and Waterways, 2006 addresses some practical matters involved in design, construction, and maintenance of trails.

Permits

Most trail projects will need land use review and many will require building permits. Projects in environmental zones, crossing drainageways, and along creeks and rivers will all be more complex. Staff at the Bureau of Development Services and appropriate state and federal agencies should be contacted early in the planning process. Adequate funds should be budgeted for application and permit fees.

Erosion Control

Specific erosion and sediment control solutions have not been added to these details. This should be done when a construction management plan is developed and makes site specific edits to trail cross-sections and/or adds specific erosion control details to plan drawings. Additional information is included in the project specifications.

Grading and Drainage

Ranges of longitudinal slope (along length of trail) and cross-slope are provided for different trail types. However, consideration of soil, surface water movement, and site hydrology will help determine appropriate trail alignment with crowned or side slope, swales, and/or rolling grade. Water is a valuable asset in the landscape but needs careful management to not cause problems on trails.

Vegetation Clearing Distances

The figures for vertical and horizontal clearance shown in the Trail Types and illustrated in Trail Details apply to woody plants. The actual cleared distance may be wider during construction due to cutting and filling on slopes. Generally, native herbaceous vegetation will repopulate sloped areas in natural areas not worn by passage of feet or wheels. Staff and/or volunteers should monitor for and manage any non-native invasive plants that appear. Trails in many developed parks will be bounded by mowed grass. When trails pass through landscapes with groundcover, shrubs, and trees, they should be sited to provide adequate visibility and enough space for plant growth.

Vehicle Usage

PP&R staff use a wide range of vehicles in park and natural area sites. In some locations, utility and security companies, fire, and police may also access trails. Since driving or parking on soil or turf compacts it, trail widths should be adequate for the largest vehicle anticipated. Where regular park maintenance is provided, additional width or turnouts are needed for trail users to pass a parked vehicle. Designers must also provide adequate turning radius and pavement strength. Bureau of Development Services uses load standard of 100 psi (pounds per square inch) while the American Association of State Highway and Transportation Officials (AASHTO) uses 60 psi. Avoid siting benches, tables, lights, drinking fountains, and similar site furniture on the inside of curves where vehicles are more likely to damage them. PP&R electricians use a large boom truck to access park lights or buildings for maintenance and repairs. Maintenance staff use large dump trucks. Urban Forestry crews provide both regular and emergency maintenance with boom trucks.

Wood Preservatives

The question of using native, rot-resistant woods versus a variety of wood preservatives and/or plastic lumber arouses fierce debates.

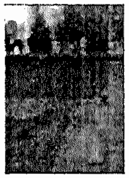
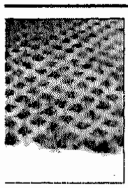
PP&R has included its most current details, but note the materials and preservatives are subject to change. Research continues on the effects of various substances on wildlife, fish, aquatic life, and humans so staff will address the topic with each design.

Trail Maintenance

Trails wear out and types and numbers of users can change over time. Adjustments may be necessary through major maintenance, realignment or reconstruction. Seasonal maintenance techniques and schedules are not included in these *Trail Design Guidelines*. However, the Trail Details can provide basis for restoring slopes, surfaces, and vegetation clearances or improving management of water.

PP&R Vehicles	Length / wheel base	Width	Height	Weight	Turning Radius
Freightliner FL60	150" wheelbase		11'	20,000 lbs	
Six-Yard Dump Truck	160" wheelbase	9' - 6"	10' - 6"	35,000 lbs (loaded)	22'
O&M boom truck (for unloading "deep" cans) smaller than six-yard dump truck			20' above trash cans		
Urban Forestry Crane Truck	34' w/24' wheelbase	98"	13'		
Fire Bureau Apparatus					
Pumper	31'-3" w/184" wheelbase	9' - 10"	10' - 4"	37,660	23'
Brush Unit	20'-5" w/143" wheelbase	8'	8' - 3"	17,500	51' outside wall to wall
Water Tender	28' - 8" w/195" wheelbase	9' - 10"	10' - 7"	51,940	31' - 7"
Aerial (Tractor and Trailer)	53' - 10" overall length tractor = 140" wheelbase trailer = 305" wheelbase	9' - 10"	11' - 6"	58,000	15' -7"

	facility name	surface	width	longitudinal slope	cross slope	ADA	walker	runner	dog walker	equestrian	wheelchair or electricmobility device	skateboarder	rollerblader	cyclocross rider	mtn biker	road biker	gator	maintenance vehicle	police car	firetruck	Notes
	hiking (high challenge)	soil / stairs	18" - 30"	0 - 15% (short segments steeper than 15%)	2% min 4% max	steepest (steps, rocks, roots)	◆	○	○												
	hiking (moderate challenge)	soil / stairs	18" - 30"	0 - 8%	2% min 4% max	○ steep	◆	○	○		limited										landings of 60'
	hiking (accessible)	soil / gravel / engineered wood fiber or wood chips	4' (with passing areas) - 10'	0 - 5% (8% for max. 50')	2%	◆	◆	◆	◆	○	◆										Columbia Slou (or equivalent closed to dogs for poorly drair
	walking ****	engineered wood fiber or chips / gravel / pavers asphalt / concrete / wood or plastic lumber	6' - 12' (8' min if paved for vehicles)	0 - 8%	1 - 2%	◆	◆	○	○		○	○	○				○	○	○		sidewalks, boa parks, sometin for maintenanc chipseal; avoic walking loops x 60" every 10
	exercise / fitness (resilient track)	synthetic rubber	2-4' / lane	0 - 1%	1%	○	○	◆													discourage us to protect resil
	biking ****	asphalt / concrete	6' one-way, 10' min. - 12' pref. two-way	0 - 3% pref. (to 5% if needed, up to 10% for 500', up to 12% for 50' and ramps)	2%						*○	○	○		○	◆	○	○	○	○	to 12% for sho paving may be rollerbladers; paired with 10' dual trail in hig
	mountain biking	soil / gravel / wood	18" - 4'	0 - 12%	2 - 5%										◆						18" one-way s (superelevatio compacted soi

	facilityname	surface	width	longitudinal slope	cross slope	ADA	walke	runne	dog wa	equestr	wheelch electricmc devic	skateboa	rollerbla	cyclocros	mtn bil	road bi	gato	mainten vehicl	police	firetru	Notes
	cyclocross ****	soil / wood / grass / concrete / asphalt	6' - 12'	varies	varies									◆							site specific loop mud)
	equestrian**	soil / gravel / wood chips	3' - 6' (pair of riders)	0-12% (prefer 5% max.)	2%					◆											wood chips diffi
	hiking and mountain biking	soil / gravel	4' (with passing areas) - 10'	0-5% (to 12% if needed)	2%	◆	◆	◆	○	○	○				◆		○	○			adjust width for gravel allows wh
	hiking and equestrian	soil / gravel / wood fiber	4' - 6' (pair of riders) - 10'	0-12% (prefer 5% max.)	2%	◆	◆	◆		◆	○						○				adjust width for gravel causewa chips difficult to
	walking and biking ****	gravel / asphalt / concrete	8' - 25' (10' - 12' pref. maint. vehicles)	0-3% (5% as needed) (8% max.)	1%	◆	◆	◆	◆		◆	◆	◆		***	***	○	◆	○	○	8' asphalt for mi - 14' max) for m trail; add fencing 1' gravel should - 25' concrete fo
	walking, biking and equestrian ****	gravel / asphalt / concrete	8' - 25' (10' - 12' pref. maint. vehicles)	0-3% (5% max)	2%	◆	◆	◆	◆	◆	◆	◆	◆		○	◆	○	◆	○	○	6' asphalt for mi - 14' max) for m trail; add fencing 1' gravel should - 25' concrete fo
	fire and maintenance ****	gravel / turf block	10 - 14'	0-5% (to 12% as needed)	2%	◆	○	○	○	○	○				○	○	◆	◆	◆	◆	Forest Park "fire hiking and/or ma

Trail Type A – Hiking (high challenge)

DEFINITION

High challenge hiking trails are steep, narrow, irregular routes that may include steps and obstacles such as rocks and roots. They are located where accessible trails would have unacceptable impacts to the site and where the natural setting lends itself to a low impact trail. This type of trail may not be appropriate in areas where the resource value of the site is exceptionally high. Although used in limited hillside settings, they require higher physical exertion and increase the diversity of trail experience.

SW Trail #5 at Dickinson Park - steep segment on fill slope of SW 55th Avenue

USERS

The high challenge hiking trail is strenuous and requires good balance and moderate to high fitness. Single-file scrambling, walking, and (sometimes) running are desired uses.

MATERIALS

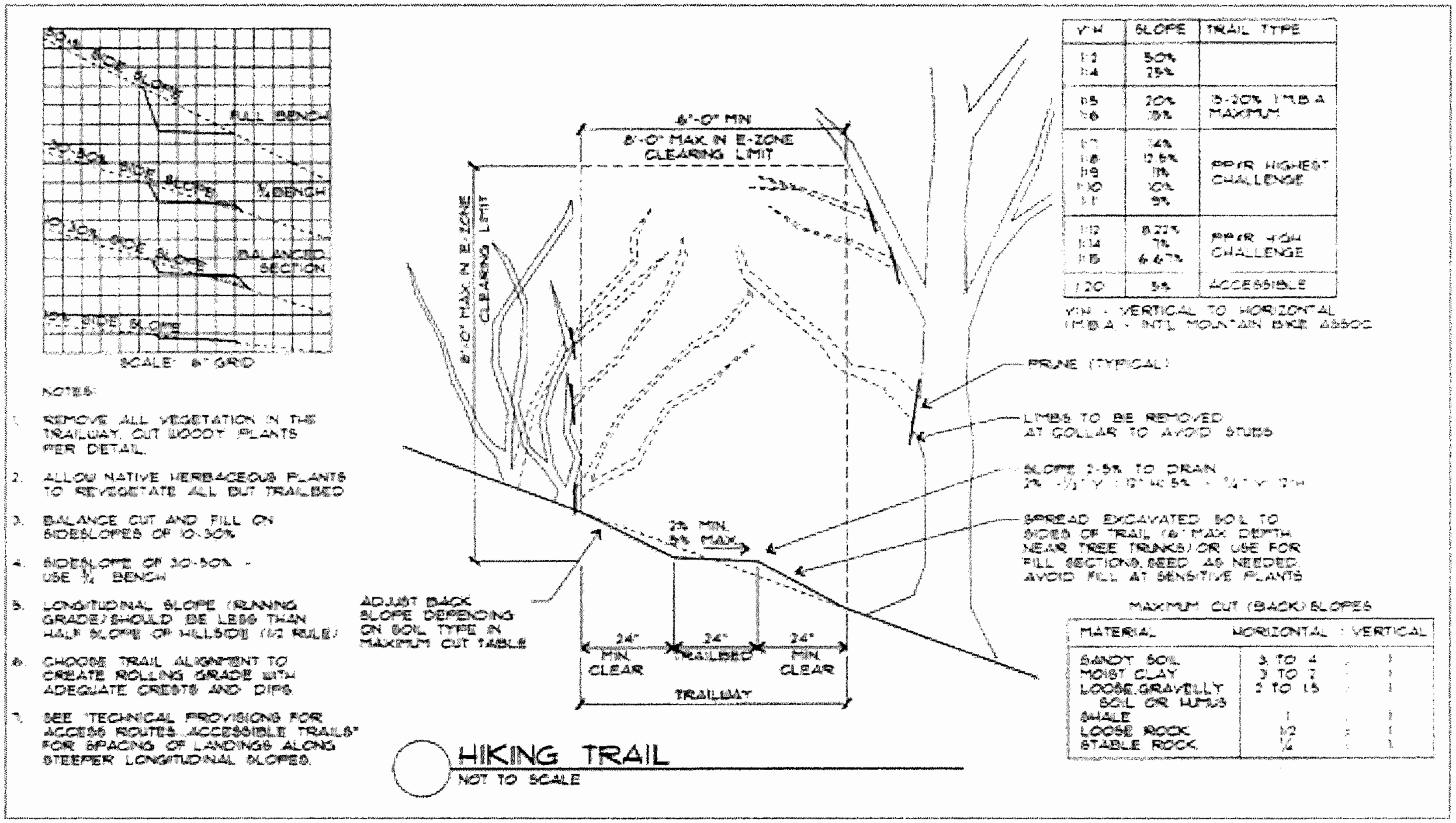
Native soil and rock are most common although steps, railings, and boardwalks are used as needed. [See Technical Provisions table on page 8.]

Width	18" - 30"
Surface	Soil / stairs
Longitudinal Slope	0 - 15% (short segments steeper than 15%)
Cross-Slope	2% min. - 4% max.
Radius	N/A - switchbacks
Sight Distance	Limited, consider safety needs
Easement Width	Tread + 10' min.
Side Slope	Varies
Vertical Clearance	8'
Horizontal Clearance	2' from side of tread

Marshall Park Trail - steps built around tree root

Lower Macleay Trail in Forest Park

Trail Type A – Hiking (high challenge)



Also see Trail Details: 01-Cribbed Steps, 02-Timber Steps, 03-Boardwalk, 04-Wood Bridge, 05-Wood Bridge with Railing, 08-Causeway, 13-Signs, 14-Alignment Tread Crests, 15-Alignment Tread Dips

Trail Type B – Hiking (moderate challenge)

DEFINITION

Moderate challenge hiking trails may include steps and obstacles such as rocks and roots. They are located where some segments with slopes as steep as 8% are needed to avoid multiple switchbacks, tree removal or slope destabilization. Although less difficult than the high challenge hiking trails, they also require higher physical exertion and increase the diversity of trail experience.

USERS

The moderate challenge hiking trail requires good balance and moderate fitness. Single-file walking and (sometimes) running are desired uses. Moderate challenge trails are accessible to users who can navigate steeper slopes although there may be barriers such as steps, rocks or roots. Signs (Detail 12) or steps may be used at entry points to signal less accessible trail ahead.

MATERIALS

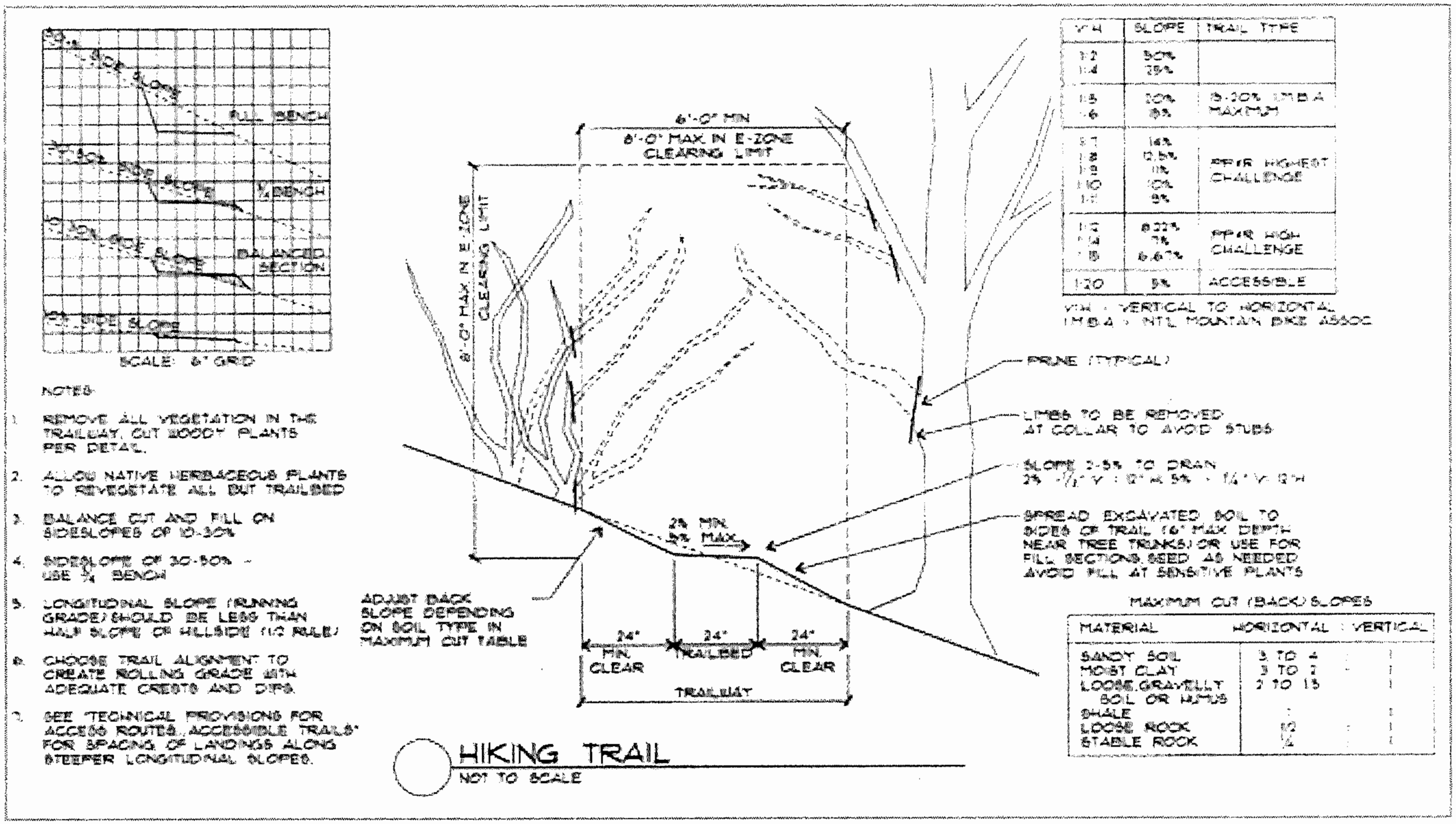
Native soil and rock are most common although steps, railings, and boardwalks are used as needed. [See Technical Provisions table page 8 for landings and passing area.]

Width	18" - 30"
Surface	Soil / stairs
Longitudinal Slope	0 - 8%
Cross-Slope	2% min. - 4% max.
Radius	NA - switchbacks
Sight Distance	Limited, consider safety needs
Easement Width	Tread + 10' min.
Side Slope	Varies
Vertical Clearance	8'
Horizontal Clearance	2' from side of tread

Wildwood Trail - steep topography requires steep longitudinal slope

Connor Trail - steep segment of climbing turn near OHSU

Trail Type B – Hiking (moderate challenge)



Also see Trail Details: 01-Cribbed Steps, 02-Timber Steps, 03-Boardwalk, 04-Wood Bridge, 05-Wood Bridge with Railing, 08-Causeway, 13-Signs, 14-Alignment Tread Crests, 15-Alignment Tread Dips

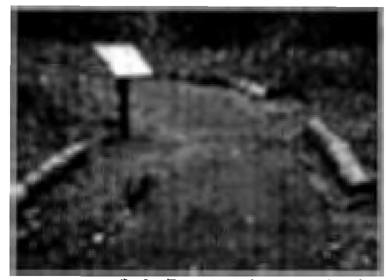
Trail Type C – Hiking (accessible)

DEFINITION

PP&R's accessible hiking trails have surface, slopes, and width that meet or exceed the dimensions of the *Forest Service Trail Accesssibility Guidelines (FSTG)*. Trails with a longitudinal slope of less than 1 vertical to 20 horizontal and cross-slope that is less than or equal to 2% can be traversed by wheelchairs. Trail surfaces are firm and stable. Barriers such as steps, rocks or roots do not exist although the natural surface may have some irregularities, not to exceed 2" high. The goal is to provide access to natural settings without adding pavement. Path width is minimized unless high use is expected. Landings or wider portions of the trail are provided for resting and passing other trail users. [See Technical Provisions table on page 8.]

Hoyt Arboretum - Wildwood Trail

40-Mile Loop Trail at base of Forest Park's Ridge Trail, next to Bridge Access Road for St Johns Bridge



Oaks Bottom - interpretive loop

USERS

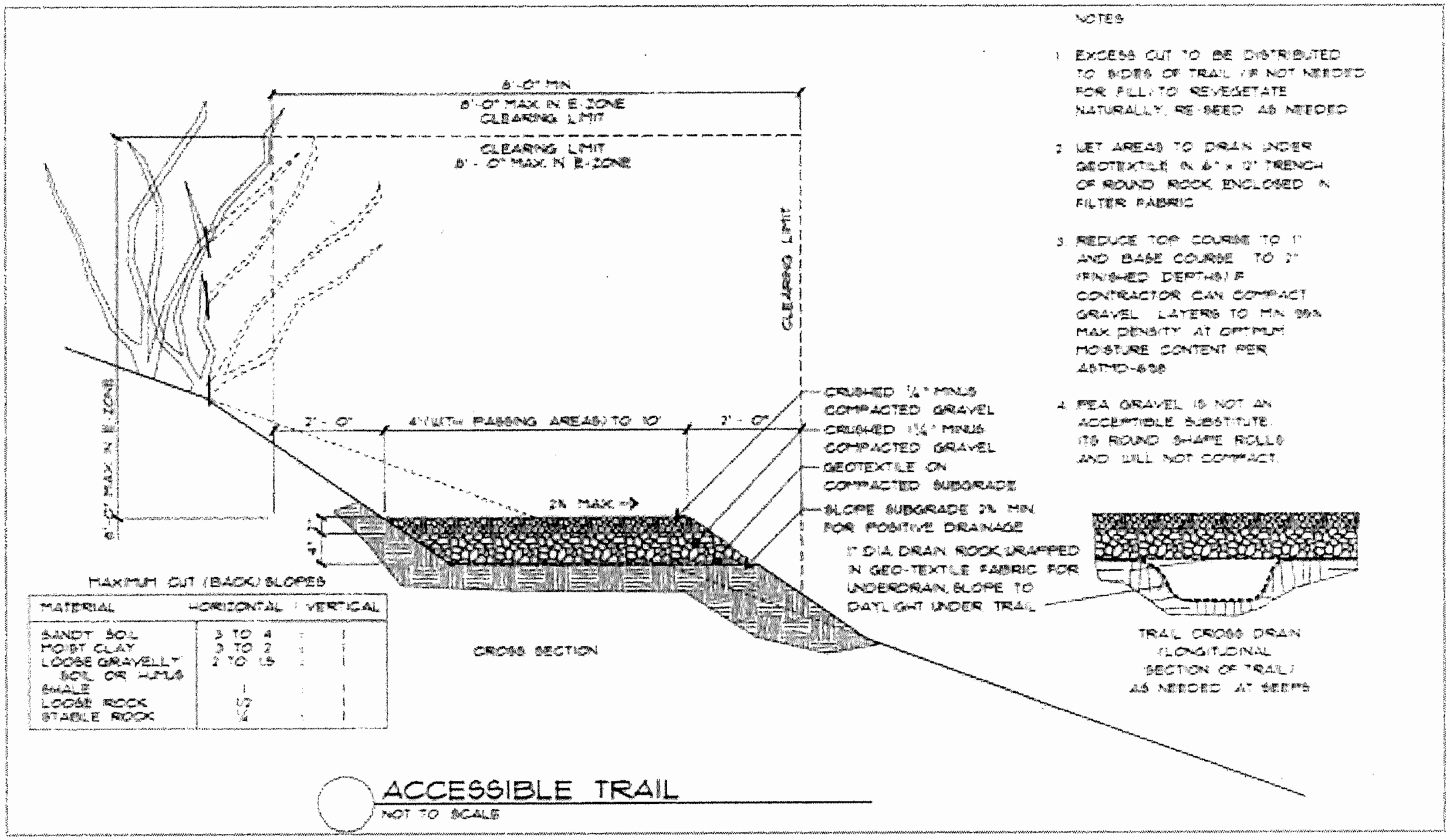
The accessible hiking trail requires fair balance and fitness. Single-file walking and (sometimes) running are desired use at minimum width. Wheelchairs (motorized or human-powered) and mobility scooters may be used, but surface is not as reliably firm and slip-resistant as a paved walking trail.

MATERIALS

Native soil and rock are most common although crushed rock or wood fiber are used as needed. Hand or guard railings and boardwalks may be added if necessary. Excellent drainage and gravel may be necessary at wet sites to provide slip-resistant surface through winter. Fibar is the brand name of an engineered, interlocking wood fiber that is accessible to wheeled modes. Equivalent products produced locally may be substituted. Wood chips biodegrade and are difficult to maintain so provide width for hauling additional material. [See Trail Detail 13 for signs regarding accessibility.]

Width	4' (with passing areas) - 10'
Surface	Soil, gravel, Fibar (or engineered wood fiber equivalent), wood chips
Longitudinal Slope	0 - 5% (8% for max. 50')
Cross-Slope	2%
Radius	Aesthetic consideration
Sight Distance	N/A except road crossings
Easement Width	Tread + 10' min.
Side Slope	Varies
Vertical Clearance	8'
Horizontal Clearance	2' from side of tread

Trail Type C – Hiking (accessible)



Also see Trail Types B and D and Trail Details: 03-Boardwalk, 04-Wood Bridge, 05-Wood Bridge with Railing, 08-Causeway, 13-Signs, 14-Alignment Tread Crests, 15-Alignment Tread Dips

Trail Type D – Walking

DEFINITION

Walking trails are typically fully accessible with a maximum longitudinal slope of 5%. Some short segments of up to 8% longitudinal slope are used with slip-resistant paving. They offer a shorter, less vigorous "walk in a park" than the hiking trails. Sidewalks are in the public right-of-way and managed by PBOT. [See *Portland Pedestrian Design Guide*] In some locations, PBOT has allowed walking trails that meander farther into the park and away from the curb, instead of sidewalks, in order to improve the walking environment. These walking trails still need curb ramps and connections to sidewalks or road crossings in order to connect to the adjoining sidewalk system.

Lents Park - wood chip exercise loop path

USERS

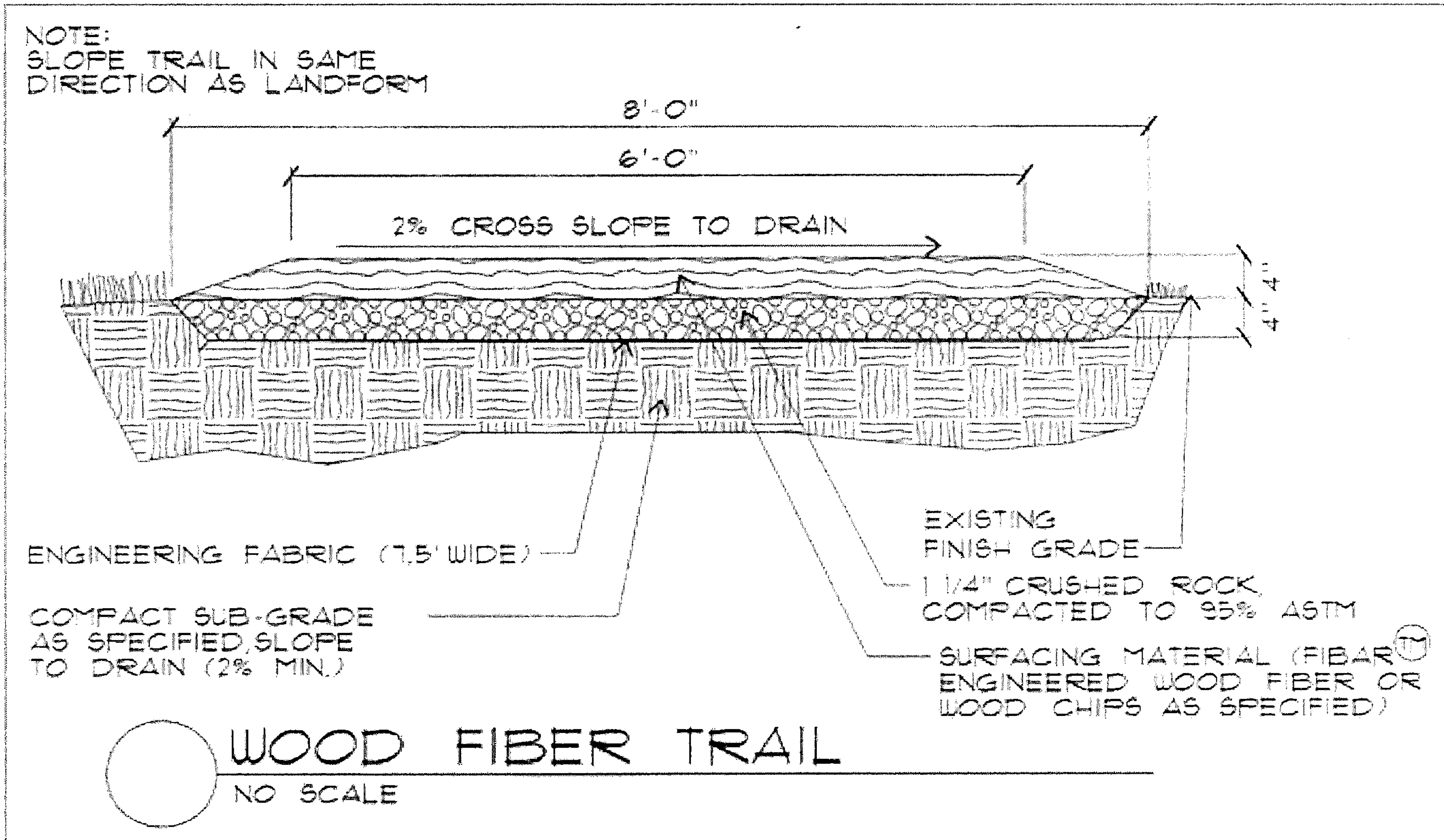
Walking trails serve all pedestrians, including those with fitness and balance limitations. These routes are the main circulation system in, around, and/or through developed parks. People of all ages walk and run to enjoy the environment, socialize, exercise, and access other parts of the community. Walking trails also serve wheelchairs and electric mobility devices used by persons who need assistance to be mobile. Bicycles are not allowed due to trail surface, width, adjacent uses, sight distance or desired environment. The walking trail is also used in combination with a bike trail to form a dual trail system to separate slower speed 'feet' from higher speed 'wheels' (bicycles, scooters, skateboards, rollerbladers) in corridors of high density, such as the South Waterfront neighborhood.

MATERIALS

Walking trails are generally paved with unit pavers, asphalt or concrete. Trail width is based on projected use with a minimum expectation that two adults can walk side-by-side, or one user can pass another. Additional width is provided where the walking trail is also used for maintenance access.

Wood chips are used where desired for exercise loops or required by *33.515 Columbia South Shore Plan District* (based on the *Columbia South Shore Slough Trail Masterplan)*. Code requires Fibar (or engineered wood fiber equivalent) for accessible segment between I-205 and NE 122 Avenue and wood chips between NE 122 and 185 Avenues (to discourage bicycles). Wood chips should not be used where flooding is likely.

Width	6' - 12'
Surface	Engineered wood fiber or wood chips, gravel, a.c., concrete, pavers, wood or plastic lumber
Longitudinal Slope	0 - 8%
Cross-Slope	1% - 2%
Radius	Aesthetic consideration
Sight Distance	N/A except road crossings
Easement Width	Tread + 10' min.
Side Slope	Varies
Vertical Clearance	8'
Horizontal Clearance	1' from side of tread



Also see Trail Types B, C and M and Trail Details: 01-Cribbed Steps, 02-Timber Steps, 03-Boardwalk, 04-Wood Bridge, 05-Wood Bridge with Railing, 11-Soft Surface Switchback on Levee, 13-Signs, 14-Alignment Tread Crests, 15-Alignment Tread Dips

Trail Type E – Exercise/Fitness (Resilient Track)

DEFINITION

Exercise/fitness tracks are resilient surfaces developed primarily for competitive track events and training. They also serve for non-competitive walking, jogging, and running. Tracks are precisely engineered to be virtually flat with enough slope to shed rainfall. There are currently no resilient surfaces along narrow linear routes, although demand paths of hardened earth frequently develop next to asphalt or concrete walking (such as Laurelhurst Park), or walking and biking trails (such as Terwilliger Trail).

Laurelhurst Park - "runners' rut"

Duniway Track

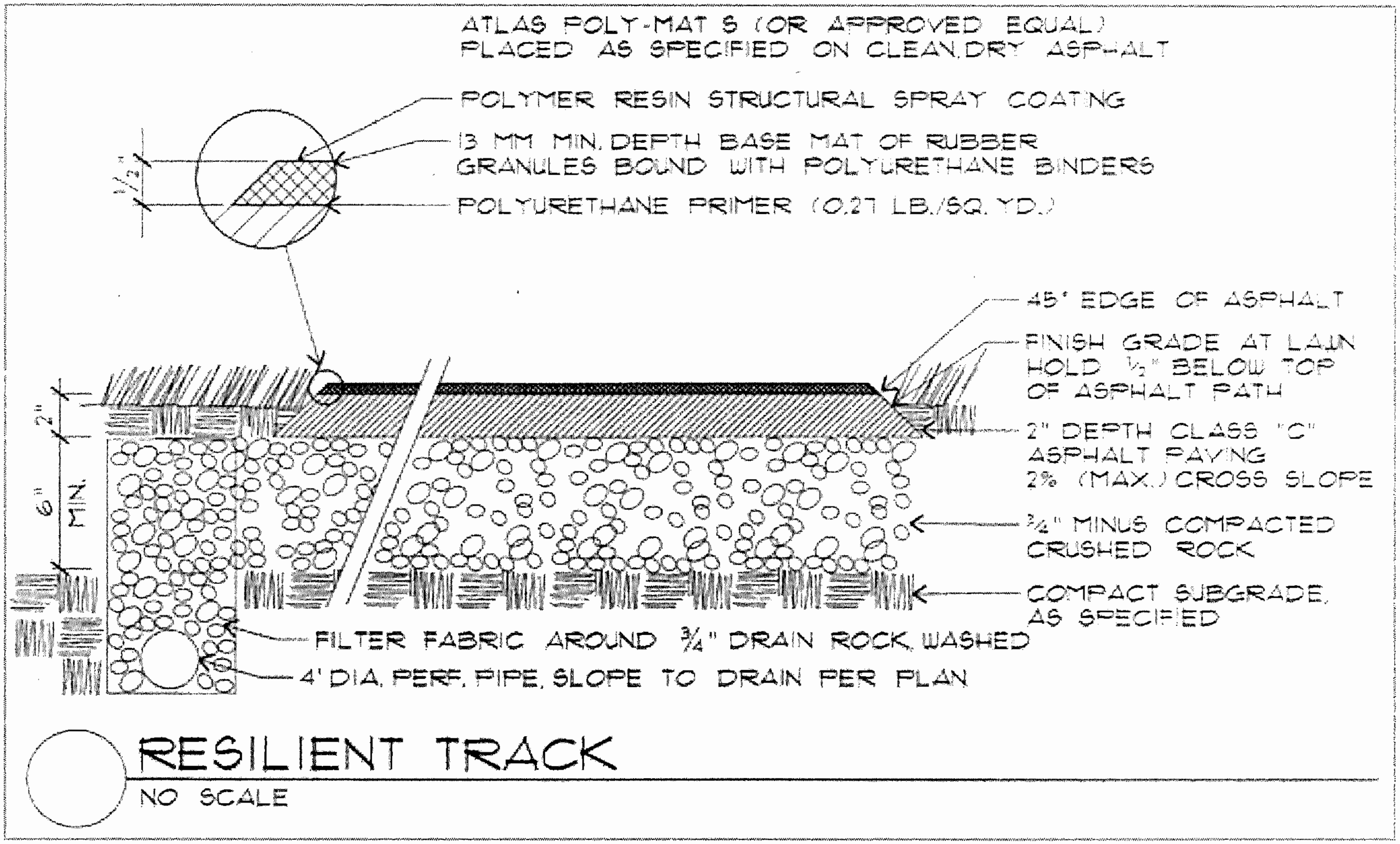
USERS

Exercise/fitness trails are designed for competitive runners. Although the track may sometimes be scheduled for track and field events, there are frequent walkers, joggers, and/or runners who are encouraged to use the outer lanes in order to balance wear of racers on inner lanes. Wheelchairs, bicycles, and baby strollers are not allowed in order to preserve the resilient surface.

MATERIALS

Exercise/fitness tracks are synthetic rubber (sometimes recycled athletic shoes) over an asphalt base. The number of lanes is based on projected use with a minimum of six lanes. Surface and/or subsurface drain systems ensure that runoff from adjacent areas is intercepted before reaching resilient surface.

Width	2' - 4' if developed as linear route
Surface	Synthetic rubber over a.c. or concrete
Longitudinal Slope	0 - 1%
Cross-Slope	1%
Radius	Use standard oval dimensions for track
Sight Distance	N/A
Easement Width	As needed
Side Slope	0%
Vertical Clearance	8'
Horizontal Clearance	Mowed grass next to tread



Also see Trail Type F and Trail Detail 13-Signs

Trail Type F – Biking

DEFINITION

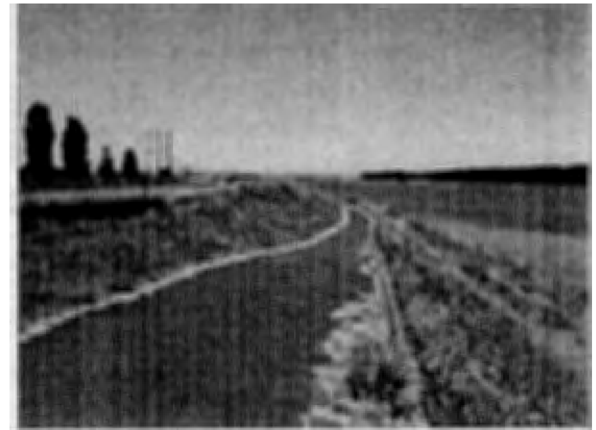
Biking trails have width, slope, cross-slope, and curve radii to enable one-way or two-way bicycle travel at various speeds. Bike lanes and bicycle boulevards are in right-of-way, subject to PBOT guidelines.

USERS

Biking trails serve all cyclists, particularly those using road bikes. When there are no slower users, bicycle speed can be approximately 20 mph on flat trails and 30 mph on downgrade of 4%. Other higher speed wheeled users (scooters, skateboards, rollerbladers) use the bike portion of a dual (parallel, but separated) bike and walking trail system if their speeds are similar to cyclists. Motorized wheelchairs might use biking trails if they can match the speed of cyclists. Non-motorized or slower motorized wheelchairs would be more appropriate on adjacent walking paths.

MATERIALS

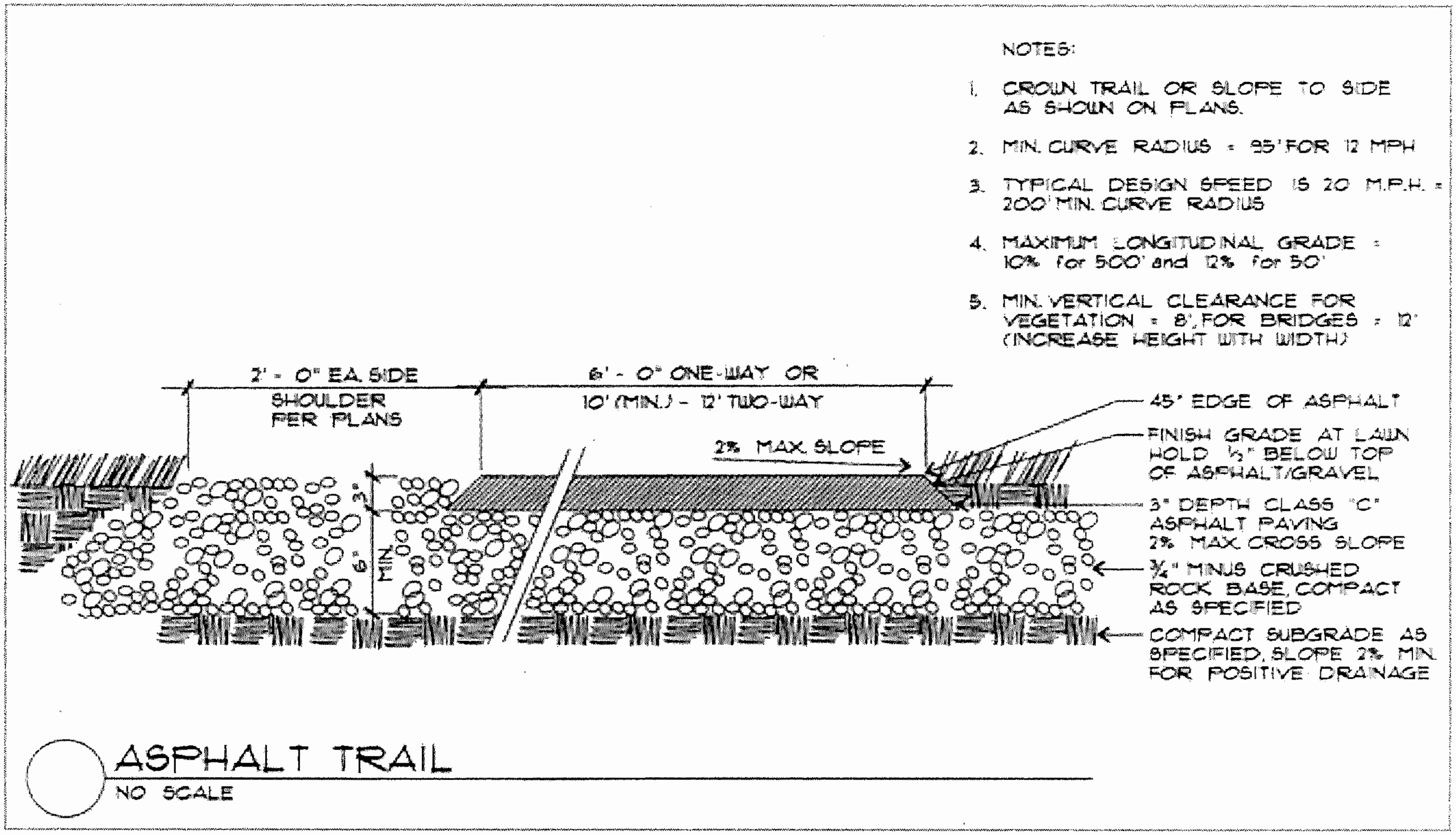
Biking trails are generally paved asphalt or concrete. Trail width is determined based on projected use. Constrained sites may mean that bicyclists travel single-file with no passing. Additional width is provided for passing or where the biking trail is used for two-way travel and/or maintenance access. The biking trail is also used in combination with walking trail to form a dual trail to separate slower speed 'feet' from higher speed 'wheels' in corridors of high density, as planned for the Willamette Greenway in South Waterfront. Some of the public perceives asphalt as too 'road-like' when new, but it weathers to less black color over time. Porous asphalt (Trail Detail 12) should be used where a more rough surface is acceptable and infiltration through trail is desired.



Marine Drive Trail - looking west at Columbia River

Width	6' one-way, 10' min. - 12' preferred two-way
Surface	Asphalt (porous or not), concrete
Longitudinal Slope	0 - 3% (preferred) (to 5% if needed, up to 10% for 500', up to 12% for 50' and ramps)
Cross-Slope	2%
Radius	Varies with design speed: 12 mph = 36'(95' preferred); 20 mph = 200'
Sight Distance	150'
Easement Width	Tread + 10' or code requirement
Side Slope	Varies
Vertical Clearance	8' (12' + under bridges)
Horizontal Clearance	2' from side of tread

Trail Type F – Biking



Also see Trail Types F and M and Trail Details: 12-Open-Graded Asphalt Trail and 13-Signs

Trail Type G – Mountain Biking

DEFINITION

Mountain biking trails are narrow, sometimes steep and curving trails of soil often strengthened with gravel. They may be designed as either one-way single track or wider two-way routes. Steepness may require higher physical exertion and obstacles such as rocks and roots may increase the diversity of trail experience. Narrow width and sharp turns may be required in steep, irregular topography and increase trail difficulty. This trail type is not intended for the high speed, downhill, jumps, structures, and/or technical features of 'free-riding.'

USERS

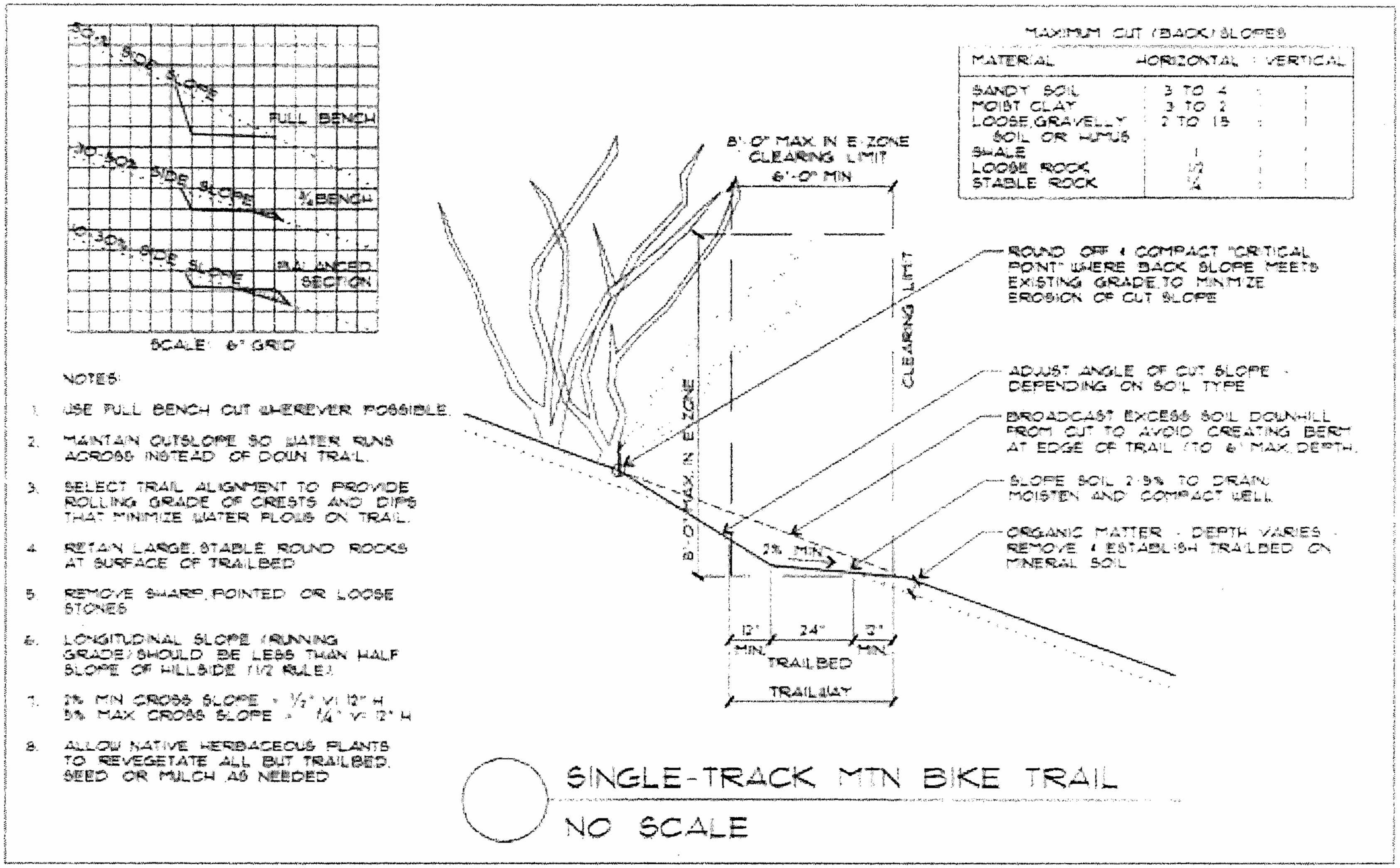
Mountain bikers range from beginner to expert so that a range of trail types is desirable. Mountain bikes typically have shock absorbers and wider tires with special tread. This allows use on soil and gravel trails with irregular surfaces, boulders, and logs. Introductory trails are wider with alternative routes at boulder or log 'obstacles.' The most technically challenging mountain biking trail is strenuous and requires excellent balance and fitness. If the single-track flows with no sharp curves, mountain bicycle speed can be approximately 15 mph.

MATERIALS

Native soil and gravel are most common although rock and boardwalks are used when needed. Trails at sites with silty soils, heavy use or high soil moisture may benefit from mixing a thin layer of gravel into soil and compacting it well. Curves may need to be banked and reinforced to resist soil displacement. Careful alignment for even flowing speed will reduce the skidding that loosens soil in the trail tread. Trail beds can also be armored with larger rocks in braking sections to reduce formation of brake bumps. Seasonal trail closures may be needed to prevent erosion. A site developed for free-riding might also use boulders, logs, steps, ladders, boardwalks, and varying widths to add challenge.

Forest Park - Firelane 5 improvements by PUMP, Portland United Mountain Pedalers

Width	18" (one-way single-track) - 4' (add width & super-elevation at curves as needed)
Surface	Soil (& gravel hardening where needed) (use caution with wood bridges, boardwalks & railings)
Longitudinal Slope	0 - 12%
Cross-Slope	2% - 5% (varies on curves)
Radius	4' min, 8'+ preferred
Sight Distance	10-100' depending on speed/flow
Easement Width	Tread + 10' min
Side Slope	Varies
Vertical Clearance	8' (max. to avoid e-zone review)
Horizontal Clearance	1' from side of tread



Also see Trail Type C and Trail Details: 04-Wood Bridge, 05-Wood Bridge with Railing, 08-Causeway, 13-Signs, 14-Alignment Tread Crests, 15-Alignment Tread Dips

Trail Type F – Biking

DEFINITION

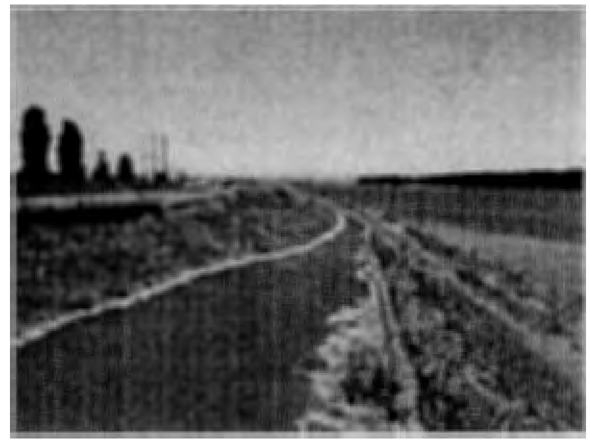
Biking trails have width, slope, cross-slope, and curve radii to enable one-way or two-way bicycle travel at various speeds. Bike lanes and bicycle boulevards are in right-of-way, subject to PBOT guidelines.

USERS

Biking trails serve all cyclists, particularly those using road bikes. When there are no slower users, bicycle speed can be approximately 20 mph on flat trails and 30 mph on downgrade of 4%. Other higher speed wheeled users (scooters, skateboards, rollerbladers) use the bike portion of a dual (parallel, but separated) bike and walking trail system if their speeds are similar to cyclists. Motorized wheelchairs might use biking trails if they can match the speed of cyclists. Non-motorized or slower motorized wheelchairs would be more appropriate on adjacent walking paths.

MATERIALS

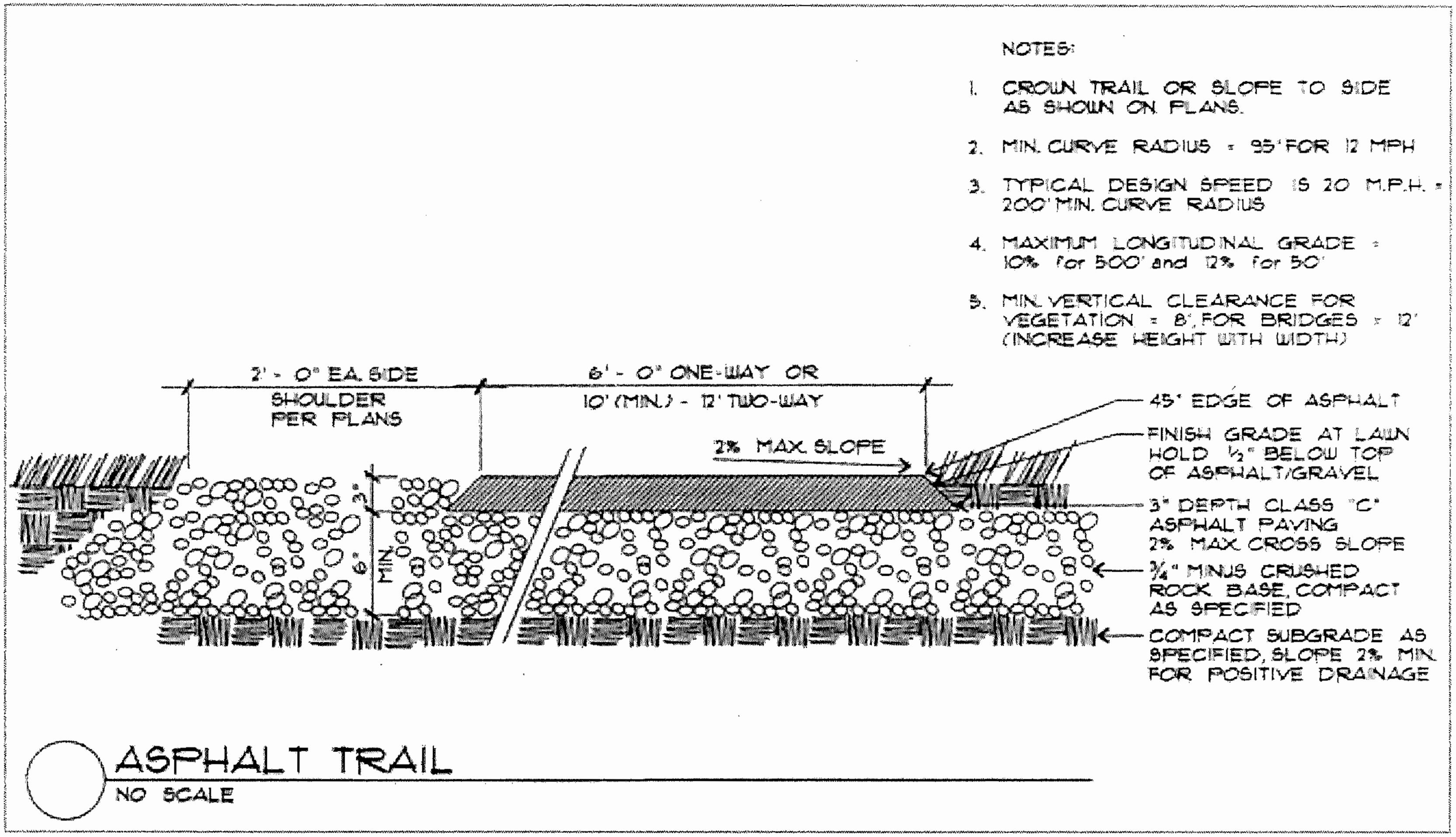
Biking trails are generally paved asphalt or concrete. Trail width is determined based on projected use. Constrained sites may mean that bicyclists travel single-file with no passing. Additional width is provided for passing or where the biking trail is used for two-way travel and/or maintenance access. The biking trail is also used in combination with walking trail to form a dual trail to separate slower speed 'feet' from higher speed 'wheels' in corridors of high density, as planned for the Willamette Greenway in South Waterfront. Some of the public perceives asphalt as too 'road-like' when new, but it weathers to less black color over time. Porous asphalt (Trail Detail 12) should be used where a more rough surface is acceptable and infiltration through trail is desired.



Marine Drive Trail - looking west at Columbia River

Width	6' one-way, 10' min. - 12' preferred two-way
Surface	Asphalt (porous or not), concrete
Longitudinal Slope	0 - 3% (preferred) (to 5% if needed, up to 10% for 500', up to 12% for 50' and ramps)
Cross-Slope	2%
Radius	Varies with design speed: 12 mph = 36'(95' preferred); 20 mph = 200'
Sight Distance	150'
Easement Width	Tread + 10' or code requirement
Side Slope	Varies
Vertical Clearance	8' (12' + under bridges)
Horizontal Clearance	2' from side of tread

Trail Type F – Biking



Also see Trail Types F and M and Trail Details: 12-Open-Graded Asphalt Trail and 13-Signs

Trail Type G – Mountain Biking

DEFINITION

Mountain biking trails are narrow, sometimes steep and curving trails of soil often strengthened with gravel. They may be designed as either one-way single track or wider two-way routes. Steepness may require higher physical exertion and obstacles such as rocks and roots may increase the diversity of trail experience. Narrow width and sharp turns may be required in steep, irregular topography and increase trail difficulty. This trail type is not intended for the high speed, downhill, jumps, structures, and/or technical features of 'free-riding.'

USERS

Mountain bikers range from beginner to expert so that a range of trail types is desirable. Mountain bikes typically have shock absorbers and wider tires with special tread. This allows use on soil and gravel trails with irregular surfaces, boulders, and logs. Introductory trails are wider with alternative routes at boulder or log 'obstacles.' The most technically challenging mountain biking trail is strenuous and requires excellent balance and fitness. If the single-track flows with no sharp curves, mountain bicycle speed can be approximately 15 mph.

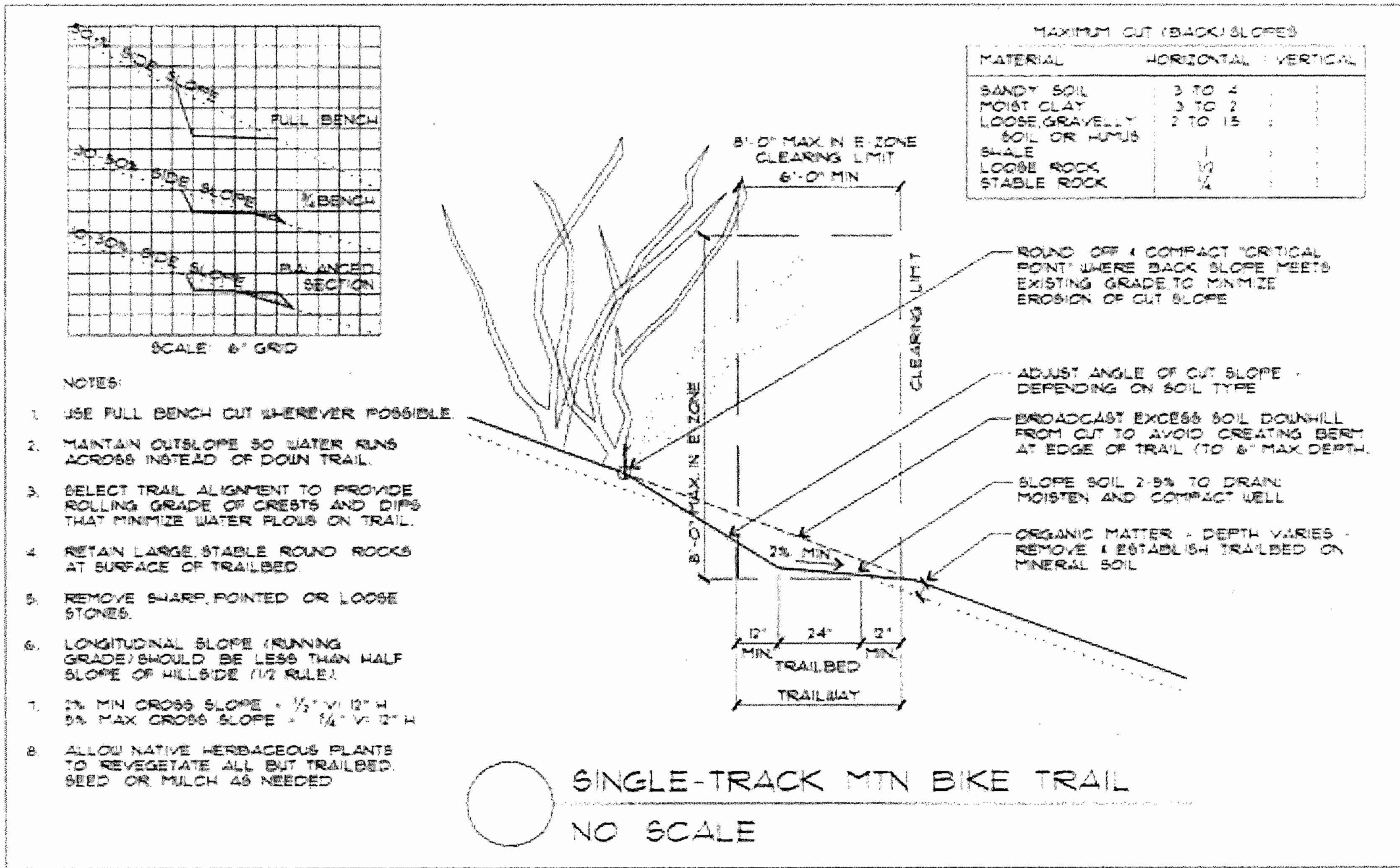
MATERIALS

Native soil and gravel are most common although rock and boardwalks are used when needed. Trails at sites with silty soils, heavy use or high soil moisture may benefit from mixing a thin layer of gravel into soil and compacting it well. Curves may need to be banked and reinforced to resist soil displacement. Careful alignment for even flowing speed will reduce the skidding that loosens soil in the trail tread. Trail beds can also be armored with larger rocks in braking sections to reduce formation of brake bumps. Seasonal trail closures may be needed to prevent erosion. A site developed for free-riding might also use boulders, logs, steps, ladders, boardwalks, and varying widths to add challenge.

Forest Park - Firelane 5 improvements by PUMP, Portland United Mountain Pedalers

Width	18" (one-way single-track) - 4' (add width & super-elevation at curves as needed)
Surface	Soil (& gravel hardening where needed) (use caution with wood bridges, boardwalks & railings)
Longitudinal Slope	0 - 12%
Cross-Slope	2% - 5% (varies on curves)
Radius	4' min, 8'+ preferred
Sight Distance	10-100' depending on speed/flow
Easement Width	Tread + 10' min
Side Slope	Varies
Vertical Clearance	8' (max. to avoid e-zone review)
Horizontal Clearance	1' from side of tread

Trail Type G – Mountain Biking



Also see Trail Type C and Trail Details: 04-Wood Bridge, 05-Wood Bridge with Railing, 08-Causeway, 13-Signs, 14-Alignment Tread Crests, 15-Alignment Tread Dips

Trail Type H – Cyclo Cross

DEFINITION

According to *Wikipedia* and cyclo cross regulations, cyclo cross is a form of bicycle racing. Races take place typically in the autumn and winter, and consist of many laps of a short (1.5 – 2 miles) course featuring pavement, wooded trails, grass, steep hills, and obstacles requiring the rider to quickly dismount, carry the bike while navigating the obstruction, and remount in one motion. Races for senior categories are generally between 30 minutes and an hour long, with the distance varying depending on the ground conditions, which often become muddy.

USERS

Cyclo cross bicycles are similar to racing bicycles but have special tread and brakes needed for muddy conditions. Cyclo cross racing requires aerobic endurance and strong bike-handling skills. Different classes of men, women, children, and masters compete against one another.

MATERIALS

Native soil and turf are the most common course surfaces and wet conditions tend to generate mud. Careful design and/or maintenance is required to avoid erosion and to repair the course after the cyclo cross season.

SITES

Cyclo cross events at both Creston and Pier Parks were phased out due to impacts to the sites and surrounding neighborhoods. The November 2008 Cycle Cross Crusade event held outside the track at Portland International Raceway had approximately 1,300 participants plus additional spectators. Potential new sites will need access, adequate parking, and funding for restoration and should minimize impact on natural resources. Sites such as Gateway Green might be developed as practice course if funding were secured for maintenance.

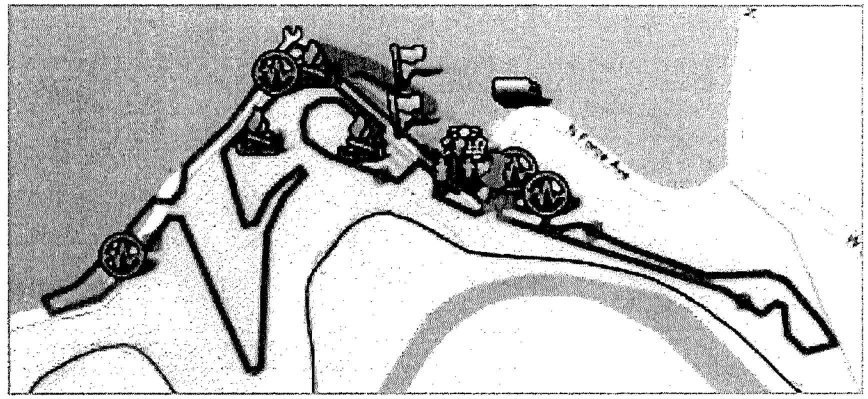
Cyclo Cross Crusade course at Portland International Raceway - using concrete vault as obstacle

Width	6' min - 12' typical (plus 20' - 40' at starting area)
Surface	Soil, wood, grass, gravel, concrete, asphalt
Longitudinal Slope	0 - 60%
Cross-Slope	0 - 50%
Radius	8' min.
Sight Distance	20' min.
Easement Width	N/A
Side Slope	0 - 50%
Vertical Clearance	10'
Horizontal Clearance	1' from side of tread

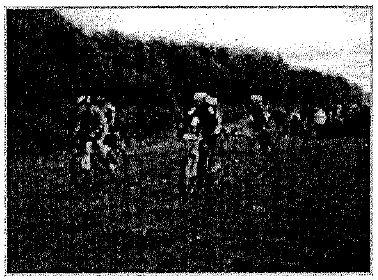
Trail Type H – Cyclo Cross

Cyclo Cross Crusade courses comply with these characteristics:

- About 75% of the course should be rideable. No more than half will be paved.
- Each lap should be at least 1 km in length.
- The start should be wide and long so that the stronger riders can get to the front before the narrower part.
- The course will be of sufficient width at all points to allow room for one rider to pass another.
- The course must be clearly marked. Riders are expected to remain inside the course following all markings.
- Barriers will not exceed 40 cm in height. Riders must go over artificial barriers placed on the course and may not ride around a barrier for any reason.



Race track



A - Start of race, groups of riders

B - Long, level paved stretch

C - Sharp turn on gravel & asphalt

D - Ride, push or carry bike

E - Sharp turn on turf

F - Plank barriers on uphill

G - Far turn on side of levee

H - Levee and maintenance road

Trail Type I – Equestrian

DEFINITION

Equestrian trails serve horseback riders. Horses prefer soil surfaces and require wider and higher clear areas than people on foot or wheels. There are some sites or regional trails in which a separate equestrian-only route could be developed.

USERS

Equestrians currently share some trails in Forest Park and Powell Butte Nature Park with hikers, and the Springwater Corridor with walkers, runners, and bicyclists. Horses have good peripheral vision, but the location of their eyes causes a 5' wide blind spot directly in front. They often travel at about 4-6 mph. Bicycles are specifically not allowed in order to not startle more nervous horses.

MATERIALS

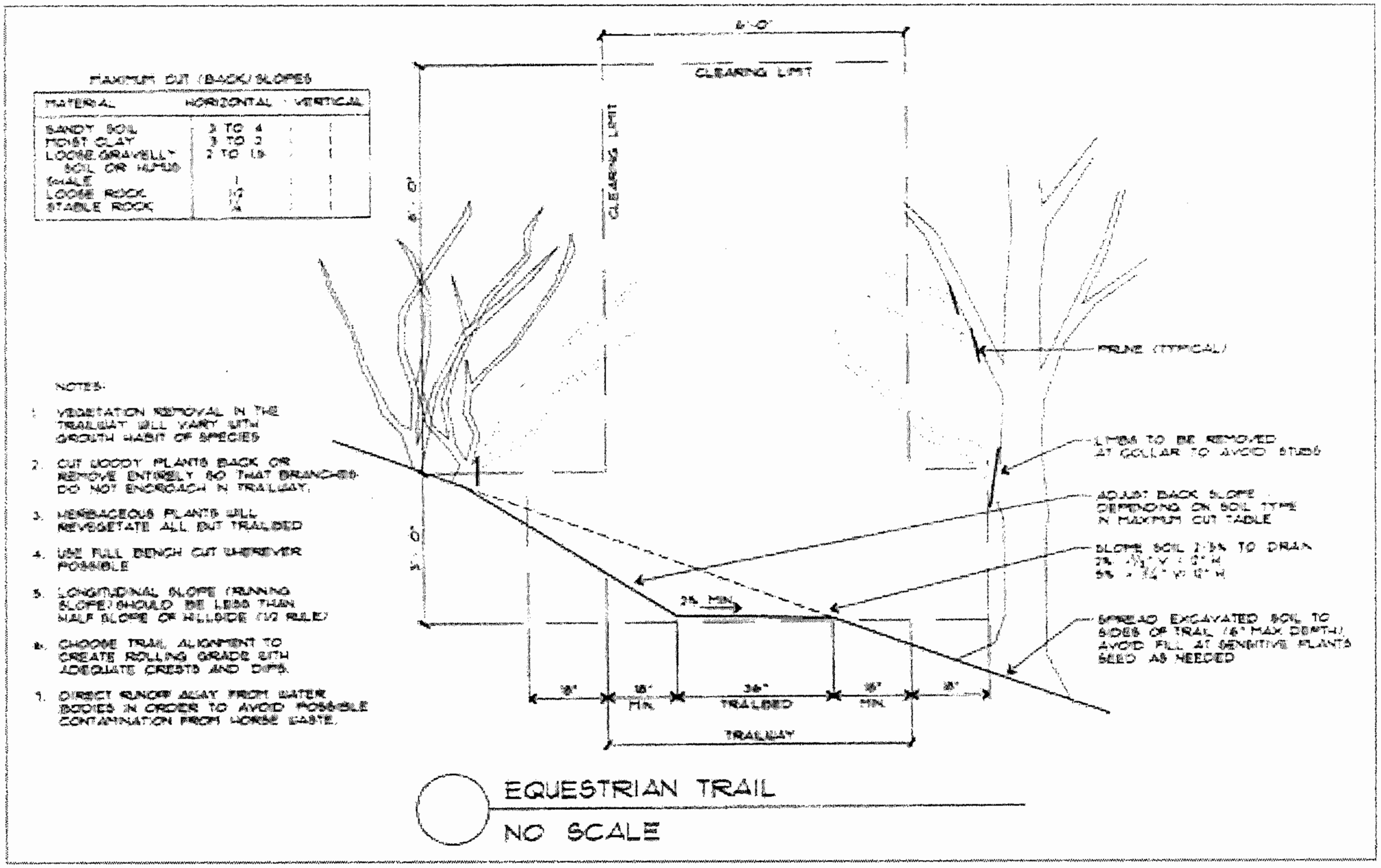
Equestrian trails are generally soil or gravel. Horse riders often request wood chips, but this is difficult to maintain. The Gresham portion of the Springwater Corridor has some wood chip segments, which are occasionally maintained by equestrian user groups. Additional vertical clearance is needed in forested areas. Where there are creek crossings or narrow trail corridors, equestrians must share walking and biking trails and bridges with other users. Special care should be taken to direct runoff (that may be contaminated by horse droppings) away from water bodies. See *Equestrian Design Guidelines for Trails, Trailheads & Campgrounds* by Jan Hancock, Jeff Engelmann, Jim Coffman & Kim Vander Hoek. Seasonal trail closures may be needed to prevent erosion.

Springwater Corridor in Gresham - wood chips on equestrian-only trail parallel to paved walking/biking trail

Springwater Corridor in Gresham - equestrian-only path splits from paved walking/biking trail

Width	3' min. - 6' (pair of riders)
Surface	Soil, gravel, wood chips (not preferred)
Longitudinal Slope	0 - 12% (prefer 5% max.)
Cross-Slope	2%
Radius	Avoid sharp turns
Sight Distance	50-100'
Easement Width	Treat + 10' min.
Side Slope	Varies
Vertical Clearance	11'
Horizontal Clearance	3' from side of tread, at least 3' high, then 18" from side of tread above 3' high

Trail Type I – Equestrian



Also see Trail Types C and D and Trail Details: 03-Boardwalk, 04-Wood Bridge, 05-Wood Bridge with Railing, 08-Causeway,10-Trail on Levee; 11-Soft-Surface Switchback on Levee, 13-Signs, 14-Alignment Tread Crests, 15-Alignment Tread Dips

Trail Type J – Hiking & Mountain Biking

DEFINITION

Shared hiking and biking trails have surface and slope for both mountain bike and hiker. Additional width allows side-by-side hiking or riding or room for on-coming or overtaking trail users. There are no barriers such as steps, rocks or roots although the natural surface may have some irregularities. The goal is to provide access to natural settings without adding paving.

USERS

The hiking and biking trail requires moderate balance and fitness. Walkers, mountain bikers, and runners are desired users. Since this trail does not have the obstacles desired by expert riders, it is more suitable for beginning and less experienced mountain bikers. Wheelchairs (motorized or human-powered) and mobility scooters may be used, but the surface is not as reliably firm and slip-resistant as on a paved walking trail.

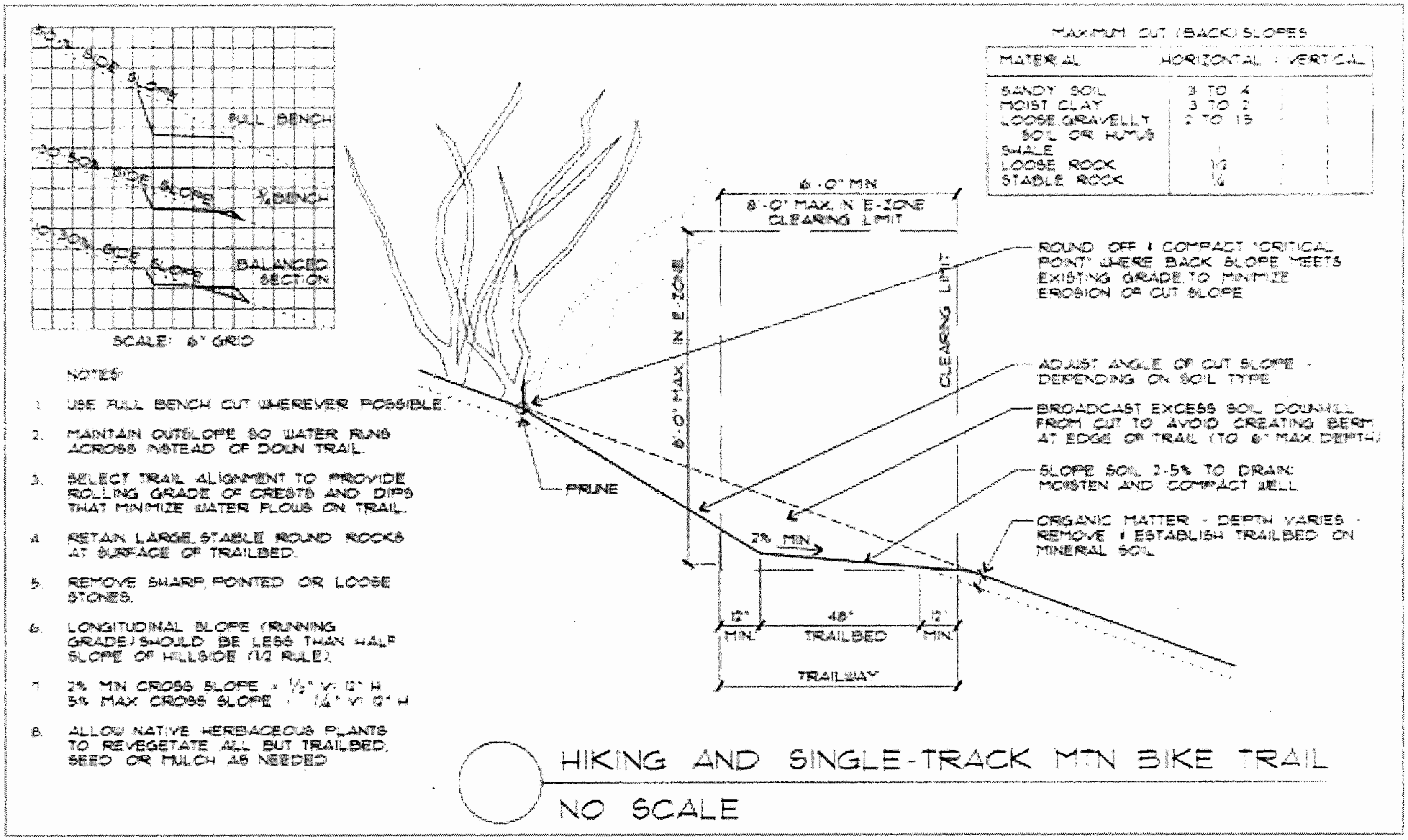
MATERIALS

Native soil and rock are most common although crushed rock and boardwalks are used as needed. Curves may need to be superelevated (banked) and reinforced to resist soil displacement. Trail beds can also be armored with larger rocks in braking sections to reduce formation of brake bumps. Curve radii and sight lines should be adequate to serve two-way travel. Path width is minimized unless high use is expected or maintenance vehicle access is needed. Hand or guard railing may be added in some areas for safety. Seasonal trail closures to mountain bikes may be needed to prevent erosion.

Pioneer Orchard Trail - one of the Powell Butte Nature Park trails reserved for hiking and biking

Kelley Point Park - gravel trail

Width	4' (with passing areas) - 10'
Surface	Soil, gravel
Longitudinal Slope	0 - 5% (to 12% if needed)
Cross-Slope	2%
Radius	10' min.
Sight Distance	40 - 100' depending on speed / flow
Easement Width	Tread + 10' min.
Side Slope	Varies
Vertical Clearance	8' (avoids e-zone review)
Horizontal Clearance	1' from side of tread



Also see Trail Type C and Trail Details: 03-Boardwalk, 04-Wood Bridge, 05-Wood Bridge with Railing, 08-Causeway, 13-Signs, 14-Alignment Tread Crests, 15-Alignment Tread Dips

Trail Type K – Hiking & Equestrian

DEFINITION

Shared trails with surface, slope, and vegetation clearance that allows both hiking and equestrians. Hiking and equestrian trails are located in a few natural areas and regional trails. Barriers such as steps, rocks, and roots do not exist although the natural surface may have some irregularities. Landings or wider portions of the trail are provided for resting and passing on-coming trail users.

USERS

Single-file walking, running, and horse riding are desired use. Bicycles are specifically not allowed in order to not startle more nervous horses. Dogs on regional trails such as the Springwater must be on-leash.

MATERIALS

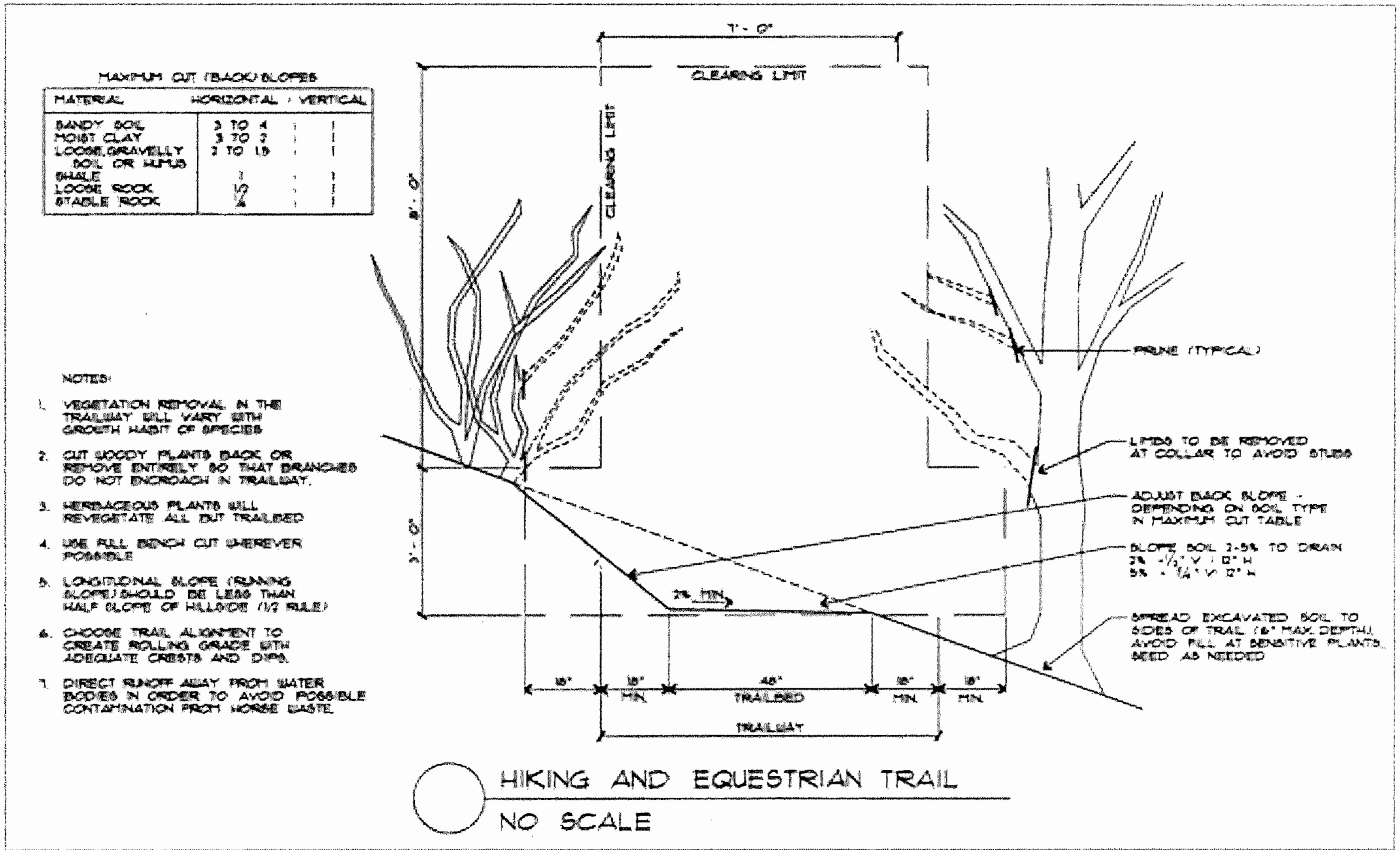
Hiking and equestrian trails are generally soil or gravel. Horse riders often request wood chips, but they are difficult to maintain. Additional vertical clearance is needed in forested areas. Where there are creek crossings or narrow trail corridors, equestrians must share walking and biking trails and bridges with other users. Special care should be taken to direct runoff (that may be contaminated by horse droppings) away from water bodies.

Springwater between Palmblad and Rugg Roads - one gravel shoulder widened for equestrian and runner use

Wild Hawthorn Trail - one of the Powell Butte Nature Park trails reserved for mountain biking and equestrian use

Width	4' - 6' (pair of riders) - 10'
Surface	Soil, gravel, wood chips (not preferred)
Longitudinal Slope	0 - 12% (prefer 5% max.)
Cross-Slope	2%
Radius	Avoid sharp turns
Sight Distance	50 - 100'
Easement Width	Tread + 10' min.
Side Slope	Varies
Vertical Clearance	11'
Horizontal Clearance	3' from side of tread, at least 3' high, then 18" from side of tread above 3' high

Trail Type K – Hiking & Equestrian



Also see Types C and D and Trail Details: 03-Boardwalk, 04-Wood Bridge, 05-Wood Bridge with Railing, 07-Trail with Swale & Culvert, 08-Causeway, 09-Trail with Infiltration Trench, 10-Trail on Levee, 11-Soft-Surface Switchback on Levee, 13-Signs, 14-Alignment Tread Crests, 15-Alignment Tread Dips

Trail Type L – Walking & Biking

DEFINITION

Shared walking and biking trails are paved with asphalt or concrete and are generally fully accessible. They are often developed to connect parks and natural areas as part of the regional trail system. These multi-modal, multi-use paths (MUPs) have width, slope, cross-slope, and curve radii to enable two-way pedestrian and bicycle travel at various speeds.

USERS

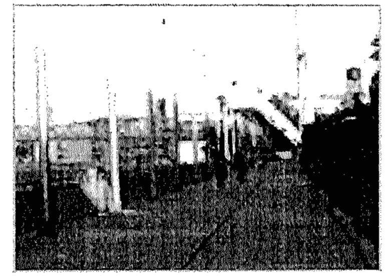
Walking and biking trails serve the greatest diversity of users: pedestrians, including those with fitness and balance limitations; cyclists, particularly those using road bikes; scooters; skateboards; rollerbladers; wheelchairs; and electronic mobility devices used by persons who need assistance to be mobile. People of all ages walk, run, ride, and roll to enjoy the environment, socialize, exercise, and access other parts of the community. Since user speeds can vary substantially, this trail type requires extra courtesy in sharing the trail.

Many existing park trail systems were not designed for bicycles, although cyclists often ride to parks and young riders may come to develop bicycling skills in the park. If a city bikeway is allowed to connect to existing park paths, it is important that commuting cyclists slow down. In some sites, park character, sight distance, trail width or pre-existing uses (playgrounds, playing fields, natural resource protection, off-leash dog areas) may be negatively impacted and the bikeway system should not connect to park trails. In other sites, adding new bike trails or widening existing walking trail may be needed.

MATERIALS

Walking and biking trails are generally paved asphalt or concrete. Trail width is based on projected use with a minimum expectation that two adults can walk side-by-side, or that a runner or cyclist can pass a walker.

Marine Drive Trail



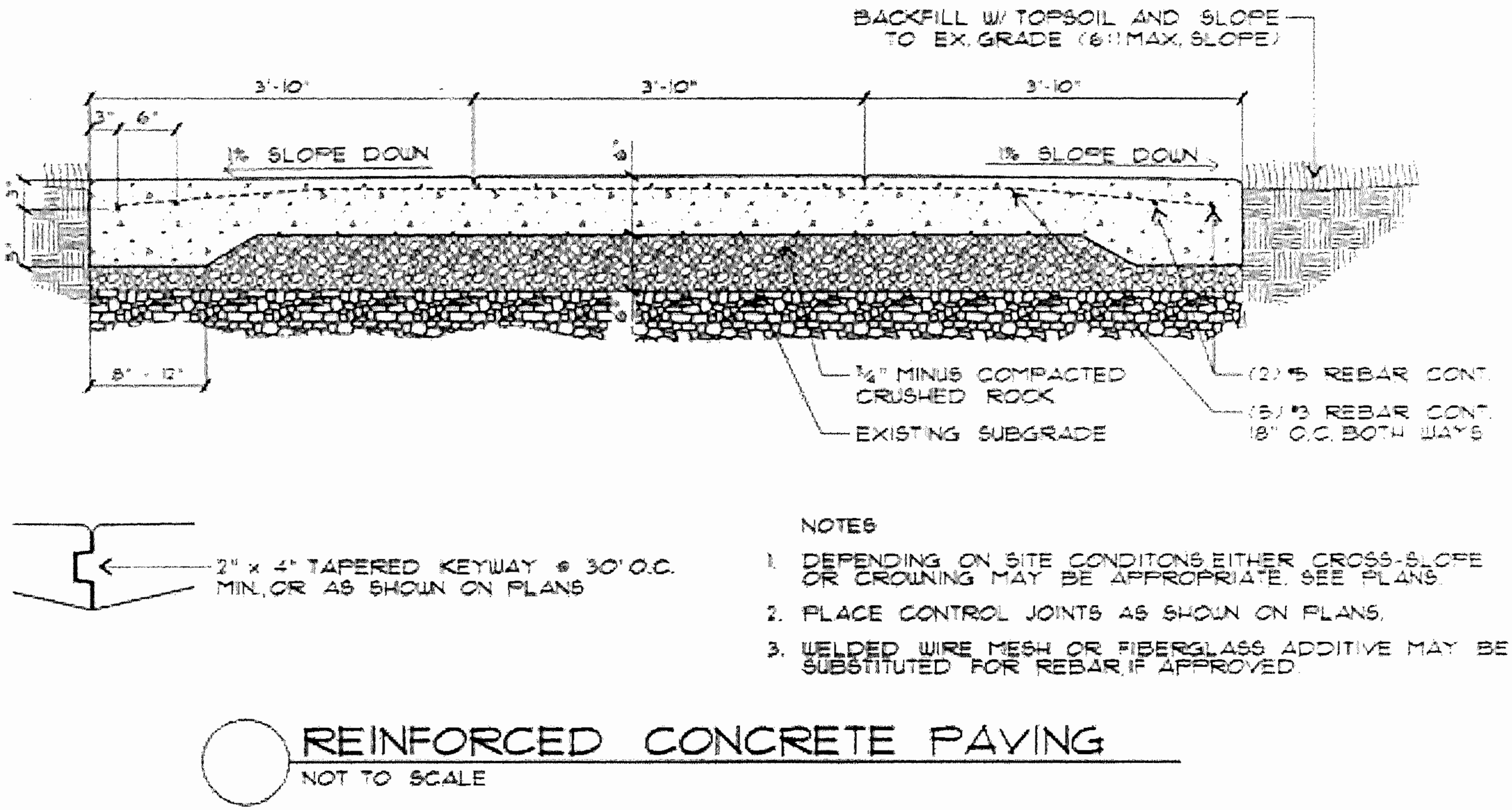
NW Willamette Greenway at Riverscape

Additional width is provided where the walking and biking trail is also used for maintenance access.

Sidewalks, bike lanes, and bicycle boulevards are in right-of-way, subject to PBOT guidelines (*Portland Pedestrian Design Guide* and City Engineer review). In some locations, PBOT has allowed trails in the park and away from the curb in order to improve the walking and cycling environment. These trails still need curb ramps and connections to sidewalks or road crossings in order to connect to the adjoining sidewalk and bikeway system.

Width	8' - 25' (Willamette Greenway esplanade) (prefer 10 - 12' for maintenance vehicles)
Surface	Gravel, asphalt, concrete
Longitudinal Slope	0 - 3% (to 5% if needed, 8% max.)
Cross-Slope	1%
Radius	Varies with design speed: prefer 12mph speed = 95'; 20 mph = 200' (if pedestrians use allows)
Sight Distance	150'
Easement Width	Tread + 10' min. or code requirement
Side Slope	Varies
Vertical Clearance	8' min (12' + under bridges)
Horizontal Clearance	1' from side of tread

Trail Type L – Walking & Biking



Also see Trail Types C, F and M and Trail Details: 03-Boardwalk, 04-Wood Bridge, 05-Wood Bridge with Railing, 07-Trail with Swale & Culvert, 08-Causeway, 09-Trail with Infiltration Trench, 10-Trail on Levee, 11-Soft-Surface Switchback on Levee, 13-Signs

Trail Type M – Walking, Biking & Equestrian

DEFINITION

Shared walking, biking, and equestrian trails are paved with asphalt or concrete and have gravel shoulders. The maximum longitudinal slope of 1 vertical to 20 horizontal (5%) is fully accessible. They are often developed to connect parks and natural areas as part of the regional trail system. These multi-modal, multi-use paths (MUPs) have width, slope, cross-slope, and curve radii to enable two-way pedestrian, bicycle, and equestrian travel at various speeds. Equestrians use either pavement or shoulder, typically using the trails in rural segments that have fewer road crossings.

USERS

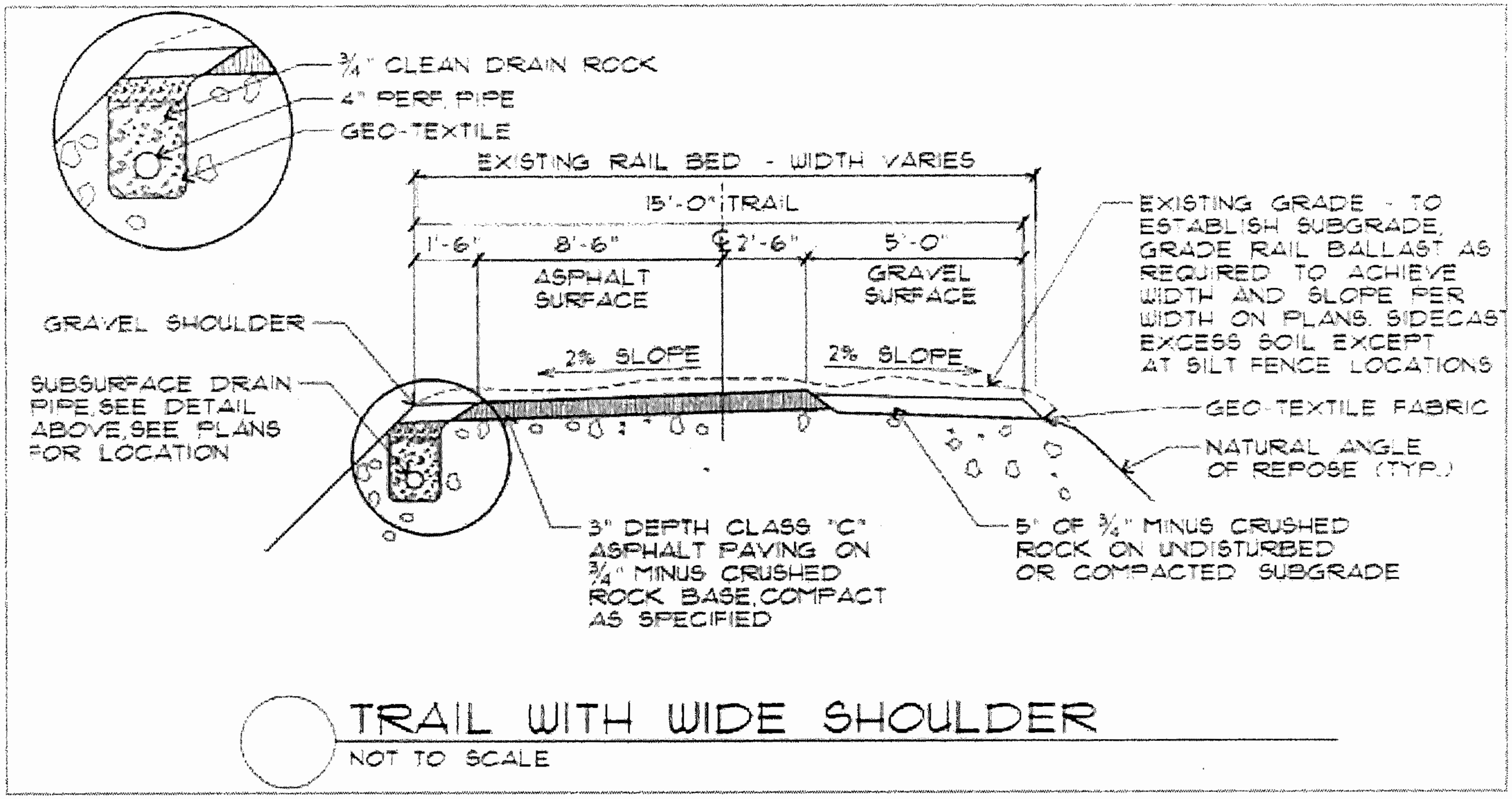
Walking, biking, and equestrian trails serve the greatest diversity of users: pedestrians, including those with fitness and balance limitations; cyclists, particular those using road bikes; scooters; skateboards; rollerbladers; wheelchairs and electric mobility devices used by persons who need assistance to be mobile; and equestrians. People of all ages walk, run, ride, and roll to enjoy the environment, socialize, exercise, and access other parts of the community. Since user speeds can vary substantially, this trail type requires extra courtesy in sharing the trail.

MATERIALS

Walking, biking, and equestrian trails are generally paved asphalt or concrete. Trail width is based on projected use with a minimum expectation that two adults can walk side-by-side, or that a runner or cyclist can pass a walker. Gravel shoulders on asphalt trails are used by equestrians, especially when at least one side is widened. Additional width is provided where the trail is also used for maintenance access. Special care should be taken to direct runoff (that may be contaminated by horse droppings) away from water bodies. Seasonal trail closures to mountain bikes and equestrians may be needed to prevent erosion.

Springwater between Palmblad and Rugg Roads - one gravel shoulder widened for equestrian and runner use

Width	8' - 25' (prefer 10 - 12' for maintenance vehicles)
Surface	Gravel, asphalt, concrete
Longitudinal Slope	0 - 3% (5% max.)
Cross-Slope	2%
Radius	Varies with design speed: prefer 12mph speed = 95'; 20 mph = 200' (if pedestrians and equestrian use allows)
Sight Distance	150'
Easement Width	Tread + 10' min. or code requirement
Side Slope	Varies
Vertical Clearance	11'
Horizontal Clearance	3' from side of tread, at least 3' high, then18" from side of tread above 3' high



Also see Trail Types C, F, and M and Trail Details: 03-Boardwalk, 04-Wood Bridge, 05-Wood Bridge with Railing, 07-Trail with Swale & Culvert, 08-Causeways, 09-Trail with Infiltration Trench, 13-Signs

Trail Type N – Fire & Maintenance

DEFINITION

Fire lanes and/or maintenance trails have surface, slope, and width for use by various vehicles. The goal is to provide maintenance and emergency access to parks and natural areas.

USERS

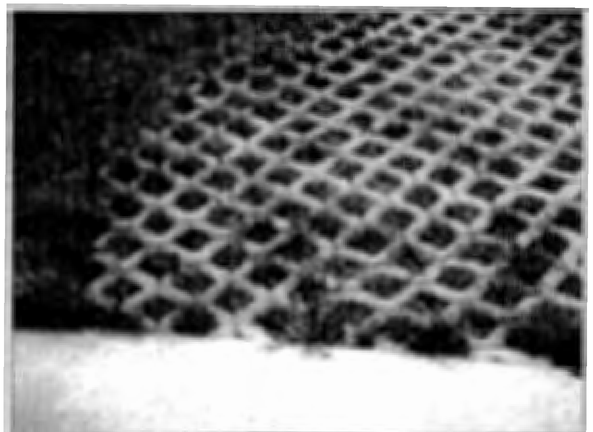
Although various walkers, runners, cyclists, and equestrians also use these trails, they are intended for park maintenance vehicles, fire trucks, and police cars.

MATERIALS

Materials vary depending on site and vehicles to be served. In some locations, crushed rock is added to native soil and compacted. In other locations, turf block (or similar concrete paver with openings) is used in order to minimize paving in turf areas but support vehicle loads. Asphalt and concrete roads for vehicles are not included in these *Trail Design Guidelines*.

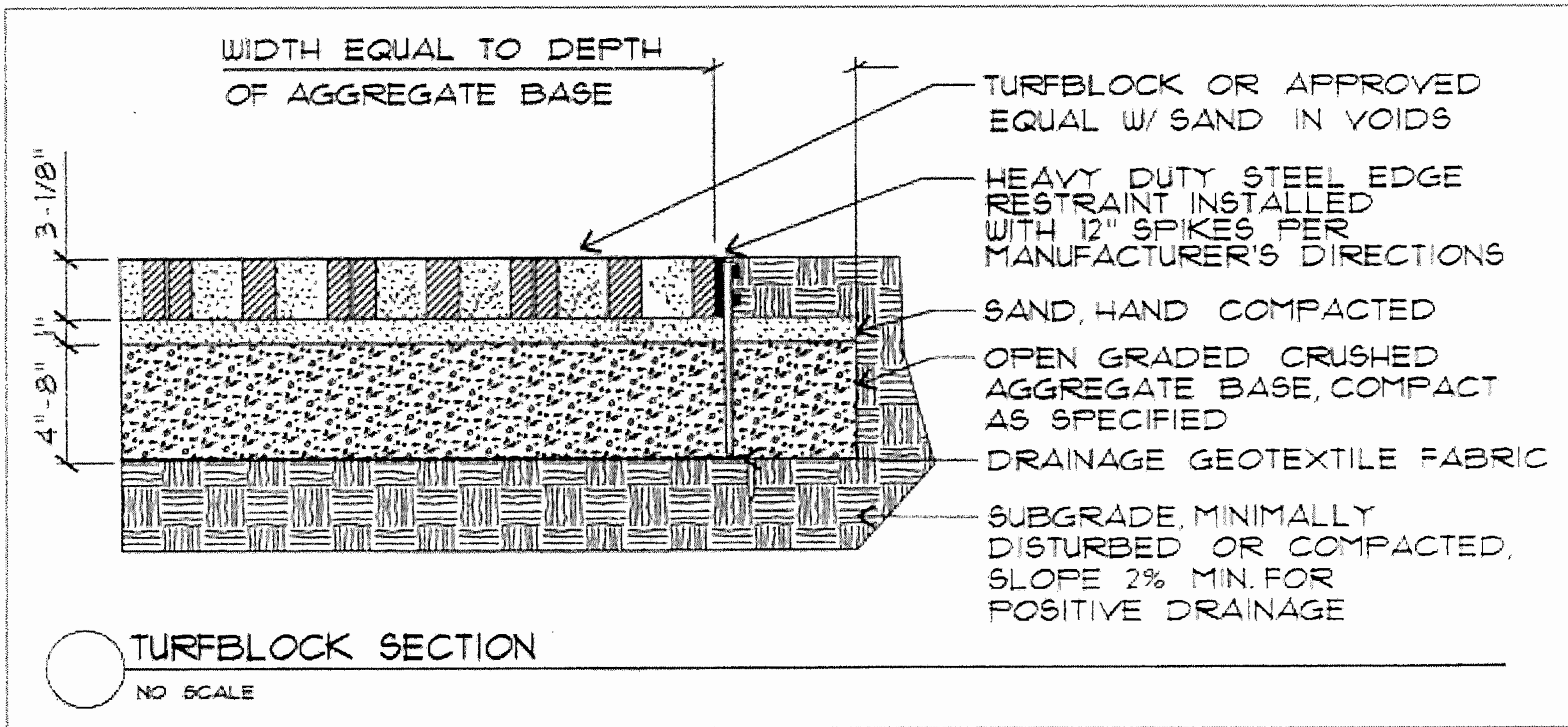
Width	10' - 14'
Surface	Gravel, turf block
Longitudinal Slope	0 - 5% (to 12% for fire lanes in hills)
Cross-Slope	2%
Radius	See table on vehicles on page 10
Sight Distance	50' min.
Easement Width	25' preferable, tread + 10' min.
Side Slope	Varies
Vertical Clearance	14' (20' above "deep" trash cans)
Horizontal Clearance	1' from side of tread

Forest Park - Leif Erikson near Ridge Trail



Concrete turf block used to provide maintenance access in Vancouver, B.C.

Trail Type N – Fire & Maintenance



Also see Trail Types C, F, and M and Trail Detail 13-Signs

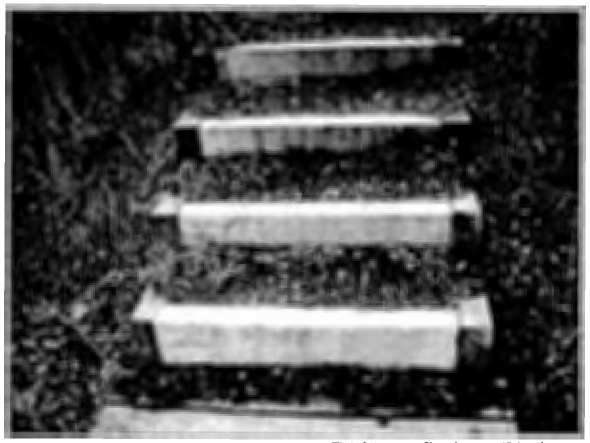
Trail Detail 01 – Cribbed Steps

CRIBBED STEPS

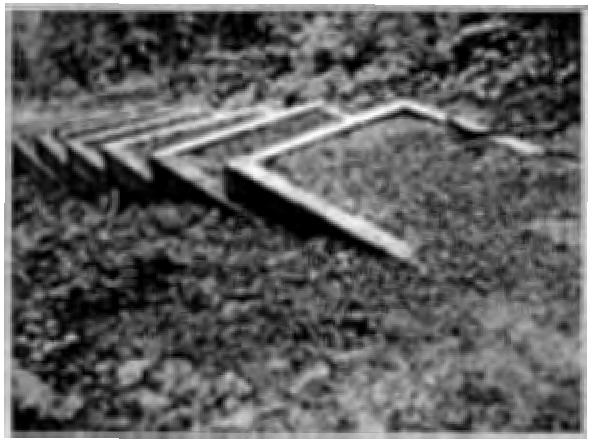
Cribbed stairs (that use 'cribbing,' a framework of wooden bars for support) are very stable and long lasting. They are more challenging to site and construct, fitting most easily into hillsides with consistent slope. This allows uniform riser and tread, improving safety.

There are several styles and a variety of materials for use in stairs. In general, steps are avoided if a longer, sloped route is possible. However, sometimes a more vertical route is needed to minimize the impact of a longer, sloped trail.

Steps and stairs should not be used on outdoor access routes and accessible trails. They can be used at the beginning of a trail to signal that trail is not accessible or is closed to bicycles and wheeled vehicles.

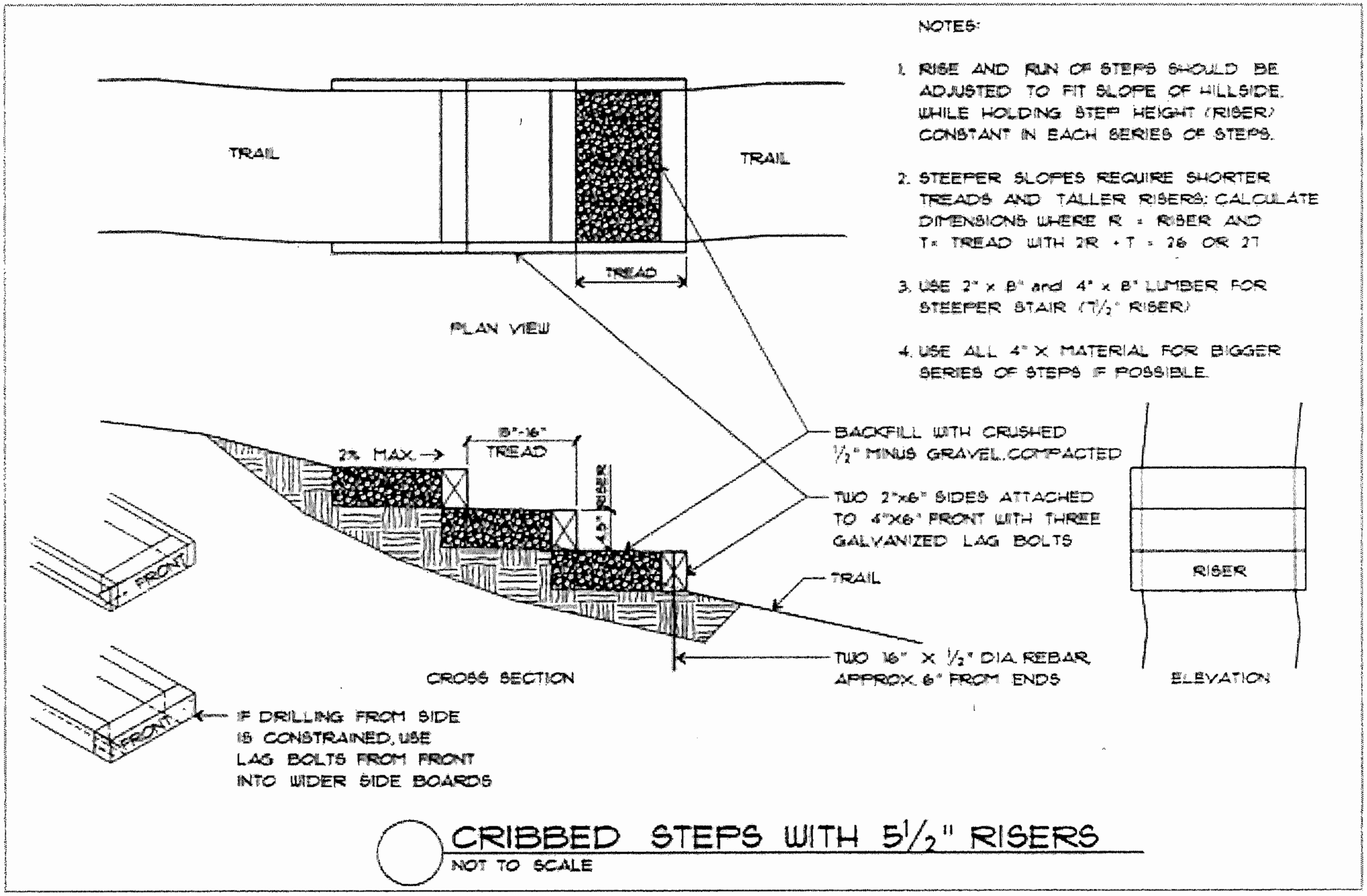


Dickinson Park - cribbed steps



Woods Memorial Park - cribbed steps under construction

Trail Detail 01 – Cribbed Steps



Trail Detail 02 – Timber Steps

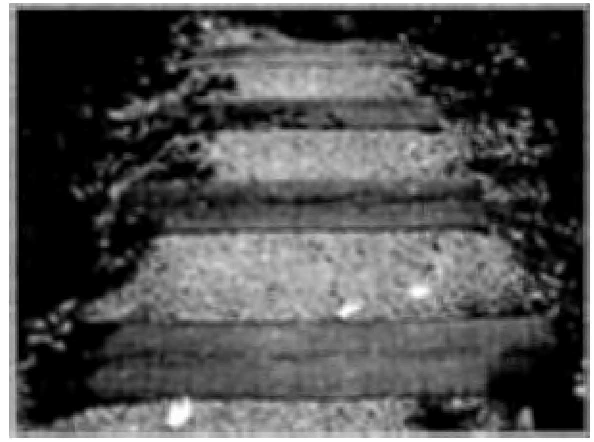
TIMBER STEPS

Timber steps are easier to build than cribbed steps. They may be more easily fitted into slopes that do not have a consistent slope. Although it is desirable to have consistent tread depths, timbers allow a consistent riser height and varying tread that can adjust to slope of the hillside.

Since the timber steps lack the side-boards of the cribbed steps, fill will tend to fall to the side and may create tripping hazards. This can be minimized by adding native soil or larger rocks at the sides of the backfill.

There are several styles and a variety of materials for stairs. In general, steps are avoided if a longer, sloped route is possible. Maintenance access with wheelbarrows is much easier on slopes than steps. However, sometimes a more vertical route is needed to minimize the impact of a longer, sloped trail or to discourage bicycles.

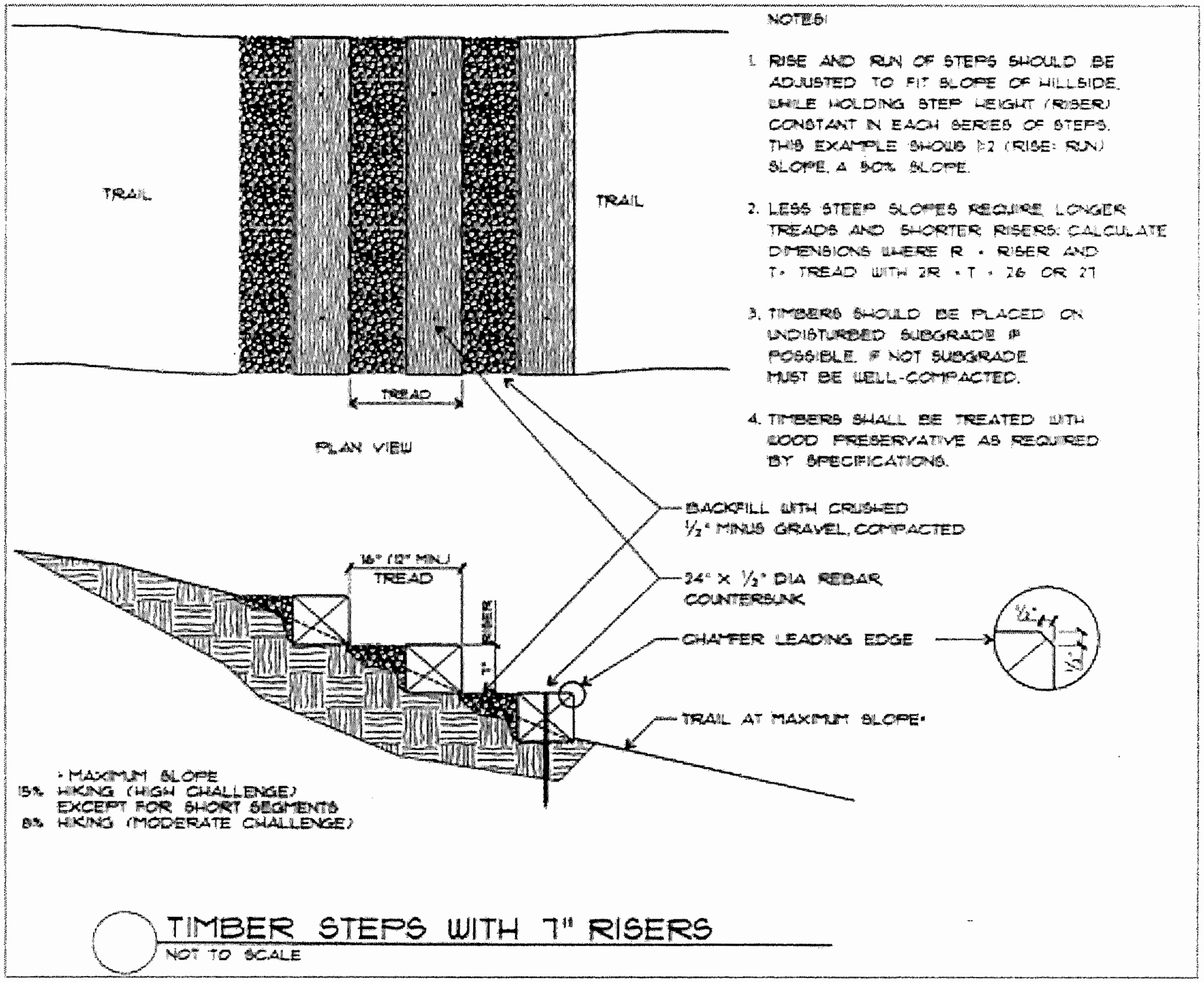
Steps and stairs should not be used on outdoor access routes and accessible trails. They can be used at the beginning of a trail to signal that trail is not accessible or is closed to bicycles and wheeled vehicles.



Raz-Baack crossing at Stephens Creek Nature Park - timber steps

Mt Tabor Park - timber steps

Trail Detail 02 – Timber Steps

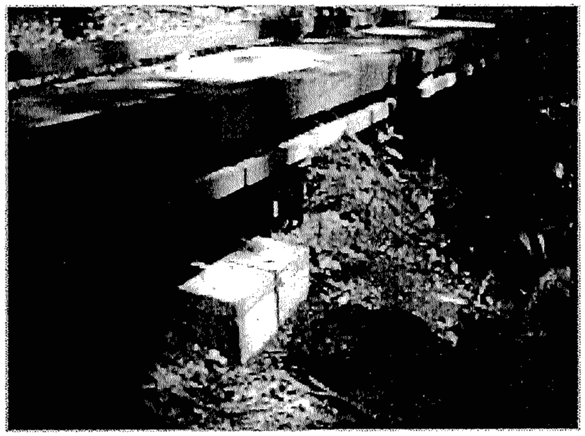


BOARDWALK

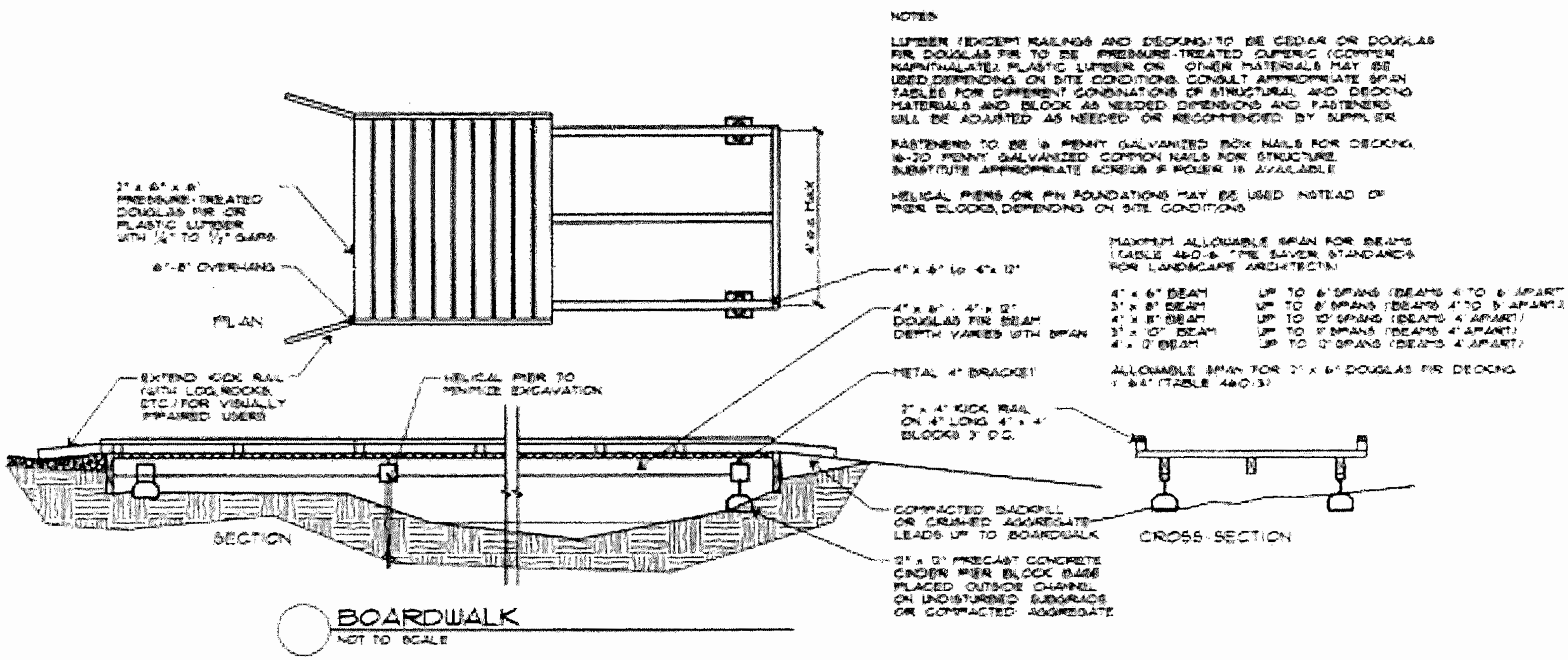
Boardwalks are used to span unavoidable wet areas or depressions. They also can be used to provide trail in areas where grading and filling might harm tree roots or create trail surface that wildlife such as amphibians will not cross. Footings vary depending on soil conditions. Plastic lumber is more expensive than wood but very long-lasting for deck boards. Its heavier weight can help avoid floating in sites that flood and the pronounced texture can reduce slippery surfaces. Check test results on new products to find the least slippery product and maintain as recommended.

Wood surfaces in shaded or moist sites may become slick or even grow moss. This can be managed by attaching 1/2" hardware cloth (wire mesh), especially where boardwalks follow creek grade. Fasten with 1 1/2" heavy-duty staples approximately 8 - 12" apart. Upper side of mesh should have wires perpendicular to direction of travel. Ends of hardware cloth should be tucked between deck boards or lapped over sides and stapled every 4 - 6". Paint with sand texture may also help, depending on site conditions. An annual cleaning (after autumn leaves fall) is recommended. A kick rail is particularly important along accessible trails where it helps people using canes or wheelchairs stay on the structure.

Raz-Baack crossing at Stephens Creek Nature Park - boardwalk with plastic lumber decking



Stephens Creek Nature Park - side view of boardwalk structure


NOTES
PLAN
SECTION
CROSS SECTION
METAL 4" BRACKET
BOARDWALK
NOT TO SCALE

Trail Detail 04 – Wood Bridge

WOOD BRIDGE

Bridging a small swale or ravine is often preferable to using a culvert, particularly in fish-bearing streams. This avoids the frequent maintenance needed to prevent culverts clogging with debris and associated damage if a culvert is blocked and water overtops the trail.

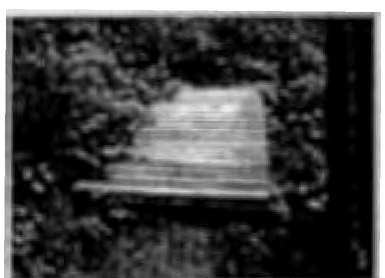
Bridges should be level and avoid a step up if the trail is intended to be accessible. Plastic lumber or wood may be used for the deck material. Spans greater than 10' should generally be engineered and may require site specific geotechnical work. The Cannon Trail Bridge design should be consulted for spans of 10' or more.

Wood surfaces in shaded or moist sites may become slick or even grow moss. This can be managed by attaching 1/2" hardware cloth (wire mesh) or painting with sand texture, depending on the site conditions. An annual cleaning (after autumn leaves fall) is recommended. [See Trail Detail 03 for guidance on using hardware cloth.]

Building codes require a guard rail if the fall distance is greater than 30" (Trail Detail 05).

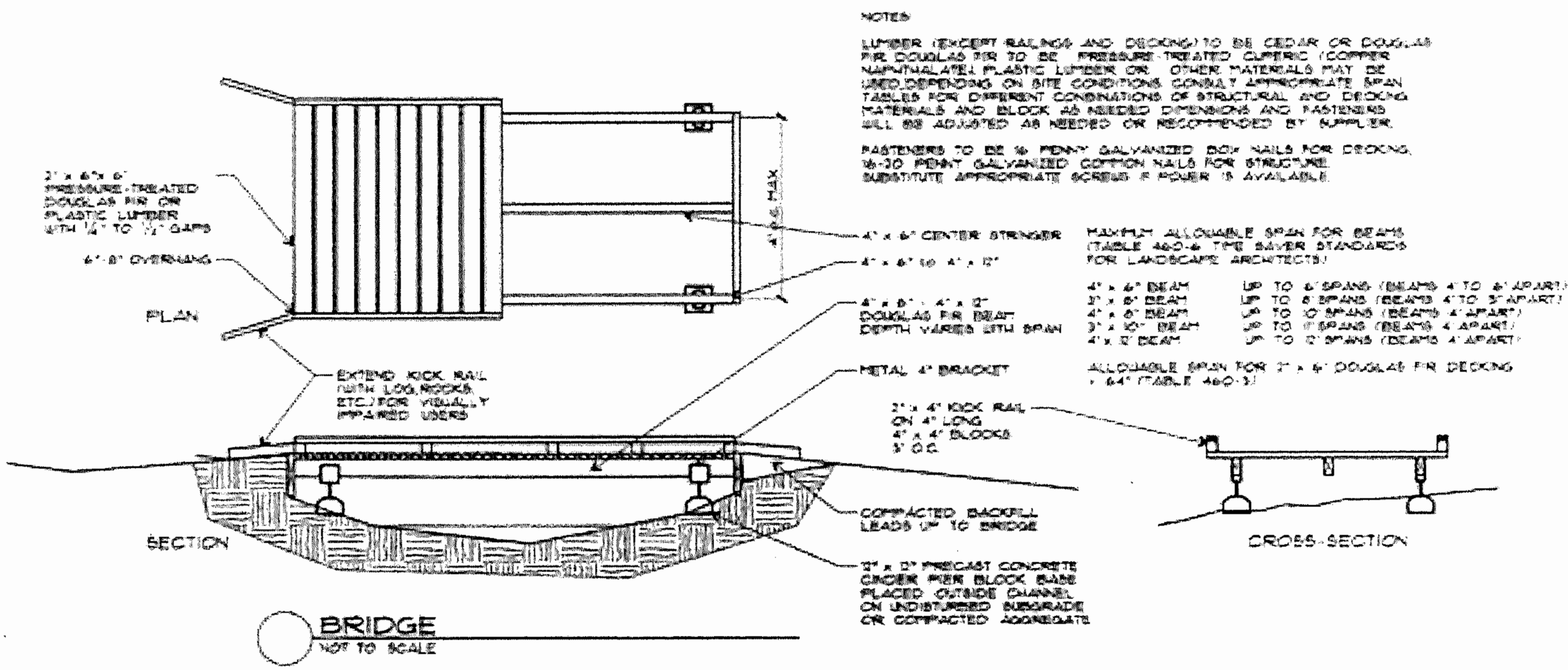
Forest Park Ridge Trail

Forest Park Ridge Trail



Woods Park SW Urban Trail #7 - step up limits accessibility

Raz-Baack crossing at Stephens Creek Nature Park - bridge pier block and beam


NOTES
4" x 6" CENTER STRINGER
METAL 4" BRACKET
PLAN
SECTION
CROSS-SECTION
COMPACTED BACKFILL LEADS UP TO BRIDGE
BRIDGE
NOT TO SCALE

Trail Detail 05 – Wood Bridge with Railing

WOOD BRIDGE WITH RAILING

The *2007 Oregon Structural Specialty Code* (Section 1013) requires a guard rail if fall distance is greater than 30". Guard rails should be at least 42" higher than the adjacent walking surface. Additional fall protection may be used at bridges that have high use or children.

Code specifies balusters (small posts that support the railing) such that a 4-inch-diameter sphere cannot pass through any opening up to a height of 34" and a sphere 8" in diameter at 34 - 42". In natural areas along low use trails, a second horizontal railing (that makes opening less than 21" wide) is sometimes used instead of balusters (1013.3 Opening limitations exception 3).

PP&R recommends more simple railings in remote, less used trails because railings are sometimes vandalized by rocking against the whole railing or jumping on individual pieces. Consult with the Environmental Protection Agency for current information on wood preservatives deemed safe for skin contact to be used on railings.

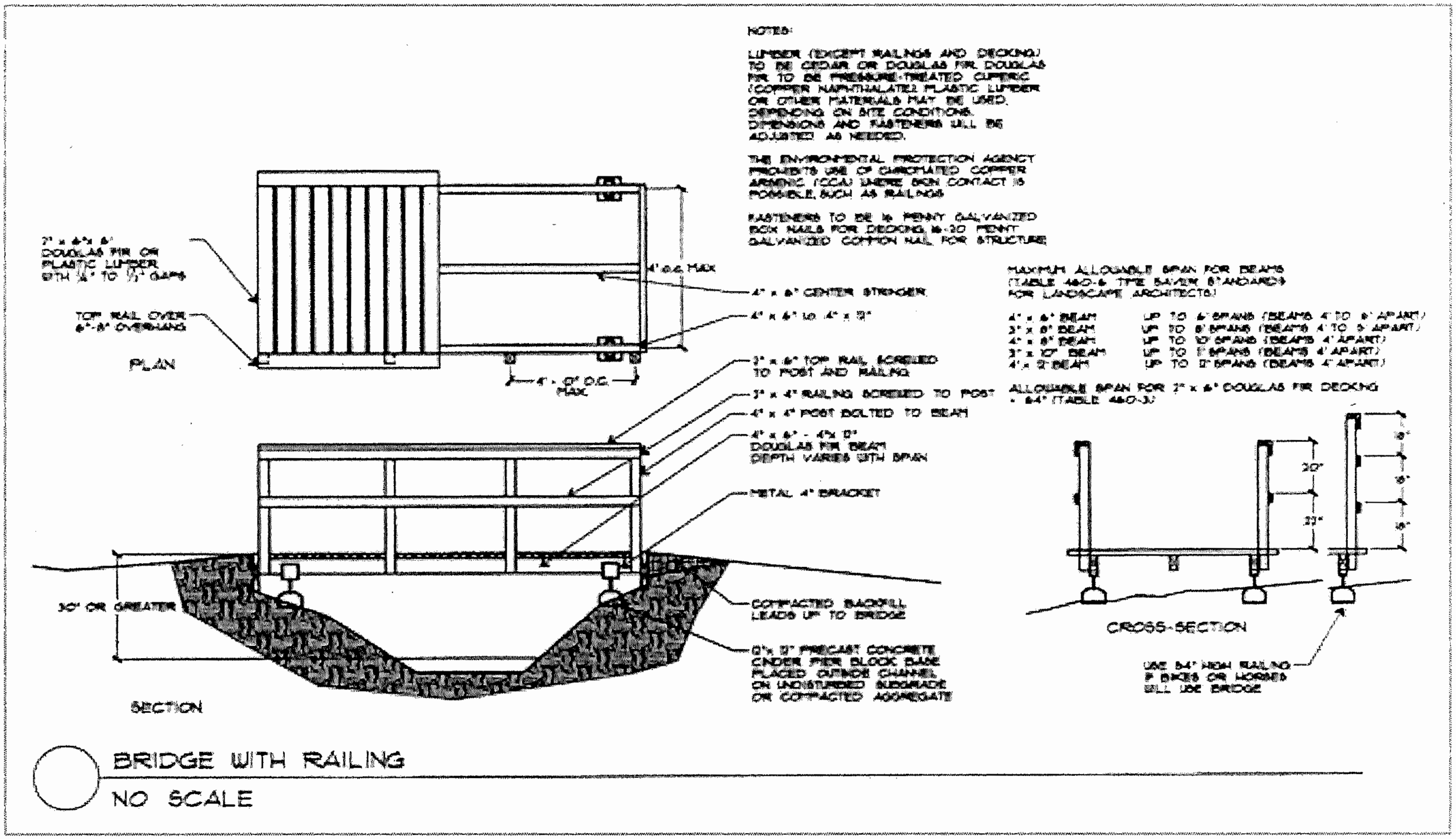
Spans greater than 10' should generally be engineered and may require site specific geotechnical work. The Cannon Trail Bridge design should be consulted for spans of 10' or more.

Wood surfaces in shaded or moist sites may become slick or even grow moss. This can be managed by attaching 1/2" hardware cloth (wire mesh) or painting with sand texture, depending on the site conditions. Fasten hardware cloth with 1 1/2" heavy-duty staples approximately 8 - 12" apart. Upper side of mesh should have wires perpendicular to direction of travel. Ends of hardware cloth should be tucked between deck boards or lapped over sides and stapled every 4 - 6". An annual cleaning (after autumn leaves fall) is recommended.

Horizontal railing on side of bridge with minimal fall hazard - Ridge Trail in Forest Park

Balch Creek bridge on Lower Macleay Trail in Forest Park (part of an accessible trail) has balusters to prevent falls into creek

Trail Detail 05 – Wood Bridge with Railing



Trail Detail 06 – Erosion Control at Bridge

EROSION CONTROL AT FENCE

Trail construction uses typical erosion control methods (silt fence, fiber rolls and wattles, mulch, surface roughening) and City of Portland standard details. In some instances, native groundcovers and duff in a forest setting are an existing 'vegetated buffer' as described in the Portland *Erosion and Sediment Control Manual.* The native groundcovers or mowed grass on the side slopes of levees also infiltrate runoff.

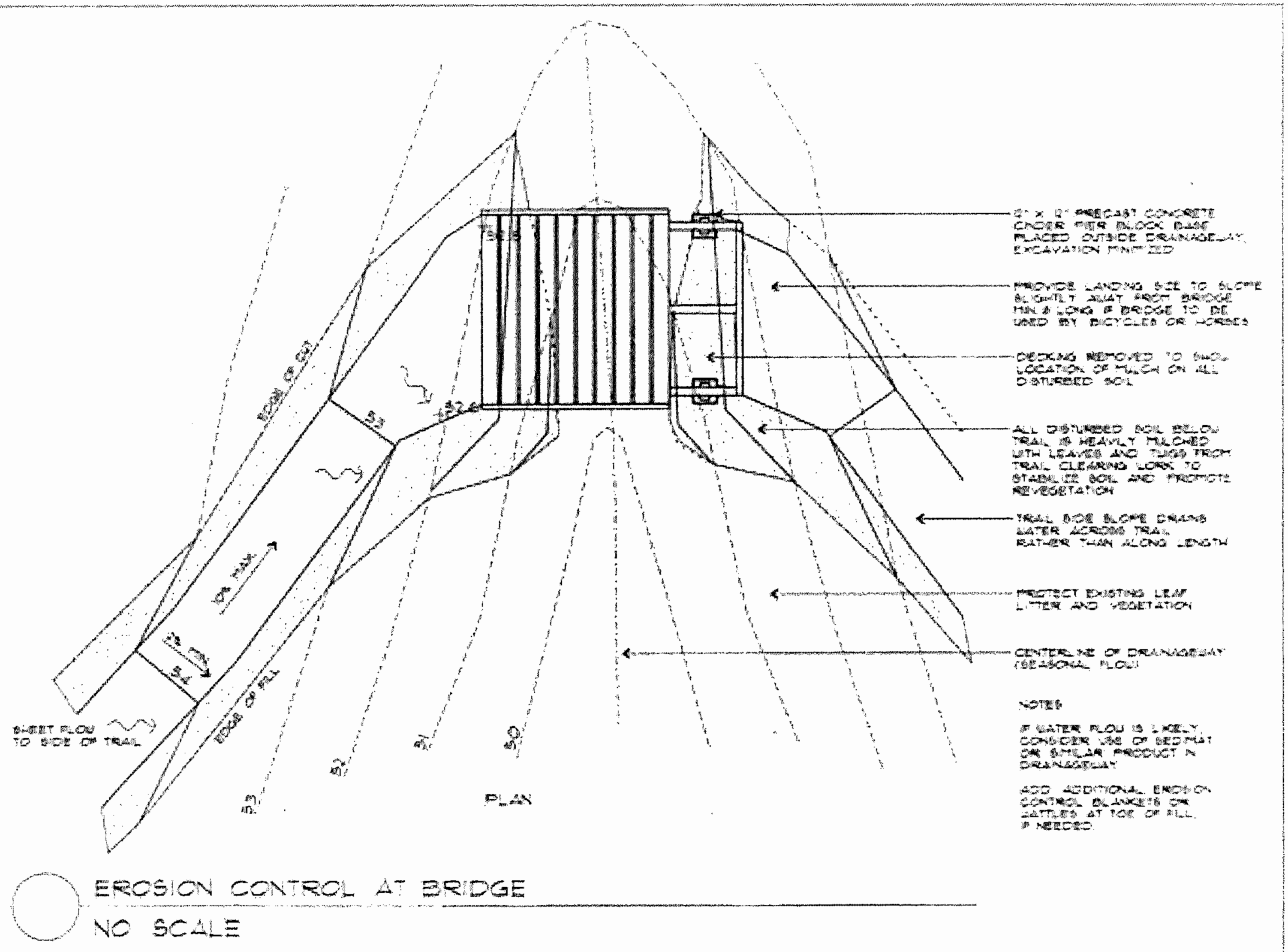
This detail supplements the Wood Bridge (Trail Detail 05) details. Additional erosion control methods will be added during the design process for sites with streams, but these techniques protect drainageways with small or infrequent flows.

Woods Memorial Natural Area - silt fence between Woods Creek and trail relocation farther from waterway

Silt fence at base of timber steps protecting Woods Creek

Woods Memorial Natural Area - straw wattles and mulch protect Woods Creek from restoration planting and trail improvements

Trail Detail 06 – Erosion Control at Bridge



TRAIL WITH SWALE AND CULVERT

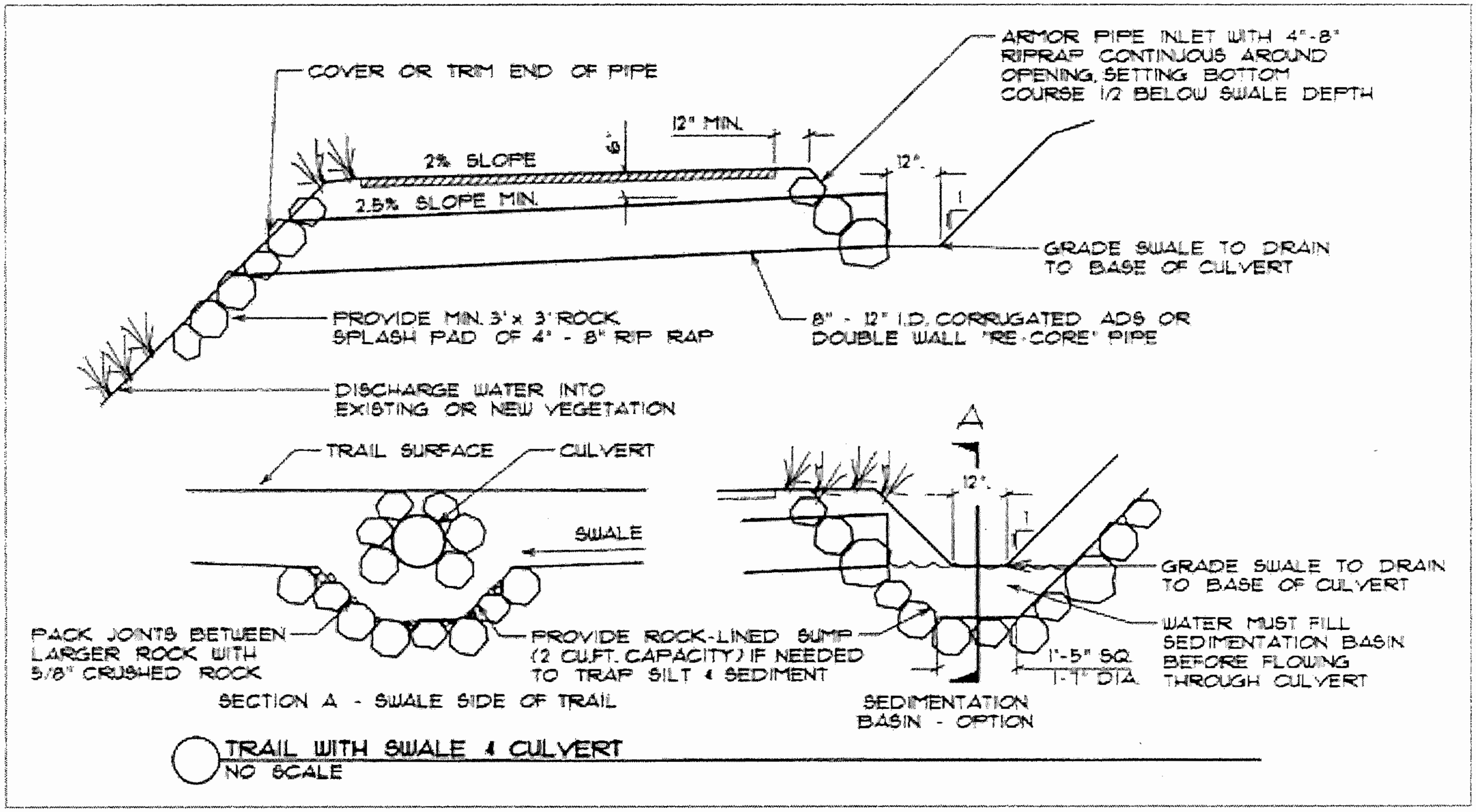
Trails built in hillsides often intercept runoff. Although cross-slope and rolling grade dips are often used to carry water over and off the trail, it can also be intercepted by a swale on the upper side of the trail. When the trail is paved and the adjacent cut bank may tend to slough on to trail, a swale and rock edge can support the toe of slope and collect runoff.

Connor Trail (from Marquam Nature Park to OHSU) - well-disguised culvert

Woods Memorial Park - hiking path (under construction), intercepting runoff in swale and piping under segment of causeway in poorly drained area near Woods Creek

SE 146 Ave connector path to Springwater Corridor (southwest of Powell Butte) right after installation - water in swale next to rail berm and trail flows through corrugated metal pipe, vegetation will grow and obscure pipe

Trail Detail 07 – Trail with Swale & Culvert



Trail Detail 08 – Causeway

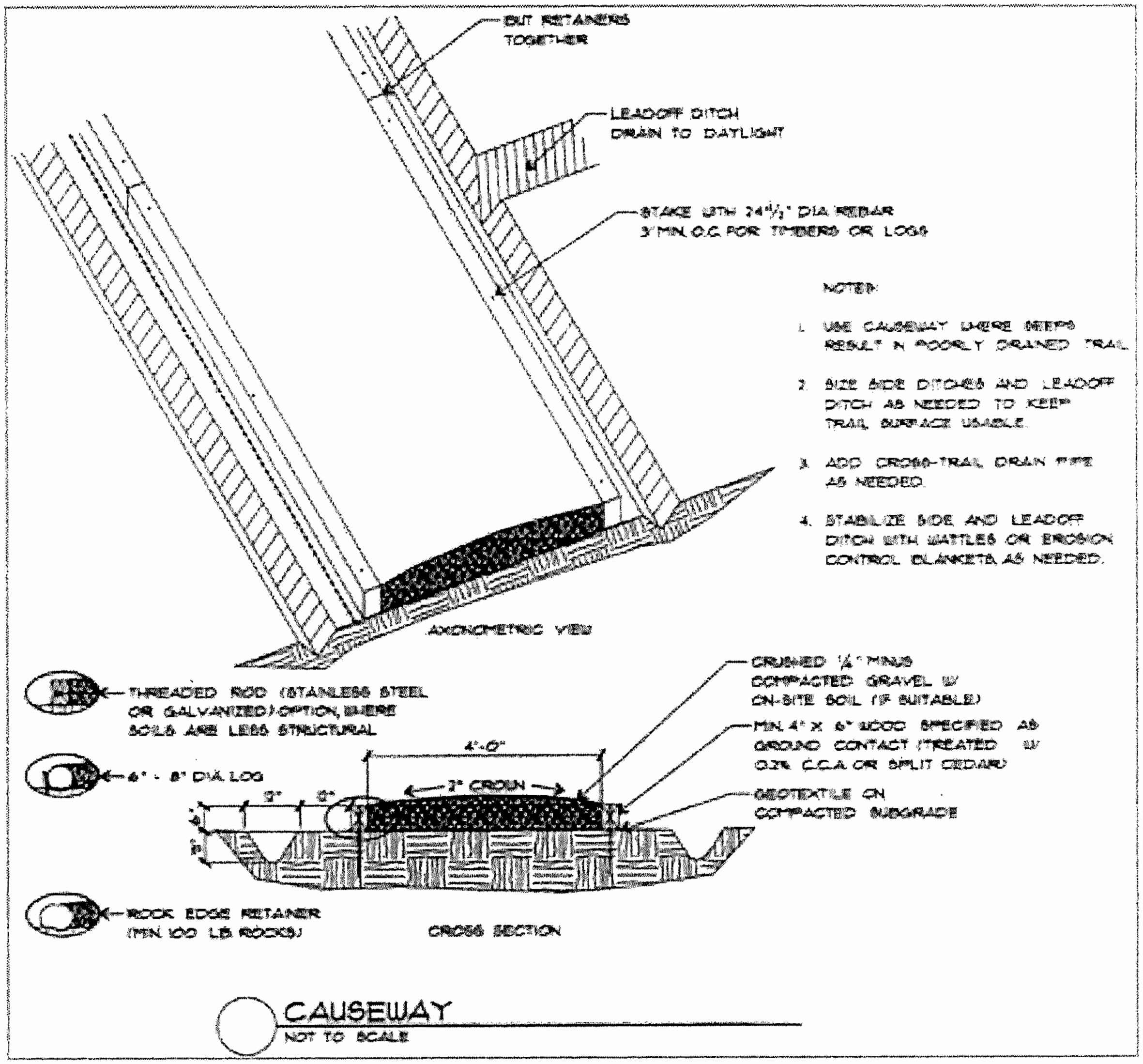
CAUSEWAY

Causeways are raised portions of trails that are useful in poorly drained soils or where seeps moisten soil tread. Adding rock and elevating the trail allow water to drain to the side and help avoid trails that are widened when users walk at edge of damp areas. Causeways are not intended for use crossing wetlands.

Wild Hawthorn Trail in Powell Butte - split cedar causeway and small drain pipe

Woods Memorial Park - causeway using 4" x 6" timbers (under construction with temporary metal fence to protect new plantings and prevent trampling of bank of Woods Creek)

Wild Hawthorn Trail in Powell Butte - cedar log causeway in level, poorly drained area near base of bluff


BUT RETAINERS TOGETHER
LEADOFF DITCH DRAIN TO DAYLIGHT
STAKE WITH 24"½" DIA REBAR 3' MIN. O.C. FOR TIMBERS OR LOGS
NOTES:
1. USE CAUSEWAY WHERE SEEPS RESULT IN POORLY DRAINED TRAIL
2. SIZE SIDE DITCHES AND LEADOFF DITCH AS NEEDED TO KEEP TRAIL SURFACE USABLE.
3. ADD CROSS-TRAIL DRAIN PIPE AS NEEDED.
4. STABILIZE SIDE AND LEADOFF DITCH WITH WATTLES OR EROSION CONTROL BLANKETS AS NEEDED.
AXONOMETRIC VIEW
THREADED ROD (STAINLESS STEEL OR GALVANIZED) OPTION, WHERE SOILS ARE LESS STRUCTURAL
6" - 8" DIA. LOG
ROCK EDGE RETAINER (MIN 100 LB ROCKS)
4'-0"
2" CROWN
CRUSHED ¼" MINUS COMPACTED GRAVEL W/ ON-SITE SOIL (IF SUITABLE)
MIN. 4" X 6" WOOD SPECIFIED AS GROUND CONTACT (TREATED W/ 0.2% C.C.A OR SPLIT CEDAR)
GEOTEXTILE ON COMPACTED SUBGRADE
CROSS SECTION
CAUSEWAY
NOT TO SCALE

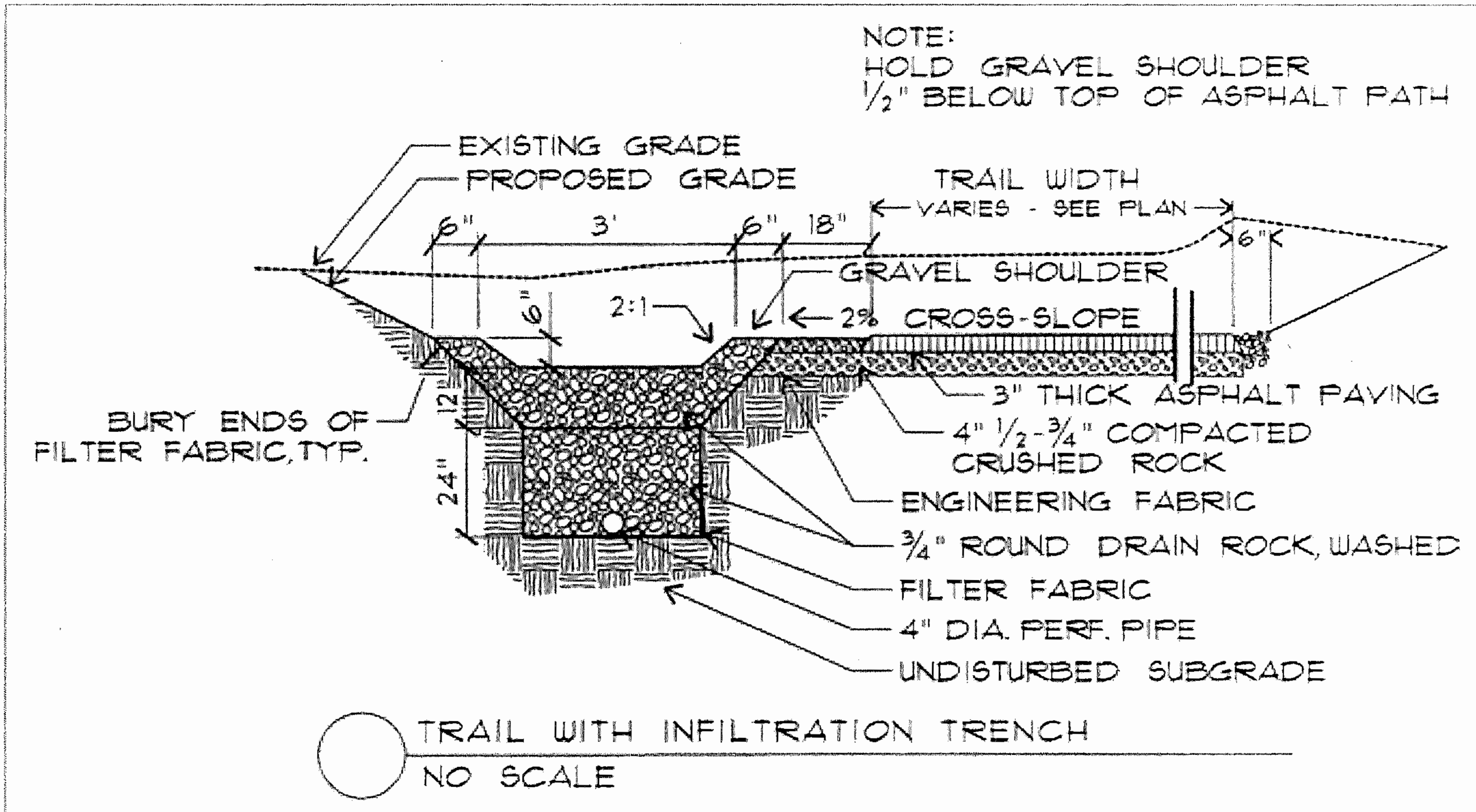
Trail Detail 09 – Trail with Infiltration Trench

TRAIL WITH INFILTRATION TRENCH

Trail materials are often impervious, whether constructed from compacted gravel, asphalt or concrete. Although porous asphalt and concrete are available, some subgrades of old railroad berms or gravel roads may not be pervious, so runoff will still drain to the side of the trail rather than infiltrate under the trail surface. The pores in porous paving are also vulnerable to clogging by dust and seed (often plentiful in natural areas). Unless equipment is available to vacuum particles from the pores, pervious pavement may not remain porous. Alternate ways to clean and infiltrate stormwater are desirable. Although many trails do get limited use by maintenance vehicles, the stormwater is much cleaner than from roads and parking lots. The narrow width of impervious area and linear nature of most trails mean bioswales and infiltration trenches are particularly easy to site. Trails on levees can also use the adjacent mowed grass slopes as biofiltration strips.

Oaks Bottom Connector at undercrossing to Springwater on the Willamette - infiltration trench on right side

Trail Detail 09 – Trail with Infiltration Trench



Trail Detail 10 – Trail on Levee

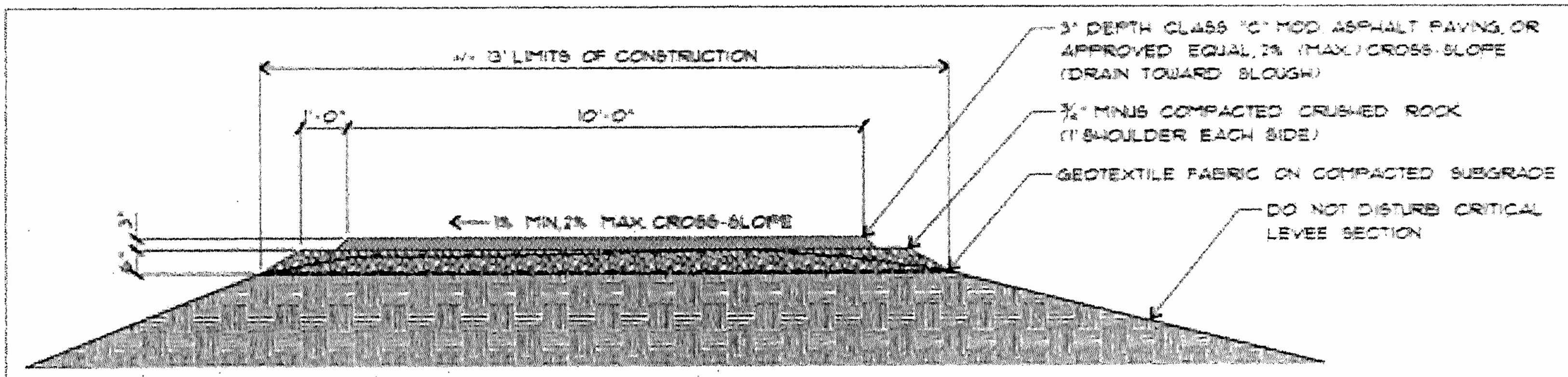
TRAIL ON LEVEE

Portions of the Marine Drive and Columbia Slough trails are placed on top of or on benches on flood control levees. The trail is often an upgrade to the route used to inspect and maintain the levee.

Site specific details are developed cooperatively with the drainage district staff. They can provide information on dimensions and location of 'critical levee section' and help secure project approval from the Army Corps of Engineers. In some locations, porous pavement, filling or special water quality features may be needed. The district staff also work closely with the landowners and can help with neighbors' concerns regarding trail design and management.

Marine Drive Trail near the airport - stormwater runoff from asphalt infiltrates on grassy side slopes

Columbia Slough Trail at PIR and Heron Lakes Golf Course - this segment is surfaced with chipseal, a product no longer used by PP&R due to its rough surface and lack of durability



TRAIL ON LEVEE

N.T.S.

NOTES:

1. Stake alignment, all curves to be smooth with gradual transitions. Limits of construction not to exceed +/- 13' wide.
2. Verify critical levee section with Peninsula Drainage District No 2 (PDD No. 2). DO NOT DISTURB CRITICAL LEVEE SECTION.
3. Excavate and remove existing topsoil (depth to be field verified). Maintain clean, crisp edges. Remove all organic materials. Limit disturbance area to the minimum. Alternate construction shall be approved by the City of Portland and PDD No. 2.
4. Level top of levee to provide uniform slope, grade and width. Recompact the existing subgrade to minimum 90% Standard Proctor. Notify Owner's Representative when subgrade is substantially complete in order to receive approval prior to placing crushed rock.
5. Treat subgrade with approved herbicide or alternate approved treatment.
6. Provide new, approved geotextile fabric under crushed rock in accordance with manufacturer's directions.
7. All materials and construction shall be per Portland Parks and Recreation specifications.
8. Install and maintain erosion prevention and sediment control measures per City of Portland standards.
9. All excess materials shall be placed in approved, designated areas as approved by the Peninsula Drainage District No. 2 and the City of Portland.

Trail Detail 11 – Soft-Surface Switchback on Levee

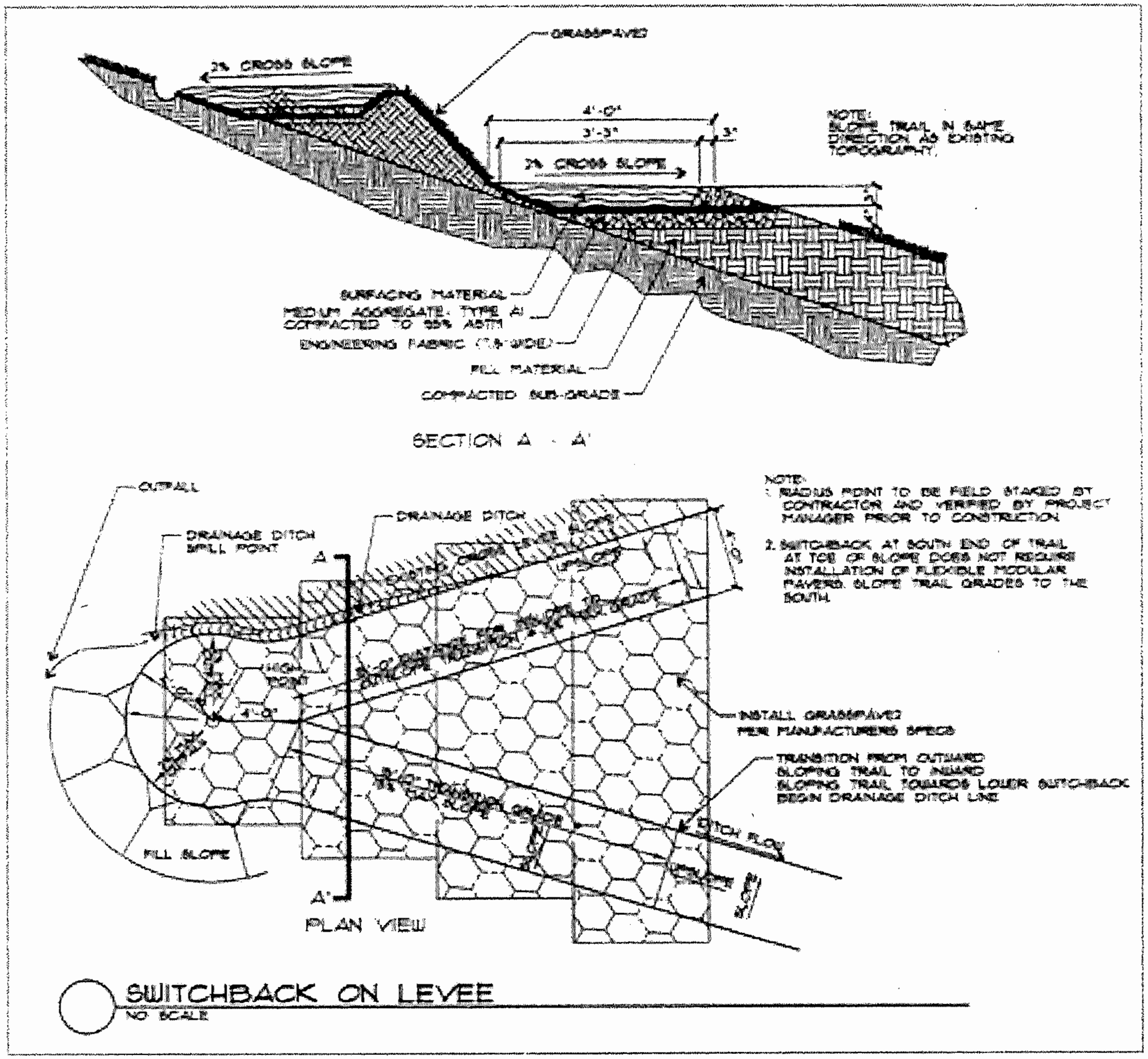
SWITCHBACK ON LEVEE

There are three cross-levees between and at right angles to the longer levees along the Columbia River and Columbia Slough. The cross-levees divide the protected area into sub-basins for additional flood protections. At approximately 30' feet height above adjacent land, they require a substantial climb for hikers or portage for those using water trails. The switchback is used to create a zig-zag up the hillside so that the top of portage is near (but above) the bottom of portage route.

This detail was developed for a portion of the Columbia Slough Trail that is constructed of wood chips. It can be adapted to other sites, preferably with more easily maintained materials.

Columbia Slough Trail switchback on west side of cross-levee - grass has grown so vigorously that grasspave material and swale are no longer visible

Trail Detail 11 – Soft Surface Switchback on Cross-Levee



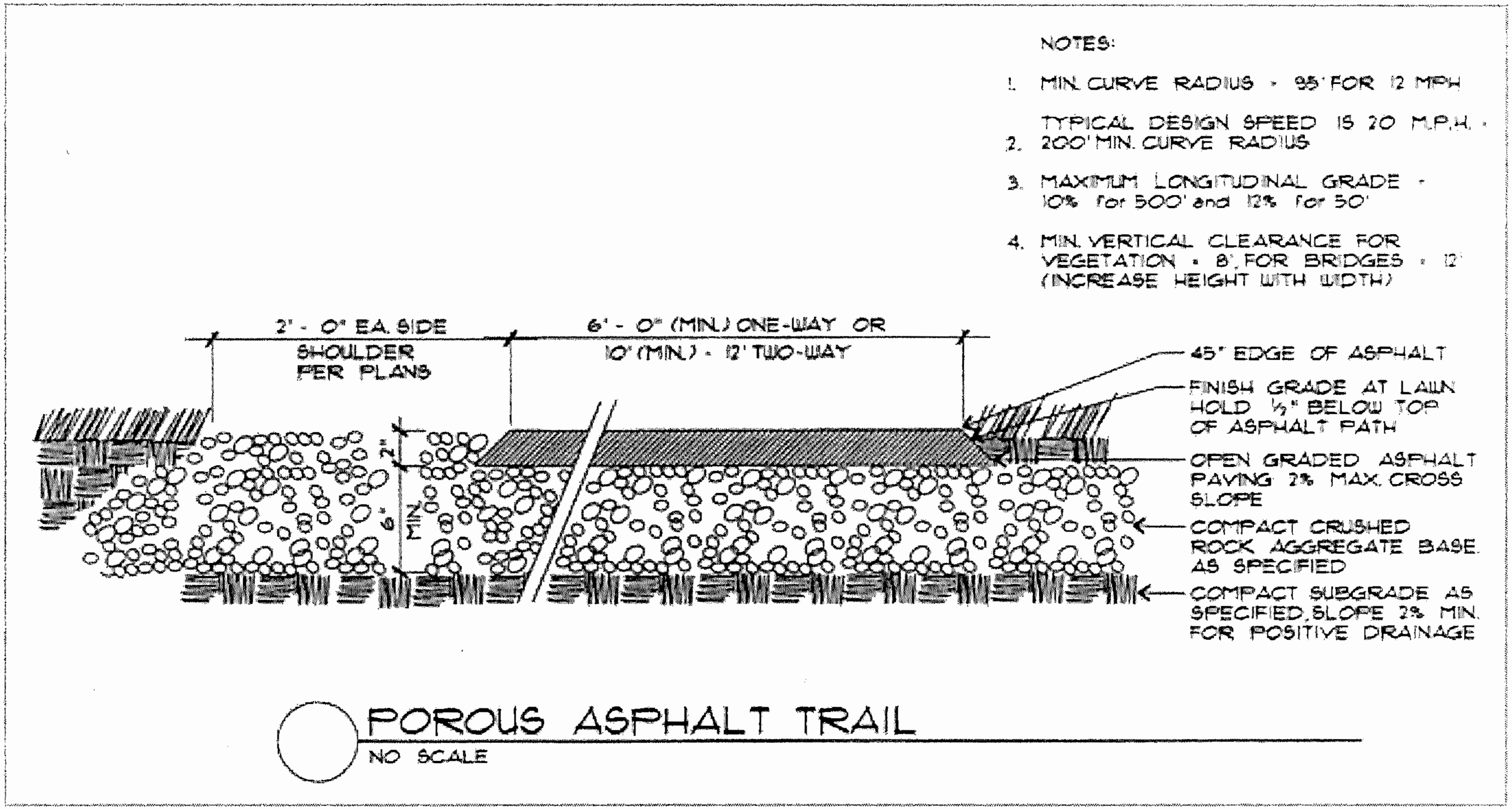
Trail Detail 12 – Porous Asphalt Trail

POROUS ASPHALT TRAIL

Asphalt is the most commonly used trail material in the PP&R system. It can be readily placed on slopes and curves. Porous asphalt is created by eliminating the smaller, graduated sizes of crushed rock and using a larger, uniform size. This results in a rougher surface that has open pores. If the pore space is maintained, water will seep through the trail, minimizing puddles and potential hydroplaning. This helps infiltrate stormwater through the trail if the existing subgrade is suitable. If the subgrade is too compact, it should be sloped so that water drains to an appropriate water quality treatment facility. Porous asphalt is not recommended for sites that flood or are likely to receive large amounts of seed that can clog the pores. The smoother surface of regular asphaltic concrete is preferred by rollerbladers and skateboarders.

Kelley Point Park - newly installed porous asphalt trail

Trail Detail 12 – Porous Asphalt Trail



SIGNS

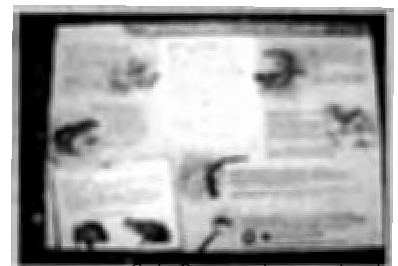
There are four basic types of signs: identity, wayfinding, regulatory, and interpretive. PP&R has a variety of trail signage plans that have been developed over the years. The *PP&R Signage Standards Manual* that was developed for park signage in 1998 did not fully incorporate the range of existing or needed trail signage. So the current practice is to apply individual sign plans (for 40-Mile Loop, Springwater Corridor, Powell Butte, Willamette Greenway, etc.) as needed. This helps with identity and wayfinding, but regulatory and interpretive signs are less methodical.

The overall intention is to minimize sign clutter. PBOT uses the Manual on Uniform Traffic Control Devices (MUTCD) and some locally devised directional signs and pavement markings in the public right-of-way. Although individual projects have developed accessibility signs to indicate higher level of challenge, a system similar to ski slopes with symbols for difficulty would be useful.

Columbia Slough Trail

Proposed pavement marking at Riverplace

Springwater Corridor



Oaks Bottom - interpretive sign

Powell Butte Nature Park

Marquam Nature Park

Forest Park

Springwater on the Willamette

Willamette Greenway

Trail Detail 13 – Signs

Slope caution

A.D.A. caution uphill


A.D.A. access

No bikes


Grooved pavement

Stay on path

Traffic caution

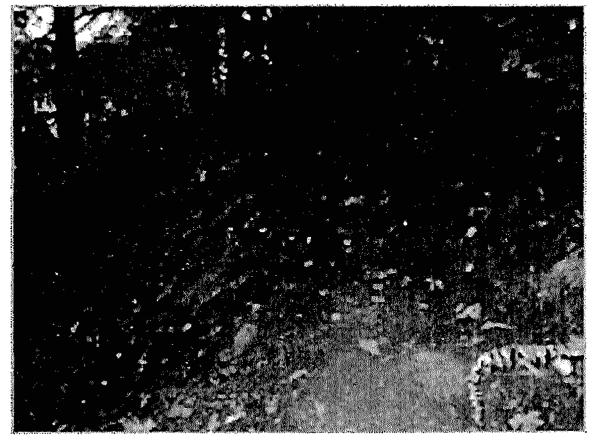
A.D.A. caution downhill

Trail Detail 14 – Alignment Tread Crests

ALIGNMENT TREAD CRESTS

'Rolling grade design' fits trails to topography so that water is shed to the side of the trail. It responds to small drainageways or ridges on hillside and individual trees as opportunities to create small trail watersheds. A rolling grade mixes short segments of downgrade into an ascending trail or vice versa. Depending on underlying topography, the trail may curve to the side to create dip or crest, or a straight alignment will form a dip or crest when it crosses even a small valley or ridge.

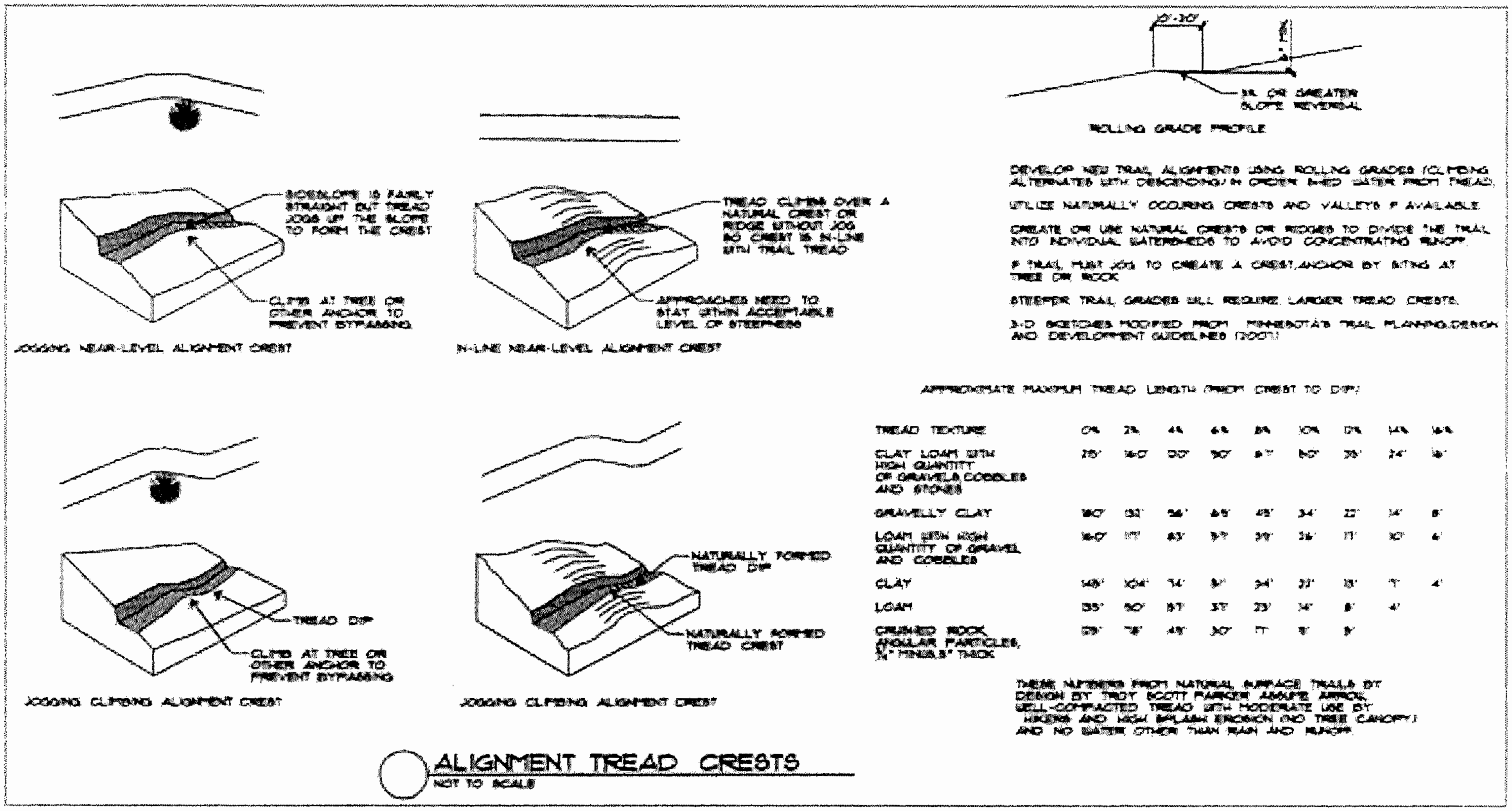
Although most trails drain to the side (cross-slope or outslope), alternating up and down grades will help prevent water flowing and potentially eroding long lengths of trail. Tread shape can change over time through soil compaction or displacement, but a rolling grade with adequately sized crests and dips will periodically force water flowing down the trail to drain to the side. Since the erosive force of water increases with slope and different soil types, distance between crests and dips will vary. Spacing can be increased with thick, evergreen tree canopy to intercept rainfall. Spacing should be decreased with higher amounts of trail use.



Connor Trail - rolling grade construction

Forest Park - Ridge Trail about three years after construction

Trail Detail 14 – Alignment Tread Crests



Also see Trail Detail 15-Alignment Tread Dips

Trail Detail 15 – Alignment Tread Dips

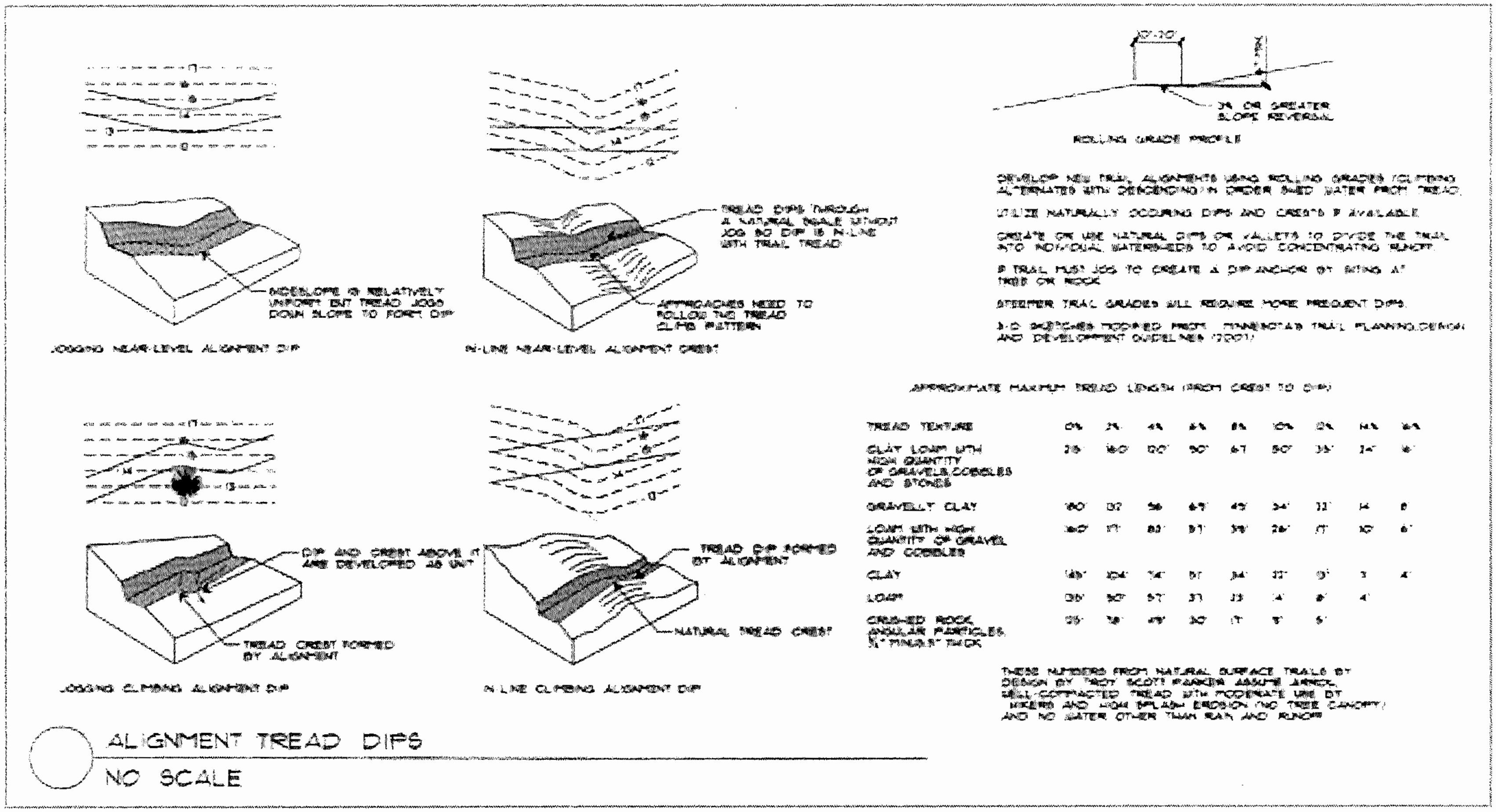
ALIGNMENT TREAD DIPS

'Rolling grade design' fits trails to topography so that water is shed to the side of the trail. It responds to small drainageways or ridges on hillside and individual trees as opportunities to create small trail watersheds. A rolling grade mixes short segments of downgrade into an ascending trail or vice versa. Depending on underlying topography, the trail may curve to the side to create dip or crest, or a straight alignment will form a dip or crest when it crosses even a small valley or ridge.

Although most trails drain to the side (cross-slope or outslope), alternating up and down grades will help prevent water flowing and potentially eroding long lengths of trail. Tread shape can change over time through soil compaction or displacement, but a rolling grade with adequately sized crests and dips will periodically force water flowing down the trail to drain to the side. Since the erosive force of water increases with slope and different soil types, distance between crests and dips will vary. Spacing can be increased with thick, evergreen tree canopy to intercept rainfall. Spacing should be decreased with higher amounts of trail use.

Connor Trail - rolling grade construction

Forest Park - Ridge Trail about three years after construction



Also see Trail Detail 14-Alignment Tread Crests

Trail Detail 16 – Removable Bollard

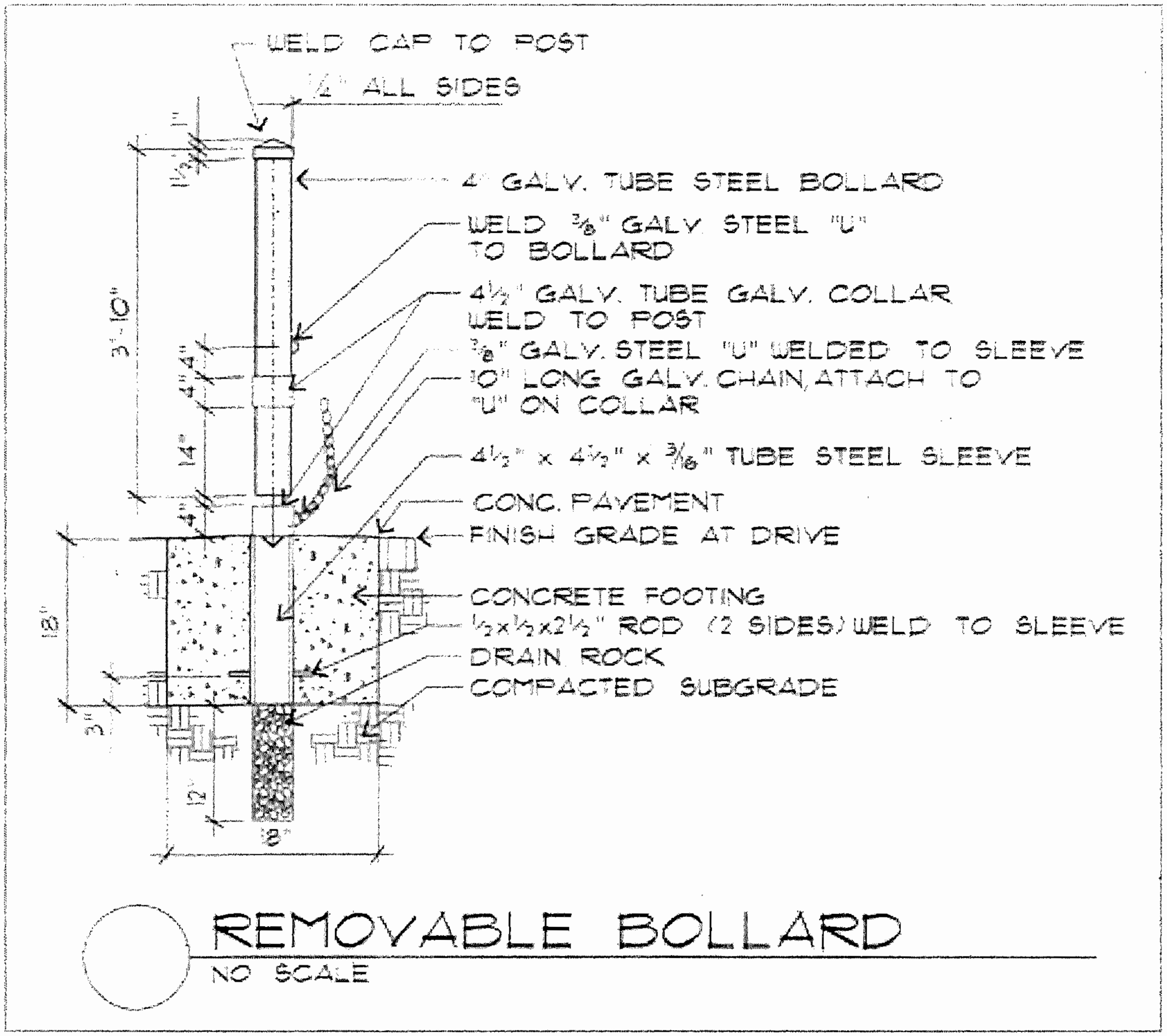
REMOVABLE BOLLARD

Bollards are used primarily to prevent unauthorized vehicular access to off-street trails. They can also warn trail users of vehicle crossings, identify the trail or cross-streets, and slow trail users near crossings. The removable bollard is placed in center of the trail and locked in place. The space between the fixed (side) and removable bollards is too narrow for vehicles but allows passage by pedestrian, cyclists, and horses. The PP&R design for the center, removable bollard has evolved over the years but still needs improvement. The weight has been reduced by using thinner metal but still needs revised security solution. The current design has a sleeve in the ground with hasp and chain. This base protrudes several inches above the trail surface and can trip users if the bollard is not replaced right after driving into trail. Alternate designs that are flush with the trail surface can fill with liquid and do not lock well.

Until the design is revised, one solution is to remove the center bollard in some trail segments that have frequent road crossings that slow down maintenance access. Signage allowing only authorized vehicles does seem to prevent illegal use of ODOT's I-205 trail.

Columbia Slough Trail near N. Portland Road - two of three bollards to control access

Trail Detail 16 – Removable Bollard



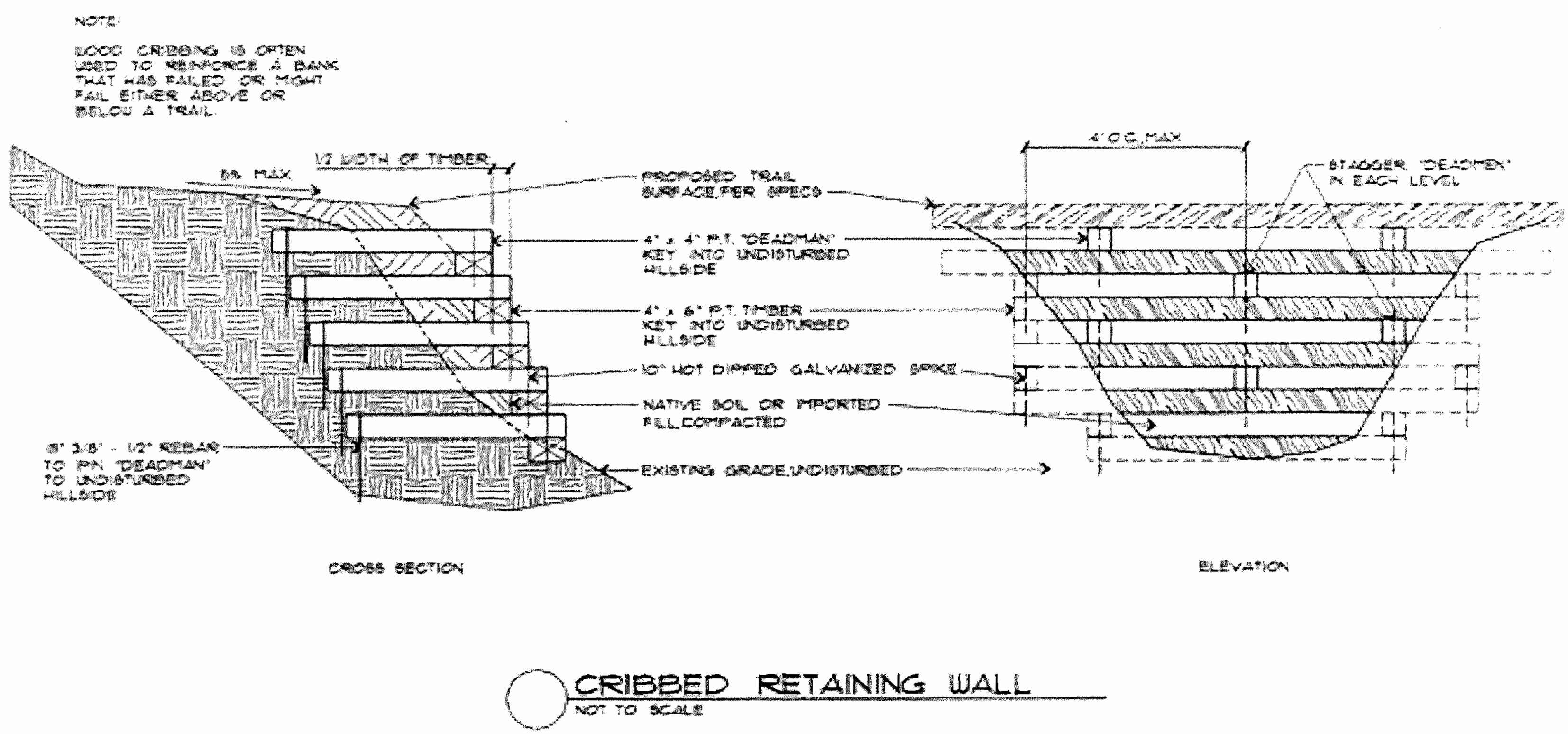
Trail Detail 17 – Cribbed Retaining Wall

CRIBBED RETAINING WALL

Cribbing is typically used if a segment of trail has failed or the side slope is steeper than desirable. The individual pieces are more portable than stone, minimizing the weight carried to sometimes remote areas along narrow trails. The 'deadmen' pieces that are perpendicular to the face of the wall must be keyed into undisturbed slope and securely fastened to the pieces parallel to edge of trail. The weight of soil on the 'deadman' helps secure the entire structure. The openness allows water to move through the wall without building up pressure or lubricating slide-prone soils.

Woods Memorial Natural Area - this cribbed retaining wall helped relocate trail away from edge of creek

Trail Detail 17 – Cribbed Retaining Wall



Appendix A – References

REFERENCES

2007 Oregon Structural Specialty Code (based on the *2006 International Building Code*), State of Oregon, January 2007

2020 Refinement Plan on Portland's Trails and Natural Areas, Portland Parks and Recreation, October 2003

40-Mile Loop Master Plan, David Evans and Associates, Inc., May 1983

Accessibility Guidelines for Outdoor Developed Areas: Final Report, Regulatory Negotiation Committee on Accessibility Guidelines for Outdoor Developed Areas, September 1999

Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities, Access Board, 2002

Americans with Disabilities Act Transition Plan, Bureau of Parks & Recreation, April 1993

Bicycle Master Plan: Making Bicycling an Integral Part of Daily Life in Portland, City of Portland Bureau of Transportation, May 1996

Columbia South Shore Slough Trail Masterplan: Staff Recommendations to City Council, Portland Parks and Recreation - Bureau of Planning - Portland Development Commission, July 2, 1993

Columbia South Shore Slough Trail Permit & Construction Handbook, Bureau of Planning, October 1995

Erosion and Sediment Control Manual, City of Portland, March 2008

Forty Mile Loop Signing Guidelines, Mayer/Reed, September 1991

[Forty Mile Loop] Trail Segment Sign Schedule, Mayer/Reed, September 1991

Green Trails: Guidelines for environmentally friendly trails, Metro, 2004

Oregon Statewide Comprehensive Outdoor Recreation Plan 2003-2007, Oregon Parks and Recreation Department

Oregon Trails 2005 - 2014: Non-Motorized Trails Plan, Oregon State Parks, February 2005

Parks 2020 Vision, Portland Parks and Recreation, July 2001

Parks 2020 Vision Appendix, Portland Parks and Recreation, July 2001

Portland Parks and Recreation Signage Standards Manual, Mayer/Reed, October 1998

Portland Pedestrian Design Guide, City of Portland Bureau of Transportation Engineering & Development Pedestrian Transportation Program, October 1998

Proposed Architectural Barriers Act Accessibility Guidelines for Outdoor Developed Areas [in *Federal Register*], Architectural and Transportation Barriers Compliance Board, June 2007

Revised DRAFT Public Rights-of-Way Accessibility Guidelines (*PROWAG*), U.S. Access Board, November 2005

Swan Island TMA Trails Action Plan: Connecting the Bluff to the Willamette River, Alta Planning + Design, January 2004

References

Springwater Corridor Master Plan, Portland Parks and Recreation, November 1992

Trail Planning, Design, and Development Guidelines: Shared Use Paved Trails, Natural Surface Trails, Winter-Use Trails, Bikeways, Minnesota Department of Natural Resources Trails and Waterways, 2006

Trails for the Twenty-First Century: Planning, Design, and Management Manual for Multi-Use Trails (Second Edition), Charles A. Flink, Kristine Olka and Robert M. Searns, Rails-to-Trails Conservancy, 2001

Trails Plan for the Tualatin Hills Park & Recreation District, Alta Planning + Design

Transportation System Plan, Portland Bureau of Transportation, October 2002

Standard Specifications for Construction of Trails, USDA Forest Service Engineering Staff, June 1984

Universal Access to Outdoor Recreation: A Design Guide, PLAE, Inc., 1993

USFS Trail Design Parameters, United States Department of Agriculture Forest Service, June 2002

Willamette Greenway Plan, Bureau of Planning, November 1987

Willamette Greenway Trail Signing Program, Mayer/Reed, December 1987

Effects of Sediment on the Aquatic Environment:

Potential NRCS Actions to Improve Aquatic Habitat - Working Paper No. 6

Janine Castro and Frank Reckendorf
Natural Resources Conservation Service
Oregon State University, Department of Geosciences

August 1995

Contents

Introduction
Historical Perspective
System Complexity
The Hillslopes
The Streams
The Lakes and Reservoirs
The Estuaries
Influence of Land Use
Conservation Management Systems
Concluding Remarks
References
The Effects of Fine Sediment on Aquatic Habitat: A Comprehensive Bibliography

Introduction

The issue of sediment in aquatic environments has been a topic of concern for many decades. During the nineteen-thirties, erosion became a national issue because of the dust bowl and as a result the Soil Erosion Service was established. Since the nineteen-thirties, the study of sediment erosion, transport, deposition, and intrusion has increased exponentially in the United States. Considering all of the past and current research, it is difficult to focus on essential research, but with limited resources it is imperative to refine the topics and prioritize the necessary areas of study. The same scoping is also true for treatment practices. The best and most effective treatment should be used on the most critical habitat. Establishing this systematic prioritization is a challenging but substantive endeavor.

Historical Perspective

One of the first well-distributed articles published was written by M.M. Ellis in 1936. Ellis covered many aspects of the effects of silt in aquatic systems, including light penetration, temperature adjustment, electrolytes, bottom conditions, and retention of organic matter. For sediment intrusion into streambeds, Ellis (1936) reported, from experimental data, very high mortality rates for freshwater mussels living in gravel-bedded or sand-bedded channels. These findings have been empirically supported by hundreds of subsequent studies. Only one study, written by Ward (1938a, 1938b), has refuted the effects of fine sediment on the health of aquatic ecosystems and this study has been heavily criticized in subsequent studies.

A substantiating study was conducted in 1943 by Shaw and Maga; this study investigated the effects of silt on the survival of salmon fry. The experiment was conducted in a flume with control groups. Salmon eggs were placed in nests and mining silt was introduced into the water supply periodically. Their results showed an average decrease of 64 percent in survival rates with a range of 80 percent to 16 percent. Subsequent studies were modeled after this laboratory experiment with very similar results.

The nineteen-fifties brought more experiments on survival rates. Land-use effects were being considered with an emphasis on logging. That approach refined previous knowledge but did not propose treatments for excess sediment in aquatic systems. Logging was still relatively unrestricted and economic concerns were a priority over the environment.

The nineteen-sixties resulted in more research and the idea of watershed management related to aquatic health was extensively explored. Many pioneers in the field -- such as McNeil, Shapely, Phillips, Platts, Bjornn, and others -- were establishing themselves as the experts. Since there is now such a large volume of material available, this paper will emphasize the review of theories, concepts, and established practices that are representative of the field as a whole. This methodology, although expedient, will most certainly leave out some pertinent information and practices. The attached bibliography (Appendix: The Effects of Fine Sediment on Aquatic Habitat: A Comprehensive Bibliography) should be consulted as a more thorough representation of where this field of study has gone and is going.

A trend which is apparent in the literature, when it is reviewed chronologically, is that of scale. Older studies (pre-1950) have more of a watershed or system approach. As studies progressed through the decades the system emphasis was lost to specialized studies for very specific areas. Specialized studies are important because they provide quantitative data, but it is important to relate this information to the larger system, whether it is a stream, watershed, or continent.

System Complexity

There are many problems associated with sediment in the aquatic environment and difficulties with the study of aquatic systems. They are complex interactive systems. Isolation of sedimentation effects on an aquatic system has not been effectively accomplished and is probably not a reasonable expectation for research in a natural interactive and responsive system. Many studies have been conducted in laboratories, but questions can be raised as to their applicability to natural systems.

Many laboratory studies of sediment intrusion have used mono-modal or simplified gravel mixtures. Some researchers have determined that a certain size class (often d50 or d84) is the most representative or critical of the particle size distribution. This leads to experiments utilizing mono-modal sizes and eliminates mitigating or aggravating factors that are not accounted for in the laboratory (Everest et al. 1987). Mitigating factors may be a local increase in velocity or shear stress to offset an increase in sediment input, while aggravating factors would be a decrease in velocity or shear stress.

Another important limitation is combined or cumulative effects. Sedimentation does not usually spontaneously start increasing in a system; there are reasons for increased sedimentation. On occasion there are natural system changes such as volcanic eruptions or earthquakes that cause debris flows, mud flows, and landslides, or human activities such as clear cuts that cause sudden mass movement. However, most sediment increases are gradual and are caused by changes such as land management, instream alterations, or short-term climatic events. In assessing sedimentation, evaluation of environmental change will help to identify other factors such as precipitation, discharge, shear stress, or a change in channel planform or geometry that may also accompany the sedimentation changes.

An increase in fine sediment in gravel-bed streams has been interpreted by fishery biologists as having an adverse effect on fisheries. Opinions vary as to the upper limit of the fines interpreted to have adverse effects, but particle diameters less than 6.3 mm are generally defined as fine sediment (King and Potyondy 1993). An overall decrease in fine sediment accumulation is not conclusive evidence that a system is healthy or "recovered." Fine sediment has a negative connotation because it is usually associated with the degradation of a fish population, but this sediment is a crucial part of an ecosystem. Because sediment is connected with degradation it is often assumed that "less is better," but this may not be the case. Some aquatic systems may function with high background levels of fine sediment. It is when the system is either aggrading or degrading at an accelerated rate that the sediment is usually a problem, and we should be clear whether the change is natural or human-induced.

The study of the effects of sediment is distorted when fishery habitats are managed for a single species because of its dollar value. This past orientation has caused the emphasis of the effects of fine sediment to be placed on fish and away from the effects of sediment on stream morphology and habitat structure. It may be argued that salmonids are the most sensitive fish indicators of sediment in an aquatic system, but the other organisms have not had the advantage of in-depth research and experimentation to reveal their responses. From an ecosystem perspective, we must still deal with the long-term, very real problem of excess sediment in aquatic ecosystems and the effects on aquatic habitat.

The Hillslopes

An appropriate place to begin when discussing sedimentation is at its source. Sheet & rill, gully, and ephemeral gully erosion from hillslopes are the major source of most sediment introduced into stream channels. Exceptions to this are where sediment is substantially produced by landslides, debris flows, streambanks, irrigation, and roadsides. The hillslopes are the portions of the landscape that are zones of sediment production. The movement of sediment from the hillslopes may be transport and/or supply (weathering) limited.

The most effective way to deal with the accumulation of fine sediment in aquatic habitats is to stop the excess at its source. This is feasible only for the sediment derived from accelerated erosion. If the degree of erosion has progressed too far (e.g. like gully headcuts), then accelerated erosion requires stabilization and revegetation of slopes and possibly other measures. Timing of agriculture, forestry, and construction operations with weather patterns and maintaining at least minimal levels of residual plant material on the ground are important for reducing sediment delivery to stream channels.

The Natural Resources Conservation Service, when working on sediment quantity and quality problems, should initially recognize and delineate the erosion source of sediment and establish sediment delivery rates for each type of erosion. The rate of background erosion, that which occurs in the undisturbed system, should also be determined because this will become the target goal for restoration success. If the sediment problem is severe, then instream restoration can also be addressed. If the problem is not or cannot be corrected in the water-shed, then treating the instream symptoms will be an ongoing and costly exercise.

The Streams

Once sediment has been delivered from the hillslope to the valleys and associated channels, it becomes a fluvial problem. Several issues should be addressed: (1) natural watershed sediment yield; (2) temporary versus chronic sediment problems; (3) temporary problems such as construction sites; (4) separable sediment effects (see Table 1) and quantification of these effects, which could include capitalized benefits for any proposed treatment; (5) sediment's cumulative effects and quantification of these effects; and (6) potential ways to reduce the sediment for each type of effect and comparing their effects and potential treatment cost in the action and nonaction condition. Correcting instream problems may require treating some of the other sediment problems (Table 1) as well as the stream problems. This may require spot treatment or significant channel alteration that results in short-term habitat loss. The scale of the project, both spatial and temporal, needs to be addressed.

Table 1. Types of effects from sediment delivery to soil, water, and air

I. Soil Resource (referring to consideration on land)
    A. Deposition -- Resource Consideration
        Identifiable or Predictable Problems
        1. Sediment deposition causing land damage (e.g., need to rework ground because of sediment thickness or distribution, or crop loss), on-site or off-site.
        2. Sediment deposition on roads, railroads, or bridges, causing safety problems for transportation, on-site or off-site.

II. Water Resource
    A. Water Quantity -- Resource Consideration
        Identifiable or Predictable Problems
        1. Restricted capacity from sediment deposition in small conveyances (drainage ditches, road ditches, culverts, and canals), on-site and off-site.
        2. Restricted capacity from sediment deposition in streams and lakes, on-site and off-site.
    B. Surface Water Quality -- Resource Consideration
        Identifiable or Predictable Problems
        1. Suspended sediment and turbidity.
        2. Suspended sediment or bed material having adsorbed pesticides and nutrients.
        3. Degradation of aquatic habitat for preferred species.

III. Air Resource
    A. Air Quality -- Resource Consideration
        Identifiable or Predictable Problems
        1. Airborne sediment and smoke causing safety hazards (vehicle travel on roads), on-site and off-site.
        2. Airborne sediment causing vehicle, machinery, and structure problems, on-site and off-site.
        3. Airborne sediment and smoke causing health problems, on-site and off-site.
        4. Airborne sediment causing conveyance problems in ditches, canals, and streams, on-site and off-site.

Once sediment is in the channel it is necessary to know how fast it is moving and what its effects are. It is desirable to analyze individual streams and to determine if high sediment yields are a natural phenomenon (as for example, in a decomposed granitic terrain in which the hydraulic geometry may support few pools). If this is the case, minimal action would be appropriate because instream work to create aquatic habitat would be very expensive with only limited and temporary results. If the sediment yield is higher than the natural or "background" rates, then action should be considered. Instream channel alteration to create aquatic habitat should be reserved as secondary work after the usually less expensive watershed treatment effects are analyzed. If instream action is required, a careful evaluation of treatment solutions should take place.

Other factors of importance in determining sediment impacts are the temporal variations of sediment yield. Sediment can be divided into three categories that are helpful in the evaluation of aquatic systems: framework bedload, matrix bedload, and suspended load. This categorization works well for heterogeneous sediment with a size range of several orders of magnitude. Framework bedload refers to the larger particles that are moved only during large flow events. They create the structure of the bed. The matrix bedload refers to that part of the bed material that is small enough to be frequently entrained by low to moderate flows but is large enough to settle out of the water column in lower velocities. This also includes sediment deposited by intragravel flow. This would incorporate the sand and silt size material. The matrix bedload is often referred to as "sediment" by fisheries biologists and is the size class that is of most interest and concern in fisheries studies. The suspended load is the smallest size class of the total sediment load of a fluvial system. It is held in the water column as suspended material for extended periods of time. The conditions when this material is deposited are usually slow-moving water, intrusion when a higher part of the bed is encountered, or deposition in bars and on floodplains.

As an example, assume that there has been a large storm event where all of the material on the bed of the channel has been disrupted and moved. Now the storm is over and particles begin to deposit on the bed of the channel. The largest, or framework material, will deposit first on the streambed and on bars. There is void space between these large particles. The matrix material then begins to settle out, filling in the voids with fine material. Water also moves through the permeable framework gravels below the surface. Because the movement of water through bed material is slower than in the open channel, more material is deposited in the interstices of this gravel, filling the voids even more. These are the basic dynamics of bed formation in an active creek after high flows.

Many species of fish spawn in gravel, depositing eggs in the void spaces between the framework particles. The eggs require fresh, moving water to survive and grow and then an escape route after they have hatched. If the matrix fills in these spaces, mortality rates of the fish eggs become very high. When the fish deposit their eggs they create an area free of fine matrix material by using their bodies to wash the gravel. These areas are called redds. Because of the indentation that they make in the bed, the water eddies and actually flows upstream over and through the redd, providing water and associated sediment with a lower, less damaging velocity than the main channel flow. The fish create a microenvironment within the streambed, but the degree of bed inundation varies by species. For example, Chinook salmon dig their redds to depths ranging from 8 to 14 inches (Beauchamp et al. 1983). In contrast, Cui-ui suckers lay their eggs essentially on the streambed, and some of the eggs fall down within the available pore space (Jones and Stokes 1990); other fish species, such as the slackwater darter found in Alabama and Tennessee, require shallow, marshy areas for spawning with vegetation providing the depository for eggs (Mitsch and Gosselink 1993). In this fine balance between discharge, velocity, and bed material, spawning has been very successful. Researchers have consistently found that the introduction of excess matrix bedload can have disastrous results for the spawning habitat of fish that require gravel substrate for spawning and for the habitat of gravel-dwelling benthic organisms.

Types of streams and planform characteristics

There are many ways to classify streams, based on stream geometry, flow, and planform characteristics (Leopold and Wolman, 1957; Lane, 1957; Śchumm, 1963, 1977, 1981; Brice and Blodgett, 1978; Rosgen, 1994; Montgomery and Buffington, 1993; and others). Some of these systems are based on discharge, sediment transport, gradient, bed material size, stream geometry, and other physical properties of streams. Leopold and Wolman (1957) proposed a classification scheme based on flow and broad-scale geometry. Their three major categories are braided, meandering, and straight. Although this appears to relay very little information, the definition of these three channel types provides more than the planform type on a general level. Schumm (1963) proposed a scheme to divide streams into three categories: bedload channels, mixed-load channels, or suspended-load channels. This is limiting because it refers to the type of sediment transport occurring, which is difficult to determine. Inferences can be made about these channel types but will be purely supposition; however, the system did separate streams by the width-to-depth ratio and sinuosity, which is a first step to describing streams by hydraulic geometry. Probably the most comprehensive system of stream classification that uses measurable stream morphology variables and is applicable over broad hydrophysiographic provinces and various sizes of streams is the Rosgen (1994) "Classification of Natural Channels."

The Rosgen classification system (Figure 1) is useful as a mechanism to communicate information about streams that by definition fall within a range of hydraulic geometry characteristics. The system also allows for interpretation of the planform characteristics of channels (Figure 2) that have habitat value. In addition, the stream types themselves can be used to some degree (Table 2) to separate out degraded conditions resulting from channel changes or sediment load conditions. However, management interpretation based on stream types should be used with caution and with a clear understanding of field conditions and direction of change. In most situations, local streambank stabilization structures or entire streambank reconstruction should be done in the context of stream types.

A detailed evaluation of the planform characteristics of streams has been developed by Montgomery and Buffington (1993), Figure 3. Each bed form, such as the types shown in Figure 4, provides hydraulic roughness elements and the stable channel configuration for a given regime of sediment supply and shear stress. The six alluvial channel reach types (cascade, step-pool, plane bed, pool-riffle, regime, and braided channels) in large part separate different spawning and rearing habitats as well as different benthic habitats.

There are certainly variations in bed form characteristics with changes in the river regime. For example, at low-flow conditions, pools appear as flat reaches with slow flow and riffles as steeper reaches of higher velocity (Montgomery and Buffington, 1993). In contrast, studies have shown that as discharge increases, the velocity across pools increases faster than across riffles, so that at bankfull discharge the flow over pools exceeds that over riffles (Keller 1971). At these higher flows, shear stresses are greater in the pools than in the riffles; this keeps the pools scoured and maintains the channel pattern. On the receding limb of the hydrograph, the opposite process occurs and the deposition of matrix bedload in pools is reestablished. There will be associated impacts on spawning and rearing habitat with the changes in flow regime, as with benthic habitat.

The general relationship of large woody debris to planform characteristics is also shown by Figure 3. The degree to which large woody debris is transient in the channel is dominated by the degree to which the debris sticks out into the channel. A general rule is that debris that occupies less than half the width of the channel is transient

(Montgomery and Buffington 1993). Where the wood is immobile, the sediment yield and associated planform characteristics are modified, as are the habitats of fish and benthic aquatic organisms.

Adjustable components of a stream system are variable with time. Relative scale determines whether a variable is dependent, independent, or interdependent (Table 3). For environmental management, a scale of 10 to 100 years is the usual period of interest or concern. An awareness of the larger time frame helps to put these variables in their proper perspective. In contrast to a time scale distribution, a hierarchical organization of stream systems on a linear spatial schedule is shown in Figure 5.

Assuming that the independent variables remain constant, emphasis should be placed on interdependent or dependent variables. These would include vegetative cover, valley slope (including channel slope and channel pattern), and channel morphology (including slope, sinuosity, shape, velocity, flooding regime, and sediment transport). Knighton (1984) uses four degrees of freedom for adjustment of channel geometry: cross-sectional form, bed configuration, planimetric geometry or channel pattern, and channel bed slope. Each of these can be addressed individually, but they are not independent of one another. A change in sediment transport can affect many of these variables or be affected by them. From this we can surmise that sediment is probably an interdependent variable.

Figure 1. Key to classification of natural rivers

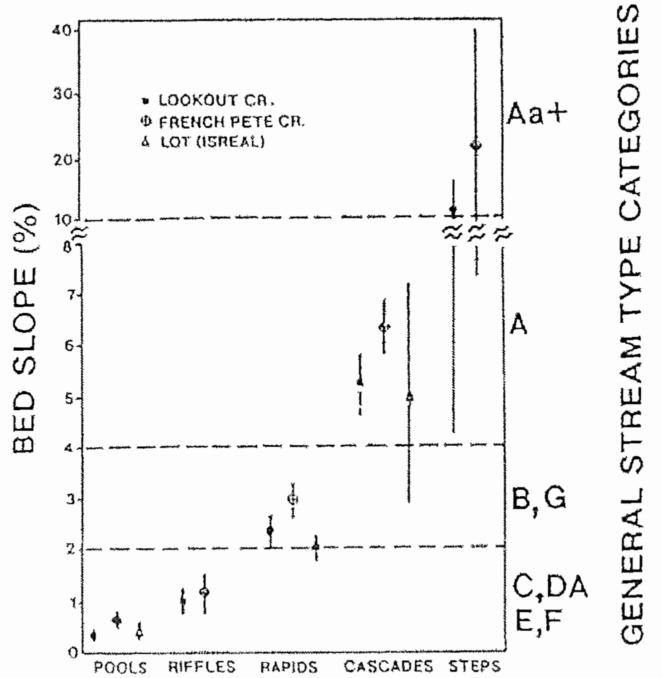


Figure 2. Relationship of bed slope to bed forms

Figure 3. Idealized long profile

Figure 4. Channel morphologies

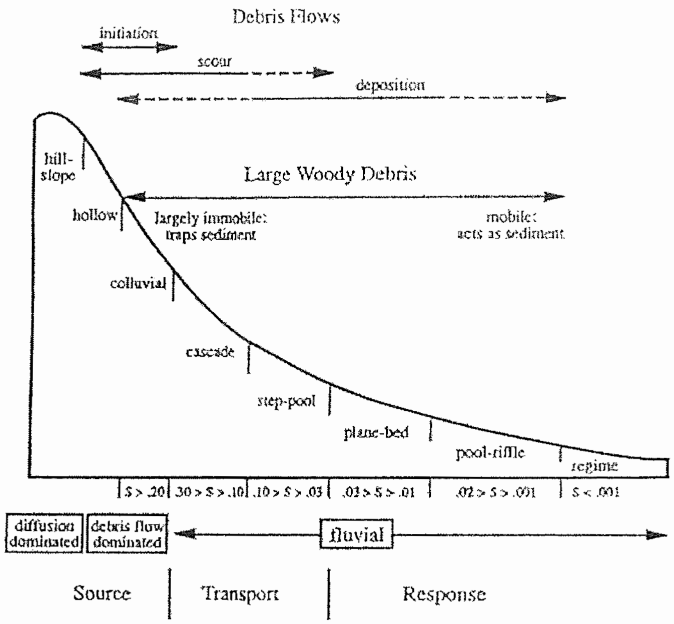
Figure 5. Hierarchical organization of stream system and its habitat subsystems

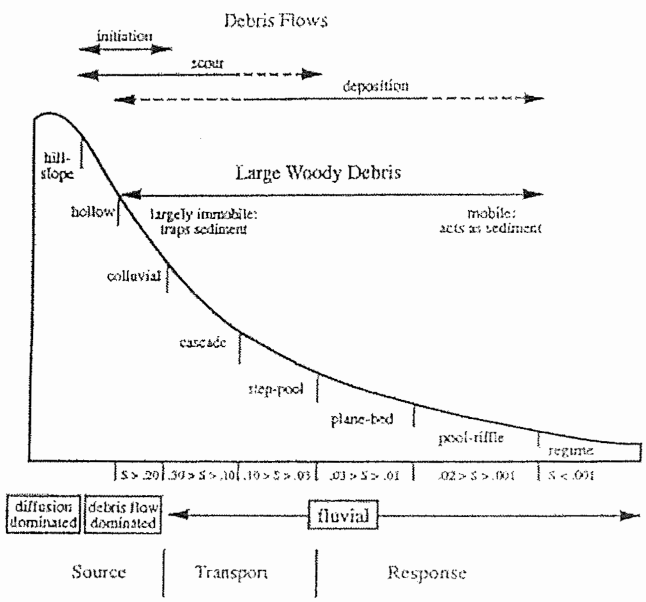
Hydraulic and sediment characteristics of streams

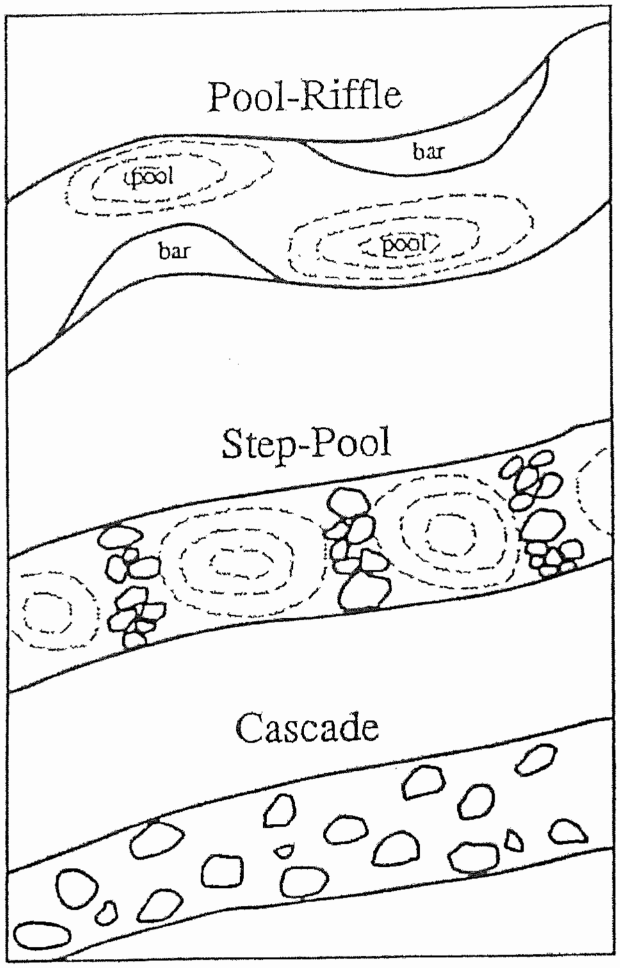
The size and specific gravity of a particle dominate but do not entirely control the movement of the particle. It is necessary to understand why and how sediment moves in a fluvial system. A rough estimate can then be made of how a system will respond to a change in its sediment state.

There are two main opposing forces acting on a submerged particle. The retaining force that holds a particle in place is the weight of the particle and the vector of the drag force acting normal to the bed. The entrainment force, that force causing a particle to move, is composed of a lift force and the component of the drag force acting upwards on the particle, which is caused by eddying (Knighton 1984). Other compounding variables, such as particles surrounding the particle of interest, complicate this seemingly simple relationship between two opposing forces.

The shape of the particle is also important for transportability. If a particle is flat, it will be harder to entrain than if it were spherical. The most easily entrained particle is fine sand. Sands are very spherical while silts and clays are progressively flatter. Clays are platelike and are very difficult to entrain once they have been deposited. The shear stresses required to entrain a clay particle may be as large as the shear stress required to entrain a large cobble, but the difference in transport between these two particles is significant. Once a clay particle is entrained it will stay in the water column as suspended sediment. Deposition will occur only at very low to zero velocities. A large cobble requires high shear stresses for entrainment and relatively high shear stresses for transport. Once the velocity begins to drop, the particle will be deposited.


Debris Flows
initiation
scour
deposition
hill-
slope
Large Woody Debris
hollow
largely immobile:
traps sediment
mobile:
acts as sediment
colluvial
cascade
step-pool
plane-bed
pool-riffle
regime
S > .20
.30 > S > .10
.10 > S > .03
.03 > S > .01
.02 > S > .001
S < .001
diffusion
dominated
debris flow
dominated
fluvial
Source
Transport
Response


Debris Flows
initiation
scour
deposition
hill-
slope
Large Woody Debris
hollow
largely immobile:
traps sediment
mobile:
acts as sediment
colluvial
cascade
step-pool
plane-bed
pool-riffle
regime
diffusion
dominated
debris flow
dominated
fluvial
Source
Transport
Response



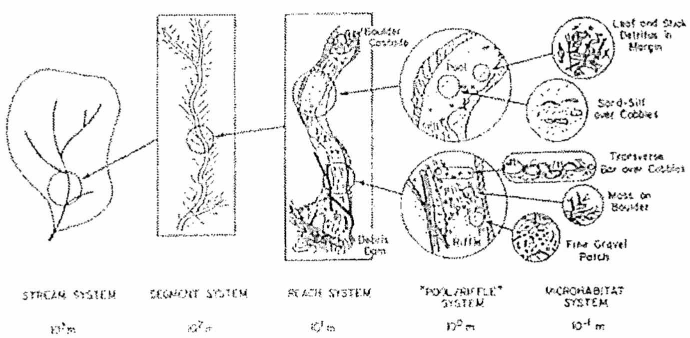


Table 2. Management interpretations of various stream types

Stream type	Sensitivity to disturbance1	Recovery potential2	Sediment supply3	Streambank erosion potential	Vegetational controlling influence4
A1	very low	excellent	very low	very low	negligible
A2	very low	excellent	very low	very low	negligible
A3	very high	very poor	very high	high	negligible
A4	extreme	very poor	very high	very high	negligible
A5	extreme	very poor	very high	very high	negligible
A6	high	poor	high	high	negligible

B1	very low	excellent	very low	very low	negligible
B2	very low	excellent	very low	very low	negligible
B3	low	excellent	low	low	moderate
B4	moderate	excellent	moderate	low	moderate
B5	moderate	excellent	moderate	moderate	moderate
B6	moderate	excellent	moderate	low	moderate
C1	low	very good	very low	low	moderate
C2	low	very good	low	low	moderate
C3	moderate	good	moderate	moderate	very high
C4	very high	good	high	very high	very high
C5	very high	fair	very high	very high	very high
C6	very high	good	high	high	very high
D3	very high	poor	very high	very high	moderate
D4	very high	poor	very high	very high	moderate
D5	very high	poor	very high	very high	moderate
D6	high	poor	high	high	moderate
DA4	moderate	good	very low	low	very high
DA5	moderate	good	low	low	very high
DA6	moderate	good	very low	very low	very high
E3	high	good	low	moderate	very high
E4	very high	good	moderate	high	very high
E5	very high	good	moderate	high	very high
E6	very high	good	low	moderate	very high
F1	low	fair	low	moderate	low
F2	low	fair	moderate	moderate	low
F3	moderate	poor	very high	very high	moderate
F4	extreme	poor	very high	very high	moderate
F5	very high	poor	very high	very high	moderate
F6	very high	fair	high	very high	moderate
G1	low	good	low	low	low
G2	moderate	fair	moderate	moderate	low
G3	very high	poor	very high	very high	high
G4	extreme	very poor	very high	very high	high
G5	extreme	very poor	very high	very high	high
G6	very high	poor	high	high	high

1. Includes increases in streamflow magnitude and timing and/or sediment increases.
2. Assumes natural recovery once the cause of instability is corrected.
3. Includes suspended load and bedload from channel-derived sources and/or from slopes adjacent to the

stream.
4. Vegetation that influences stability of the width-depth ratio.
(After Rosgen 1994)

From this simple example it becomes evident that in a system with heterogeneous bed material the small material will be moved further than the large material and the larger material will move only short distances. This causes a coarsening of the bedload because the small material is preferentially moved out of the system or winnowed. The sediment supply controls the character of the bed along with transport capacity and capability. Transport capacity refers to the amount of material that a stream can transport, and capability refers to the largest particle size class that a stream can transport.

Currently there is no precise method for measuring bedload transport. Several methods are in use but results of sampling vary widely. Measurements are commonly made with the Helley-Smith bedload sampler. This technique is limited by large flows, size of bed material, and access to appropriate sampling locations.

It is difficult to quantitatively describe the fluvial geomorphology and sediment transport of all streams because of the lack of fluvial determinate equations that fully describe stream behavior. However, there are hydraulic functional relationships between some stream variables that can be used to describe what generally happens along rivers. A primary functional relationship is that given by Lane (1955):

QwS Qsd50

Qw = Water Discharge
Qs = Sediment Discharge
S = Water Surface Slope
d50 = Median Particle Size of Streambed

This is logical since the ability of a stream to transport sediment depends on stream power, and stream power is proportional to the product of QsS. If Qw is held constant and a stream channel is straightened, or base level is lowered (i.e., slope is increased) then Qs must also be increased by erosion of the bed and banks, or d50 must be increased. What develops is a sediment transport imbalance where sediment transport capacity exceeds the sediment supply. Therefore, erosion becomes the negative feedback mechanism that works to restore stream channel stability by lowering channel gradient and increasing bed material size.

Conversely, if the sediment load is suddenly increased, as by removing the watershed cover by forest clear-cutting and new road construction, then slope tends to increase to accommodate the additional sediment load. This usually results in the stream channel more vigorously attacking the streambanks because of channel migration as the stream cannot transport all of the load provided. The additional sediment load from the streambanks worsens the transport problem and causes the stream to widen further. Obviously, changes in both discharge and sediment load may lead to conflicting responses, so it is not easy to precisely predict channel changes and the associated effects on habitat.

Table 3. Control at different time scales

Control	**Effect**	**Status of control at time scales of (years)**			
		10^7	**10^5**	**10^3**	**10^1**
Physiographic province:					
Megatectonic cycle	-- rifting, sea-floor spreading, subduction, continental collision, orogeny	I	I	NA	NA
Tectono-eustasy	-- base-level change	I	I	NA	NA
Neotectonic pulses	-- uplift, subsidence, faulting	X	X	I	I
Earthquakes	-- uplift, subsidence, faulting -- mass movements -- drainage changes	X	X	X	I
Climatic change	-- glaciation -- hydrologic cycle changes	X	I	I	I
Change in vegetation cover	-- changes in rates of sediment yield and/or runoff	X	I	I	I
Glacio-isostasy	-- base-level change	X	I	I	NA
Glacio-eustasy	-- base-level change	X	X	I	NA

Drainage basin:					
Geology (lithology, structure)	-- controls drainage pattern, slope morphology, sediment type	I	I	NA	NA
Climate	-- influences type and rate of weathering, hydrologic regime, vegetation cover	X	I	I	I
Relief	-- controls slope morphology, erosion potential	D	D	I	I
Vegetation cover	-- changes in erosion rates	D	D	D	I
Human impacts	-- changes in land cover, hydrologic system, erosion rates	X	D	I	I
Drainage network and morphology	-- influences delivery of water and sediment	D	D	I	I
Hillslope morphology	-- influences erosion rates, water delivery to channel, mass-movement rates	D	D	I	I
River channel:					
Geology	-- influences valley slope, sediment type	I	I	NA	NA
Climate	-- influences runoff into channel, vegetation	X	I	I	I
Vegetation	-- influences bank stability, roughness	D	D	I	I
Human impacts	-- dams, channel modifications, water diversions	X	D	I	I
Valley slope	-- influences channel slope, channel pattern	D	D	D	I
Channel morphology (slope, sinuosity, shape, etc.)	-- influences velocity, flooding regime, sediment transport	X	X	D	I

Note:
I = independent; characteristic that operates independently of, and to some extent controls, geomorphic variation.

D = dependent; characteristic that is determined by geomorphic variation.

X = indeterminate; characteristic that is too variable to be reconstructed at the time scale.

NA = not applicable; characteristic that is not controlled by geomorphology, or that varies too slowly to be significant.

(After McDowell, Webb, and Bartlein 1991)<

Transport patterns of sediment and organic material

Sediment is transported through a fluvial system as bedload or suspended load. Suspended load is held in the water column and is transported at roughly the same velocity as the water. The bedload is transported by bouncing or rolling along the bottom of the streambed. Measuring the rate of sediment transport for suspended sediments is done by finding the discharge of the stream (Q) and the concentration of sediment in the water column. Measuring the rate of bedload transport is more difficult.

There is an ongoing debate about the way that bedload moves down a fluvial system. This is especially true for gravel-bed streams that form armor layers. A paper by Parker, Klingeman, and McLean (1982) proposed the idea of equal mobility. Equal mobility refers to a small range of discharge that moves a large range of bedload; in other words, when a threshold discharge is reached, the armor layer is disrupted and a large percentage of the bedload is moved. Although this was only to be used as a first approximation for transportation rates, the idea of equal mobility has been challenged, supported, and dismissed as nonsense. Komar and Shih (1992) refute the idea of equal mobility and, through calculations, show that equal mobility cannot occur. A compromise between these two views is given by Jackson and Beschta (1982). Their two-phase bedload transport includes both equal mobility and differential movement. During low flows small particles that are available on the stream bed are moved (Phase I). Bedload movement is supply-limited. Phase II occurs at higher flows after the armor layer has been disturbed and a whole range of particle sizes is being transported. Bedload movement is transport-limited (Jackson and Beschta 1982).

The dynamics of bedload movement are not clearly understood. The total amount of bedload transport can be measured using a sediment interceptor (such as a vortex bedload sampler). However, the way that this sediment moves is not well understood. Migration of bedforms (such as gravel bars) is a common hypothesis for bedload movement but the exact dynamics are unknown.

The movement of organic matter through a fluvial system is more difficult to measure than sediment movement. This is because the size range is much greater (leaf litter to logs) and most organic matter is buoyant to a certain extent. Modeling organic matter transport is being attempted, but this will be a much more complex problem than sediment transport.

Streambank stratigraphy, characteristics, and types of failures

Streambanks can be extremely erodible to very resistant to erosion. Bedrock-controlled banks are extremely resistant and are not easily modified. Alluvial banks are erodible and can be modified by erosion and accretion. Of alluvial banks, there are two ends of a continuum. Cohesive banks are resistant to erosion and tend to be very steep. These contain a high percentage of clay or other cementing agents such as iron oxide. Noncohesive banks are more erodible, are composed of sands or gravels with very few fines, and may be a source for a large percentage of a stream's bedload. Most alluvial banks fall somewhere in between these two end members because their geomorphic history reflects a mixed stratigraphy.

When a streambank is interacting with a local or regional aquifer, water moves through the banks to recharge the aquifer during high flows and out of the aquifer into the stream during low flows; this establishes a base flow. If the movement of water is primarily out of the aquifer, the banks may be destabilized as winnowing of the fine material reduces the shear strength of the banks. If water moves primarily from the stream into the aquifer, the banks may become sealed with silt and clay. This occurs when there is a large suspended sediment load; the banks act as a filter for the fine sediment.

Streambanks are quite variable, and they have high sediment delivery ratios because of their proximity to the stream. Therefore, the sediment yield from streambank erosion is variable but has significant impacts on aquatic habitat. In addition, streambank stratigraphy along stream types (Figure 1) is quite variable, as are the types of failures that occur along stream channels.

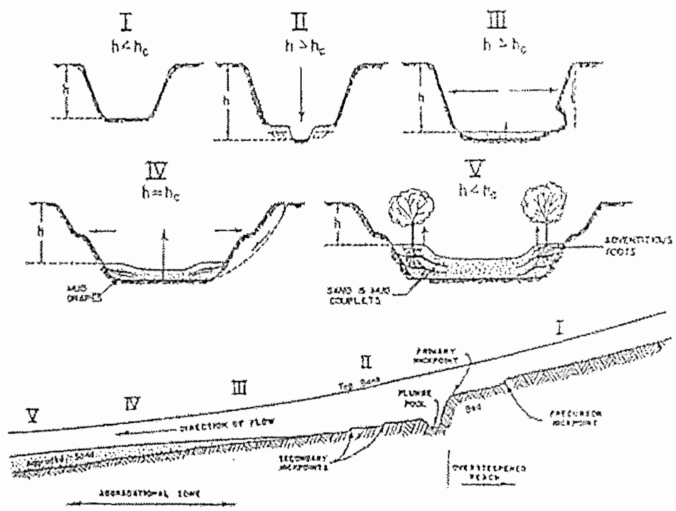
Probably the most common type of streambank failures in gravel-bed streams are undercut slab failures. This occurs when the matrix material in gravel banks is removed. Once vegetative cover is removed and associated root strength is diminished, the smaller matrix material in the streambanks tends to winnow because of high flows, wave action, seepage forces coming out of the streambank, or livestock and human disturbance. Once the gravel unit is weakened and an overhang develops, the overlying units, which may be relatively stable to tractive stream forces, develop tension cracks and essentially drop vertically into the channel. This material is readily reworked by channel flows, especially those that occur at bankfull flow (1- to 2-year recurrence interval) or higher flood stages.

The streambank's erodibility is strongly influenced by the kind, amount, and character (dispersive or aggregated) of clay, the amount and size distribution of coarse particles, and the nature and amount of cementing agents (USDA, SCS, 1977). In addition, geomorphic history and climatic history since deposition of streambank deposits have a strong bearing on the streambank's stability.

For cohesive streambanks, the Channel Evolution Model (Schumm et al. 1981), shown in Figure 6, provides a good basis for evaluation of potential failure in straight stream reaches. The model shows that if the bank height (h) exceeds the critical bank height (hc), channel widening will continue.

Figure 6. Channel evolution phases.

There is no comprehensive database that reflects the degree of streambank erosion in the United States. However, there are some regional databases. For example, in the Columbia Basin in the Pacific Northwest, there are an estimated 29,800 streambank miles with at least moderate streambank erosion that needs some type of soil bioengineering treatment (USDA, SCS 1992a). The Natural Resources Conservation Service defines soil bioengineering as "the use of live, woody vegetative cuttings to repair slope failures and increase slope stability. The cuttings serve as primary structural components, drains, and barriers to earth movement" (USDA, SCS 1992b). This represents about 22 percent of the streambanks in the Columbia Basin. The National Research Council Committee on Restoration of Aquatic Ecosystems recommends a 20-year restoration target of 400,000 stream miles. This is approximately twelve percent of the 3.2 million U.S. river miles (CRAE 1992).



Aquatic habitat characteristics of streambeds

Streambed particle distributions range from boulder dominated to clay dominated. Boulder-bed streams are controlled by the watershed geology and are generally not self-formed. They are mountainous streams with high gradients and a cascade and step-pool profile. The streambed is stable during most flows and becomes mobile only at very high flows. Organic and large woody debris is important in boulder-bed streams; it creates part of the stream geomorphology and has a stabilizing effect.

Gravel-bed streams generally have a lower gradient than boulder-bed streams and are characterized by bimodal particle size distributions and armoring of the bed. There is usually constant flow through the hyporheic zone (intragravel flow). The bed is mobile up to several times a year. Winnowing of fines from the surface of the bed material forms the armor layer. This layer is more difficult to entrain because the particles are larger and are interlocked with other particles. Gravel-bed streams have large, diverse macroinvertebrate populations (ASCE 1986) and are extremely important spawning areas for anadromous fish, as indicated in Table 4 and Figure 7. The level of the macroinvertebrate population controls the fish population because it is the primary food source. An average of 70 percent of freshwater fish species depend on insects as a food source (Healey 1984). Table 5 presents a classification of aquatic trophic invertebrates (Cummins 1973). The composition of the communities of these invertebrates varies throughout the watershed, as shown in Figure 8.

Table 4. Stream reach classification based on bed material

Bed type	Partical size(mm)	Relative frequency of bed movement	Typical benthic macroinvertebrates		Fish use of bed sediments
			Density	Diversity	
Boulder--Cobble	>=64	Rare	High	High	Cover, spawning, feeding
Cobble--Gravel	2-256	Rare to periodic	Moderate	Moderate	Spawning, feeding
Sand	0.062-2	Continual	High	Low	Off-channel fine deposits used for feeding
Sand	0.062-2	Continual	High	Low	Off-channel fine deposits used for feeding
Fine material	<0.062	Continual or rare	High	Low	Feeding

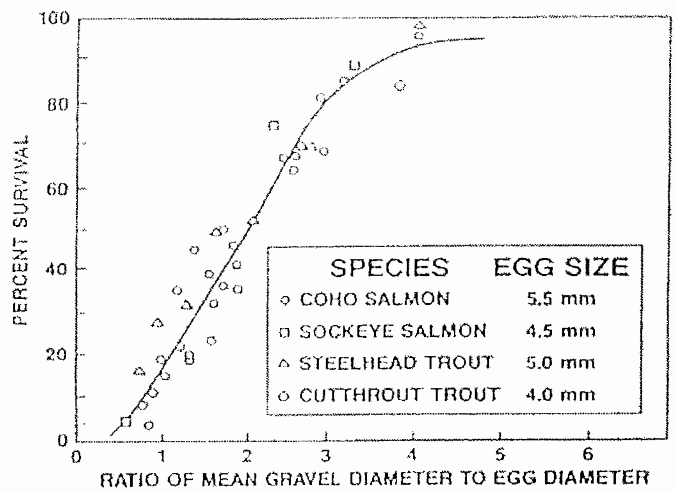
(After ASCE Task Committee 1992)

Figure 7. Salmonid embryo survival

Sand-bed streams are characteristic of larger rivers such as the Mississippi and of low-gradient, smaller rivers. There is constant movement of the bedload, which eliminates the larger macroinvertebrates. There are, however, other invertebrates that live successfully in sand-bed streams. Organic matter and snags in the stream are important breeding grounds for many of these invertebrates, which in turn provide food for fish (Minshall 1984).

Fine-bed streams have silt or clay bottoms. These types of streams are unusual in western mountainous watersheds except in the estuaries. However, in the lower topography of the Midwest they are common. Once these fine sediments have been entrained, they are generally not redeposited in the stream. This is why sand beds dominate in low-gradient streams even when the sediment load is primarily silt or clay-sized particles.

A study by Gore (1978) indicates that the highest faunal diversity of benthic macroinver-tebrates occurs in gravel-bed streams. Within the gravel-bed streams there are optimal conditions for faunal diversity. Gore (1978) found that depths ranging from 20 to 40 cm with flows ranging from 75 to 125 cm/s produced the greatest diversity



(Table 6). He also assessed faunal diversity by using the Froude number and the Microprofile Index (Table 7). The Froude number is a relative index of turbulent flow. At numbers less than unity, the flow is considered tranquil; at numbers greater than unity the flow is considered shooting or rapid. Froude numbers in the range of 0.4 to 0.5 were found in conjunction with high faunal diversity (Table 8, Gore 1978).

The Microprofile Index (Table 6, Gore 1978) is a technique for measuring the relative roughness of the stream bottom for a small area (0.1 m2). This is useful for estimating the thickness of the laminar layer and the availability of protection for macroinvertebrates. High faunal diversity is found in areas with relatively high Microprofile values (Table 6, Gore 1978).

Using these four measurements (velocity, depth, Froude number, and Microprofile Index), appropriate indicator species, those with the same requirements as the conditions for highest faunal diversity for a particular area, can be identified. If the environmental tolerance limits for a specific species have a range similar to the environmental conditions necessary for high faunal diversity, that species is considered a good indicator (Gore 1978).

Using benthic macroinvertebrates as indicators for appropriate velocity ranges as shown by Gore (1978) is a concept that can easily be applied to sediment yield. Using the same techniques, proper indicator species to determine appropriate sediment levels can be identified. For example, this method would be more useful than relying on survival and emergence of salmonid embryos. The migration of salmonids from the spawning grounds introduces many confounding variables, including the effects of dams, downstream pollution problems, and commercial fisheries. Benthic macroinvertebrates would be more useful in determining the effects of sediment in an area because they are less affected by many off-site environmental conditions and human influences but are very sensitive to localized pollution loadings. Benthic macroinvertebrate populations will also reflect differences in gradient, stream geometry, and bed particle size as shown in Figure 9.

In another study, Newlon and Rabe (1977) stated that the two most important factors affecting macroinvertebrates are substrate and suspended sediment. They found that there are four to five physical and chemical factors that have significant influence over biomass and diversity of macroinvertebrates. These factors include substrate, suspended sediment, gradient, water temperature, and stream order and width. Minshall (1984) supports these findings and provides a literature review of insect-substratum relationships.

Aquatic plants are affected by both increased bedload and suspended load. An increase in bedload may bury an area in which a plant species is growing. Subaqueous plants will be significantly affected by increased suspended sediment loads because primary plant production is reduced with increases in turbidity. This results in a decrease in benthic organism diversity and density because of a limited food supply. The reduction in the benthic organism popula-tion finally results in a reduced food supply for fish and if the food (benthic organisms) is limited, the fish will migrate to other reaches of the stream. It would be possible to take data (developed on the relationship of sediment to planform characteristics and flow) to develop a habitat suitability index for various species. Data such as water temperature, dissolved oxygen, and percentage of cover would be necessary.

Sediment quality of streams

Sediment quality is another widespread problem in freshwater and marine systems (EPA 1992). Sediment quality problems can occur throughout stream types, but tend to occur where there are fine textural stream bottoms and at the lower end of the stream system (i.e. estuaries and deltas). The contaminated sediments can have both direct adverse impacts on bottom fauna, and indirect effects as the toxic substances move up the food chain.

Because of the variability of conditions encountered in stream systems, lake systems, estuaries, and oceans, a variety of tests may be needed to characterize the physical, chemical, and biological systems that may be affected. In addition, microbial and benthic species will likely reflect sediment contamination that is not revealed by sampling only fish (Burton 1988). In other words, toxic impacts may be occurring in a river, lake, estuary, or ocean, even though sampling in the water column over the sediments may show water that meets water quality standards. Because there is no single method that captures all the spatial and temporal impacts of contaminated sediment upon all organisms, a compendium has been developed to present several complementary methods to assess sediment contamination (EPA 1992).

Table 5. A general classification system for aquatic invertebrate trophic categories

General category based on feeding mechanism	General particle size range of food (microns)	Subdivision based on feeding mechanisms	Subdivision based on dominant food	North American aquatic invertibrate taxa containing predominant examples
Shredders	$>10^3$	Chewers and miners	Herbivores: living vascular plant tissue	Trichoptera (phyganeidae, Leptoceridae) Lepidoptera Coleoptera (Chrysomelidae) Diptera (Chironomidae, Ephydridae)
		Chewers, miners, and gougers	Detritivores (large particle): decomposing vascular plant tissue; wood	Plecoptera (Filipalpia) Trichoptera (Limnephilidae, Lepidostomatidae) Diptera (Tipulidae, Chironomidae)
Collectors	$<10^3$	Filter or suspension feeders	Herbivore - detritivores: living algal cells, decomposing organic matter	Ephemeroptera (Siphlonuridae) Trichoptera (Philopotamidae, Psychomyiidae, Hydropsychidae, Brachycentridae) Lepidoptera Diptera (Simulidae, Chironomidae, Culicidae)
		Sediment or deposit (surface) feeders	Detritivores (fine particle): decomposing organic matter	Ephemeroptera (Caenidae, Ephemeridae, Leptophlebiidae, Baetidae, Ephemerellidae, Heptageniidae) Hemiptera (Gerridae) Coleoptera (Hydrophilidae) Diptera (Chironomidae, Tabanidae)
Scrapers	$<10^3$	Mineral scrapers	Herbivores: algae and associated material (periphyton)	Ephemeroptera (Heptageniidae, Baetidae, Ephemerellidae) Trichoptera (Glossosomatidae, Helicopsychidae, Molannidae, Odontoceridae, Goeridae) Lepidoptera Coleoptera (Elmidae, Psephenidae) Diptera (Chironomidae, Tabanidae)
		Organic scrapers	Herbivores: algae and associated material (periphyton)	Ephemeroptera (Canidae, Leptophlebiidae, Baetidae, Heptageniidae) Hemiptera (Corixidae) Trichoptera (Leptoceridae) Diptera (Chironomidae)
Predators	$>10^3$	Engulfers	Carnivores: whole animals (or parts)	Odonata Plecoptera (Setipalpia) Megaloptera Trichoptera (Rhyacophilidae, Polycentropodidae, Hydropsychidae) Lepidoptera Coleoptera (Dytiscidae, Gyrinidae) Diptera (Chironomidae)
		Piercers	Carnivores: cell and tissue fluids	Hemiptera (Belostomatidae, Nepidae, Notonectidae, Naucoridae) Diptera (Rhagionidae)

Figure 8. Composition of aquatic organism communities by stream order

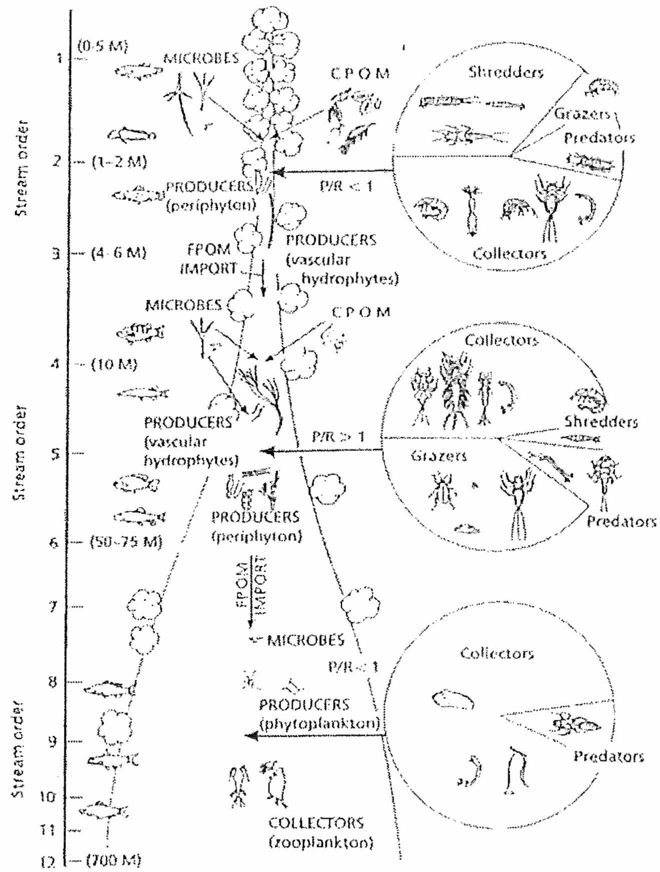


Table 6. Average faunal diversities for increments of depth and current velocity

Velocity	Depth (cm)				
(cm/s)	0-10	10-20	20-30	30-40	40-50
>120	0.541	1.802	2.131	2.301	1.817
105-120	1.386	1.661	2.612	2.027	1.724
91-104	1.203	1.983	2.211	1.844	2.072
76-90	1.652	1.809	2.319	2.190	2.156
61-75	1.523	1.703	1.728	2.034	1.612
46-60	1.440	1.721	1.605	1.958	1.812
31-45	1.628	1.893	1.977	1.933	1.845
16-30	1.348	1.218	1.957	1.054	1.505
0-15	0.667	1.112	1.405	1.530	1.371

(After Gore 1978)

Table 7. Characteristics of the Microprofile Index (MI)

MI	Profile Type
0-0.5	Smooth
0.5-1.0	Moderately smooth (gravel)
1.0-1.5	Small cobbled
1.5-2.0	Smooth, medium cobbled

2.0-2.5	Rough, medium cobbled
2.5-3.0	Large cobbled
3.0-4.0	Bouldered
4.0+	Critical (angular boulders)

(After Gore 1978)

Table 8. Average faunal diversities for microprofile and turbulence

	Microprofile Index					
Turbulence	**0.5-1.0**	**1.0-1.5**	**1.5-2.0**	**2.0-2.5**	**2.5-3.0**	**3.0-4.0**
>0.7	1.476			2.025	1.750	
0.6-0.7			2.111	1.875		2.600
0.5-0.6		2.763	2.040	1.560	1.072	
0.4-0.5	1.946	2.080	1.745	2.017	1.959	3.366
0.3-0.4	1.310	1.871	1.689	1.978	2.064	
0.2-0.3		2.119	2.099	2.000	1.657	
0.1-0.2	1.609		1.356	1.400	1.995	
0.0-0.1		1.399	1.327	1.744		

(After Gore 1978)

Some states (Oregon, DEQ, 1992) have proposed a tiered evaluation to determine potential sediment contamination. Their approach starts with an analysis of the physical properties to determine where the fines (i.e. silts and clays) and organics are located in the depositional areas.This is Tier I testing. Once the fines are located, a chemical analysis can be conducted based on potential categories of problems (metals, pesticides, coliforms, PCB's, and hydrocarbon derivatives), which is Tier II testing. If the chemical level exceeds established standards or toxic thresholds established by the scientific community, then a third level of testing is indicated. This Tier III level is bioassays. Obviously, if there are already known contaminant areas, Tier I or even Tier II could be bypassed and testing would start at Tier III.

Determination of trends in sediment quality depends on sampling over long periods of time. If long-term sample results are available, trends can be established, but this may be complicated by changes in analytical methods over the time frame. This has been a particular problem with some metals such as cadmium.

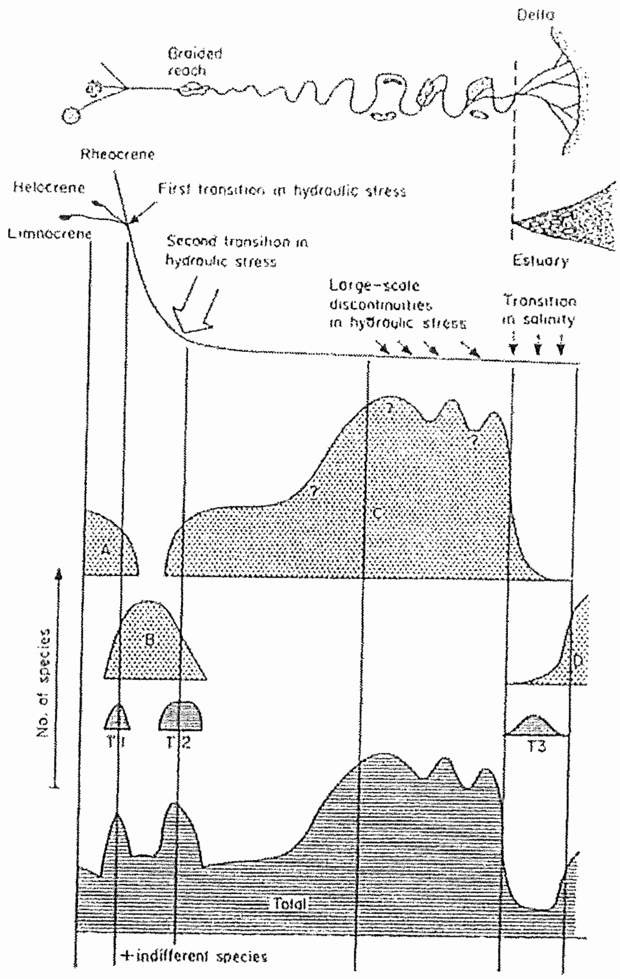
Current status of research

During the past decade, research in the area of stream sediments has focused almost entirely on the effects of fine sediment on salmonid spawning. The trend seems to be to greater quantification and greater accuracy in testing and monitoring. There have been recent studies of macroinvertebrates, which are becoming an important factor in aquatic habitat evaluation as it relates to fish.

Figure 9. General faunistic zonation patterns of the benthos in pristine streams

A comprehensive paper on the effects of sediment on aquatic habitat was written by Alexander and Hansen (1986). The focus of the paper is on brook trout but the methodology provides a complete and comprehensive review of their particular study area. This study encompassed 15 years' worth of work with daily monitoring and measurements. Instead of moving fish embryos to a lab setting, Alexander and Hansen introduced sand into a stream system for a total of 5 years and monitored the response of the aquatic habitat. They collected aquatic data for 5 years prior to the experiment and continued the monitoring after the introduction of sand was halted. This provided data before, during, and after the excess fines were introduced into the low-gradient stream. Besides measuring the effects on brook trout, Alexander and Hansen (1986) also studied the effects on the macroinvertebrate population. While not being overly quantitative, the data are complete enough to draw strong conclusions with statistical significance.

A review paper written by Kondolf and Wolman (1993) provides an excellent overview of salmonid spawning-gravel sizes. This is a literature review of 22 sources that reported particle-size distributions for many fish species. Kondolf and Wolman (1993) analyzed the data and plotted cumulative size distributions to calculate particle size mean,



geometric mean, sorting index, skewness, and graphic mean. The limitations of their study and studies that they analyzed were adequately discussed. The paper is mostly a discussion of the statistical tests that were performed, but it is an excellent source of data because only 4 of the 22 sources are in open literature (Kondolf and Wolman 1993).

Recommendations for future research in streams

Evaluating the health of a stream system is difficult, and it is not possible to do an in-depth and thorough investigation each time an evaluation is necessary. This requires other, less intensive techniques for monitoring. Fish have been used as indicator species. As the number of fish declines, a system is thought to be degrading. It takes at least a season to monitor and compare differences in populations of fish. Because of the number of factors that influence fish (dams, fishing, and pollution for example) it is difficult to evaluate the effects of a single component in the system.

Fish are not great indicators of excess sedimentation. Separating the effects of sediment from other environmental factors can be impossible in a natural system. Sometimes the effects are obvious when there are excessive amounts of fine sediment, but often they are not apparent. A slight decline in the fish population may be attributed to sediment but may actually be the result of dams in the stream system. To eliminate this problem, other indicator species should be found. Those species are preferable that are more sensitive to very small changes in sediment quality and quantity, less mobile, and have shorter life cycles. This would allow more frequent monitoring which would produce information about sediment in a limited geographic area.

Gore (1978) presents a technique that determines tolerances of benthic macroinvertebrates to water depth and current velocity. This same technique could be employed to determine the tolerance of specific macroinvertebrates to fine sediment. Gore (1978) was able to find an indicator species (Rhithrogena hageni) that had tolerances closely matching the depth and current conditions for optimum community diversity. Finding sediment-sensitive macroinvertebrates seems to be the next logical step for monitoring of fine sediment in stream systems.

There seems to be a lack of negative data in the literature. Studies that have been completed and have failed to produce positive results generally are not published. This is a tremendous source of data that are being lost. If these data were available, many researchers could save time and energy by learning from previous mistakes. Negative results should not be viewed as failure, but as a valuable learning experience which furthers the goals of research. In addition, there is also a significant lack of long-term data, and there are few studies that are ongoing. Short studies provide a great deal of information but they need to be monitored to determine their relative effectiveness or value. This can be accomplished by an ongoing study that is maintained for many years, or it can be accomplished by later studies in the same area.

The Lakes and Reservoirs

Research focusing on aquatic effects of sediment in lakes and reservoirs is limited. This is especially true for research in the Western United States. Lakes in the Northeastern United States have been more thoroughly studied because of the influence of the Great Lakes region. The emphasis in lake studies is different from studies of the stream environment. Because lakes are sediment sinks and essentially closed systems (for sediment), toxins are of great concern. Once a lake has been polluted, it is difficult to clean. Sediment is important in these environments because many inorganic toxins bind to fine sediments. A large percentage of lake sediment literature is aimed towards sediment toxicity.

Lake pollution generally gains local but not regional or national interest. This is a result of ecologic isolation; if one lake is polluted or destroyed, it usually does not have an impact on other systems unless there is a stream emanating from the lake. Concern does arise on a regional or national level when megafauna, such as birds or deer, are affected. This is very different from streams which express environmental changes throughout their systems.

Types of lakes and reservoirs

Lake and reservoir classification systems can be described using five broad categories. These include but are not limited to (1) origin, shape, and location, (2) physical properties, (3) chemical properties, (4) assemblage of fish species and fish habitat, and (5) trophic status (Leach and Herron 1992).

The origin, shape, and location of natural lakes can be the result of geomorphology, climate, or local/regional geology. Classification by origin (usually the geologic history) was popular during the nineteenth and early twentieth centuries (Leach and Herron 1992). Although lake origin may be interesting to the physical scientist, it does not convey information about the habitat type of the lake. Lake morphometry and morphology (shape) is a classification type similar to lake origin; however, morphology and morphometry can be quantified. The size and shape of a lake do reflect, in part, the aquatic habitat available in the lake, but it is primarily a physical description. The location of a lake may be important on a global scale (tropical versus arctic) but is less important on a regional scale. Early limnologists had two main categories for lake location: caledonian-subalpine and baltic. This was soon proved to be useless because two lakes, one from each category, were found closely situated in Germany (Leach and Herron 1992).

The physical properties of lakes include thermal mixing and optical characteristics. One of the first thermal classifications was by Forel (1892) and was limited to temperate, tropical, and polar. This system was later expanded to differentiate between ice-covered lakes, stratification, and frequency of mixing (Leach and Herron 1992). Optical characteristics refer to the depth of light penetration. The more organic material or inorganic sediment in the water, the less light will penetrate. This observation has been incorporated into trophic classification because low light penetration generally correlates with high trophic levels (biologic productivity). This can be misleading because high levels of suspended inorganic sediment may be found in a lake with very low trophic levels. This is also true for very deep lakes which have low light penetration and low trophic levels. Wiederholm (1984) found that high inputs of mineral sediments can actually cause oligotrophication of lakes (a net reduction in biologic productivity).

Chemical properties include edaphic inputs and water quality. Classification by edaphic inputs is useful in areas where there has been significant human disturbance. Urban lakes, forest harvesting, and agricultural practices are the types of uses that would favor lake classification by edaphic inputs. The amount and distribution of total dissolved solids are the decisive criteria in an edaphic classification system. Water quality has also been important for heavily utilized lakes. Typical classifications include relative pollution categories for bathing, consumption, fishing, irrigation, and aquatic habitat (Leach and Herron 1992). The water quality classification is used primarily for human protection.

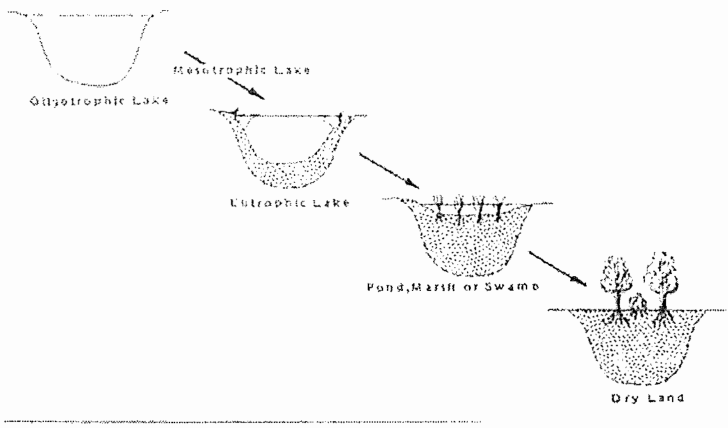
Classification by assemblage of fish species and fish habitat is specialized for fishery managers and can be modified for local conditions or management needs (Leach and Herron 1992). The type of fish present in a lake is somewhat informative of the type or quality of habitat available but it is relatively subjective. This is especially true for lakes which are stocked with hatchery fish. This classification system may be very useful for fishery managers but has limited application for land-use managers and other non-fishery people.

Trophic status is one of the most widely used and accepted systems for lake classification. There are three fundamental trophic levels: oligotrophic, mesotrophic, and eutrophic. Trophic status can be determined by (1) a single parameter such as phosphorus levels, (2) composite indices such as the Quality Index, which includes many single parameters, (3) biologic indicators such as benthos, or (4) regional typologies which include local inputs and perturbations (Leach and Herron 1992).

Oligotrophic lakes are low in biological productivity and total nutrient availability. These are typically deep, cold lakes with limited phytoplankton. Salmonids and whitefish are native to oligotrophic lakes. Eutrophic lakes are the opposite extreme. Biologic productivity is high and the nutrient load is also high. Lack of dissolved oxygen may occur in the deeper parts of a eutrophic lake because of thermal stratification. When lake temperatures are homogenous or the surface water is colder than the deep water, mixing occurs. If the deep water is colder than the surface water, no mixing will occur and the deeper water is essentially isolated from the oxygen and nutrients of the surface. This stratification is normally seasonal and occurs during the summer months. Warm-water fish, such as perch, pike, and bass, are native to eutrophic lakes (EPA 1973).

The evolution of natural lakes is normally from oligotrophic to eutrophic (Figure 10). This results from the delivery of sediment and nutrients to the lake, which slowly causes the lake to fill in and become shallower. This generally causes an increase in temperature and biologic productivity. Lakes in transition between oligotrophic and eutrophic states are mesotrophic. Some lakes, such as glacial lakes or very large, deep lakes, remain oligotrophic; however, human activity has caused an acceleration of eutrophication even for lakes that would normally remain oligotrophic (EPA 1973). An increase in sediment delivery to lakes can accelerate the eutrophication process because of nutrients that bind to fine sediments. Continued filling with sediments leads to advanced eutrophication, swampy or marshy conditions, and finally total infilling of the prior lake environment.

Figure 10. Eutrophication



Hydraulic and sediment characteristics of lakes

Particle-size trends in lakes are more predictable and stable than sediment in streams. In a perfectly round lake, sediment would be segregated into concentric circles with the coarsest material near the edge and gradual fining towards the center; this is called sediment focusing. Particle-size trends in lakes do not usually represent short-term variations in sedimentation but are integrations of longer periods of time (weeks to months) (Herdendorf 1992).

Particle-size distributions in lakes can be a useful tool for interpreting the aquatic environment. Generally, particle size decreases with decreasing hydraulic energy. However, relict sediment may imply a high-energy environment when a low-energy environment actually exists or vice versa. An example is lag gravel from an old stream deposit. If there is sufficient pore space for fines to deposit in, the gravel may remain exposed, suggesting a high-energy environment. Coarse sands and sandy gravels are good indicators of high-energy environments if they are modern deposits. They are also good indicators of active sediment transport (Herdendorf 1992).

The direction of sediment transport can be determined from the direction trend of the deposited sediments. A well-established particle-size trend or a relict sediment deposit is a good indication of a stable environment. The characteristics of sediment deposits are dependent on sediment supply, so if a particle size class is missing, it may not be the result of hydraulic energy patterns but rather the result of sediment availability (Herdendorf 1992).

Particle-size trends are very useful as sediment transport indicators but they are poor evidence for erosion and deposition. To evaluate erosion and deposition trends, profile changes or bed-elevation changes should be monitored (Herdendorf 1992). Other factors affecting erosion, deposition, and particle-size trends are boat wakes, recreational use, industrial use, dredging, and other human influences. All factors affecting hydraulic and sediment characteristics, usually including the human factor, should be addressed when a lake sediment evaluation is necessary.

Aquatic habitat characteristics

Regional classification of lakes is probably the best first-order approach to describe lakes according to their aquatic habitat characteristics (Leach and Herron 1992). This allows certain variables (climate and geology for example) to be held constant within a geographic area. However, aquatic habitats within lakes can be very diverse and complex and may require detailed field analysis to describe the lake characteristics accurately.

The history of the lake formation, combined with its current hydraulic condition, to a large extent controls biologic suitability. An example is an exposed clay surface which has hardened and cracked and then been resubmerged. This provides a "bedrock" environment rather than a fine-sediment environment. The benthic invertebrates living in such an environment may be different from the expected species based on preliminary examination of the lake substrate.

Under normal environmental conditions, benthic invertebrates can move quickly enough to keep ahead of fluctuations in natural sedimentation. Artificial dumping and/or accelerated sedimentation introduces too much sediment too quickly for benthic invertebrate organisms to avoid it (Herdendorf 1992). Case-dwelling mobile macroinvertebrate species can do very well in areas of rapid sedimentation because of the decrease in competition and their ability to escape the sediment (Wiederholm 1984). Loss of benthic communities may also occur if an increase in wave action erodes the substrate (Herdendorf 1992).

Preferred spawning habitat in lakes can be similar to that in streams, but because of the diverse and relatively more stable environment, spawning occurs in a large variety of substrates. Lake trout in Lake Huron prefer cobble and rubble and do not generally use coarse sands or gravels to spawn. Lake trout, like stream trout, cannot successfully spawn in areas that are blanketed with fine sediments (Nester and Poe 1987). Other lake species prefer sand, rocks, inshore environments, logs, sticks, plants, or vegetative nests (Herdendorf 1992).

Lag cobbles or gravels are often used for spawning while modern deposits may be avoided. Lag deposits are usually stable, while modern deposits may still be actively transported (Herdendorf 1992). Areas that meet the size criteria for spawning grounds may not have the appropriate stability. The relative location of spawning grounds is important in large lakes. Large substrate material combined with strong wave action is preferable. Spawning grounds are generally located near deeper water (>15 meters) (Nester and Poe 1987) where wave action is the strongest. This provides an environment where the spawning grounds are flushed with water and are supplied with oxygen and nutrients.

Determination of important feeding and spawning grounds in lakes should be made by consistent and sound sampling and monitoring methods. Identification of suitable habitat for feeding and/or spawning based on substrate characteristics is probably insufficient because of seasonal variability and the complex interactions between the physical and biologic environments.

Sediment quality of lakes

Sediment quality in lakes is extremely variable geographically. The introduction of excess fine sediment can be addressed in lake tributaries or in the watershed, but the actual sediment quality is difficult to alter because once it is in the lake, it is hard to remove. Sediment traps such as filter dams and desilting basins can be used in the tributaries above a lake to reduce the amount of fine sediment that is delivered to the lake (EPA 1973).

Dredging of lake bottoms is often considered as a remedial technique to remove excess sediment, increase lake depth, or remove toxic or nutrient-rich sediment from the lake environment. There are many problems associated with dredging lake bottoms. Dredging temporarily increases turbidity in the lake and can cause environmental degradation because of the decrease in primary productivity. The sediment may be a nutrient sink and dredging may reintroduce the nutrients back into the lake. The interstitial water may also be high in nutrients or toxins, and removing this interstitial water is very difficult and expensive. The loss of shallow zones may result in the loss of large macrophyte beds, resulting in turn in an increase in the algal population. The disposal of dredged material can be a problem, especially if the sediment contains toxins (EPA 1973). To further complicate the dredging issue, lakes and other bodies of water are often used for disposal of sludge, which can contain very high levels of toxins. Similar problems exist for river and bay dredging as well. Because of the potential problems and the potential for further damage, obtaining permits for dredging can be a long and costly process.

Another method of mitigating sedimentation effects is physically covering the lake sediments. Sheeting material (plastic or rubber) has been used to seal the sediments at the bottom of a lake. Particulate matter (clay or fly ash) is also used to seal the sediments. These methods stop the exchange of nutrients in the sediment with the overlying water. Associated problems include ballooning of the sheeting material, rupturing of a seal, and the migration of gases generated within the sediments. The particulate matter apparently works better than the sheeting material because it effectively seals the sediment. Fly ash, when used as a particulate-matter seal, also removes phosphate from the water column, which can be an added desirable effect (EPA 1973).

Tiered sampling and various sampling methodologies are as stated previously in the stream section.

Current status of research

Classification by trophic level has been extensively studied. Within this area, the focus has been on biologic indicators of trophic status. A study by Manny and others (1989) assesses fish spawning success in response to cultural eutrophication. The preferred trophic status indicator has been benthos, unlike indicators in stream or estuary systems. Problems that arise with benthic indicators are limitations with sampling and sorting of the benthic species. The overall emphasis of research has been on quantification of the eutrophication process (Leach and Herron 1992).

There are limitations to the current feasibility of lake sediment studies. One limitation is freezing. Constant monitoring is impeded in lakes that freeze over during the winter. This applies to a significant portion of the lakes in North America and is a particular problem for the Great Lakes Region, where most lake studies are conducted in this country. Another limitation is water depth. This is easily overcome with diving gear but the real limitation is money and access. When diving gear and divers are required to obtain field data, the cost of the study increases considerably. This is also a limitation for the number of times samples are to be taken and obviously prohibits daily monitoring for many locations. Spawning grounds in the Great Lakes are often 10 to 15 meters below the surface of the lake, so that special equipment is necessary for sampling and monitoring (Manny, Jude, and Eshenroder 1989).

Methods for sedimentation monitoring have become more sophisticated with the technological advances of the past 20 years. Remote sensing (satellite imagery) can be used to monitor surface water color. This provides data about the amount and distribution of fine sediments in larger lakes. This technology is available but is still fairly difficult and expensive to apply (Bukata 1992).

Side-scan sonar is another technological advance which can be applied to sedimentation effects. Systematic mapping of lake beds and identification of potential spawning habitat is feasible with side-scan sonar. Ground truthing with remotely operated submersibles which contain video recorders and camera equipment can be used in conjunction with the side-scan sonar to provide highly accurate mapping capabilities (Edsall 1992). Again, this is a very expensive method and is still in its experimental stage.

Recommendations for future research in lakes and reservoirs

More basic data on lake sedimentation are needed. There has been a strong emphasis on sediment/toxin relationships and the effect on lake habitat, but the actual effects of the sediment have been neglected. A significant amount of work has focused on aquatic insects and sediment (Resh and Rosenberg 1984) and their interaction, but this work does not address the effects of excess fine sediment.

A review by Minshall (1984) strongly supports the need for more research in lake environments and the determination of indicator species. In the field of freshwater benthic invertebrate ecology, the insect/sediment relationship has been intensively studied (Minshall 1984). This knowledge base should be utilized for future studies in aquatic ecosystem dynamics.

Besides more intensive and quantitative studies, improved communication between disciplines is necessary. Often published material is lumped into journals of the particular discipline of the researcher and becomes hidden in the morass of material. This problem is being overcome with databases that list individual articles. Researchers must be willing to look beyond their own fields into related areas where the research has a different perspective. Eliminating repetitive studies will allow for a greater variety of studies. Publication of negative results would be a large step towards reducing duplication.

There is a shortage of long-term, well-monitored projects. This may be the result of funding limitations or time limitations. Theses and dissertations are a large source of information but are limited as to the length of the study period, which also precludes monitoring. An empirical study is greatly strengthened by monitoring before, during, and after the study. The time frame of these studies is dependent on the phenomenon that is being studied, or on the length of academic enrollment.

Evaluation of studies after they are completed provides information about the scientific method and applicability of the techniques employed. This type of evaluation provides information and direction for future studies and allows an objective review of research techniques.

The Estuaries

Estuaries have been studied in depth by numerous disciplines. Biologists are interested in estuaries for their biotic diversity and production. Geophysicists are interested in the fluid/mud dynamics, as are civil engineers who are concerned about navigation channels. The use of estuaries by fish is of concern to fisheries management specialists. Most of this knowledge and interest has been limited to the researcher's own professional peers and has lacked the advantages of interdisciplinary research.

The concern for estuaries is growing, and there is a need for practical, useful data and associated management practices. Estuaries have been recognized for their large biomass production and pollution-filtering systems. The emphasis has been primarily on the flora of estuaries and not the fauna, except for bird uses. Estuaries are important for anadromous fish because it is an passage that they must make when migrating from the streams to the ocean or on their return to spawn. Estuaries also serve as a feeding ground and nursery for many fish and shellfish species. Catadromous fish, such as eels, spawn at sea but spend a large portion of their lives in coastal estuaries. Because of the physical, chemical, and biotic diversity of estuarine systems, they are among the most biologically diverse and richest systems found on earth.

Estuaries are extremely sensitive to human action. Most large bays have associated large estuaries and also have sizable seaport cities associated with them. A majority of the world's population lives along the coast line, so estuaries are significantly impacted by land-use practices, recreation, and exploitation. Ship traffic near estuaries can be especially heavy and affects the entire estuarine ecosystem, because it introduces new variables including physical and chemical alterations.

One of the major estuarine sediment alterations imposed by industrialized societies is dredging. Estuary channels are dredged to keep shipping corridors open. Estuaries are also sites of dredging for sand and gravel for industrial and commercial use. Filling in bays and estuaries for development purposes has been a practice adopted by many coastal cities. The San Francisco Bay is an excellent example of aquatic habitat loss due to filling. Now that the ecologic importance of estuarine environments has been acknowledged, the preservation and restoration of these environments has begun.

Types of estuaries

Estuary classification can be based on a number of parameters. Classification by salinity and by morphology are the two most common approaches.

There are three basic estuary types based on salinity classification: freshwater, brackish, and marine. The freshwater estuaries are dominated by inflow from the rivers, which keeps the salt water pushed out of the estuary. Brackish estuaries exhibit a mixing of salt water and fresh water. Marine estuaries are dominated by tidal action and can have salt levels very close to those of the offshore ocean. Another salinity classification can be made based on relative evaporation rates. If evaporation at the surface of the estuary is less than the river inflow, then it is considered a positive estuary; if evaporation exceeds river inflow, then hypersaline conditions exist and the estuary is considered to be negative. Positive estuaries are by far the most common (Dyer 1973). The relative mixing between fresh water and salt water in each of these types depends on relative salinity and temperature differences between the two sources of water. It is common to have a wedge effect. If two sources of water (one saline, the other fresh) of the same temperature converge, the salt water will wedge beneath the fresh water because the fresh water has a lower density than the salt water. However, if the salt water is warmer, a convection current may form causing vertical mixing. This is referred to as thermohaline convection (Dyer 1973).

A topographic or morphologic approach to classification was introduced by Pritchard (1952). This system also has three basic estuary types: drowned river valley, fjords, and bar-built estuaries. The drowned river valley is a result of the post-Pleistocene marine transgression. The lower portions of stream valleys are flooded due to rising sea level. These estuaries typically are triangular in shape (small at the stream channel, wide at the mouth), and have a small sediment load compared to the stream discharge. These types of estuaries are common in the temperate mid-latitudes and many are found along the west coast of the United States such as San Francisco Bay. Fjords are the result of glaciation and are found in the higher latitudes and in mountainous areas. They typically are rectangular in cross-section and have a low width to depth ratio (10:1). Deposition of sediment in fjords is generally limited to the upper end of the estuary where the stream encounters standing water. Fjords are very common in Scandinavia; the Hardangerfjord in Norway is an excellent example. Bar-built estuaries are similar to drowned river valleys. The major difference is the sediment input into the system and the bar across the mouth of the estuary. A large sediment supply creates shallow lagoons and marshes and helps to maintain the bar. These types of estuaries are found in the tropics and in areas with active coastal deposition (Dyer 1973). Galveston Bay is an example of a Gulf Coast bar-built estuary. For sediment studies, Pritchard's 1952 classification remains the most useful.

Hydraulic and sediment characteristics of estuaries

A characteristic of estuaries is that their beds are constantly moving because of river inflow and tidal fluctuations. The bedload is composed mainly of sand-sized particles which are easily entrained and move for long distances. The bed material is not always transported in a downstream direction. Depending on tidal influences, material may be moved up and down the channel. Fine silts and clays flocculate in the salt water and are deposited in tidal marshes.

The dynamics of sediment transport in and through estuaries is extremely complex. Many studies have been done in the field of geophysics to gain an understanding of the transport processes. The equations and theories derived from fluvial studies are not directly applicable (if at all) to the estuarine environment. The complicating factors include diurnal and biweekly tidal cycles, salinity influences, temperature differences, and fine-sediment transport. When clays encounter saline water their electrical charges are affected and the clay will flocculate and form larger particles. Thus, when the sediment settling velocity is determined using Stoke's Law (an equation used to calculate settling velocity of different-sized particles), the actual settling velocity may be much higher.

A study of the sediment delivery to Atlantic estuaries of the United States by Phillips (1991) focused on the bedload transport through these systems. The relative effects of land-use practices or changes were evaluated on the basis of soil erosion and the possible effect that this would have on downstream estuaries. This study did not rely on complex equations to model sediment transport but rather focused on sediment yield and sediment delivery ratios.

Phillips (1991) found that estuarine sediment is derived from fluvial sediment input, shoreline erosion, and migration of marine sediments inland. Fluvial sediment inputs were the dominant process affecting these estuaries. Of the estuaries studied, a fluvial sediment delivery ratio of 4 percent was derived: that is, only 4 percent of the sediment eroded from the uplands and delivered to the stream ever makes it to the estuary. If this is occurring then a huge amount of sediment is being stored in and along these stream channels. Phillips (1991) also indicates that sediment storage is much more environmentally sensitive than basin sediment yield and concludes that dramatic changes in the watershed would be required to alter the sediment budget in the estuary. However, processes that mobilize stored sediment would have a large effect on the sediment budget. Another important statistic discussed by Phillips (1991) is the storage capacity of the estuaries. He believes that 90 to 95 percent of all coastal sediment storage occurs in estuaries and coastal wetlands and that up to 95 percent of watershed-derived sediment is stored in the basin.

This has interesting implications for management. Even though sediment delivery may be low, total sediment input can be high. Stopping sediment before it reaches the stream channel is important because once it becomes stored in the channel it can be easily remobilized. Efforts to reduce sedimentation rates will be long-term because large quantities of sediment are already in stream channels due to agricultural and land-use practices of the early twentieth century. If sediment is in long-term storage in estuaries, rather than en route to the continental shelf, then sedimentation rates should be of great importance.

Increased fluvial sediment in estuaries may result in extended tidal marshes, shoaling, infilling of navigation channels, reduction of benthic and aquatic habitat, and reduced primary productivity due to turbulence and limited light penetration (Phillips 1991).

Another sediment transport study by Horne and Patton (1989) came up with conflicting results. They found that the trapping mechanism in an east coast stream was inefficient and that "partially mixed estuaries on microtidal coastlines may in fact be effective conduits of bedload sediment onto the continental shelf" (Horne and Patton 1989). They also stated that there are not sufficient data available on river inflow into estuaries to explain this disparity completely.

Aquatic habitat characteristics

Estuaries are utilized by specialized organisms that have adapted to fine sediments, high sedimentation rates, and mobile substrate. The macroinvertebrates that are found in the substrate of estuaries are much smaller than those found in streambeds with larger particle sizes. Common benthic organisms found in estuaries tend to be opportunistic rather than an equilibrium type of species (Schaffner et al. 1987). Within the estuary, the density of fauna is commonly greater in the freshwater tidal areas than in other parts of the estuary (Schaffner et al. 1987). The species diversity of macroinvertebrates is usually lower in fine-sediment substrates than that in coarser-particle substrates. The diversity and evenness of species decline with an increasing percentage of silt/clay and organic matter (Junoy and Vieitez 1990). However, fine-sediment beds are important for burrowing tube-making invertebrates and other burrowing species (Minshall 1984).

Sediment quality of estuaries

Sediment quality is very important in estuaries because of the residence time of the sediment. A study by Cunningham and others (1987) addressed the issue of sediment in estuaries and the interaction with pesticides. The pesticide that they were interested in was diflubenzuron or DFB. This chemical is commonly used as a larvicide to control mosquitoes. This product has not, however, been approved for use in salt marshes. DFB interferes with chitin formation, which would negatively affect crustaceans when they molt. The study by Cunningham and others (1987) focused on two crustaceans: brachyuran crabs and caridean shrimp. There were two test groups and a control group of these crustaceans. Two environments had the same levels of DFB, but one contained sediment while the other did not. After 22 days, the environment with sediment contained only 5 percent of the original DFB in the water column and survival of that test group compared with the control group was good. The environment without sediment still had high levels of DFB and there was no survival of the crustaceans (Cunningham et al. 1987). This indicates the important chemical bonding that occurs between biocides and fine sediments, but the biocides remain stored in the estuary sediment and do not disappear. Cunningham and others (1987) warn that the DFB in the sediment may affect juvenile and adult crustaceans because they feed on detritus and organic matter found on the bottom of estuaries.

Similar sediment quality issues exist for all chemicals that enter estuaries and are bound to sediment. The sediment is stored on the bottom of the estuary until it is disturbed by natural processes or human activities. The impacts of dredging become a critical issue when sediments are the storage facility for industrial and agricultural chemicals.

Tiered sampling and various sampling methodologies are as stated previously in the stream section.

Current status of research

Estuaries have recently obtained national recognition. Many estuaries are now being studied and evaluated for restoration efforts. Tillamook Bay in northwestern Oregon is one such estuary that is now part of the National Estuarine Program (NEP). Pollution caused by agricultural runoff is a major concern for many estuaries in the United States. What once was considered "useless" land is now being utilized for its filtering and cleansing effects. The estuary at Arcata, California, was rehabilitated and enhanced for wildlife habitat, for recreational use, and for tertiary sewage treatment, which performs a final filtering of sewage water before it enters the ocean. This system has been very successful and is being duplicated in many other areas, not only in estuaries but also in interior wetlands.

The study of estuaries has been emphasized in the United States, the Netherlands, Australia, Germany, Denmark, France, and South Africa. Most of the work has dealt with estuarine biotas, but significant work has been done on the physical environment. Much of the work being done is to supplement or test computer models. Estuaries are such complex systems that modeling was not really feasible without computers. Modeling requires diverse information about a system if it is to be truly representative of the system. This encourages and almost mandates interdisciplinary work.

Recommendations for future research in estuaries

Basic research and baseline data are needed for estuaries. Long-term monitoring and evaluation should be set up to provide as much base information as possible. Since this is one of the richest and most sensitive aquatic environments, the concern for estuaries will probably continue to expand during the next several decades. Restoration efforts and municipal interests (such as tertiary sewage treatment) will require more information and data about estuaries and their dynamics.

Emphasis should be placed on interdisciplinary studies. The Panel on Estuarine Research Perspectives (1983) recommended that "the primary focus of future research in estuaries should be on interdisciplinary relationships." They also recommended that government and universities provide data and the basic framework for informed estuary management. The interdisciplinary research is beginning to happen in estuarine studies as it is in many other ecosystem-based studies. Much of the government data about estuaries is provided by the Environmental Protection Agency. Universities are providing a large source of data about estuaries especially those estuaries which are a part of the National Estuarine Program. A comprehensive approach that examines interactions of physical, geologic, chemical, and biologic components is desperately needed in this field of study, and if the current trend continues this need may be met within the next few decades (PERP 1983).

According to Junoy and Vieitez (1990), soft-bottom macrozoobenthos has been relatively neglected by benthic researchers. This is a very important area in estuary sedimentation evaluations, especially if an indicator species is a necessary part of the evaluation. The lack of data about sediment transport into estuaries from rivers makes it extremely difficult to develop an accurate sediment budget for estuaries (Horne and Patton 1989). Sediment budgets are necessary for long-term planning in coastal areas. Sedimentation in the fluvial/estuarine interface is another area that requires more in-depth research. This area is very sensitive to disturbance because of the change in gradient and the sediment storage that occurs at this transition (Phillips 1991). Mobilization of this stored sediment can have a dramatic impact on the quality of the estuary.

Influence of Land Use

The effects of land use are apparent across the spectrum of problems associated with aquatic environments. Increased erosion and acceleration of sediment transport can frequently be related to land-use changes or to poor land management. Effective land management or watershed management can lead to a reduction in the amount of sediment delivered to a stream channel. Prevention of erosion is a first step; if erosion occurs, keeping the sediment on the hillslopes is a second step; if the sediment is delivered to the stream channel, estuary, or lake, then the third step is restoration of the aquatic environment. Land use can be broken down into six broad categories: forest, range, agriculture, industrial, urban, and water resources.

Forestry

The work in forestry applications and effects has been intensely studied. There are many excellent papers that discuss forest management and the impacts of harvesting activities. One interesting finding is that the logging roads, not the harvesting practice itself (unless both sides of a streambank were clear-cut), are responsible for a large percentage of the sediment that enters an aquatic environment at an accelerated rate (Everest et al. 1987). In effect, the channel network is increased because the roads act as tributaries, creating a more efficient sediment delivery system. Sediment that was once far from the stream channel is now transported through a series of inboard ditches and culverts directly to the stream. Practices that keep sediment out of the stream, such as stream buffers, are not sufficient when a significant road network is in place. Sediment must also be kept off of the roads, which are essentially part of the stream system. Erosion of cut banks and fill slopes is a severe problem where culverts are in place. The concentrated flow can easily erode a fill slope if the culvert is not properly sized or placed.

Another impact of forest roads is the direct interface with riparian vegetation. In areas where stream crossings are required, riparian vegetation is removed. The removal of vegetation destabilizes the banks and may result in bank erosion. If proper mitigation techniques are used (revegetation efforts), the loss of riparian vegetation should only be temporary.

Timber harvest practices, such as clear-cutting and selective cutting, have a direct impact on sedimentation rates in a stream system. When vegetation is removed, soils are destabilized because of slope characteristics, loss of moisture, loss of canopy cover, and loss of root strength. The sediment is mobilized during storm events and is moved initially by sheet & rill erosion or gully erosion. Other sediment transport occurs as debris flows or landslides. Proper timber harvesting techniques can minimize the mobilization of sediment.

Many current state and federal forestry regulations minimize or prohibit timber harvesting in riparian zones. This provides a buffer strip between harvested land and streams. By quantifying the physical parameters of the riparian buffer zone, a truly protective buffer width can be determined. Phillips (1989) has proposed a model including soil type, geomorphic features, and vegetative complexes, to determine the necessary width of a riparian buffer which would adequately filter sediment and nutrients and protect the stream. Myers and Swanson (1992) have found that stream stability and resilience are closely tied to stream type. They utilized Rosgen's 1985 stream classification system to generalize stream stability and resilience. Using these tools, forestry managers can more adequately determine the width of riparian buffer zones to allow maximum harvesting potential while concurrently protecting a stream system.

Range

Research in the area of rangeland impacts has been significantly less than that of forestry. Nevertheless, grazing on rangeland has serious implications for the increased sediment supply moving into aquatic systems. Compaction of the soil by grazing animals along with a reduction in ground cover causes increased runoff and less infiltration into the soil. The increased runoff causes the hydrograph to become steeper with higher peak flows. This excess energy may be expended in incision of the stream channel or erosion of the stream banks.

Direct effects of the grazing animals are also important to recognize. If the animals have no source of water, such as a watering trough, they will migrate towards rivers and lakes, trampling down vegetation and destabilizing banks. Livestock spend more time in riparian areas than in upland areas; consequently the riparian areas are more intensively grazed (Armour et al. 1991). Besides the direct impact on streams and lakes from trampling, there are secondary effects as well. Increased turbidity from erosion of the banks reduces primary productivity in the stream, in turn reducing the available food in the stream and adversely affecting the fish habitat. The destabilized banks may cause the channel to become wider and shallower (CIEATFWH 1982). Once the channel becomes wider and shallower it may continue to meander within the banks and increase bank erosion, causing an increase in the sediment supply and a decrease in the stream's ability to move all of the sediment in the channel.

Fencing off riparian zones for protection from grazing cattle has proven to be very successful. Recovery rates are generally rapid (within 5 years) and the cost is relatively low. Other alternatives to total livestock exclusion include light grazing levels, late-season grazing, and rest-rotation grazing systems (Sedgwick and Knopf 1991). Sedgwick and Knopf (1991) found that year-long and spring-summer grazing were especially damaging to range quality. They also found that two factors, initial grazing at proper levels and late-year grazing, were most responsible for range resilience. Late-year grazing is important in the western United States because it is the dormant season for most range plants and it is also a period of low rainfall and low stream discharge (Sedgwick and Knopf 1991).

A position statement by the American Fisheries Society (Armour et al. 1991) states, "The riparian problem is further complicated because today's range management guidelines do not call for different management strategies for upland and riparian vegetative types. Because riparian environments are lumped into broad terrestrial environmental classifications, they become unidentifiable for land-management purposes." The authors believe that the primary effect of grazing on aquatic systems is the addition of fine sediment from bank erosion and upland soil erosion. The American Fisheries Society supports livestock management that includes the protection and recognition of riparian zones (Armour et al. 1991).

Agriculture

If the trend in agriculture is towards increased production, utilization of marginal lands for crop production could cause increases in erosion and sedimentation. This is a major concern for marginal lands that are currently under the Conservation Reserve Program (CRP) and will presumably return to agricultural production when their owners' contracts expire. However, producers will be required to place their land into acceptable conservation systems to retain USDA support. The future conversion of rangeland and woodlands will be controlled by the Sodbuster provisions of the Food Security Act of 1985, but any conversion to crop production will require increased use of agricultural chemicals to attain acceptable yields. Marginal lands are typically more erodible because of steeper slopes (CIEATFWH 1982).

The loss of small farms to large industrial farms may also lead to erosion problems. Fencerows are eliminated as single properties become larger. These fencerows act as a buffer strip and can trap sediment. Because of increasing demands for agricultural products, crop rotation may become less frequent and double cropping will become more frequent (CIEATFWH 1982).

The arid West is limited in the amount of land that can be converted to cropland because of water and energy limitations. Drip irrigation should lead to a reduction in sediment and nutrient transport to local water systems as well as to increased water efficiency. The regions east of the Mississippi still have potential for further agricultural development: productivity could be greatly increased by the use of double cropping and irrigation. That would lead to greater erosion and runoff (CIEATFWH 1982).

The primary effect of agriculture is agricultural runoff. Runoff may simply cause erosion of the topsoil, but it may also transport agricultural chemicals that are bound to the particles being eroded. The concern for agricultural runoff is not only excess sediment, but also the potential for the introduction of toxins into an aquatic system. Significant technology exists to prevent agricultural erosion and runoff but it is often expensive and underutilized. Debris basins, settling ponds, and other structures can be used to catch sediment and clarify water before it enters a hydrologic system. However, keeping the soil on the field makes the most ecologic and financial sense.

In areas where surface water is unavailable because of prior allocation or seasonal fluctuations, ground water is utilized. If the ground water is heavily used, local lowering of the water table may occur. This can result in the death of riparian vegetation, which may rely on shallow ground water for the dry seasons of the year. Death of the riparian vegetation causes destabilization and erosion of streambanks and the riparian buffer is eliminated. Lowering of the water table may also result in the lowering of a nearby, hydrologically connected lake or reservoir.

Another impact of past agricultural practices was the removal of riparian vegetation to increase arable lands. Floodplain soils commonly are very fertile, productive, and relatively level. Those qualities combined with proximity to water all promote conversion to cropland. Because of the proximity to water, sediment delivery tends to be high (i.e. >60 percent). There is considerable public interest in restoring streams and riparian areas, so there may be some reversal of the recent losses.

The riparian buffer strip is important because it acts as a filter between the agricultural land, or any other land use, and the stream. If this buffer is removed to increase cropland or dies because of dewatering of the local aquifer, sediment has a more direct path to the stream channel. A study by Lowrance and others (1984) found that riparian forests in agricultural watersheds play an important role in nutrient and sediment filtering. These riparian forests are usually not managed because the soils tend to be poorly drained and require a considerable initial economic investment to bring them into cultivation. The potential benefits of riparian forests in agricultural watersheds should be investigated and maximized in designs for water-shed management (Lowrance et al. 1984).

Industrial

Industrial uses include large manufacturing companies, open pit mining, sewage treatment plants, and many other consumptive industries. Mining was the focus of many papers in the first half of this century. Mining spoil was allowed to enter lakes and fluvial systems with very little regulation. Because this was generally point-source pollution with sometimes devastating effects, legislation was passed to prevent severe environmental degradation due to mining operations. The motive of such laws was not always or even primarily environmental concern; for example, the prohibition of hydraulic mining was implemented on economic grounds because it was destroying agricultural lands.

Several papers have dealt with the effects of industrial sediment pollution. This work has been carried out primarily in the eastern United States as a result of heavy industry along many of the eastern rivers and in the Great Lakes region. An example is a study by Alexander and Hansen (1977), which addresses the effects of sediment from a gas-oil well drilling accident in Michigan. This study focuses on high-level, instantaneous industrial pollution. Low-level industrial pollution occurring over the span of years or decades is also extremely important. This type of pollution does not easily lend itself to single studies which are limited temporally. Low-level pollution requires years of monitoring to establish trends of toxin migration, uptake, and deposition. More long-term studies of low-level industrial pollution are needed.

The effects of mining include not only an increase in sediment but also an introduction of toxins. These toxins, very often heavy metals, are bound to the sediment which is eroded and washed into the hydrologic system.

Urban

Urban sediment pollution usually consists of temporary sediment pulses associated with construction of buildings and roads. However, longer-term stream and streambank erosion problems do occur because of floodplain and channel filling. Channel constriction causes an increase in tractive stress (boundary shear stress), which may lead to erosion and sedimentation problems.

There has been a large push to limit the amount of runoff that moves directly into a fluvial system from urban land use, but much remains to be done. Increased runoff because of decreased infiltration rates has the same effect as overgrazing. The peak flows are increased, which increases velocities and causes incision and erosion of the stream channel. Again, most sediment moving from urban areas moves from point sources, such as drainage ditches. A practice that is being utilized for urban storm drain mitigation is detention ponds. These are often incorporated into the landscape as scenic open areas while serving an important hydrologic purpose.

New engineering technology and protective measures have greatly reduced the amount of erosion that occurs during the construction phase of a development project. In addition, many units of government have passed urban erosion control ordinances to address urban erosion problems.

Water Resources

Among the largest impacts on sedimentation and the associated effects in aquatic systems are those caused by instream structures designed for water storage, diversion, and flood control. Dams are one of the most severe alterations to a stream. Bedload transport is stopped and peak flows are reduced. The reduction in peak flow quantity and intensity results in a reduced capacity to carry sediment. The flushing effect of large storm events is essentially halted. All this can result in a buildup of tributary sediment in the channel over many seasons, rather than a dry-season buildup with periodic flushing. Downstream scour as a result of long-duration clean water releases from dams is also a problem because there is high sediment recruitment directly below the dams. Stream diversions for agricultural water or hydroelectric generation also diminish the stream's capacity for sediment transport. The reduced tractive stress results in aggradation of sediment in the stream channel.

Conservation Management Systems

The best way to reduce all sedimentation effects (Table 1) is to plan conservation management systems throughout whole watersheds. NRCS in future will plan for the soil, water, air, plant, and animal resources and their interrelationships. The agencies can no longer provide alternatives and assistance that address individual problems like sheet & rill erosion without taking the effects on all five natural resources into account. Our involvement with water quality has brought this "reality" concern to the surface, as has the public's growing concern for the environment, especially wetland protection, food and water safety, fish and wildlife protection and enhancement, and a sustainable agriculture. Therefore, the effects of sediment (displayed in Table 1) need to be addressed in planning, with one focus being the effects of sediment on aquatic habitats.

As a technical agency, NRCS must constantly strive to improve methods to evaluate the potential effects of conservation practices on the natural resources when providing technical assistance. It is necessary to determine the physical effects relevant to each resource during the planning process because a conservation practice which has a positive effect on one resource may have positive or negative effects on other resources. One conservation practice usually does not completely solve a problem because consideration must be given to all five resources (soil, water, air, plants, and animals) and to the human factor.

Conservation Management Systems (CMS) are used to identify the two levels of soil, water, air, plant, and animal resource conservation that can be achieved through NRCS assistance to clients with planning and application. These two levels of treatment are Resource Management Systems (RMS) and Acceptable Management Systems (AMS). The quality criteria for both RMS and AMS are in Section III of the NRCS Field Office Technical Guide (FOTG).

Natural resource planning assistance will be directed toward development and implementation of Resource Management Systems (RMS). An RMS is defined as a combination of practices for land or water used within their capabilities that, as planned, will at a minimum meet established quality levels, and when installed, will provide for the conservation, protection, and/or improvement of the resource base for soil, water, air, plant, and animal resources. An RMS can be developed for any conservation treatment unit, depending on the needs and desires of the decisionmaker; however, one RMS will seldom suffice for an entire planning unit. When the RMS concept is applied on a watershed-wide basis, then all of the interactions and cumulative effects can be considered, and effects such as sediment reduction can be addressed in an ecosystem context.

To date, Resource Management Systems have been applied on more than 587 million acres throughout the United States. In fiscal year 1994, RMS were applied on 17.5 million acres. The 1994 application occurred when there was still a heavy NRCS program emphasis on sheet & rill erosion under the Food Security Act (FSA) of 1985 and the Food, Agriculture, Conservation and Trade Act (FACTA) of 1990. In addressing just sheet & rill erosion on highly erodible cropland, the NRCS in fiscal year 1994 provided assistance to treat more than 3.5 million acres, thus reducing average sheet & rill erosion on those acres from 17.7 tons per acre to 5.9 tons per acre, a decrease of 67 percent.

The impacts of the Food Security Act of 1985 on the area above the Lower Granite Reservoir in Oregon were addressed by Reckendorf and Pedone (1989). They determined that 820,416 acres of dry cropland in that area were eroding at an average rate of 17 million tons per year. By retiring highly erodible land and putting conservation systems into effect, an 85 percent rate of landowner participation would result in a 67-percent reduction in annual erosion on dry cropland (from 21.5 tons per acre to 7.1 tons per acre). This would further result in a 42 percent reduction of sediment yield (959,460 tons) into the Lower Granite Reservoir.

It is difficult to project the effect of this sediment yield reduction on the aquatic habitat along the rivers leading to the reservoir. However, a study by McNamee (1985) along Mission Creek, which is a tributary of the Lower Granite Reservoir, projected that there would be an average annual benefit to the steelhead fishery from erosion control and sediment reduction of $0.41 per ton of sediment.

Not all of the sediment yield from the highly erodible land that was treated may have reached streams to impact aquatic habitat. However, the treated sheet & rill erosion areas, particularly those converted to grasslands under the Conservation Reserve Program of FSA, would reduce erosion of the finer particles (clay, silt, and fine sand) that have a higher sediment delivery ratio to reach streams and impact aquatic habitat.

In resource areas where social, cultural, or economic characteristics make it infeasible to implement a Resource Management System, planning to the Acceptable Management System level may apply. An Acceptable Management System is designed to treat soil, water, air, plant, and animal resources at a level which is achievable in view of the social, cultural, and economic characteristics of the resource involved.

Rarely does conservation planning result in an RMS that is quickly applied. Much of the time a customer's decisions to treat resource problems are reached progressively over time. This progressive planning (consultative selling in private industry) is the incremental process of building a plan on part or all of the planning unit consistent with the decision maker's ability to introduce improvements over a period of time. Even though the planning and decision making may be done progressively, it will always be directed toward the planning and ultimate implementation of a Resource Management System.

Concluding Remarks

The emphasis of this paper is on sediment and its effects on the aquatic environment. This has become a very important issue in the United States and other countries because of expanding urban centers, greater use of natural resources, and the expansion of agriculture onto marginal lands. The more intensively the land is used, the greater is the potential for erosion and sedimentation problems. Erosion and sedimentation can adversely effect aquatic habitat and the species that depend on it. It will become imperative for land-use managers and natural resource planners to recognize, emphasize and mitigate erosion and sedimentation problems.

Streams, lakes, and estuaries are all susceptible to sedimentation and erosion problems. Each system responds in a different way to accelerated sedimentation, so each system should be evaluated independently of the others, recognizing that hydrologically these systems may be closely connected.

Not all streams respond to sedimentation in the same way. Depending on the stream character (gradient, sediment transport, discharge), accelerated erosion and sedimentation will have varying effects. By knowing the basic characteristics of certain types of streams through a classification system, some generalizations and predictions can be made about channel response. This does not replace a thorough stream investigation but it provides information for planning purposes.

Lake sedimentation requires a different method of evaluation because treating the watershed problem may not be enough. Lakes do not flush their systems of fine sediment, so sediment removal may be required to restore aquatic habitat. For this reason lakes are much more sensitive to sedimentation than are streams. Estuary sedimentation is very complex because sediment transport is not always unidirectional. Tidal fluxes and stream fluxes are combined, making sediment yield estimates very difficult, and effects along shorelines are as important as effects in the watershed. Flocculation and significant human influences. can further aggravate the problems.

These three systems (streams, lakes, and estuaries) seem to be very different, yet they are all part of a larger, even more complex ecosystem. The interrelationship must be recognized and addressed when planning any type of basin or watershed projects.

Environmental sensitivity and environmental activism are on the rise and the result will be increasing demand for a cleaner, healthier environment. This healthier environment must be balanced with an ever increasing need for forest products, agricultural products, and rangeland for cattle. Keeping sediment on the watershed, whether it be forest, range, agricultural, industrial, or urban lands, makes economic and ecological sense. For NRCS, the best opportunities to reduce sediment's effects come when planning with individuals, groups, and units of government. The importance of ecosystem-based assistance must be emphasized in planning conservation management systems that integrate the effects on soil, water, air, plants, animals, the land user, and the community. The greatest reduction of sediment impacts on aquatic habitat will occur when conservation management systems are planned and installed on a whole-watershed basis.

References Cited

Alexander, G.R. and E.A. Hansen. 1977. The effects of sediment from a gas-oil well drilling accident on trout creeks of the Williamsburg area, Michigan. Lansing, Michigan Department of Natural Resources; Fisheries Research Report No. 1851.

Alexander, G.R. and E.A. Hansen. 1986. Sand bed load in a brook trout stream. North Amer. Journal of Fisheries Management 6:9-23.

American Society of Civil Engineers (ASCE) Task Committee on Sediment Transport and Aquatic Habitats. 1992. Sediment and aquatic habitat in river systems. Journal of Hydraulic Engineering 118(5):669-687.

Armour, C.L., D.A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. Fisheries 16(1):7-11.

Beauchamp, D.A., M.F. Shepard, and G.B. Pauley. 1983. Chinook salmon. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates. U.S. Fish and Wildlife Service, FWS/OBS-82/11.6:7REL 82.4, Washington D.C.

Bjornn, T.C. 1974. Sediment in streams and its effects on aquatic life. Moscow, Idaho: Water Resources Research Institute, Research Technical Completion Report, Project No. B-025-IDA.

Brice, J.C. and J.C. Blodgett. 1978. Counter measures of hydraulic problems at bridges. Vol. 1, Analyses and Assessment. Report No. FHWA-RD-78-1622, Federal Highway Admin. Washington, DC. 169 pp.

Brusven, M.A., F.J. Watts, R. Leudtke, and T.L. Kelley. 1974. A model design for physical and biotic rehabilitation of a silted stream. Water Resources Research Institute, University of Idaho, Moscow, ID. Report No. W75-06077; OWRT-A-032-IDA(2), 107 pp.

Bukata, R.P. 1992. State of the art techniques for inventory of Great Lakes aquatic habitats. Part D: Remote sensing as an aid to aquatic habitat surveillance. In The development of an aquatic habitat classification system for lakes, ed. W.D.N. Busch and P.G. Sly. Boca Raton, Florida: CRC Press.

Bullard, W.Q.E. Jr. 1965. Role of watershed management in the maintenance of suitable environments for aquatic life. In Trans. 3rd Seminar on Biological Problems in Water Pollution, ed.C.M. Tarzwell, pp. 265-269. U.S. Public Health Serv. Publ. 999-WP-25. Robert A. Taft Sanit. Eng. Cent., Cincinnati, OH.

Burton, G.A. 1988. Stream impact assessments using sediment microbial activity tests. In Chemical and biological characterization of municipal sludges, sediments, dredge spoils, and drilling muds, ASTM STP 976, pp. 300-310. Philadelphia, PA.

Committee on Impacts of Emerging Agricultural Trends on Fish and Wildlife Habitat (CIEATFWH). 1982. Impacts of emerging agricultural trends on fish and wildlife habitat. National Academy Press: Washington, D.C.

Committee on Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy (CRAE). 1992. Restoration of aquatic ecosystems: Science, technology, and public policy. Water Science and Technology Board, Commission on Geosciences, Environment, and Resources. National Research Council: National Academy Press, Washington, D.C.

Cordone, A.J. and D.W. Kelly. 1961. The influences of inorganic sediments on the aquatic life of streams. California Fish and Game 47(2):189-228.

Cummins, K.W. 1973. Trophic relations of aquatic insects. Annual Review of Entomology 18:183-206.

Cummins, K.W. 1992. Invertebrates. In The rivers handbook: Hydrological and ecological principles, ed. P. Calow and G.E. Petts. Blackwell Scientific Publications: London.

Cunningham, P.A., J.E.H. Wilson, D.W. Evans, and J.D. Costlow, Jr. 1987. Effects of sediment on the persistence and toxicity of diflubenzuron (Dimilin) in estuarine waters: a laboratory evaluation using larvae of two estuarine crustaceans. In Pollution physiology of estuarine organisms, ed. W.B. Vernberg, A. Calabrese, F.P. Thurberg, and F.J. Vernberg, pp. 299-331. Columbia, SC: University of South Carolina Press.

Dyer, K.R. 1973. Estuaries: A physical introduction. London: John Wiley & Sons.

Edsall, T.A. 1992. State of the art techniques for inventory of Great Lakes aquatic habitats. Part C: Use of side-scan sonar to inventory and map Great Lakes benthic habitat. In The development of an aquatic habitat classification system for lakes, ed. W.D.N. Busch and P.G. Sly, chapter 3, p. 27-57. Boca Raton, Florida: CRC Press.

Ellis, M.M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17:29-42.

Environmental Protection Agency. 1990. Draft ecological evaluation of proposed discharge of dredged material into ocean waters. EPA-503-8-90/002.

Environmental Protection Agency. 1992. Sediment classification methods compendium. EPA-823-R-92-006.

Environmental Protection Agency. 1973. Measures for the restoration and enhancement of quality of freshwater lakes. EPA-430/9-73-005. Washington, D.C.

Everest, F.H., Beshta, R.L., Scrivener, J.C., Koski, K.V., Sedell, J.R. and Cederholm, C.J. 1987. Fine sediment and salmonid production: A paradox. In Streamside management and forestry and fishery interactions, ed. E. Salo and T. Cundy, pp. 98-142. Contribution 57, College of Forest Resources, University of Washington, Seattle.

Frissell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. Environmental Management 10(2):199-214.

Gammon, J.R. 1979. The effect of inorganic sediment on stream biota. USEPA, Water Pollution Control Research Series 18050DWC12/70, Water Quality Office, Washington, D.C.

Gore, J.A. 1978. A technique for predicting in-stream flow requirements of benthic macroinvertebrates. Freshwater Biology 8:141-151.

Hansen, E.A. 1971. Sediment in a Michigan trout stream: its source, movement, and some effects on fish habitat. St. Paul, Minnesota: USDA-Forest Service; Research Paper NC-59

Healey, M. 1984. Fish predation on aquatic insects. In The ecology of aquatic insects, ed. V.H. Resh and D.M. Rosenberg. New York: Praeger Special Studies--Praeger Scientific Publications.

Heede, B.H. and J.N. Rinne, 1990. Hydrodynamic and fluvial morphologic processes: implications for fisheries management and research. North Am. Jour. of Fisheries Management 10(3):249-268.

Herdendorf, C.E., L. Hakanson, D.J. Jude, and P.G. Sly, 1992. A review of the physical and chemical components of the Great Lakes: a basis for classification and inventory of aquatic habitats. In The development of an aquatic habitat classification system for lakes, ed. W.D.N. Busch and P.G. Sly, chapter 6, pp. 109-159. Boca Raton, Florida: CRC Press.

Horne, G.S. and P.C. Patton. 1989. Bedload-sediment transport through the Connecticut River estuary. Geol. Soc. Amer. Bulletin 101:805-819.

Jackson, W.L. and R.L. Beschta. 1982. A model of two-phase bedload transport in an Oregon Coast Range stream. In Earth surface processes and landforms, vol. 7, pp. 517-527. New York: John Wiley & Sons, Ltd.

Jones and Stokes Associates. 1990. Channel stabilization and riparian restoration plan for the lower 23 miles of the Truckee River. Draft Report to US Fish and Wildlife Service. Sacramento, CA.

Junoy, J. and J.M. Vieitez. 1990. Macrozoobenthic community structure in the Ria de Foz, an intertidal estuary (Galicia, Northwest Spain). Marine Biology 107:329-339.

Keller, E.A. 1971. Aerial sorting of bedload material; the hypotheses of velocity reversal. Geol. Soc. Amer. Bulletin 82:753-756.

King, R. and J. Potyondy. 1993. Statistical testing of Wolman pebble counts. Stream Notes, October, 1993. Stream System Technology Center, USFS, Fort Collins, CO.

Komar, P.D. and S.M. Shih. 1992. Equal mobility versus changing bedload grain sizes in gravel-bed streams. In Dynamics of gravel-bed rivers, ed. P. Billi, R.D. Hey, C.R. Thorne, & P. Tacconi, pp. 73-106. Chichester, U.K.: John Wiley & Sons Ltd.

Kondolf, G.M. and M.G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29(7):2275-2285.

Lane, E.W. 1957. A study of the shape of channels formed by natural streams flowing in erodible material. Missouri River Diversion. Sediment Series No. 9, U.S. Army Engineer Division, Missouri River, Corps of Engineers, Omaha, NE.

Leach, J.H., and R.C. Herron. 1992. A review of lake habitat classification. In The development of an aquatic habitat classification system for lakes, ed. W.D.N. Busch and P.G. Sly, chapter 3, pp. 27-57. CRC Press: Boca Raton, Florida..

Leopold, L.B. and M.G. Wolman. 1957. River channel patterns: braided, meandering, and straight. U.S. Geological Survey Prof. Paper 282-B.

Lowrance, R., R. Todd, J. Fail Jr., O. Hendrickson Jr., R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34:374-377.

Manny, B.A., D.J. Jude, and R.L. Eshenroder, 1989. Field test of a bioassay procedure for assessing habitat quality on fish spawning grounds. Trans. Am. Fisheries Society 118:175-182.

McDowell, P.F., T.W. Webb III, and P.J. Bartlein. 1990. Long-term environmental change. In The earth as transformed by human action, ed. B.L. Turner II, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Meyer, pp. 143-162. Cambridge University Press: Cambridge, MA.

McNamee, W.H. 1985. Economics of soil loss control on the Mission-Lapwai Watershed, Idaho. Doctoral thesis, Oregon State University, Corvallis, OR.

Minshall, G.W. 1984. Aquatic insect-substratum relationships. In The ecology of aquatic insects, ed. V.H. Resh and D.M. Rosenberg. New York: Praeger Special Studies--Praeger Scientific Publications.

Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands. New York: Van Nostrand Reinhold.

Montgomery, D.R. and J.M. Buffington. 1993. Channel classification, prediction of channel response, and assessment of channel conditions. TFW-SH10-93-002. University of Washington, Seattle.

Mudroch, A. and S.D. MacKnight, 1991. CRC handbook of techniques for aquatic sediments sampling. Boca Raton, Florida: CRC Press, Inc.

Myers, T.J., and S. Swanson. 1992. Variation of stream stability with stream type and livestock bank damage in northern Nevada. Water Resources Bulletin 28(4):743-754.

Nester, R.T. and T.P. Poe. 1987. Visual observations of historical lake trout spawning grounds in western Lake Huron. North Am. J. Fish. Management 7:418-424.

Newlon, T.A. and F.W. Rabe 1977. Comparison of macroinvertebrate samplers and the relationship of environmental factors to biomass and diversity variability in a small watershed. Research technical completion report, project A-049-IDA; Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho.

Nuttall, P.M. 1972. The effects of sand deposition upon the macroinvertebrate fauna of the River Camel, Cornwall. Freshwater Biology 2:181-186.

Oregon Department of Environmental Quality. 1988. Oregon Dredged Sediment Guidelines Workshop, June 21-23, 1988, Lincoln City, Oregon.

Panel on Estuarine Research Perspectives (PERP). 1983. Fundamental Research on Estuaries: The importance of an interdisciplinary approach. Geophysics Study Committee, Geophysics Research Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council. National Academy Press: Washington, D.C.

Parker, G., P.C. Klingeman, and D.G. McLean. 1982. Bedload and size distribution in paved gravel-bed streams. Proc. Am. Soc. Civil Engs., J. Hydraulics Div. 108(HY1):585-587.

Phillips, J.D. 1989. Nonpoint source pollution control effectiveness of riparian forests along a coastal plain river. Journal of Hydrology 110:221-237.

Platts, W.S. 1968. South Fork Salmon River, Idaho, aquatic habitat survey with evaluation of sediment accruement, movement, and damages. USDA-Forest Service, Region 4.

Pritchard, D.W. 1952. Estuarine hydrography. Advances in Geophysics 1:243-280.

Resh, V.H. and D.M. Rosenberg, eds. 1984. The ecology of aquatic insects. New York: Praeger Special Studies-Praeger Scientific Publications.

Reckendorf, F. and P. Pedone. 1989. Erosion and sediment impacts of the 1985 Food Security Act above the Lower Granite Reservoir, Idaho, Oregon, and Washington. In: Proceedings of the National Nonpoint Source Conference, St. Louis. National Association of Conservation Districts, League City, Texas.

Robinson, A.R. 1970. Sediment, our greatest pollutant. USDA-Agricultural Research Service, Oxford, MS. Sedimentation Lab Paper 70-701.

Rosgen, D.L. 1994. A classification of natural rivers. Elsevier (Catena) In press.

Schaffner, L.C., R.J. Diaz, C.R. Olsen, and I.L. Larsen. 1987. Faunal characteristics and sediment accumulation processes in the James River Estuary, Virginia. Estuarine, Coastal, and Shelf Science 25:211-226.

Schumm, S.A. 1963. A tentative classification of alluvial river channels. U.S. Geological Survey Circular 477. Washington, DC.

Schumm, S.A. 1977. The fluvial system. New York: John Wiley & Sons. 338 pp.

Schumm, S.A., M.D. Harvey, and C.C. Watson. Yazoo Basin geomorphology. Final Report USDA, SCS, Project SCS 23-MS-80, 483 pp.

Sedgwick, J.A. and F.L. Knopf. 1991. Prescribed grazing as a secondary impact in a western riparian floodplain. Jour. Range Management 44(4):369-373.

Shaw, P.A. and J.A. Maga. 1943. The effect of mining silt on yield of fry from salmon spawning beds. California Fish and Game 29:29-41.

Statzner, B. and B. Higler. 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. Freshwater Biology 16:127-139.

USDA, SCS, 1977. Design of Open Channels, Chapter 3, Site Investigations. Technical Release No. 25, Washington, D.C.

USDA, SCS, 1992a. Problem Statement, Columbia Basin Salmonids. Portland, Oregon.

USDA, SCS, 1992b. Soil bioengineering for upland slope protection and erosion reduction. In: USDA, SCS, Engineering Field Handbook. Chapter 18. Government Printing Office: Washington, D.C.

Wilson, J.N. 1957. Effects of turbidity and silt on aquatic life. In Biological problems in water pollution, ed. C.M. Tarzwell. U.S. Dept. Health, Educ., and Welfare, Cincinnati, OH.

The Effects of Fine Sediment on Aquatic Habitat: A Comprehensive Bibliography

Adams, J.N. 1979. Variations in gravel bed composition of small streams in the Oregon Coast Range. M.S. thesis, Oregon State University, Corvallis, OR.

Adams, J.N. and Beschta, R.L. 1980. Gravel bed composition in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 37:1514-1521.

Adams, P.W. and Andrus, C.W. 1991. Planning timber harvesting operations to reduce soil and water problems in humid tropic steeplands. In Proceedings of the symposium on forest harvesting in Southeast Asia, 17-20 June 1991, Singapore. Forest Engineering, Inc. and Oregon State University, Forest Engineering Dept., Corvallis, OR.

Adams, P.W. and Andrus, C.W. 1990. Planning secondary roads to reduce erosion and sedimentation in humid tropic steeplands. In Research needs and applications to reduce erosion and sedimentation in tropical steeplands: Proceedings of the Fiji symposium, pp. 318-327. International Association of Hydrologic Scientists, Wallingford, U.K. publ. no. 192.

Adams, P.W., Beschta, R.L., and Froehlich, H.A. 1988. Mountain logging near streams: Opportunities and challenges. In Proceedings of the international mountain logging and Pacific Northwest skyline symposium, December, 1988, pp. 153-162.

Alderice, D.F., Bams, R.A., and Velsen, F.P.J. 1977. Factors affecting deposition, development, and survival of salmonid eggs and alevins: bibliography, 1965-1975. Canada Fisheries and Marine Service, Tech. Report 743, Nanaimo, B.C., Canada.

Alexander, G.R. 1974. Effects of sand sediment on brook trout in Hunt Creek. Lansing, Michigan Department of Natural Resources; project No. F-030-R-08, Study 1, Job 1-6.

Alexander, G.R. and Hansen, E.A. 1977. The effects of sediment from a gas-oil well drilling accident on trout in creeks of the Williamsburg area, Michigan. Lansing, Michigan Department of Natural Resources; Fisheries Research Report No. 1851.

Alexander, G.R. and Hansen, E.A. 1983. Effects of sand bedload sediment on a brook trout population. Lansing, Michigan Department of Natural Resources; Fisheries Research Report No. 1906.

Alexander, G.R. and Hansen, E.A. 1983. Sand sediment in a Michigan trout stream. Part II. Effects of reducing sand on a trout population. North American Journal of Fisheries Management 3:365-372.

Alexander, G.R. and Hansen, E.A. 1986. Sand bed load in a brook trout stream. North American Journal of Fisheries Management 6:9-23.

Allen, K.R. 1969. Limitations in production in salmonid populations in streams. In Symposium on salmon and trout in streams, ed. T.G. Northcote, pp. 3-20. H.R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver.

Alonso, C.V., Mendoza, C., and Tabios, G.Q. III. 1986. Sediment intrusion into the substrate of gravel bed streams. Water Forum '86.

Alonso, C.V. and Theuer, F.D. 1987. Modeling siltation of salmonid aquatic habitat. USDA--Agricultural Research Service, Hydro-Ecosystem Research Group, Fort Collins, CO.

Alonso, C.V., Theuer, F.D., and Zachmann, D.W. 1988. Tucannon River offsite study: Sediment intrusion and dissolved-oxygen transport model. USDA, Agricultural Research Service, Fort Collins, CO, DRAFT.

[ASCE] American Society of Civil Engineers Task Committee on Sediment Transport and Aquatic Habitats [authorship anonymous]. 1992. Sediment and aquatic habitat in river systems. Journal of Hydraulic Engineering 118(5):669-687.

Anadromous Salmonid Environmental Task Force. 1979. Freshwater habitat, salmon produced, and escapements for natural spawning along the Pacific coast of the United States. Pacific Fishery Management Council, Portland, Oregon.

Anderson, H.W. 1971. Relative contributions of sediment from source areas and transport process. In Forest land uses and stream environment: Proceedings of a symposium, ed. J.T. Krygier and J.D. Hall. Oregon State University, Corvallis, OR.

Armour, C.L., Duff, D.A., and Elmore, W. 1991. Effects of livestock grazing on riparian and stream ecosystems. Fisheries (Bethesda) 16(1):7-11.

Atlas, R.M., Horowitz, A., and Busdosh, M. 1978. Prudhoe crude oil in arctic marine ice, water, and sediment ecosystems: degradation and interactions with microbial and benthic communities. Journal of the Fishery Resource Board, Canada 35:585-590.

Bachman, R.W. 1958. The ecology of four northern Idaho trout streams with reference to forest road construction. M.S. thesis, University of Idaho, Moscow.

Bams, R.A. 1969. Adaption of sockeye salmon associated with incubation in stream gravels. In Symposium on salmon and trout in streams, ed. T.G. Northcote. H.R. MacMillan Lectures in Fisheries. University of British Columbia, Vancouver.

Barnes, R.S.K. and Mann, K.H., eds. 1991. Fundamentals of aquatic ecology. Blackwell Scientific Publications: London.

Bathurst, J.C. 1985. Literature review of some aspects of gravel-bed rivers. Institute of Hydrology, Wallingford, Oxon., UK.

Beauchamp, D.A., Shepard, M.F. and Pauley, G.B. 1983. Chinook salmon. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates. U.S. Fish and Wildlife Service, FWS/OBS-82/11.6:7 REL 82.4, Washington, D.C.

Becker, C.D. and Neitzel, D.A. 1983. Salmonid redd dewatering: What do we know? Battelle Pacific Northwest Labs, Richland, WA. Report No. PNL-SA-11841. 35 pp.

Beetschen, L.J., Schuler, V.J., Reed, J.R., and Eichelberger, J.G. 1992. Bioassay and biomonitoring help establish NPDES permit limits. Cabe Associates, Dover, DE. Water Environment & Technology 4(11):62-66.

Bennett, D.H. and Hassemer, P.F. 1982. Effects of I-90 construction activities on spawning sucess of kokanee (Oncorhynchus nerka) in Coeur d'Alene Lake. Moscow: University of Idaho.

Berg, L. and Northcote, T.G. 1985. Changes in territorial, gill-flaring, and feeding behavior in juvenile coho salmon (Oncorhynchus kisutch) following short-term pulses of suspended sediment. Canadian Journal of Fisheries and Aquatic Sciences 42:1410-1417.

Beschta, R.L. 1987. Conceptual models of sediment transport in streams. In Sediment transport in gravel-bed rivers, pp. 387-419. John Wiley & Sons Ltd., New York.

Beschta, R.L. 1984. River channel responses to accelerated mass soil erosion. In Symposium proceedings: Effects of forest land use on erosion and slope stability, ed. C.L. O'Loughlin and A.J. Pearce. Environment and Policy Institute, East-West Center, Univ. Hawaii, Honolulu. 155-163.

Beschta, R.L. 1983. Channel changes following storm-induced hillslope erosion in the upper Kowai Basin, Torlesse Range, New Zealand. Journal of Hydrology 22(2):93-111.

Beschta, R.L. 1983. Sediment and organic matter transport in mountain streams of the Pacific Northwest. In Proceedings of the D.B. Simons symposium on erosion and sedimentation, pp. 1-69 to 1-89. Simons, Li, & Assoc., Fort Collins, CO.

Beschta, R.L. 1982. Comment on "Stream system evaluation with emphasis on spawning habitat for salmonids" by Mostafa A. Shirazi and Wayne K. Seim. Water Resources Research 19(4):1292-1295.

Beschta, R.L. 1981. Management implications of sediment routing research. In Technical Bulletin No. 353, National Council of the Paper Industry for Air and Stream Improvement, 18-23.

Beschta, R.L. 1981. Patterns of sediment and organic matter transport in Oregon Coast Range streams. In Erosion and sediment transport in Pacific Rim steeplands: Symposium proceedings, pp. 179-188. International Association of Hydrologic Scientists, publ. no. 132.

Beschta, R.L. 1981. Review of theme 2; Stream channel dynamics and morphology. Journal of Hydrology (New Zealand) 20(1):90-93.

Beschta, R.L. 1980. Turbidity and suspended sediment relationships. In Proceedings of watershed management symposium, Irrigation and Drainage Division, American Society of Civil Engineers, Boise, ID, July 21-23, pp. 271-282.

Beschta, R.L. 1979. Debris removal and its effects on sedimentation in an Oregon Coast Range stream. Northwest Science 53(1):71-77.

Beschta, R.L. 1979. The effects of site preparation on water quality. In Proceedings of site preparation workshop, Medford, OR, Nov. 14-15, 1979.

Beschta, R.L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. Water Resources Research 14(6):1011-1016.

Beschta, R.L., O'Leary, S.J., Edwards, R.D., and Knoop, K.D. 1981. Sediment and organic matter transport in Oregon Coast Range streams. Water Resources Research Institute, OSU: Corvallis, Oregon.

Beschta, R.L. and Jackson, W.L. 1979. The intrusion of fine sediments into a stable gravel bed. Journal of the Fisheries Research Board of Canada 36:204-210.

Beverton, R.J.H. and Holt, S.J. 1957. On the dynamics of exploited fish populations. Min. of Ag., Fisheries and Food (United Kingdom), Fish Invest. Series II.

Bhowmik, N.G. and Adams, R.J. 1990. Sediments transport, hydraulic retention devices and aquatic habitat in sand-bed channels. In Hydraulic engineering: Proceedings of the 1990 national conference, Part 2 (of 2), pp. 1110-1115. ASCE, Boston Society of Civil Engineers Sect., Boston, MA.

Bianchi, D.R. 1963. The effects of sedimentation on egg survival of rainbow trout and cutthroat trout. M.S. thesis, Montana State College, Bozeman. 28 pp.

Birge,W.J., Black, J.A., Westerman, A.G., Francis, P.C. and Hudson, J.E. 1977. [Effects of] mercury and zinc on reproduction and survival of fish and amphibian populations in Kentucky. Kentucky Water Resources Research Institute, Lexington, KY. Report No. RR-100; W77-05003; OWRT-A-061-KY (1). 33 pp.

Birge, W.J. and Black, J.A. 1977. Embryopathic effects of waterborne and sediment-accumulated cadmium, mercury and zinc on reproduction and survival of fish and amphibian populations in Kentucky. Kentucky Water Resources Research Institution, Lexington, KY. Report No. 100. 28 pp.

Bisson, P.A. and Bilby, R.E. 1982. Avoidance of suspended sediment by juvenile coho salmon. North American Journal of Fisheries Management 2:371-374.

Bjornn, T.C. 1968. Survival and emergence of trout and salmon in various gravel-sand mixtures. In Proceedings: Forum on the relation between logging and salmon, pp. 80-88. American Institute of Fishery Research Biologists and Alaska Department of Fish and Game, Juneau, AK.

Bjornn, T.C. 1969. Embryo survival and emergence studies. Job No. 5, Salmon and Steelhead Investigation, Project F-49-R-7, Annual Completion Report, Idaho Dept. of Fish and Game. 11 pp.

Bjornn, T.C. 1971. Abundance of chinook salmon as related to sediment in the South Fork Salmon River. Unpublished report. University of Idaho, Moscow.

Bjornn, T.C. 1973. Survival and emergence of salmon and trout embryos and fry in gravel-sand mixtures. Unpublished report. University of Idaho, Moscow.

Bjornn, T.C. 1974. Sediment in streams and its effects on aquatic life. Moscow, Idaho: Water Resources Research Institute, Research Technical Completion Report, Project No. B-025-IDA.

Bjornn, T.C. 1987. A model for predicting production and yield of Tucannon River salmon and steelhead stocks in relation to land management practices.

Bjornn, T.C., Brusven, M.A., Molnau, M.P., Watts, F.J., Wallace, R.L., Neilson, D.R., Sandine, M.F., and Stuehrenberg, L.C. 1974. Sediment in streams and its effects on aquatic life. Res. Tech. Rept. OWRT Proj. B-025-IDA. Water Resources Research Institute, University of Idaho, Moscow.

Bjornn, T.C., Brusven, M.A., Molnau, M.P., Milligan, J.H., Klamt, R.A., Chacho, E. and Schaye, C. 1977. Transport of granitic sediment in streams and its effects on insects and fish. Forest, Wildlife and Range Station. Technical Report, Project B-036-IDA.

Bjornn, T.C. and Brusven, M.A. [1990?]. Effects of cottonwoods on salmonid habitat. Moscow: University of Idaho.

Bjornn, T.C., Burns, D.C., Collotzi, A.W., Newhouse, H.W., and Platts, W.S. 1980. A method for predicting fish response to sediment yields: a working draft. Ogden, Utah and Missoula, Montana: USDA--Forest Service, Intermountain and Northern regions, Wildlife Management.

Bjornn, T.C., Moffitt, C.M., Tressler, R.W., Reese, K.P., Falter, C.M., Myers, R.E., Cleveland, C.J., and Milligan, J.H. 1989. An evaluation of [effects of] sediment and nutrient loading on fish and wildlife production at Bear Lake National Refuge. Moscow: Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho; Technical Report 87-3.

Bradley, J.B., Williams, D.T., and Barclay, M. 1991. Incipient motion criteria defining "safe" zones for salmon spawning habitat. In Hydraulic engineering: Proceedings of the 1991 national conference, pp. 447-452. American Society of Civil Engineers, New York, NY.

Brice, J.C. and Blodgett, J.C. 1978. Counter measures of hydraulic problems at bridges. Vol. 1, Analyses and Assessment. Report No. FHWA-RD-78-1622, Federal Highway Administration, Washington, DC. 169 pp.

Brown, G.W. 1972. Logging and water quality in the Pacific Northwest. In Watersheds in transition: Symposium proceedings, pp. 330-334. American Water Resources Association and Colorado State University.

Brown, G.W. 1972. The Alsea Watershed study. Pacific Logging Congress, Portland, OR. Loggers Handbook 32:13-

15, 127-130.

Brown, G.W. 1973. The impact of timber harvest on soil and water resources. OSU Ext. Serv. Bull. EB 827.

Brown, G.W. 1983. Forestry and water quality. Oregon State Univ. Bookstore, Inc., Corvallis, OR.

Brown, G.W. 1985. Controlling nonpoint source pollution from silvicultural operations: What we know and don't know. In Perspectives on nonpoint source pollution, EPA, Kansas City, MO. May 19-22, 1985, pp. 332-335.

Brown, G.W. and Krygier, J.T. 1971. Clear-cut logging and sediment production in the Oregon Coast Range. Water Resources Research 7(5):1189-1198.

Brown, G.W. and McMahon, T.E. 1988. Winter ecology of juvenile coho salmon in Carnation Creek, B.C.; Summary of findings and management implications. In Proceedings of the workshop: Applying 15 years of Carnation Creek results, ed. T. Chamberlin, pp. 108-117. Pac. Bio. Sta. Nanaimo, B.C.

Brusven, M.A., Watts, F.J., Leudtke, R., and Kelley, T.L. 1974. A model design for physical and biotic rehabilitation of a silted stream. Water Resources Research Institution, Idaho University, Moscow, Report No. W75-06077; OWRT-A-032-IDA(2), 107 pp.

Brusven, M.A. and Rose, S.T. 1981. Influence of substrate composition and suspended sediment on insect predation by the torrent sculpin, Cottus rhotheus. Canadian Journal of Fisheries and Aquatic Sciences 38:1444-1448.

Buhl, K.J. and Hamilton, S.J. 1991. Relative sensitivity of early life stages of arctic grayling, coho salmon and rainbow trout to nine inorganics. Ecotoxicology and Environmental Safety 22 (2): 184-197.

Buhl, K.J. and Hamilton, S.J. 1990. Comparative toxicity of inorganic contaminants released by placer mining to early life stages of salmonids. Ecotoxicology and Environmental Safety 20 (3): 325-342.

Bukata, R.P. 1992. State of the art techniques for inventory of Great Lakes aquatic habitats. Part D: Remote sensing as an aid to aquatic habitat surveillance. In The development of an aquatic habitat classification system for lakes, ed.W.D.N. Busch and P.G. Sly. CRC Press: Boca Raton, Florida.

Bullard, W.Q.E. Jr. 1965. Role of watershed management in the maintenance of suitable environments for aquatic life. In Transactions of the 3rd seminar on biological problems in water pollution, ed. C.M. Tarzwell. U.S. Public Health Service Publ. 999-WP-25, pp. 265-269. Robert A. Taft Sanitary Engineering Center, Cincinnati, OH.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. Fishery Bulletin of the U.S. Fish and Wildlife Service 52: 97-110.

Burns, D.C. and Edwards, R.E. 1985. Embeddedness of salmonid habitat of selected streams on the Payette National Forest for Payette National Forest.

Burns, J.W. 1970. Spawning bed sedimentation studies in northern California streams. California Fish and Game 56(4):253-270.

Burroughs, E.R. and Froehlich, H.A. 1972. Effects of forest fertilization on water quality in two small watersheds. BLM Tech. Note.

Burton, G.A. 1988. Stream impact assessments using sediment microbial activity tests. In Chemical and biological characterization of municipal sludges, sediments, dredge spoils, and drilling muds, ASTM STP 976, pp. 300-310. Philadelphia, PA.

Burton, T.A., Harvey, G.W. and McHenry, M. 1990. Protocols for assessment of dissolved oxygen, fine sediment and salmonid embryo survival in an artificial redd. Report of the Idaho Department of Health and Welfare, Division of Environmental Quality, Water Quality Bureau.

Burton, T.A. and Harvey, G.W. 1990. Estimating intergravel salmonid living space using the cobble embeddedness sampling procedure. Idaho Department of Health and Welfare, Boise, ID.

Burton, T.S., Haley, R., and Stone, T.B. 1977. Potential effects of sediment control operations and structures on Grass Valley Creek and Trinity River fish and wildlife. Sacramento: California Department of Fish and Game.

Callahan, C.A., Gakstatter, J.H., and Malveg, K.W. (undated) The effects of sediment from agricultural activities on fishery resources in several midwestern states. USEPA, unpublished report. Corvallis, OR.

Campbell, H.J. 1954. The effect of siltation from gold dredging on the survival of rainbow trout and eye eggs in Powder River, Oregon. Oregon Game Commission. 3 pp.

Campbell, I.C. and Doeg, T.J. 1989. Impact of timber harvesting on production of streams: a review. Australian Journal of Marine and Freshwater Research 40(5):519-539.

Carling, P.A. and McCahon, C.P. 1987. Natural siltation of brown trout (Salmo trutta L.) spawning gravels during low-flow conditions. In Regulated streams: Advances in ecology, pp. 229-244. Plenum Press: New York, NY.

Carlson, J.Y. 1989. Effects of forest management on fish habitat macroinvertebrates in Northeast Oregon streams. M.S. thesis, Oregon State University, Corvallis, OR.

Carson, K.A. 1985. A model of salmonid egg respiration. M.S. thesis, Colorado State University, Fort Collins, CO.

Cederholm, C.J. and Lestelle, L.C. 1974. Observations on the effects of landslide siltation on salmon and trout resources of the Clearwater River, Jefferson County, Washington 1972-73. University of Washington, Fishery Research Institute. Final Report FRI-UW-7404. 89 pp.

Cederholm, C.J. and Salo, E.O. 1979. The effects of logging road landslide siltation on the salmon and trout spawning gravels of Stequaleho Creek and the Clearwater River Basin, Jefferson County, Washington, 1972-1978. Seattle: University of Washington, Fishery Research Institute. Final Report Part III, FRI-UW-7915. 99 pp.

Cederholm, C.J., Reid, L.M., and Salo, E.O. 1981. Cumulative effects of logging road sediment on salmonid populations in the Clearwater River, Jefferson County, Washington. In Proceedings from the conference: Salmon-spawning gravel: A renewable resource in the Pacific Northwest? pp. 38-74. Rep. 39. State of Washington Water Research Center, Pullman.

Cederholm, C.J., Reid, L.M., Edie, B.C., and Salo, E.O. 1981. Effects of forest road erosion on salmonid spawning gravel composition and populations of the Clearwater River, Washington. Research Contribution No. 568, College of Fishery, University of Washington, Seattle, WA.

Cederholm, C.J., Reid, L.M. 1986. The impacts of sedimentation on coho salmon populations of the Clearwater River. In Symposium on streamside management: Fishery and forestry interactions. University of Washington, Seattle, WA.

Chapman, D.W. and McLeod, K.P. 1987. Development of criteria for fine sediment in the northern Rockies ecoregion. EPA Final Report. 279 pp.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117 (1):1-21.

Chavalier, B., Carson, C., and Miller, W.J. 1984. Report of engineering and biological literature pertaining to the aquatic environment: With special emphasis on dissolved oxygen and sediment effects on salmonid habitat. ARS Proj. 5602-20813-008A. Colorado State University, Fort Collins.

Chilton, E.W. II. 1991. System for maintaining sediment suspensions during larval fish studies. Progressive Fish-Culturist 53(1):28-32.

Chutter, E.M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiologia 34:57-76.

Coats, R., Collins, L., Florsheim, J., and Kaufman, D. 1985. Channel change, sediment transport, and fish habitat in a coastal stream: effects of an extreme event. Environmental Management 9(1):35-48.

Coble, D.W. 1960. The influence of environmental conditions in redds on the survival of salmonid embryos. M.S. thesis, Oregon State University, Corvallis, OR.

Committee on Impacts of Emerging Agricultural Trends on Fish and Wildlife Habitat. 1982. Impacts of emerging agricultural trends on fish and wildlife habitat. National Academy Press: Washington, D.C.

Committee on Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. 1992. Restoration of aquatic ecosystems: Science, technology, and public policy. Water Science and Technology Board, Commission on Geosciences, Environment, and Resources. National Research Council: National Academy Press, Washington, D.C.

Conner, M.S. 1984. Fish sediment concentration ratios for organic compounds. Environmental Science and Technology 18:31-34.

Cooper, A.C. 1959. Discussion of the effects of silt on the survival of salmon eggs and larvae. In Proc. 5th symp. PNW on siltation: Its source and effects on aquatic environments, ed. E.F. Eldridge and J.N. Wilson, pp. 18-22. U.S. Dept. Health, Educ., and Welfare, Portland, OR.

Cooper, A.C. 1965. The effect of transported stream sediments on survival of sockeye and pink salmon eggs and alevin. International Pacific Salmon Fisheries Commission Bulletin 18. 71 pp.

Copp, G.H. 1991. Typology of aquatic habitats in the Great Ouse, a small regulated lowland river. Regulated Rivers Research & Management 6(2):125-134.

Cordone, A.J. and Kelly, D.W. 1961. The influences of inorganic sediments on the aquatic life of streams. California Fish & Game 47(2):189-228.

Cordone, A.J. and Pennoyer, S. 1960. Notes on silt pollution in the Truckee River drainage, Nevada and Placer Counties. CA Fish and Game, Reg. 2, inland fish admin. report 60-14.

Crisp, D.T. (1989). Some impacts of human activities on trout, Salmo trutta, populations. Freshwater Biology 21 (1):21-33.

Crouse, M.R., Callahan, C.A., Maleug, K.W., and Dominguez, S.E. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. Transactions of the American Fisheries Society 110:281-286.

Cummins, K.W. 1973. Trophic relations of aquatic insects. Annual Review of Entomology 18:183-206.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bioscience 24:631-641.

Cummins, K.W. 1975. Macroinvertebrates. In River ecology, ed. B. Whitton. London: Blackwell Scientific Publications.

Cummins, K.W. 1992. Invertebrates. In The rivers handbook: Hydrological and ecological principles, ed. P. Calow and G.E. Petts. Blackwell Scientific Publications: London.

Cunjak, R.A. 1988. Behaviour and microhabitat of young Atlantic salmon (Salmo salar) during winter. Canadian Journal of Fisheries and Aquatic Sciences 45 (12):2156-2160.

Cunningham, P.A., Wilson, J.E.H., Evans, D.W., and Costlow, J.D. Jr. 1987. Effects of sediment on the persistence and toxicity of diflubenzuron (Dimilin) in estuarine waters: a laboratory evaluation using larvae of two estuarine crustaceans. In Pollution physiology of estuarine organisms, ed. W.B. Vernberg, A. Calabrese, F.P. Thurberg, and F.J. Vernberg, pp. 299-331. Columbia, SC: University of South Carolina Press.

Daykin, P.N. 1965. Application of mass transfer theory to the problem of respiration of fish eggs. Journal of the Fisheries Research Board of Canada 22(1):159-171.

Deusen, M.S. and Adams, P.W. 1989. Riparian areas: Fish and wildlife havens. Woodland Fish and Wildlife Pub., World For. Cent., Portland, OR.

Dill, L.M. and Northcote, T.G. 1970. Effects of gravel size, egg depth, and egg density on intragravel movement and emergence of coho salmon (Oncorhynchus kisutch) alevins. Journal of the Fisheries Research Board of Canada 27:1191-1199.

Duncan, S.H. and Ward, J.W. 1985. The influence of watershed geology and forest roads on the composition of salmon spawning gravel. Northwest Science 3:204-212.

Dyer, K.R. 1973. Estuaries: A physical introduction. London: John Wiley & Sons.

Dykstra, D.P. and Froehlich, H.A. 1976. Costs of stream protection during timber harvest. Journal of Forestry 74(10):684-687.

Edgington, J.R. 1984. Some observations of fine sediment and gravels of five undisturbed watersheds. In Fish and wildlife relationships in old-growth forests: A symposium. Morehead City, NC: American Institute of Fishery Research Biologists.

Edsall, T.A. 1992. State of the art techniques for inventory of Great Lakes aquatic habitats. Part C: Use of side-scan sonar to inventory and map Great Lakes benthic habitat. In The development of an aquatic habitat classification system for lakes, ed. W.D.N. Busch and P.G. Sly, chapter 3, pp. 27-57. Boca Raton, Florida: CRC Press.

Ellis, M.M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17:29-42.

Environmental Protection Agency. 1990. Draft ecological evaluation of proposed discharge of dredged material into ocean waters. EPA-503-8-90/002.

Environmental Protection Agency. 1992. Sediment classification methods compendium. EPA-823-R-92-006.

Environmental Protection Agency. 1973. Measures for the restoration and enhancement of quality of freshwater lakes. EPA-430/9-73-005. Washington, D.C.

Envirowest Environmental Consultants Ltd. (Vancouver, British Columbia). 1990. Fish habitat enhancement: A manual for freshwater, estuarine, and marine habitats. Ottawa, Ontario: Department of Fisheries and Oceans.

Espinosa, A., Vogelsang, R., and Murphy, W. 1985. Eldorada Creek: A plan for enhancement of key anadromous fish habitat in the Clearwater River Basin. In Natural propagation and habitat improvement, Volume II -- Idaho: Annual and Final Reports, pp. 137-193.

Everest, F.H. and Harr, R.D. 1982. Silvicultural treatments. In Influence of forest and rangeland management on anadromous fish habitat in western North America. USDA--Forest Service, General Technical Report PNW-96. Pacific Northwest Forest and Range Exp. Station, Portland, OR.

Everest, F.H., Lotspeich, F.B., and Meehan, W.R. 1982. New perspectives on sampling, analysis, and interpretation of spawning gravel quality. In Acquisition and utilization of aquatic habitat inventory information, ed. N.B. Armantrout, pp. 325-333. Western Division, American Fisheries Society, Portland, OR.

Everest, F.H., Armantrout, N.B., Keller, S.M., Parante, W.D., Sedell, J.R., Nickelson, T.N., Johnson, J.M., and Haugen, G.N. 1985. Salmonids. In Management of wildlife and fish habitats in forests of western Oregon and Washington, ed. E.R. Brown, Part 1: Chapter narratives, pp. 199-230. USDA--Forest Service, Pacific Northwest Region, Portland, OR.

Everest, F.H., Beshta, R.L., Scrivener, J.C., Koski, K.V., Sedell, J.R. and Cederholm, C.J. 1987. Fine sediment and salmonid production: A paradox. In Streamside management and forestry and fishery interactions, ed. E. Salo and T. Cundy, pp. 98-142. Contribution 57, College of Forest Resources, University of Washington, Seattle.

Fairchild, J.F., Boyle, T., English, W.R., and Rabeni, W.R. 1987. Effects of sediment and contaminated sediment on structural and functional components of experimental stream ecosystems. Water, Air, and Soil Pollution 36:271.

Fessler, J.L. 1970. Spawning area development for fall chinook salmon. In Progress in game and sportfish research 1963-1970, ed. H.J. Rayner, H.J. Campbell, and W.C. Lightfoot. Oregon State Game Commission, Research Division Report, Portland, Oregon.

Finnigan, R.J., Marshall, D.E, Mundie, J.H., Slaney, P.A., and Taylor, G.D. 1980. Stream enhancement guide. Vancouver, British Columbia: Ministry of the Environment.

Frissell, C.A., Liss, W.J., Warren, C.E., and Hurley, M.D. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. Environmental Management 10(2):199-214.

Gakstatter, J.H., Krawczyk, D.B., and Katko, A. 1980. Effects of agricultural pesticides on fishery resources. In Sediments and chemicals from ag resources: An analysis of environmental issues. Water Pollution Control Federation, Champaign, Illinois.

Gamblin, M.S. 1986. Taft/Bell sediment and fishery monitoring project. Idaho Dept. of Fish and Game draft progress report for BPA Intergovernmental Agreement DE-AI 79-85 BP 23203.

Gammon, J.R. 1979. The effect of inorganic sediment on stream biota. USEPA, Water Pollution Control Research Series 18050DWC12/70, Water Quality Office, Washington, D.C.

Gangmark, H.A. and Bakkala, R.G. 1960. A comparative study of unstable and stable (art. channel) spawning streams for incubating king salmon at Mill Creek, CA. California Fish and Game 46:151-164.

Garbrecht, J. and DeCoursey, D.G. 1986. Model relating water and sediment yield to upstream agricultural practices. In WaterForum '86: World water issues in evolution, Proceedings of the conference August 4-6, Long Beach, CA, pp. 1759-1766. ASCE, New York.

Garbrecht, J. and Theurer, F.D. 1986. A computer program simulation of the effect of upstream agricultural practices on the survival of salmonid embryos. In WaterForum '86: World water issues in evolution, Proceedings of the conference August 4-6, Long Beach, CA. ASCE, New York.

Garcia, B. and Williams, R.L. 1991. The Strawberry Valley Project: a history and initial experiences. Park City, Utah: USDA-Forest Service, Uinta National Forest, General Tech. Report RM-211.

Garrison, R.L. 1971. Spawning area development for fall chinook and subsequent survival from egg deposition to seaward migration. Oregon State Game Commission, Project AFS-27-1, Job Final Report, Portland, OR.

Gerke, R.J. 1973. Spawning ground improvement study. Washington State Department of Fisheries, Project AFC-59-2. Project Completion Report, Olympia, WA.

Gerke, R.J. 1974. Salmon spawning habitat improvement study. Washington State Department of Fisheries, Project 1-93-D, Project Progress Report, Olympia, WA.

Gibbons, D.R. and Salo, E.O. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. USDA--Forest Service Gen. Tech. Rep. PNW-10. Pacific Northwest For. and Range Experiment Station, Portland, OR.

Gloss, S.P. and Scott, N.S. 1978. The influence of inorganic sediment on fishes with particular reference to New Mexico. New Mexico Department of Natural Resources, Soil and Conservation Division, Albuquerque, NM.

Gore, J.A. 1978. A technique for predicting in-stream flow requirements of benthic macroinvertebrates. Freshwater Biology 8:141-151.

Gorini, R.F. 1987. Industrial and commercial applications: dredging for lake restoration. In Beneficial uses of dredged material: Proceedings of the first interagency workshop, October 7-9, 1986, Pensacola, Florida. Technical Report No. D-81-1.

Greene, E.A., Sowards, C.L., and Hansmann, E.W. [1990?]. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Angostura Reclamation Unit, Southwestern South Dakota. Rapid City, SD: U.S. Geological Survey Water Resources Investigation WRI-90-4152.

Hall, T.J. 1984. The effects of fine sediment on salmonid spawning gravel and juvenile rearing habitat: A literature review. Stream Improv. Tech. Bull. 428. National Council of the Paper Industry for Air and Stream Improvement, New York.

Hall, T.J. and Ice, G.G. 1981. Forest management practices, sediment load characterization, streambed composition and predicting aquatic organism response: Where we are and where we need to go. Tech. Bull. 353, p. 33-37, National Council of the Paper Industry for Air and Stream Improvement, New York.

Hanafi, A. 1980. Toxicity and residual effect of malathion in water, sediment, fish, and shrimp. Bull. Den. Perikanan [Indonesian or Malaysian; full title not found] 1(1):34-44.

Hansen, E.A. 1971. Sediment in a Michigan trout stream: its source, movement, and some effects on fish habitat. St. Paul, Minnesota: USDA--Forest Service; Research Paper NC-59.

Hansen, E.A. and Alexander, G.. 1976. Effect of an artificially increased sand bedload on stream morphology and its implications on fish habitat. In Proceedings of the 3rd Federal inter-agency sedimentation conference. United States Water Resources Council, NTIS PB-245100, Washington, D.C.

Hansen, E.A., Alexander, G.R., and Dunn, W.H. 1983. Sand sediment in a Michigan trout stream. Part 1. A technique for removing sand bedload from streams. North American Journal of Fisheries Management 3: 355-364.

Harris, R.R. 1988. Associations between stream valley geomorphology and riparian vegetation as a basis for landscape analysis in the eastern Sierra Nevada, California, USA. Environmental Management 12(2):219-228.

Harrison, C.W. 1923. Planting eyed salmon and trout eggs. Transactions of the American Fisheries Society 52:191-200.

Harshbarger, T.J. and Porter, P.E. 1982. Embryo survival and fry emergence from two methods of planting brown trout eggs. North American Journal of Fisheries Management 2:84-89.

Hartman, G.F. and Holtby, L.B. 1982. An overview of some biophysical determinants of fish production and fish population responses to logging in Carnation Creek, British Columbia. In Proceedings of the Carnation Creek workshop: A ten-year review, ed. G.F. Hartman, pp. 348-372. Pacific Biological Station, Nanaimo, B.C.

Hartman, G.F., Holtby, L.B., and Scrivener, J.C. 1984. Some effects of natural and logging-related winter stream temperature changes on the early life history of coho salmon (Oncorhynchus kisutch) in Carnation Creek, British Columbia. In Fish and wildlife relationships in old-growth forests: Proceedings of a symposium, ed. W.R. Meehan, T.R. Merrell, and T.A. Hanley, pp. 141-149. American Institute of Fishery Research Biologists. (Available from J.W. Reintjes, Rt. 4, Box 85, Morehead City, NC 28557.)

Harvey, G.W. 1989. Technical review of sediment criteria. Water Quality Bureau Report, Idaho Dept. Health and Welfare.

Hausle, D.A. and Coble, D.W. 1976. Influence of sand in redds on survival and emergence of brook trout (Salvelinus fontinalis). Transactions of the American Fisheries Society 105(1): 57-63.

Healey, M. 1984. Fish predation on aquatic insects. In The ecology of aquatic insects, ed. V.H. Resh and D.M. Rosenberg. Praeger Special Studies--Praeger Scientific: New York.

Hecht, B. 1982. Sediment transport, water quality and changing bed conditions, Tucannon River, Southeastern Washington. Prepared for the USDA Soil Conservation Service, Spokane, WA.

Heede, B.H. and Rinne, J.N. 1990. Hydrodynamic and fluvial morphologic processes: implications for fisheries management and research. North American Journal of Fisheries Management 10(3):249-268.

Held, J.W. 1978. Environmental impact of dredged material disposal on the upper Mississippi River at Crosby Slough. Wisconsin University--La Crosse River Studies Center, Report No. WES-MP-D-78-2. 94 pp.

Herdendorf, C.E., Hakanson, L., Jude, D.J., and Sly, P.G. 1992. A review of the physical and chemical components of the Great Lakes: a basis for classification and inventory of aquatic habitats. In The development of an aquatic habitat classification system for lakes, ed. W.D.N. Busch and P.G. Sly, chapter 6, pp. 109-159. Boca Raton, Florida: CRC Press.

Hickman, T. and Raleigh, R.F. 1982. Habitat suitability index models: Cutthroat trout. Habitat Evaluation Procedures Group, Western Energy and Land Use Team, U.S. Fish and Wildlife Service, Fort Collins, CO.

Hicks, B.J, Beschta, R.L., and Harr, R.D. 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. Water Resources Bulletin 27(2):217-226.

Hollis, E.H., Boone, J.G., DeRose, C.R., and Murphy, G.J. 1964. A literature review of the effects of turbidity and siltation on aquatic life. Staff Report, Dep. Chesapeake Bay Aff. Annapolis, MD.

Horne, G.S. and Patton, P.C. 1989. Bedload-sediment transport through the Connecticut River estuary. Geol. Soc. Amer. Bulletin 101:805-819.

Horner, N. and Rieman, B. 1981. Cascade Reservoir fisheries investigations. Boise: Idaho Department of Fish and Game; Job Performance Report, Project F-73-R-3, Study VII.

Hupp, C.R. 1991. Riparian vegetation recovery patterns following stream channelization: a geomorphic perspective. Ecology 73(3):1209-1226.

Ingram, W.M. and Tarzwell, C.M. (unknown date). Selected bibliography of publications relating to undesirable effects upon aquatic life by algicides, insecticides, weedicides. U.S. Public Health Service, Cincinnati, OH.

Irving, J.S., Shepard, B., Bjornn, T.C., Horner, N., and Ringe, R.R. 1983. Fish resources in the Gospel-Hump area of central Idaho and potential impacts of forest management activities. Moscow, Idaho: USDA--Forest Service, Agreement 12-11-204-11.

Irving, J.S. and Bjornn, T.C. 1984. Effects of substrate size composition on survival of kokanee salmon and cutthroat and rainbow trout. Idaho Coop. Fishery Research Unit Tech. Report, pp. 84-86.

Iwamoto, R.N., Salo, E.O., Madej, M.A., and McComas, R.L. 1978. Sediment and water quality: A review of the literature including a suggested approach for water quality criteria. US Environmental Protection Agency, Region 10, Seattle.

Jackson, W.L. and Beschta, R.L. 1984. Influences of increased sand delivery on the morphology of sand and gravel channels. Water Resources Bulletin 20(4):527-533.

Jackson, W.L. and Beschta, R.L. 1982. A model of two-phase bedload transport in an Oregon Coast Range stream. In Earth surface processes and landforms, vol. 7, pp. 517-527. New York: John Wiley & Sons.

Jackson, W.L. and Beschta, R.L. 1981. Factors affecting changes in the percent of fine sediment in gravel bedded channels. In Tech. Bull. No. 354, National Council of the Paper Industry for Air and Stream Improvement.

Johnson, B.W., Miller, E.M., and Ellis, C.H. 1952. A report on steelhead egg and fry survival experiments on the North Fork Stillaguamish River with relation to the North Fork earth slide. Unpublished report. Washington State Department of Fisheries, Olympia, WA.

Johnson, L.D. 1966. Factors that influence muskellunge egg mortalities in lakes. In Proceedings of the 28th Midwest fish and wildlife conference.

Jones and Stokes Associates. 1990. Channel stabilization and riparian restoration plan for the lower 23 miles of the Truckee River. Draft report to U.S. Fish and Wildlife Service. Sacramento, CA.

Junoy, J. and Vieitez, J.M. 1990. Macrozoobenthic community structure in the Ria de Foz, an intertidal estuary (Galicia, Northwest Spain). Marine Biology 107:329-339.

Keller, E.A. 1971. Aerial sorting of bedload material; the hypotheses of velocity reversal. Geol. Soc. Amer. Bulletin 82:753-756.

Kelley, D.W. and Dettman, D.H. 1980. Relationships between streamflow, rearing habitat, substrate conditions, and juvenile steelhead populations in Lagunitas Creek, Marin County, 1979. Unpublished report, Marin County Water District. 23 pp.

King, R. and Potyondy, J. 1993. Statistical testing of Wolman pebble counts. Stream Notes, October, 1993. Stream System Technology Center, USFS, Fort Collins, CO.

Kingsbury, A.P. (1973. The relationship between logging activities and salmon production. Completion report. Comm. Fishery Research and Development Act 5-24-R. July 1, 1970 to June 30, 1972. Alaska Department of Fish and Game, Juneau, AK.

Klamt, R.R. 1976. The effects of coarse granitic sediment [sand?] on the distribution and abundance of salmonids in the central Idaho batholith. M.S. thesis, University of Idaho, Moscow, ID. 85 pp.

Klingeman, P.C. and MacArthur, R.C. 1990. Sediment transport and aquatic habitat in gravel-bed rivers. In Hydraulic Engineering: Proceedings of the 1990 National Conference, Part 2 (of 2), pp. 1116-1121. ASCE, Boston Society of Civil Engineers Sect., Boston, MA.

Komar, P.D. and Shih, S.M. 1992. Equal mobility versus changing bedload grain sizes in gravel-bed streams. In Dynamics of gravel-bed rivers, ed. P. Billi, R.D. Hey, C.R. Thorne, and P. Tacconi; pp. 73-106. Chichester, U.K.: John Wiley & Sons Ltd.

Kondolf, G.M. 1988. Salmonid spawning gravels: A geomorphic perspective on their size distribution, modification by spawning fish, and criteria for gravel quality, 419 pp. Vol. 49/09-B of Dissertation Abstracts International, page

247.

Kondolf, G.M., Cada, G.F., Sale, M.J., and Felando, T. 1991. Distribution and stability of potential salmonid spawning gravels in steep boulder-bed streams of the eastern Sierra Nevada. Transactions of the American Fisheries Society 120:177-186.

Kondolf, G.M. and Wolman, M.G. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29(7):2275-2285.

Kondolf, G.M., Wolman, M.G., and Sale, M.J. 1993. Modification of fluvial gravel size by spawning salmonids. Water Resources Research 29(7):2265-2274.

Konopacky, R.C. 1984. Sedimentation and productivity in salmonid streams. Ph.D. dissertation, University of Idaho, Moscow.

Koski, K.V. 1983. Effects of sediment on the reproduction of salmonids. In Salmonid reproduction: An international symposium, p. 13[-?]. Washington University.

Koski, K.V. 1966. The survival of coho salmon (Oncorhynchus kisutch) from egg deposition to emergence in three Oregon streams. M.S. thesis, Oregon State University, Corvallis. 84 pp.

Koski, K.V., Heifetz, J., Johnson, S., Murphy, M., and Thedinga, J. 1984. Evaluation of buffer strips for protection of salmonid rearing habitat and implications for enhancement. In Proceedings: Pacific Northwest stream habitat management workshop, ed. T.J. Hassler, pp. 138-155. California State University, Humboldt; Arcadia, California.

Koski, R.R. 1972. Effects of sediment on fish resources. Presented at the Washington State Department of Natural Resources Seminar, Lake Limerick, April 18-20, 1972.

Kucera, P.A. and Johnson, D.B. 1987. Biological and physical inventory of the streams within the Nez Perce Reservation: Juvenile steelhead survey and factors that affect abundance in selected streams in the Lower Clearwater River Basin, Idaho: Final Report. Nez Perce Tribe, Lapwai, ID. Fisheries Resource Management. Department of Energy, Washington D.C., Report No. DOE/BP/10068-1.

Lane, E.W. 1957. A study of the shape of channels formed by natural streams flowing in erodible material. Missouri River Diversion. Sediment Series No. 9, U.S. Army Engineer Division, Missouri River, Corps of Engineers, Omaha, NE.

Leach, J.H. and Herron, R.C. 1992. A review of lake habitat classification. In The development of an aquatic habitat classification system for lakes, ed. W.D.N. Busch and P.G. Sly, chapter 3, pp. 27-57. Boca Raton, Florida: CRC Press.

Leopold, L.B. and Wolman, M.G. 1957. River channel patterns: Braided, meandering, and straight. U.S. Geological Survey Prof. Paper 282-B.

Lindquist, D.S. and Filmer, C.L. 1988. Revegetation to control erosion on a degraded Sierra Nevada stream. In Erosion control: Stay in tune: Proceedings of the conference XIX. Pinole, California: International Erosion Control Association.

Lisle, T.E. 1989. Sediment transport and resulting deposition in spawning gravels, north coastal California. Water Resources Research 25:1303-1319.

Lisle, T.E. and Eads, R.E. 1991. Methods to measure sedimentation of spawning gravels. Pacific Southwest Research Station, P.O. Box 245, Berkeley, CA, 94701, Report No. FSRN-PSW-411. 9 pp.

Lloyd, D.S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. North American Journal of Fisheries Management 7:34-45.

Lloyd, D.S., Koenings, J.P., and LaPerriere, J.D. 1987. Effects of turbidity in fresh waters of Alaska. North American Journal of Fisheries Management 7:18-33.

Lorenz, J.M. and Eiler, J.H. 1989. Spawning habitat and redd characteristics of sockeye salmon in the Glacial Taku River, British Columbia and Alaska. Transactions of the American Fisheries Society 118(5):495-502.

Lotspeich, F.B. and Everest, F.H. 1981. A new method for reporting and interpreting textural composition of spawning gravels. Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, for U.S. Forest Service. Research Note PNW-369. 11 pp.

Lowrance, R., Todd, R., Fail, J. Jr., Hendrickson, O. Jr., Leonard, R., and Asmussen, L. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34:374-377.

Luedtke, R.J., Brusven, M.A., and Watts, F.J. 1976. Benthic insect community changes in relation to in-stream alterations of a sediment polluted stream. Melanderia 23:21-39.

Lund, J.A. 1984. Fine sediment analysis of chinook spawning sites in the Secesh River, 1982-1983. McCall, Idaho: McCall Ranger District, Payette National Forest.

Luntz, J.D., Zeigler, T.W., Huffman, R.T., Diaz, R.J., and Clairain, E.J. 1978. Habitat development field investigations: Windmill Point Marsh development site, James River, Virginia. Summary Report. Army Engineer Waterways Experiment Station, Vicksburg, MS, Report No. WES-TR-D-77-23. 147 pp.

MacCrimmon, H.R. and Gots, B.L. 1986. Laboratory observations on emergent patterns of juvenile rainbow trout, Salmo gairdneri, relative to test substrate composition. In Fifth trout stream habitat improvement workshop, sponsored by American Fisheries Society, Pennsylvania State Fish Commission, Sport Fishery Research Foundation, Trout Unlimited, and U.S. Forest Service; pp. 63-76. Lock Haven, PA: Lock Haven University.

Manny, B.A., Jude, D.J., and Eshenroder, R.L. 1989. Field test of a bioassay procedure for assessing habitat quality on fish spawning grounds. Transactions of the American Fisheries Society 118:175-182.

Marcuson, P. 1968. Stream sediment investigation. Montana Dept. of Fish and Game, South Central Montana Fish Study. Job Completion Report, Proj. F-20-R-13. [trout]

Martin, D.J. 1976. The effects of sediment and organic detritus on the production of benthic macroinvertebrates in four tributary streams of the Clearwater River, Washington.

Marty, C., Beall, E. and Parot, G. 1986. Influence of some environmental parameters upon survival during embryonic development of Atlantic salmon, Salmo salar L., in an experimental stream channel. Internationale Revue der gesamten Hydrobiologie 71 (3):349-361.

Marzolf, R.G. 1978. The potential effects of clearing and snagging on stream ecosystems. U.S. Fish and Wildlife Service: FWS/OBS-78/14; January, 1978.

Mason, J.C. 1969. Hypoxial stress prior to emergence and competition among coho salmon fry. Journal of the Fisheries Research Board of Canada 26:63-91.

McCall, S.K. [1989 or 1991?]. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Gunnison and Uncompahgre River Basins and at Sweitzer Lake, west-central Colorado. Albuquerque, NM: U.S. Geological Survey Water Resources Investigation WRI-91-4103. (Also held by BLM.)

McConnell, R.J., Lipovsky, S.J., Misitano, D.A., Craddock, D.R. and Hughes, J.R. 1978. Habitat development field investigations, Miller Sands Marsh and upland habitat development site, Columbia River, Oregon. Appendix B: Inventory and assessment of predisposal and postdisposal aquatic habitats. 344 pp. Report No. WES-TR-D-77-38-APP-B. National Marine Fisheries Service, Prescott, OR.

McCuddin, M.E. 1977. Survival of salmon and trout embryos and fry in gravel-sand mixtures. M.S. thesis, Moscow, ID: University of Idaho.

McDowell, P.F., Webb, T.W. III, and Bartlein, P.J. 1990. Long-term environmental change. In The earth as transformed by human action, ed. B.L. Turner II, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Meyer; pp. 143-162. New York: Cambridge University Press.

McFadden, J.T. 1969. Dynamics and regulation of salmonid populations in streams. In Symposium on salmon and trout in streams, ed. T.G. Northcote, pp. 313-329. H.R. MacMillan Lectures in Fisheries, Institute of Fisheries, University of British Columbia, Vancouver, B.C.

McGie, A.M. 1981. Trends in the escapement and production of fall chinook and coho salmon in Oregon. Oregon

Dept. of Fish and Wildlife, information reports (fish) 81-7, Portland, OR.

McLeay, D.J., Birtwell, I.K., Hartman, G.F., and Ennis, G.L. 1987. Responses of Arctic grayling (Thymallus arcticus) to acute and prolonged exposure to Yukon placer mining sediment. Canadian Journal of Fisheries and Aquatic Sciences 44:658-673.

McLeay, D.J., Ennis, G.L., Birtwell, I.K., and Hartman, G.F. 1984. Effects on Arctic grayling (Thymallus arcticus) of prolonged exposure to Yukon placer mining sediment: a laboratory study. Canadian Technical Reports on Fisheries and Aquatic Sciences, Report 1241.

McMahon, T.E. and Hartman, G.F. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon. Canadian Journal of Fisheries and Aquatic Sciences.

McNamee, W.H. 1985. Economics of soil loss control on the Mission-Lapwai Watershed, Idaho. Doctoral thesis, Oregon State University, Corvallis, OR.

McNeil, W.J. 1964. A method of measuring mortality of pink salmon eggs and larvae. Fishery Bulletin of the U.S. Fish and Wildlife Service 63(3):575-588.

McNeil, W.J. 1964. Environmental factors affecting survival of young salmon in spawning beds and their possible relation to logging. U.S. Fish and Wildlife Service, Bur. Comm. Fish Manuscript Report 64-1. Auke Bay Biol. Lab, Auke Bay, Alaska.

McNeil, W.J. and Ahnell, W.H. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Department of the Interior, Fish and Wildlife Service Specific Sci. Rep. Fisheries No. 469, Washington, D.C.

McNeil, W.J. 1966. Effects of the spawning bed environment on reproduction of pink and chum salmon. Fishery Bulletin of the U.S. Fish and Wildlife Service 65(2):495-523.

McNeil, W.J. 1969. Survival of pink and chum salmon eggs and alevins. In Symposium on salmon and trout in streams, ed. T.G. Northcote. H.R. MacMillan Lectures in Fisheries. University of British Columbia, Vancouver.

McNeil, W.J., Shapley, P., and Bevan, D.E. 1962. Effects of logging on pink salmon and spawning-bed improvement. In Research in Fisheries, Coll. Fish Contrib. (ed. T.S.Y. Koo) 139:15-18. Seattle: Univ. of Washington.

Meade, R.H., Yuzyk, T.R., and Day, T.J. 1990. Movement and storage of sediment in rivers of the United States and Canada. In Surface water hydrology, ed. M.G. Wolman and H.C. Riggs, vol. 1, ch. 11. Geol. Soc. Amer.

Meehan, W.R. and Swanston, D.N. 1977. Effects of gravel morphology on fine sediment accumulation and survival of incubation salmon eggs. USDA--Forest Service Research Paper PNW-220.

Meehan, W.R. 1971. Effects of gravel cleaning on bottom organisms in three southeast Alaska streams. Progressive Fish-Culturist 33:107-111.

Mih, W.C. 1976. Literature search of stream gravel for spawning and rearing of salmon species. Washington State Department of Fisheries, Progress Report 3815-1460, Olympia, WA.

Mih, W.C. 1978. A review of restoration of stream gravel for spawning and rearing of salmon species. Fisheries 3(1):16-18.

Milhouse, R.T., MacArthur, R.C., Sheilds, D.F., Jr. and Adams, R.J. 1990. Sediment and aquatic habitat associations in river systems. In Hydraulic engineering: Proceedings of the 1990 national conference, Part 2 (of 2), pp. 1104-1109. ASCE, Boston Society of Civil Engineers Sect., Boston, MA.

Milhouse, R.T., MacArthur, R.C., Adams, R.J., Bradley, J.B., Pennington, C.H., Reuter, J., Serr, E.F., Sheilds, D.F. Jr., Sustar, J.F., and Wakeman, T.H. III. 1988. Effects of sediment transportation changes on aquatic habitat. In Hydraulic engineering: Proceedings of the 1988 national conference on hydraulic engineering, pp. 832-837. ASCE, Hydraulics Division, New York, NY.

Miller, W.J. 1985. Tucannon River percent fry emergence model. Department of Fishery and Wildlife Biology, Colorado State University.

Minshall, G.W. 1984. Aquatic insect-substratum relationships. In The ecology of aquatic insects, ed. V.H. Resh and D.M. Rosenberg. New York: Praeger Special Studies--Praeger Scientific Publishers.

Mitsch, W.J. and Gosselink, J.G. 1993. Wetlands. New York: Van Nostrand Reinhold.

Montgomery, D.R. and Buffington, J.M. 1993. Channel classification, prediction of channel response, and assessment of channel conditions. TFW-SH10-93-002. University of Washington, Seattle, WA.

Moring, J.R. and Lantz, R.L. 1974. Immediate effects of logging on freshwater environment of salmonids. Oregon Wildlife Commission Research Division Project AFS-58, Final Report. 101 pp.

Moring, J.R. and Lantz, R.L. 1975. The Alsea Watershed Study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part 1: Biological studies. Fisheries Research Rept. 9. Corvallis, OR: Oregon Dept. of Fish and Wildlife.

Moring, J.R. 1975. The Alsea Watershed Study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part 2: Changes in environmental conditions. Fisheries Research Rept. 9. Corvallis, OR: Oregon Dept. of Fish and Wildlife.

Moring, J.R. 1982. Decrease in stream gravel permeability after clear cut logging: An indication of intra gravel conditions for developing salmonid eggs and alevins. Hydrobiologia 88(3):295-298.

Morrill, C.F. and Bjornn, T.C. 1972. Migration response of juvenile chinook salmon to substrate and temperatures. Idaho Water Resources Research Institute, Tech. Completion Report, Project A-038-IDA, Moscow.

Mudroch, A. and MacKnight, S.D. 1991. CRC handbook of techniques for aquatic sediments sampling. Boca Raton, Florida: CRC Press, Inc.

Murphy, M.L., Hawkins, C.P., and Anderson, N.H. 1981. Effects of canopy modification and accumulated sediment on stream communities. Transactions of the American Fisheries Society 110(4).

Myers, T.J., and Swanson, S. 1992. Variation of stream stability with stream type and livestock bank damage in northern Nevada. Water Resources Bulletin 28(4):743-754.

NCASI (National Council of the Paper Industry for Air and Stream Improvement, Inc.). 1984. The effects of fine sediment on salmonid spawning gravel and juvenile rearing habitat: A literature review. NCASI Technical Bulletin No. 428.

NCASI. 1984. A laboratory study of the effects of sediments of two different size characteristics on survival of rainbow trout (Salmo gairdneri) embryos to fry emergence. NCASI Technical Bulletin No. 429.

NCASI. 1984. The relationship between fine sediment and microinvertebrate community characteristics: A literature review and results from NCASI five sediment studies. NCASI Technical Bulletin No. 418.

Nelson, K. 1989. Salvaging the Salmon River. Northwest Energy News, Sept.-Oct. 1989, V8, N5, P26(4). (The original document is available from Bowker).

Nelson, R.L., Platts, W.S., Larsen, D.P., and Jensen, S.E. 1992. Trout distribution and habitat in relation to geology and geomorphology in the North Fork Humboldt River drainage, Northeastern Nevada. Transactions of the American Fisheries Society 121(4):405-426.

Nester, R.T. and Poe, T.P. 1987. Visual observations of historical lake trout spawning grounds in western Lake Huron. North American Journal of Fisheries Management 7:418-424.

Newlon, T.A. and Rabe, F.W. 1977. Comparison of macroinvertebrate samplers and the relationship of environmental factors to biomass and diversity variability in a small watershed. Research Technical Completion Report, project A-049-IDA; Idaho Water Resources Research Institute, University of Idaho, Moscow.

Noggle, C.C. 1978. Behavioral, physiological and lethal effects of suspended sediment on juvenile salmonids. [Thesis?] Seattle: University of Washington.

Nuttall, P.M. 1972. The effects of sand deposition upon the macroinvertebrate fauna of the River Camel, Cornwall.

Freshwater Biology 2:181-186.

O'Brien, J.S. 1987. Case study for minimum streamflow for fishery habitat in the Yampa River. In Sediment Transport in Gravel-Bed Rivers. New York: John Wiley & Sons.

Olsson, T.I., and Persson, B.G. 1986. Effects of gravel size and peat material concentrations on embryo survival and alevin emergence of brown trout, Salmo trutta L. Hydrobiologia 135:9-14.

Olsson, T.I. and Persson, B.G. 1988. Effects of deposited sand on ova survival and alevin emergence in brown trout (Salmo trutta L.). Archiv fuer Hydrobiologie 113(4):621-627.

Oregon Department of Environmental Quality. 1988. Oregon Dredged Sediment Guidelines Workshop, June 21-23, 1988, Lincoln City, Oregon.

Panel on Estuarine Research Perspectives (PERP). 1983. Fundamental research on estuaries: The importance of an interdisciplinary approach. Geophysics Study Committee, Geophysics Research Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council. National Academy Press: Washington, D.C.

Parker, B.L., Lee, K.M., and Espinosa, F.A. Jr. 1989. Lochsa River tributaries sediment and fish monitoring report (for 1988 season). Powell Ranger District, Clearwater National Forest.

Parker, G., Klingeman, P.C., and McLean, D.G. 1982. Bedload and size distribution in paved gravel-bed streams. Proceedings of the American Society of Civil Engineers, Jour. Hydraulics Division 108(HY1):585-587.

Paschal, J.E. and Sherwood, D.A. 1987. Relation of sediment and nutrient loads to watershed characteristics and land use in the Otisco Basin, Onondaga County, New York. Denver, Colorado: U.S. Geological Survey Water Resources Investigations Report 86-4026.

Peters, J.C. 1965. The effects of stream sedimentation on trout embryo survival. In Transactions of the 3rd seminar on biological problems in water pollution, ed. C.M. Tarzwell, pp.265-269. U.S. Public Health Serv. Publ. 999-WP-25, Robert A. Taft Sanit. Eng. Cent., Cincinnati, OH. Originally published as a separate document in 1962 by the Montana Fish and Game Department, Billings, Montana.

Peters, J.C. 1967. Effects on a trout stream of sediment from agricultural practices. Journal of Wildlife Management 31:805-812.

Peterson, N.P., Hendry, A., and Quinn, T.P. 1992. Assessment of cumulative effects on salmonid habitat: Some suggested parameters and target conditions. Center for Streamside Studies, University of Washington (for Washington State Department of Natural Resources).

Phillips, J.D. 1989. Nonpoint source pollution control effectiveness of riparian forests along a coastal plain river. Journal of Hydrology 110:221-237.

Phillips, R.W. and Campbell, H.J. 1962. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. Pacific Marine Fishery Committee Annual Report 14.

Phillips, R.W. 1964. Influence of gravel size on survival and emergence of coho and steelhead trout. In Proceedings of the 15th Northwest fish culture conference, Oregon State University, Corvallis, OR.

Phillips, R.W. and Koski, K.V. 1969. A fry trap method for estimating salmonid survival from egg deposition to fry emergence. Journal of the Fisheries Research Board of Canada 26:133-141.

Phillips, R.W. 1971. Effects of sediment on the gravel environment and fish production. In Forest land uses and stream environment. Corvallis, OR: Oregon State University, 1970.

Phillips, R.W., Lantz, R.L., Claire, E.W., and Moring, J.R. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104(3):461-466.

Platts, W.S. 1968. South Fork Salmon River, Idaho, aquatic habitat survey with evaluation of sediment accruement, movement, and damages. USDA--Forest Service, Region 4.

Platts, W.S. 1970. The effects of logging and road construction on the aquatic habitat of the South Fork Salmon

River, Idaho.In Proceedings of the 50th annual conference of theWestern Association of State Game and Fish Commissions, pp. 182-185.

Platts, W.S. 1972. Sediment in a salmon-steelhead environment. Unpublished Progress Report 11, USDA--Forest Service, Region 4.

Platts, W.S. 1974. Geomorphic and aquatic conditions influencing salmonids and stream classification--with application to ecosystem classification. USDA--Forest Service, Surface Environment and Mining Project Report, Billings, MT.

Platts, W.W. and Megahan, W.F. 1975. Time trends in channel sediment size composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. USDA-Forest Service General Report, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Platts, W.W. and Megahan, W.F. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. In Transactions of the 40th North American wildlife and natural resources conference, pp. 229-239. Wildlife Management Institute, Washington, D.C..

Platts, W.S., Shirazi, M.A., and Lewis, D.H. 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. Corvallis, OR: U.S. Environmental Protection Agency Report EPA 600/3-79-043.

Platts,W.S. and Penton, V.E. 1980. A new freezing technique for sampling salmonid redds. Intermountain Forest and Range Experiment Station, Ogden, UT. Report No. FSRP/INT-248: 29p.

Potyondy, J.P. 1988. Boise National Forest cobble embeddedness baseline inventory: results and relationships to management activities.

Potyondy, J.P. (no date). Detecting the effect of land management on cobble embeddedness: the Boise National Forest experience. USDA-Forest Service, Boise, ID.

Pritchard, D.W. 1952. Estuarine hydrography. Advances in Geophysics 1:243-280.

Pugsley, C.W. and Hynes, H.B.N. 1983. A modified freeze-core technique to quantify the depth distribution of fauna in stony streambeds. University of Waterloo, Waterloo, Ont. N2L 3G1.

Reckendorf, F. and Pedone, P. 1989. Erosion and sediment impacts of the 1985 Food Security Act above the Lower Granite Reservoir, Idaho, Oregon, and Washington. In Proceedings of the national nonpoint source conference, St. Louis. National Association of Conservation Districts, League City, Texas.

Reckendorf, F. and van Liew, M. 1988. Streambed sampling and analysis, Tucannon Watershed, Washington. SCS, WNTC, Portland, OR.

Reckendorf, F. and van Liew, M. 1989. Sampling of sediment intrusion into artificial redds in the Tucannon watershed, Washington. In Coastal zone: Proceedings of the symposium on coastal and ocean management, vol. 1 (of 5), pp. 964-978. ASCE, New York, NY.

Reice, S.R., Wissmar, R.C. and Naiman, R.J. 1990. Disturbance regimes, resilience, and recovery of animal communities and habitats in lotic ecosystems. Environmental Management 14(5):647-659.

Reiser, D.W. 1981. Effects of streamflow reduction, flow fluctuation and flow cessation on salmonid egg incubation and fry quality. 257 pp. Vol. 42/03-B of Dissertation Abstracts International, p. 850.

Reiser, D.W. and Bjornn, T.C. 1979. Habitat requirements of anadromous salmonids. Portland, OR: USDA--Forest Service, General Technical Report PNW-96.

Reiser, D.W. and White, R.G. 1981. Influence of streamflow reductions on salmonid embryo development and fry quality. Idaho Cooperative Fishery Research Unit, Moscow for Office of Water Research and Technology, Washington, DC, Report No. W81-03606; OWRT-A-058-IDA(1). 159 p.

Reiser, D.W. and White, R.G. 1988. Effects of two sediment size-classes on survival of steelhead and chinook salmon eggs. North American Journal of Fisheries Management 8(4):432-437.

Reiser, D.W., Ramey, M.P., Bechtel Group, Inc., and Lambert, T.R. 1985. Review of flushing flow requirements in regulated streams. Pacific Gas and Electric Company, San Ramon, CA.

Resh, V.H. and Rosenberg, D.M., eds. 1984. The ecology of aquatic insects. Praeger Special Studies--Praeger Scientific: New York.

Richards, C. and Cernera, P.J. 1986. Salmon river habitat enhancement. Annual Report: FY 1986, Part 1. Shoshone-Bannock Tribal Fisheries Dept., Fort Hall Reservation, ID. (Available from the National Technical Information Service, Springfield, VA 22161, as DE88-003276.)

Richards, M. 1963. Management of the chinook salmon fishery of the South Fork Salmon River drainage. Idaho Wildlife Review 4(3):3-8.

Ries, R.D. and Burns, D.C. 1989. Embeddedness of salmonid habitat of selected streams on the Payette National Forest: 1987-1988.

Ries, R.D., Burns, D.C., and Lund, J. 1991. Fine sediment deposition in selected tributaries to the Salmon River in the Payette National Forest: Report of monitoring results 1989-1990.

Ringler, N.H. 1970. Effects of logging on the spawning bed environment in two Oregon coastal streams. [M.S. thesis?] Oregon State University, Corvallis, OR.

Ringler, N.H. and Hall, J.D. 1988. Vertical distribution of sediment and organic debris in coho salmon (Oncorhynchus kisutch) redds in three small Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences, 45(4):742-747.

Rinne, J.N. 1990. The utility of stream habitat and biota for identifying potential conflicting forest land uses: montane riparian areas. Forest Ecology and Management 33/34:363-383.

Ritchie, J.C. 1972. Sediment, fish, and fish habitat. Journal of Soil and Water Conservation 27(3):124-125.

Robinson, A.R. 1970. Sediment, our greatest pollutant. USDA--Agricultural Research Service, Oxford, MS. Sedimentation Lab Paper 70-701.

Robison, E.G. and Beschta, R.L. 1988. Physical evaluation of fisheries habitat structures. In Training in stream rehabilitation, American Fisheries Society, Feb. 7-8, 1988, Bend, Oregon.

Rodgers, J.D. 1986. The effects of nonpoint source pollution on salmonids, and techniques for restoration of degraded stream habitat: a bibliography. Portland: Oregon Department of Fish and Wildlife.

Rosgen, D.L. 1994. A classification of natural rivers. Elsevier (Catena), in press.

Salo, E.O. and Cundy, T.W., eds. 1987. Streamside management: Forestry and fishery interactions: Proceedings of a symposium, pp. 9-38. Seattle: University of Washington.

Saunders, J.W. and Smith, M.W. 1965. Changes in a stream population of trout associated with increased silt. Journal of the Fisheries Research Board of Canada 22(2):395-404.

Schaffner, L.C., Diaz, R.J., Olsen, C.R., and Larsen, I.L. 1987. Faunal characteristics and sediment accumulation processes in the James River Estuary, Virginia. Estuarine, Coastal, and Shelf Science 25:211-226.

Schumm, S.A. 1963. A tentative classification of alluvial river channels. U.S. Geological Survey Circular 477. Washington, D.C.

Schumm, S.A. 1977. The fluvial system. 338 pp. New York: John Wiley & Sons.

Schumm, S.A., Harvey, M.D., Watson, C.C. (no date) Yazoo Basin geomorphology. Final Report USDA, SCS, Project SCS 23-MS-80. 483 pp.

Scrivener, J.C. and Brownlee, M.J. 1981. A preliminary analysis of Carnation Creek gravel quality data, 1973-1980. In Salmon-spawning gravel: A renewable resource in the Pacific Northwest? Proceedings from the conference. Washington State University, Pullman.

Scrivener, J.C. and Brownlee, M.J. 1982. An analysis of Carnation Creek gravel-quality data, 1973-1981. In Proceedings of the Carnation Creek workshop: A ten-year review, pp.154-173. Pacific Biological Station, Nanaimo, B.C.

Scrivener, J.C. and Brownlee, M.J. 1987. Forest harvesting, gravel quality, and incubation survival of chum and coho salmon in Carnation Creek, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences.

Sedell, J.R., Yuska, J.E., and Speaker, R.W. 1984. Habitats and salmonid distribution in pristine, sediment-rich river valley systems. In Fish and wildlife relationships in old-growth forests: a symposium, pp. 33-46. Morehead City, NC: American Institute of Fishery Research Biologists.

Sedgwick, J.A., and Knopf, F.L. 1991. Prescribed grazing as a secondary impact in a western riparian floodplain. Journal of Range Management 44(4):369-373.

Servizi, J.A. and Gordon, R.W. 1990. Acute lethal toxicity of ammonia and suspended sediment mixtures to chinook salmon (Oncorhynchus tschawytscha). Bulletin of Environmental Contamination and Toxicology 44(4):650-656.

Shapley, S.P. and Bishop, D.M. 1965. Sedimentation in a salmon stream. Journal of the Fisheries Research Board of Canada 22(4):919-928.

Shapovalov, L. and Berrain, W. 1940. An experiment in hatching silver salmon (Oncorhynchus kisutch) eggs in gravel. Transactions of the American Fisheries Society 69:135-140.

Shapovalov, L. and Taft, A.C. 1954. The life histories of the steelhead rainbow trout and silver salmon. California Department of Fish and Game, Fish Bulletin 98, 375p.

Shaw, P.A. and Maga, J.A. 1943. The effect of mining silt on yield of fry from salmon spawning beds. California Fish and Game 29:29-41.

Shelton, J.M. 1955. The hatching of chinook salmon eggs under simulated stream conditions. Progressive Fish-Culturist 17:20-35.

Shelton, J.M. and Pollock, R.D. 1965. Siltation and egg survival in incubation channels. Transactions of the American Fisheries Society 95(2):183-187.

Shepard, B.B., Leathe, S.A., Weaver, T.M. and Enk, M.D. 1984. Monitoring levels of fine sediment within tributaries to Flathead Lake and impacts of fine sediment on bull trout recruitment. Paper presented at the Wild Trout III Symposium, Yellowstone National Park, WY, September 24-25, 1984.

Sheridan, W.L. 1968. Land use and sediment. In The proceedings of a forum on the relation between logging and salmon, ed. T.R. Merrell, pp. 62-79. Juneau, Alaska: Amer. Institute of Fishery Research Biologists.

Sheridan, W.L. and McNeil, W.J. 1968. Some effects of logging on two salmon streams in Alaska. H.R. MacMillan Lectures in Fisheries. Journal of Forestry 66(2):128-133.

Sheridan, W.L., Olson, S.T., and Hoffman, T.C. 1966. Monitoring certain land use effects on salmon spawning environments. Proceedings, Society of American Foresters, Annual Meeting, pp.49-52.

Sheridan, W.L., Perensovich, M.P., Faris, T., and Koski, K. 1984. Sediment content of streambed gravels in some pink salmon spawning streams in Alaska. In Fish and wildlife relationships in old-growth forests: Proceedings of a symposium, ed. W.R. Meehan, T.R. Merrell, and T.A. Hanley, pp.153-165. American Institute of Fishery Research Biologists. (Available from J.W. Reintjes, Rt. 4, Box 85, Morehead City, NC 28557.)

Shirazi, M.A. and Seim,W.K. 1979. A stream systems evaluation: An emphasis on spawning habitat for salmonids. EPA-600/3-70.109, Corvallis Environmental Research Lab., Corvallis, OR. 32 pp.

Shirazi, M.A. and Seim, W.K. 1981. Stream system evaluation with emphasis on spawning habitat for salmonids. Water Resources Research 17(3): 592-594.

Shumway, D.L., Warren, C.E., and Doudoroff, P. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Transactions of the American Fisheries Society 93:342-356.

Sigler, J.W. and Bjornn, T.C. 1980. Effects of chronic turbidity on feeding, growth, and social behavior of steelhead trout and coho salmon. Completion Report. Idaho Cooperative Fisheries Research Unit, University of Idaho, Moscow.

Sigler, J.W., Bjornn, T.C., and Everest, F.H. 1984. Effects of chronic turbidity on density and growth of steelhead and coho salmon. Transactions of the American Fisheries Society 113(2):142-150.

Skaugset, A.E., II. 1980. Fine organic debris and dissolved oxygen in streambed gravels in the Oregon Coast range. M.S. thesis, Oregon State University, Corvallis, OR.

Skille, J. and King, J. 1989. Proposed embeddedness sampling procedure. USDA Intermountain Research Station for Idaho Dept. Health and Welfare.

Slaney, P.A., Halsey, T.G., and Smith, H.A. 1977. Some effects of forest harvesting on salmonid rearing habitat in two streams in the central interior of British Columbia. Victoria, B.C.: Fisheries Management Report No. 71.

Smith, O.R. 1939. Placer mining silt and its relation to salmon and trout on the Pacific coast. Transactions of the American Fisheries Society 69:225-?

Smith, M.A., Dodd, J.L., Skinner, Q.D., and Rodgers, J.D. 1993. Dynamics of vegetation along and adjacent to an ephemeral channel. Journal of Range Management 46:56-64.

Snucins, E.J., Curry, R.A, and Gunn, J.M. 1992. Brook trout (Salvelinus fontinalis) embryo habitat and timing of alevin emergence in a lake and a stream. Canadian Journal of Zoology/Review of Canadian Zoology 70(3):423-427.

Sowden, T.K. and Power, G. 1985. Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrates. Transactions of the American Fisheries Society 114(6):804-812.

Sparks, R.E. 1977. Effects of sediment on aquatic life. Illinois Institute for Environmental Quality, Urbana, Illinois.

Stack, W.R. and Beschta, R.L. 1989. Factors influencing pool morphology in Oregon coastal streams. In Headwaters hydrology: Proceedings of the 1989 symposium. American Water Resources Association, Bethesda, MD.

Statzner, B. and Higler, B. 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. Freshwater Biology 16:127-139.

Steven, R. and Gessler, J., eds. 1988. The effects of sediment transportation changes on aquatic habitat. American Society of Civil Engineers, Task Committee on Aquatic Habitat and Sediment Transport, American Society of Civil Engineers: New York.

Stewart, A.J.A. and Lance, A.N. 1983. Moor-draining: A review of impacts on land use. Journal of Environmental Management [UK?] 17(1):81-99.

Stowell, R.A., Espinosa, A., Bjornn, T.C., Platts, W.S., Burns, D.C. and Irving, J.S. 1983. A guide for predicting salmonid response to sediment yields in Idaho batholith watersheds. Unpublished Report R1-R4, USDA--Forest Service.

Stuehrenberg, L.C. 1975. The effects of granite sand on the distribution and abundance of salmonids in Idaho streams. M.S. thesis, University of Idaho, Moscow. 490 pp.

Tagart, J.V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. M.S. thesis, University of Washington, Seattle.

Tagart, J.V. 1984. Coho salmon survival from egg deposition to emergence. In Proceedings of the Olympic wild fish conference, Port Angeles, WA, March 1983, ed. J.M. Walton and D.B. Houston.

Tappel, P. 1981. A new method of relating spawning gravel size composition to salmonid embryo survival. M.S. thesis, University of Idaho, Moscow.

Tappel, P.D. and Bjornn, T.C. 1980. Effects of sediment composition on salmonid egg survival. Progress Report to USDA--Forest Service.

Tappel, P.D. and Bjornn, T.C. 1983. A new method of relating size of spawning gravel to salmonid embryo survival.

North American Journal of Fisheries Management 3:123-135.

Tassone, B.L. 1987. Sediment loads from 1973 to 1984 0048 Carnation Creek at the mouth, British Columbia. In Proceedings of a workshop: Applying 15 years of Carnation Creek results, ed. T.W. Chamberlin, pp. 46-58. Nanaimo, British Columbia: Carnation Creek Steering Committee.

Tebo, L.B., Jr. 1955. Effects of siltation, resulting from improper logging, on the bottom fauna of small trout stream in the southern Appalachians. Progressive Fish-Culturist 17(2):66-70.

Tebo, L.B., Jr. 1957. Effects of siltation on trout streams. Society of American Foresters, Proceedings Annual Meeting 1956, pp. 198-202.

Thurow, R. and King, J. 1991? Effects of fine sediment on fish populations. USDA--Forest Service, Intermountain Research Station, Boise, ID.

Torquemada, R.J., and Platts, W.S. 1988. A comparison of sediment monitoring techniques of potential use in sediment/fish population relationships. USDA-Forest Service Intermountain Research Station, Boise, ID (for Idaho Fish and Game).

Turnpenny, A.W.H. and Williams, R. 1980. Effects of sedimentation on the gravels of an industrial river system. Journal of Fish Biology 17(6):681-694.

USDA--SCS. 1977. Site investigations. Chapter 3 in Design of open channels. Technical Release No. 25, Washington, D.C.

USDA--SCS. 1992. Problem statement, Columbia Basin salmonids. Portland, Oregon.

Vadeboncoeur, Y. and Kramer, R.P. 1988? Fisheries habitat and aquatic environment: 1987-1988 monitoring report for the Bitterroot, Deerlodge, and Lolo National Forest [chapter 2 only -- embeddedness].

Vronskiy, B.B. 1972. Reproductive biology of the Kamchatka River chinook salmon (Oncorhynchus tschawytscha [Walbaum]). Journal of Ichthyology 12:259-273.

Vronskii, B.B. and Leman, V.N. 1991. Spawning stations: Hydrological regime and survival of progeny in nests of chinook salmon, Oncorhynchus tschawytscha, in the Kamchatka River Basin. Journal of Ichthyology 31(4):91-102.

Washington Water Resources Center. 1981. Salmon-spawning gravel: A renewable resource in the Pacific Northwest? Proceedings from the conference. Washington State University, Water Research Center, Report 39, Pullman, WA.

Wells, R.A. and McNeil, J. 1970. Effect of quality of the spawning bed on the growth and development of pink salmon embryos and alevins. U.S. Fish and Wildlife Series Special Science Report Fish. No. 616:1-6.

WEST Consultants, Inc. 1993. Managing instream flows for salmonid spawning habitat. In Proceedings of the 20th anniversary conference on water management in the '90s, Seattle, WA, pp. 75-78. ASCE, New York, NY.

Wickett, W.P. 1959. Effects of siltation on success of fish spawning. In Proceedings 5th Symp. PNW on Siltation--Its source and effects on aquatic environments, ed. E.F. Eldridge and J.N. Wilson, pp.16-17. U.S. Dept. Health, Educ., and Welfare, Portland, OR.

Willer, D.K. 1988. The effect of fine sediment on brown trout early life history stages in Newton Creek, Clare County, Michigan. 126 pp. Vol. 26/04 of Masters Abstracts, page 400.

Williams, D.D. and Mundie, J.H. 1978. Substrate size selection by stream invertebrates and the influence of sand. Limnology and Oceanography 23(5):1030-1033.

Wilson, D.A. 1976. Salmonid spawning habitat improvement study. Washington State Department of Fisheries, Project 1-93-0, Proj. Completion Report, Olympia, WA.

Wilson, J.N. 1957. Effects of turbidity and silt on aquatic life. In Biological problems in water pollution, ed. C.M. Tarzwell. U.S. Dept. Health, Educ., and Welfare, Cincinnati, OH.

Witzel, L.D. and MacCrimmon, H.R. 1981. Role of gravel substrate on ova survival and alevin emergence of rainbow trout, Salmo gairdneri. Canadian Journal of Zoology 59(4):629-636.

Wotton, R.S., ed. 1990. The biology of particles in aquatic systems. CRC Press, Inc.: Boca Raton, Florida.

Wustenberg, D.W. 1954. A preliminary survey of the influences of controlled logging on a trout stream in the H.J. Andrews Experimental Forest, Oregon. M.S. thesis, Oregon State College, Corvallis, OR.

Young, M.K., Hubert, W.A., and Wesche, T.A. 1991. Selection of measures of substrate composition to estimate survival to emergence of salmonids and to detect changes in stream substrates. North American Journal of Fisheries Management 11(3):339-346.

Young, M.K., Hubert, W.A., and Wesche, T.A. 1989. Substrate alteration by spawning brook trout in a southeastern Wyoming stream. Transactions of the American Fisheries Society 118(4):379-385.

Young, M.K., Hubert, W.A., and Wesche, T.A. 1990. Effect of substrate composition and stock origin on the survival to emergence of brown trout: A laboratory study. Northwest Science 64(4):224-231.

< Back to RCA Publication Archive

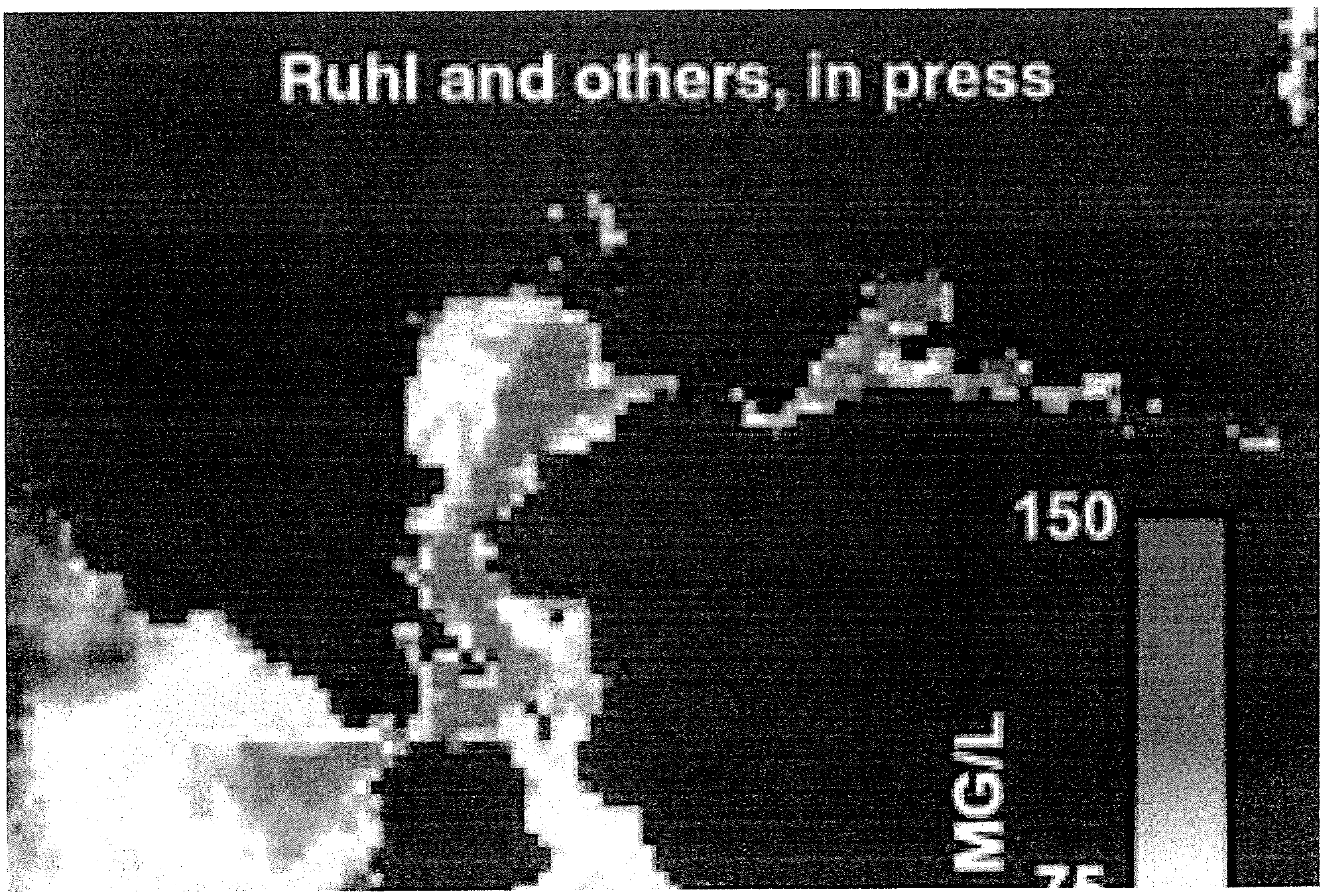
KQED Science

Exhibit 19

QUEST

GEOLOGY (HTTPS://WW2.KQED.ORG/QUEST/CATEGORY/GEOLOGY/)

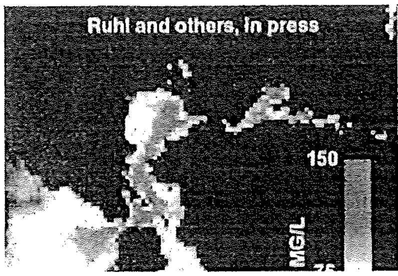
San Francisco Bay Slowly Recovering From Gold Rush Miners' Devastating Legacy



By Brian Romans (https://ww2.kqed.org/quest/author/brian-romans/)
NOV. 18, 2010

SHARE

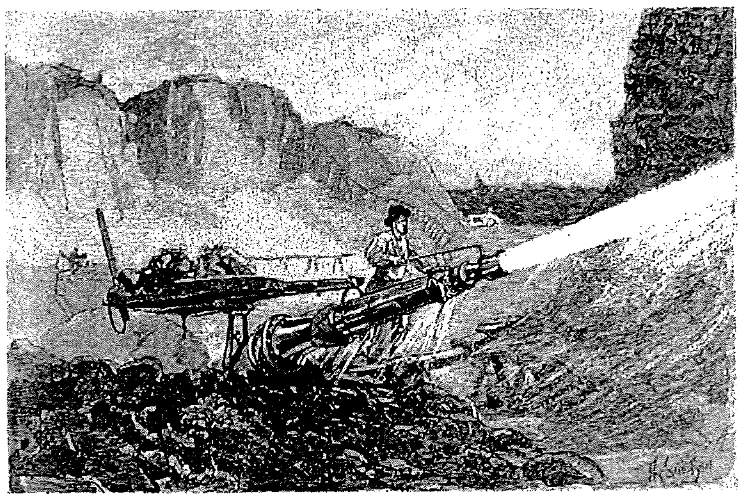
Much of the gold extracted from the Sierra foothills during the Gold Rush was in placer deposits. That is, it was mixed with the rest of the sediment naturally eroding from the mountainside. Flecks of gold have a greater density than almost all the other particles and, thus, can be concentrated through natural water movement. A similar process is seen when you go to the beach. When the mixture of minerals and waves are just right you might notice darker grains of sand creating streaks or patches in the wet sand.



Suspended Sediment Concentration in the San Francisco Bay, USGS. Click here (http://ww2.kqed.org/quest/wp-content/uploads/sites/39/2010/11/ruhl1.jpg) for a larger version of the image.

Miners had to devise ways to extract the gold because it was still a minor component even in rich placer deposits. Methods like panning and simple equipment like sluice boxes were used with moving water to enhance the natural mineral separation process.

When all this relatively easy-to-get gold was extracted from the streams and rivers prospectors turned to hydraulic mining (http://museumca.org/goldrush/fever19-hy.html) to obtain the riches. Hydraulic mining was the process of using high-powered water canons to artificially erode gold-bearing hills made of sedimentary deposits. These sedimentary deposits were ancient stream beds that contained gold in placer deposits much like the modern streams did. Essentially, hydraulic mining eroded ancient river sediment from the hillside and diverted the material into the modern river where miners then extracted the gold.


(http://ww2.kqed.org/quest/wp-content/uploads/sites/39/2010/11/800px-Henry_Sandham_-_The_Monitor1.jpg)

Unsurprisingly, the activity of hydraulic mining devastated the local environment. The landscape was scarred and the mountain streams choked with gravel and sediment. And the effects weren't just local. These rivers and streams flowed into the San Joaquin River (http://ww2.kqed.org/quest/2010/08/12/geologic-context-and-history-of-the-san-joaquin-river/) and Sacramento River and deposited some of this sediment in the Central Valley causing flooding and navigation problems. Some of the finer sediment was transported even further, to the San Francisco Bay.

The effects of hydraulic mining practices are still measurable in the Bay today. Geologists from the USGS are studying the amount of sediment the Sacramento-San Joaquin Delta delivers to the Bay and are finding that the Gold Rush-induced sediment levels might be diminishing (http://www.npr.org/templates/story/story.php?storyId=128113664):

"[USGS geologist David Schoellhamer] says all the extra sediment has finally worked its way past the Golden Gate. The bay's water is about 30 percent clearer than it was 10 years ago."

It is taken many decades for this complex sediment delivery system to reach a new equilibrium. However, the readjustment of the estuary to these 'new' conditions might create new problems:

"Less sediment in the bay could spell trouble if scientists' predictions about rising sea levels come to pass. These delicate tidal marshes could be inundated over the next century."

What I find fascinating, yet also extremely challenging, is how the choices we've made as a civilization over the decades and centuries combine and sum to create the issues we face right now. There are no simple answers. Regardless of how well-intentioned some environmental programs may be there will always be some uncertainty about how natural systems respond. Continuing scientific research of these systems will reduce that uncertainty and inform policy decisions of the future.

Images: (1) *California Water Science Center (http://ca.water.usgs.gov/sfbay/sedtrans/);* (2) *Wikipedia (http://en.wikipedia.org/wiki/File:Henry_Sandham_-_The_Monitor.jpg)*

37.7749295 -122.4194155

EXPLORE: ENVIRONMENT (HTTPS://WW2.KQED.ORG/QUEST/CATEGORY/ENVIRONMENT/), GEOLOGY (HTTPS://WW2.KQED.ORG/QUEST/CATEGORY/GEOLOGY/), GEOLOGY (HTTPS://WW2.KQED.ORG/QUEST/TAG/GEOLOGY/), GOLD (HTTPS://WW2.KQED.ORG/QUEST/TAG/GOLD/), GOLD RUSH (HTTPS://WW2.KQED.ORG/QUEST/TAG/GOLD-RUSH/), SACRAMENTO DELTA (HTTPS://WW2.KQED.ORG/QUEST/TAG/SACRAMENTO-DELTA/), SACRAMENTO RIVER (HTTPS://WW2.KQED.ORG/QUEST/TAG/SACRAMENTO-RIVER/), SAN FRANCISCO BAY (HTTPS://WW2.KQED.ORG/QUEST/TAG/SAN-FRANCISCO-BAY/), SAN JOAQUIN RIVER (HTTPS://WW2.KQED.ORG/QUEST/TAG/SAN-JOAQUIN-RIVER/), SEDIMENT (HTTPS://WW2.KQED.ORG/QUEST/TAG/SEDIMENT/)

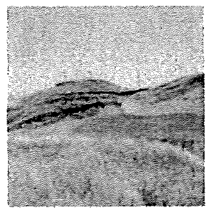
G+ (https://ww2.kqed.org/quest/2010/11/18/gold-rush-sediment-in-the-san-francisco-bay/?share=google-plus-1&nb=1)

0 Comments (https://ww2.kqed.org/quest/2010/11/18/gold-rush-sediment-in-the-san-francisco-bay/#disqus_thread)

Related

Still Mining Gold in the Golden State (http://ww2.kqed.org/quest/2013/03/07/still-mining-gold-in-the-golden-state/)

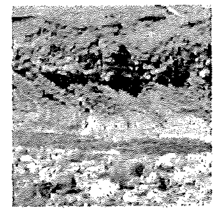
Bay Area Mercury (http://science.kqed.org/qu.../07/21/bay-area-mercury/)



The Blue Rock of Antioch (http://ww2.kqed.org/quest/... blue-rock-of-antioch/)

Confounding Concretions (http://ww2.kqed.org/quest/.../06/07/confounding-concretions/)

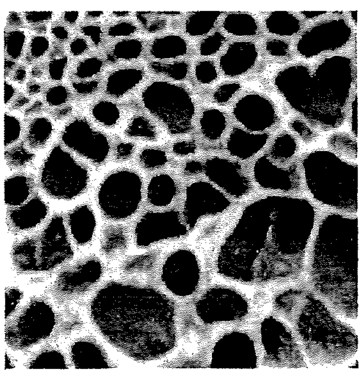
Geological Outings Around the Bay: Stinson Beach (http://science.kqed.org/quest/2011/06/23/geological-outings-around-the-bay-stinson-beach/)



The Switching Outlets of Clear Lake (http://ww2.kqed.org/quest/2c... switching-outlets-of-clear-lak...

Powered by (https://contextly.com)

AUTHOR



BRIAN ROMANS

Brian Romans is the author the popular geoscience blog Clastic Detritus where he writes about topics in the field of sedimentary and marine geology and shares photographs of geologic field work from around the world. He is fascinated by the dynamic processes that shape our planet and the science of reconstructing ancient landscapes preserved in the geologic record. Brian came to the Bay Area in 2003 and completed a Ph.D. in geology at Stanford University in 2008. He lives in Berkeley with his wife, a high school science teacher, and is currently working as a research scientist in the energy industry. Follow him on Twitter (http://www.twitter.com/clasticdetritus).

VIEW ALL POSTS BY THIS AUTHOR (https://ww2.kqed.org/quest/author/brian-romans/)

ABOUT QUEST

KQED's team of science educators and producers creates science and engineering resources for educators, students and lifelong learners.

QUEST is a project of KQED Science and KQED Education.

ABOUT KQED

About (http://www.kqed.org/about/)
Jobs (http://www.kqed.org/about/jobs/)
Internships (http://www.kqed.org/about/internships/)
Donate to KQED (https://www.kqed.org/donate/)
Website help (http://www.kqed.org/about/help/index.jsp)

QUEST IS SUPPORTED BY:

(http://www.nsf.gov)

The National Science Foundation

Funding for KQED Learning is provided by the Mary A. Crocker Trust, and the mer

Support for KQED Science is provided by Foundation, The Vadasz Family Founda Foundation and the members of KQED

LOCATION GOBLE OR

Exhibit 20

Established Series
Rev. GEO/AON
02/2001

GOBLE SERIES

The Goble series consists of moderately deep to a fragipan, moderately well drained soils that formed in silty loess over old alluvium of mixed origin. Goble soils are on long convex upland slopes and ridgetops and have slopes of 2 to 80 percent. The mean annual precipitation is about 70 percent and the mean annual air temperature is about 49 degrees F.

TAXONOMIC CLASS: Fine-silty, isotic, mesic Andic Fragiudepts

TYPICAL PEDON: Goble silt loam, woodland. (Colors are for moist soil unless otherwise noted.)

Oi--0 to 1 inch; needles, twigs, moss, leaves, etc.

A1--1 to 8 inches; very dark grayish brown (10YR 3/2) silt loam, brown (10YR 5/3) dry; strong fine granular structure; soft, friable, slightly sticky and slightly plastic; many fine roots; many fine and very fine pores; many fine concretions; moderately acid (pH 5.6); abrupt smooth boundary. (6 to 9 inches thick)

A2--8 to 15 inches; dark brown (10YR 3/3) silt loam, yellowish brown (10YR 5/4) dry; strong fine granular structure; soft, friable, slightly sticky and slightly plastic; many fine roots; many very fine pores; few fine concretions; strongly acid (pH 5.4); clear smooth boundary. (6 to 9 inches thick)

Bw1--15 to 27 inches; dark brown (7.5YR 3/4) silt loam, yellowish brown (10YR 5/4) dry; moderate fine subangular blocky structure; soft, friable, slightly sticky and slightly plastic; common fine and few medium roots; many very fine pores; strongly acid (pH 5.4); clear smooth boundary. (9 to 13 inches thick)

Bw1--27 to 38 inches; dark brown (10YR 4/3) silty clay loam, light yellowish brown (10YR 6/4) dry; moderate fine subangular blocky structure; slightly hard, firm, moderately sticky and moderately plastic; few fine roots; common very fine pores; strongly acid (pH 5.2); abrupt smooth boundary. (10 to 12 inches thick)

2Btx--38 to 51 inches; dark yellowish brown (10YR 4/4) silty clay loam, light yellowish brown (10YR 6/4) dry; many fine and medium distinct dark brown (7.5YR 3/2), strong brown (7.5YR 5/6) and light gray (10YR 7/1) redox features and light gray (10YR 7/1) tongues in fracture planes; numerous fine and medium black stains; weak very coarse prismatic and medium blocky and some subangular blocky structure; hard, brittle, very firm, moderately sticky and moderately plastic; common very fine pores; common faint clay films in fractures and on prism sides; very strongly acid (pH 5.0).

TYPE LOCATION: Multnomah County, Oregon; about 30 feet west of Skyline Blvd.; NE1/4 NW1/4 NE1/4 section 3, T.2N., R.2W., W.M.

RANGE IN CHARACTERISTICS: The soils have a udic moisture regime but have a dry period of less than 45 days during the summer. The mean annual soil temperature ranges from 47 degrees to 55 degrees F. The depth to the fragipan ranges from 30 to 45 inches. The soil is more than 60 inches deep to bedrock. The umbric epipedon is 10 to 20 inches thick.

The A horizon has value of 4 or 5 dry, and chroma of 2 or 3 moist and 2 through 4 dry.

The Bw horizon has hue of 10YR or 7.5YR, value of 3 or 4 moist and 5 or 6 dry, and chroma of 3 or 4. It is typically silty clay loam, but includes silt loam in the upper part. None to few faint mottles with chroma of 3 or 4 in hue of 5YR are near the boundary with the fragipan in some pedons. This horizon has a smeary feel when moist.

The Btx horizon (fragipan) has matrix colors similar to the horizon above it, but has distinct and prominent mottles with chroma of 2. It is hard, very firm, and has a brittle feel. Clay films on prism faces and fractures are common or continuous and thin. The fragipan is normally more than one foot thick and overlies old alluvium or loess, and residual material of mixed origin.

COMPETING SERIES: These are the Cascade, Dollar, Kinton and Powell series. Cascade soils have fragipans at depths of less than 30 inches and are mottled at depths of 20 to 30 inches. Dollar soils are fine-loamy. Kinton and Powell soils have ochric epipedons and xeric moisture regimes. Also, Powell soils are mottled at depths of 20 to 30 inches.

GEOGRAPHIC SETTING: The Goble soils are on smooth or rolling hills with convex, long slopes and ridgetops on all exposures at elevations of 200 to 1,800 feet. The soils formed in loess over mixed old alluvium or slope wash. The soils formed under a cool moist winter and a warm dry summer climate. Average July temperature is 64 degrees F., average January temperature is 34 degrees F., average annual temperature is 49 degrees F. Average annual precipitation is 60 to 75 inches. Frost-free period is 180 to 190 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Delena, Olyic and Melby soils and the competing Cascade soils. Delena soils are poorly drained, and have chroma of 2 or less and mottles throughout the B horizon and the fragipan. Olyic and Melby soils lack fragipans.

DRAINAGE AND PERMEABILITY: Moderately well drained; slow to medium surface runoff; moderate permeability above the fragipan and slow in the fragipan.

USE AND VEGETATION: Small grains and seed crops, hay, pasture, and woodland. Small areas are used for berries. Native vegetation consists of Douglas-fir, western redcedar, big leaf maple, alder, vine maple, salal, swordfern.

DISTRIBUTION AND EXTENT: Northwestern Oregon. The series is moderately extensive.

MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: Portland, Oregon

SERIES ESTABLISHED: Washington County, Oregon, 1975.

National Cooperative Soil Survey
U.S.A.

DOE/EA-0928

Exhibit 21

Burlington Bottoms Wildlife Mitigation Project

Final Environmental Assessment/ Management Plan and Finding of No Significant Impact

December 1994

U.S. Department of Energy
Bonneville Power Administration

Burlington Bottoms
Wildlife Mitigation Project

Final Environmental Assessment/Management Plan
and Finding of No Significant Impact

December 1994

TABLE OF CONTENTS

Page

CHAPTER 1: PURPOSE OF AND NEED FOR ACTION.............. 1
1.1 Proposed Action.. 1
1.2 Purpose and Need for Action.......................... 1
1.3 Background.. 2
1.3.1 Mitigation Process under Power Act............ 2
1.3.2 Relationship to Other Actions.................. 5
1.3.3 Review Schedule.................................. 6

CHAPTER 2: ALTERNATIVES INCLUDING THE PROPOSED ACTION.. 6
2.1 Alternative 1: Proposed Action (Maintenance and Enhancement/Limited Public Access)................... 7
2.1.1 Fish and Wildlife Habitat Management.......... 7
2.1.1.1 Native Vegetation.......................... 7
2.1.1.2 Non-native Vegetation...................... 8
2.1.1.3 Artificial Structures for Wildlife ... 9
2.1.2 Fish and Wildlife Management.................. 10
2.1.2.1 Native Fish Management.................... 10
2.1.2.2 Non-native Fish Management............... 11
2.1.2.3 Native Wildlife Management............... 11
2.1.2.4 Non-native Wildlife Management.......... 13
2.1.3 Hydrologic Resources Management............... 13
2.1.4 Public Access/Recreation Management........... 15
2.1.5 Cultural Resources Management................. 16
2.1.6 Operation and Maintenance..................... 16
2.2 Alternative 2: Maintenance and Enhancement/Closed to the Public.. 16
2.3 Alternative 3: No-Action............................. 16
2.3.1 Fish and Wildlife Habitat Management (Status Quo Maintained)......................... 17
2.3.2 Fish and Wildlife Management.................. 17
2.3.3 Hydrologic Resources Management............... 17
2.3.4 Public Access/Recreation Management........... 17
2.3.5 Cultural Resources Management................. 17
2.3.6 Operation and Maintenance..................... 17

CHAPTER 3: THE AFFECTED ENVIRONMENT................... 18
3.1 Background... 18
3.2 Affected Environment................................. 19
3.2.1 Fish and Wildlife Habitat Resources........... 19
3.2.2 Fish and Wildlife Resources................... 20
3.2.3 Hydrologic Resources.......................... 20
3.2.4 Air Quality................................... 21
3.2.5 Cultural Resources............................ 21

CHAPTER 4: ENVIRONMENTAL CONSEQUENCES.................. 22
4.1 Potential Environmental Impacts of Alternative 1.... 22
4.1.1 Impacts Upon Fish and Wildlife Habitat........ 22
4.1.2 Impacts Upon Fish and Wildlife Resources...... 22
4.1.3 Impacts Upon Hydrologic Resources............. 23
4.1.4 Impacts Upon Air Quality...................... 23

TABLE OF CONTENTS
(Continued)

Page

4.1.5 Impacts Upon Cultural Resources.............. 24
4.1.6 Impacts Upon Wetlands and Floodplains......... 24
4.2 Potential Environmental Impacts of Alternative 2.... 24
4.2.1 Impacts Upon Fish and Wildlife Habitat........ 24
4.2.2 Impacts Upon Fish and Wildlife Resources...... 25
4.2.3 Impacts Upon Hydrologic Resources............. 25
4.2.4 Impacts Upon Air Quality...................... 25
4.2.5 Impacts Upon Cultural Resources............... 25
4.2.6 Impacts Upon Wetlands and Floodplains 25
4.3 Potential Environmental Impacts of Alternative 3.... 25
4.3.1 Impacts Upon Fish and Wildlife Habitat........ 25
4.3.2 Impacts Upon Fish and Wildlife Resources...... 26
4.3.3 Impacts Upon Hydrologic Resources............. 26
4.3.4 Impacts Upon Air Quality...................... 26
4.3.5 Impacts Upon Cultural Resources............... 26
4.3.6 Impacts Upon Wetlands and Floodplains......... 27

CHAPTER 5: MONITORING AND EVALUATION.................. 27
5.1 Objectives.. 27
5.2 Adaptive Management................................. 27

CHAPTER 6: STATUTORY AND REGULATORY REQUIREMENTS....... 28

CHAPTER 7: CONSULTATION AND COORDINATION............... 28

CHAPTER 8: REFERENCES.................................. 29

CHAPTER 9: SCHEDULING OF IMPLEMENTATION................ 30

APPENDICES

Appendix A - Wildlife and Fish Species List........... A-1
Appendix B - Plant Species List....................... B-1
Appendix C - Recreational Report...................... C-1
Appendix D - Historical Survey Notes of 1853 and 1854. D-1
Appendix E - Historical Photos........................ E-1
Appendix F - Letter on Endangered Species............. F-1
Appendix G - Comment Letters.......................... G-1
Appendix H - Finding of No Significant Impact H-1

LIST OF FIGURES

Figure 1. Location of Burlington Bottoms within Multnomah County, Oregon..................... 3

Figure 2. Aerial Photo of Burlington Bottoms........... 4

CHAPTER 1: PURPOSE OF AND NEED FOR ACTION

1.1 PROPOSED ACTION

Bonneville Power Administration (BPA) proposes to fund wildlife management and enhancement activities for the Burlington Bottoms wetlands mitigation site. Acquired by BPA in 1991, wildlife habitat at Burlington Bottoms would contribute toward the goal of mitigation for wildlife losses and inundation of wildlife habitat due to the construction of Federal dams in the lower Columbia and Willamette River Basins. Target wildlife species identified for mitigation purposes are yellow warbler, great blue heron, black-capped chickadee, red-tailed hawk, valley quail, spotted sandpiper, wood duck, and beaver.

The Draft Management Plan/Environmental Assessment (EA) describes alternatives for managing the Burlington Bottoms area, and evaluates the potential environmental impacts of the alternatives. Included in the Draft Management Plan/EA is an implementation schedule, and a monitoring and evaluation program, both of which are subject to further review pending determination of final ownership of the Burlington Bottoms property.

1.2 PURPOSE AND NEED FOR ACTION

BPA proposes action to meet the need for mitigation for wildlife and wildlife habitat adversely affected by the development and operation of Federal dams and reservoirs on the Willamette and Columbia Rivers. The purposes of the Proposed Action are to:

1) Maintain consistency with the Pacific Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program and Amendments.

2) Increase the quality and quantity of wildlife and wildlife habitat on the Burlington Bottoms property.

3) Maintain the area primarily as wetland habitat typical of that found in the lower Columbia and Willamette River Basin systems.

4) Maintain a diversity of wildlife and wildlife habitat typical of a riverine floodplain.

5) Provide selected forms of passive wildlife oriented public recreation.

6) Favor native plants and animals over non-native.

7) Protect cultural sites.

8) Maintain or improve water quality.

9) Meet BPA's obligation under provisions of the Pacific Northwest Electric Power Planning and Conservation Act of 1980.

1.3 BACKGROUND

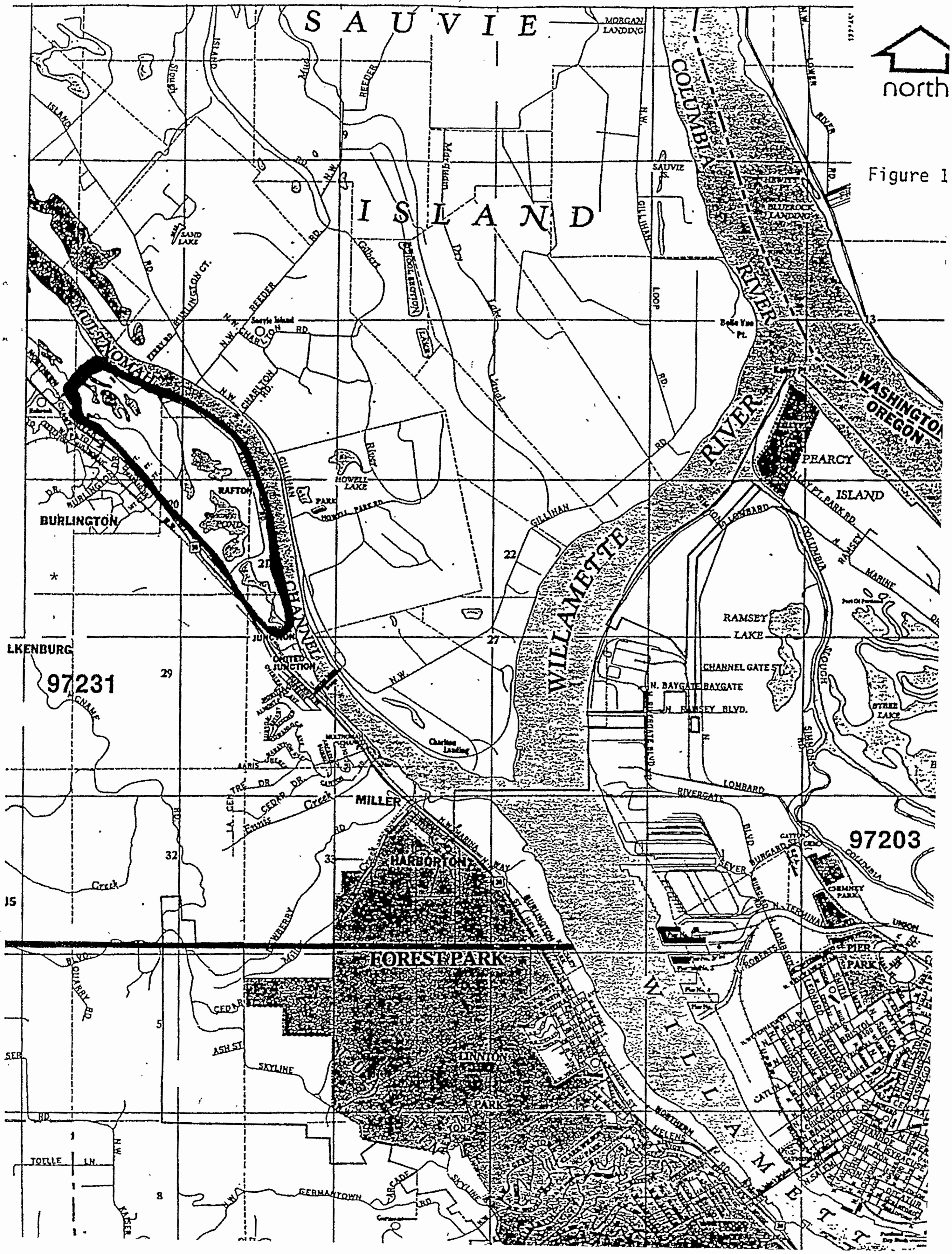
In 1991 BPA purchased the Burlington Bottoms property consisting of approximately 169 hectares (ha) (417 acres) of wetlands, riparian, and pasture (formerly wet prairie) habitat along the floodplain of the lower Columbia and Willamette Rivers. The area is located adjacent to the Multnomah Channel between Sauvie Island and the Tualatin Mountains, (see map on page 3). The area provides important seasonal and year-round habitat for many species of fish and wildlife, including the bald eagle and western painted turtle.

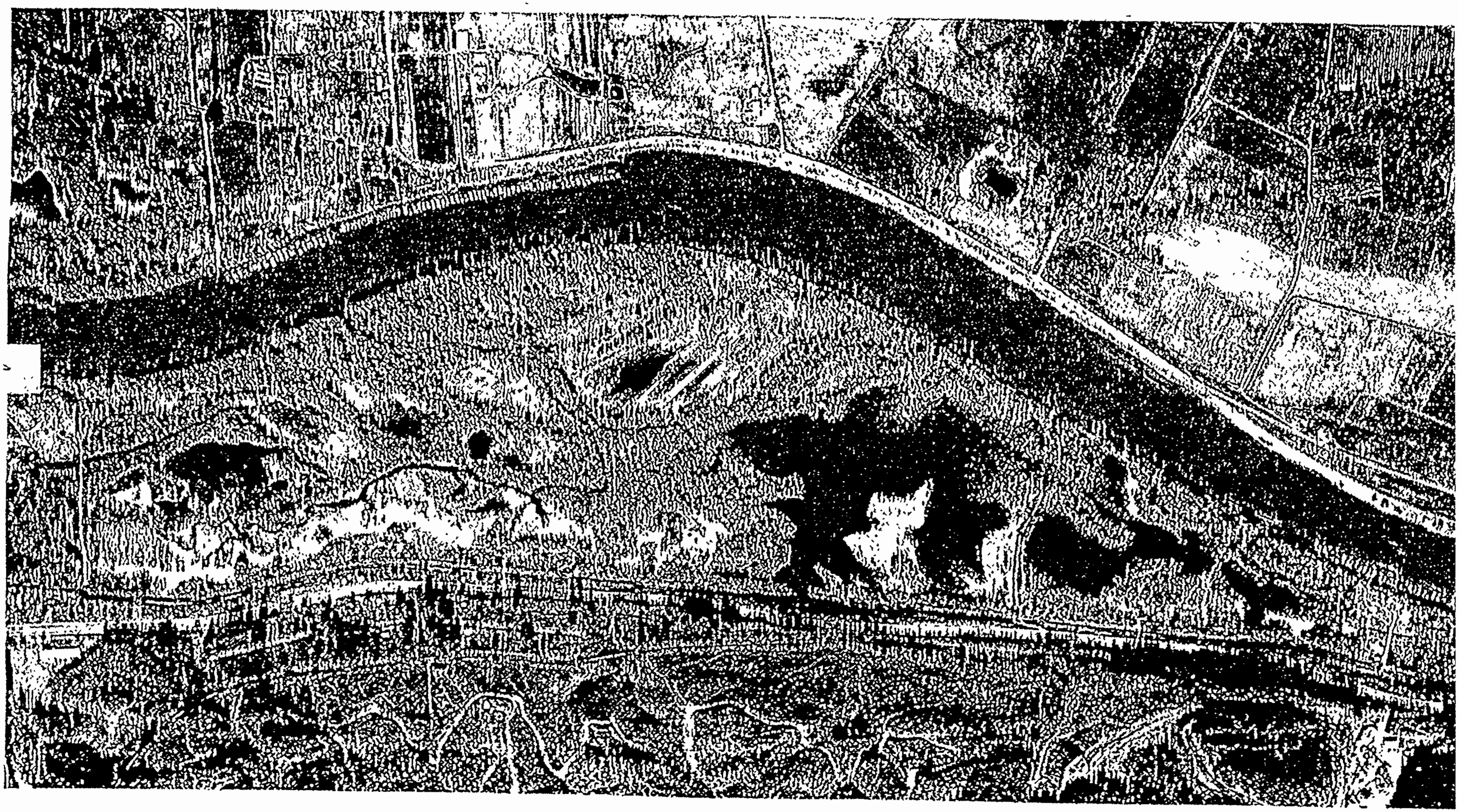
To provide a framework for the management of the area's natural resources, development of a Draft Management Plan and EA began in the fall of 1993 to address such issues as habitat management, recreation, and cultural resources. Input for the development of the Draft management Plan came from various Federal and State agencies, local environmental groups, and private citizens. A public meeting was held in June 1993, to foster discussion and formulate a list of issues and concerns for the management of Burlington Bottoms, which were then incorporated into the Plan/EA.

1.3.1 Mitigation Process under Power Act

Under provisions of the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (Northwest Power Act), BPA has the authority and obligation to fund wildlife mitigation activities approved by the Northwest Power Planning Council and included in the Council's Fish and Wildlife Program. The initial phase of mitigation planning for wildlife habitat losses was submitted to the Council for amendment into the Program in 1989. The Program includes a process for review of habitat losses and design of mitigation plans for each Federal hydro project in the Willamette and Columbia River Basins (Section 1002).

In 1989, the Council amended the Program to include wildlife habitat losses resulting from construction and operation of Bonneville, The Dalles, John Day, and McNary Dams. In


north
SAUVIE
ISLAND
MORGAN LANDING
COLUMBIA RIVER
WASHINGTON
OREGON
SAUVIE IS.
BLUEROCK LANDING
Belle Vue Pt.
Kelley Pt.
PEARCY
ISLAND
SAND LAKE
BURLINGTON CT.
N.W. REEDER
Sauvie Island
N.W. CHARLTON RD.
N.W. GILLIHAN
LOOP RD.
HOWELL LAKE
HOWELL PARK RD.
RAFTON
BURLINGTON
MULTNOMAH
CHANNEL
JUNCTION
UNITED JUNCTION
LKENBURG
97231
WILLAMETTE
RIVER
RAMSEY LAKE
CHANNEL GATE ST.
N. BAYGATE
N. RAMSEY BLVD.
LOMBARD
RIVERGATE
COLUMBIA
MARINE
SLOUGH
Charlton Landing
MILLER
Ennis Creek
HARBORTON
N.W. MARINA WAY
97203
CHIMNEY PARK
PIER PARK
FOREST PARK
LINNTON PARK
SKYLINE
ASH ST.
CEDAR
QUARRY RD.
GERMANTOWN
TOELLE LN.
N.W. KAISER
N.W. ST. HELENS RD.
NORTHERN
WILLAMETTE
Figure 1



BURLINGTON BOTTOMS 3/93

Figure 2

addition, this project would be consistent with Section 1003(7) of the Program's Wildlife Mitigation Rule.

1.3.2 Relationship to Other Actions

- Oregon Land Use Planning Act of 1973

The Oregon Land Use Planning Act of 1973 (Oregon Revised Statutes (ORS) Chapter 197.225-.245), created a state-level program to set policy for and coordinate the administration of land use planning by all levels of government in Oregon. Statewide planning goals were developed under this program which require the protection and management of land, water, coastal and ocean resources.

Goal 5 of the Oregon Land Use Planning Act requires cities and counties to adopt programs as elements of their comprehensive plans that will 1) ensure open space; 2) protect scenic and historical areas and natural resources for future generations; and 3) promote healthy and visually attractive environments in harmony with the natural landscape character. In 1988, Multnomah County identified Burlington Bottoms as being "significant wetlands" under the Goal 5 inventory.

In addition, in 1990, streams located in the contributing watershed in the northwest hills above Burlington Bottoms were identified as "significant streams and riparian resources."

Consistent with Goal 5, proposed actions under the Draft Management Plan for Burlington Bottoms would protect the historic and cultural areas and natural resources, maintain open spaces, and maintain and/or enhance the existing natural landscape.

- Goal 15: Willamette River Greenway

Under Goal 15 of the Oregon Land Use Planning Act, all of the Burlington Bottoms area is located in the Willamette River Greenway Zone. The purposes of the Willamette River Greenway subdistrict are to protect, conserve, enhance, and maintain the natural, scenic, historical, agricultural, economic, and recreational qualities of lands along the Willamette River; to implement the County's responsibilities under ORS 390.310 to 390.368; to establish Greenway Compatibility Review Areas; and to establish criteria, standards and procedures for the intensification of uses, changes of uses, or the development of lands within the Greenway.

- Sauvie Island Wildlife Area Management Plan

The Sauvie Island Wildlife Area Management Plan, prepared by the Oregon Department of Fish and Wildlife (ODFW), (January 1993), provides management direction for wildlife habitat and wildlife oriented recreation. Goals developed for this plan include maintaining natural areas for habitat diversity. Because of Sauvie Island's close proximity to Burlington Bottoms, many species of wildlife, including waterfowl, raptors, mammals, and songbirds, may use both areas for their habitat needs. Proposed management activities that would protect, maintain, and enhance fish and wildlife habitat at Burlington Bottoms coincide with management direction for Sauvie Island. Both plans provide a framework for the management of a diversity of wildlife and wildlife habitat in the area.

1.3.3 Review Schedule

The Final Management Plan would be periodically reviewed on the following schedule: once every year for the first three years, then once every five years, unless unforeseen circumstances dictate the need for a schedule change. Representatives from the following agencies and groups may be participants: Bonneville Power Administration, U.S. Fish and Wildlife Service, Oregon Department of Fish and Wildlife, Metro Regional Parks & Greenspaces Department, Oregon State Parks, The Nature Conservancy, The Wetlands Conservancy, and Burlington Northern Railroad. Other agencies may be involved if the management of the site involves their jurisdictions. These include the Oregon Division of State Lands, Oregon Dept. of Water Resources, Oregon Dept. of Environmental Quality, Oregon Dept. of Transportation, and the U.S. Army Corps of Engineers.

CHAPTER 2: ALTERNATIVES INCLUDING THE PROPOSED ACTION

The following alternative management scenarios were developed for Burlington Bottoms, based on input from various Federal, State, and local agencies, public and private interest groups, environmental groups, recreational plans, and on mitigation goals developed by the Northwest Power Planning Council. Alternatives were designed to provide varying levels of management in regard to habitat maintenance and enhancement, wildlife and fisheries management, recreation, hydrology, cultural resources, and public access to the area. Alternatives were developed that would meet the purposes and need for action as identified in Chapter 1.

2.1 ALTERNATIVE 1: PROPOSED ACTION
(Maintenance and Enhancement/Limited Public Access)

Proposed management activities under Alternative 1 would maintain a diversity of plant and animal communities that interact with each other and their environment, representative of a riverine floodplain system. The emphasis would be to manage for plant and animal communities native to the area that, and in order to thrive, require minimal interference from humans.

A low level of public access would be allowed under this alternative, with designated areas for trails and viewing blinds to provide for passive wildlife oriented recreation. Opportunities for research and environmental education would also be available under this alternative.

2.1.1 Fish and Wildlife Habitat Management

Maintenance and enhancement of native plant communities (including reestablishment), removal of non-native plant species where appropriate, and use of artificial structures could improve habitat conditions for many species of wildlife at Burlington Bottoms over time.

Prior to implementation of any management activities, a comprehensive survey would be conducted to determine the distribution of native and non-native plant communities. Long-term monitoring would occur to evaluate the success of management activities, and to ensure that, at a minimum, baseline habitat units determined by the habitat evaluation for Burlington Bottoms were being maintained.

2.1.1.1 Native Vegetation

Many areas of Burlington Bottoms contain small remnant populations of native plant species such as Creeping spikerush (Electrics palustris), and Wapato (Sagittaria latifolia). These appear to be diminishing due to the encroachment of non-native plant species (e.g. Reed canary grass (Phalaris arundinacea) and Himalaya blackberry (Rubus discolor)). In most cases, natural plant succession would be allowed to proceed, except in areas where control of non-natives would be necessary and in pasture areas where the establishment of wet prairies would be desired. Control methods would follow State and Federal regulations. Below are listed proposed general guidelines for maintaining and enhancing native plant populations at Burlington Bottoms.

1. Use of native seed and plant sources, preferably of local genotypes, for establishing native plant communities.

2. Maintenance of a variety of native plant community types, representing as best as possible historically occurring conditions.

3. Management of a diversity of plant communities could mean alteration of natural succession because of past human impacts; e.g. wetland prairie or open areas should be maintained and not be allowed to succeed to forest.

4. Planting of native vegetation would occur along areas used by humans (e.g. trails and viewing blinds) to create a buffer between sensitive wildlife habitat and human activities.

2.1.1.2 Non-native Vegetation

Control of non-native plant species at Burlington Bottoms is needed to protect native plant populations and maintain and enhance wildlife habitat. Without control of non-natives, native plant diversity could continue to decrease in many areas, and non-native populations such as Himalaya blackberry and Reed canary grass could increase.

Possible methods for controlling non-native species include manipulating water levels, scraping, disking, mowing, burning, biological control agents, herbicides, and managed grazing of cattle. Only biological and/or herbicide control methods that are approved under State and Federal guidelines would be considered for use at Burlington Bottoms.

The installation of a water control structure could be one method used to control Reed canary grass. Targeted areas could be flooded during the entire growing season, thus preventing the plant from carrying on normal plant functions, and eventually causing the plants to die.

1. Pasture habitat - All pasture habitat surveyed was predominately a combination of Reed canary grass, Canada thistle (Cirsium arvense), Tansy ragwort (Senecio jacobea), Scot's broom (Cytisus scoparius), and Himalaya blackberry. Until November 1991, pasture areas had been grazed by cattle. This exerted some control over the spread of non-native plant populations (such as Himalaya blackberry), but also caused an increase in other non-native species such as Bull thistle (Cirsium vulgare) and Canada thistle. Surveys of 1853 and 1854 indicate that historically the pasture areas at Burlington Bottoms were once wet prairie habitat.

2. Wetlands - Past human activities at Burlington Bottoms have altered some of the quality and quantity of wetlands at Burlington Bottoms. Under this alternative, existing wetlands would be maintained and where possible, enhanced to improve wildlife habitat.

Enhancement activities could include control or removal of non-native plant species such as Reed canary grass, which is present in all of the lakes and ponds. In several lakes, it covers more than 50 percent of the surface area, and appears to be spreading rapidly. Native species in these areas, such as Wapato and Burreed (Sparganium emersum), are unable to compete with the non-native populations.

Where populations of non-native vegetation are small, hand-pulling may be used. In other areas, treatment methods could include manipulation of water levels to either drown or dry up the non-native vegetation.

All activities in the wetlands, whether for maintenance or enhancement, would follow State and Federal regulations, including the following:

- Clean Water Act, Section 404, (Federal)
- Protection of Wetlands, Executive Order 11990, (Federal)
- Floodplain Management, Executive Order 11988, (Federal)
- General Authorization for Wetland Restoration and Enhancement, 141-89-020(1), (State)
- Oregon Dept. of Water Resources, permit issued for water regulation in regards to wetland restoration (State)

3. Disturbed areas - Large portions of the disturbed areas contain predominantly non-native vegetation, such as Himalaya blackberry, Scot's broom, and Reed canary grass. Some of the native plant populations in the disturbed areas are Red elderberry (Sambucus racemosa), Nootka rose (Rosa nutkana), and Scouler willow (Salix scouleriana). In many areas, especially under the powerline and along the road crossing Burlington Bottoms, non-native plants such as the Himalaya blackberry are out-competing native species. Treatment methods could include biological control agents, tilling, grazing, and herbicides.

It is recommended that reducing and controlling the amount of Reed canary grass at Burlington Bottoms be a high priority. If there are areas where vegetative barriers are desired (e.g. between a trail and sensitive wildlife habitat), use of native plant species, such as Nootka rose, Creek dogwood, and elderberry, should be emphasized. Non-native species such as Himalaya blackberry provide effective barriers, but also serve as a seed source and, therefore, are not desirable.

2.1.1.3 Artificial Structures for Wildlife

Enhancement activities could include the use of artificial structures for the improvement of wildlife habitat. Structures such as wood duck boxes, logs to provide basking areas for turtles, purple martin boxes, and bat boxes would be placed in some areas for selected wildlife species.

2.1.2 Fish and Wildlife Management

Under Alternative 1, fish and wildlife populations would be managed for a diversity of native species that occur within the area. Fish and wildlife management would focus primarily on the protection, maintenance, and enhancement of wildlife habitats. A comprehensive inventory of fish and wildlife species would be conducted prior to any management activities, this information would be used to help determine what action(s) would be taken. Long-term monitoring would occur to evaluate the success of management activities.

2.1.2.1 Native Fish Management

Under Alternative 1, angling for native fish within Burlington Bottoms would not be permitted.

As the status of anadromous fish in the Columbia River changes (particularly species listed as threatened or endangered under the Endangered Species Act (ESA) of 1973), the proposed action may have to change as well. Surveys of fish species present at Burlington Bottoms indicate juvenile salmonids (currently non-listed) are present within the inner stream/canal system and likely within the lakes and ponds as well. As a result, human caused entrapment of migratory fish would be prevented.

Natural entrapment, however, should be considered to be part of naturally occurring conditions. Therefore, unless directed by Federal or State laws regarding protection and recovery of listed species, natural entrapment at this time does not need to be prevented.

If continued loss of regional foraging habitat for anadromous fish results in Burlington Bottoms becoming a more important location for juvenile salmonid foraging, then water levels and fluctuations may have to be artificially managed. The beaver dams present in 1993 are a major factor influencing current hydrological conditions. Failure of a dam may cause loss of foraging habitat for anadromous fish.

Consumption of fish by native wildlife is considered part of a functioning ecosystem. Control of native, predatory wildlife, in order to manage native fish species would not occur unless directed to do so by Federal and State recovery plans.

Further evaluation of water quality, temperature, and hydrologic conditions for fish habitat and populations is recommended in order to adequately plan for fish needs within Burlington Bottoms. Effects of non-native fish (see next section) on native fish and aquatic habitat should be evaluated to better manage native fish populations. Surveys and long-term monitoring of invertebrate aquatic species is also recommended.

2.1.2.2 Non-native Fish Management

Under Alternative 1, populations of predatory non-native fish, would be controlled if biologically and economically feasible. Since the Burlington Bottoms system is open to the Multnomah Channel, a source for continual re-invasion by non-native fish, control of non-native fish populations rather than eradication appears to be a more feasible management approach.

Angling for non-native fish would be considered a management tool for population control. Angling would not be permitted in areas determined to be sensitive wildlife areas, such as near heron nesting colonies. Angling would be permitted only in areas designated by biologists and would be used for control of non-native fish only.

There is evidence of a large population of carp in the lakes and ponds on Burlington Bottoms. The carp population in Horseshoe Lake may be adversely affecting water quality by increasing turbidity, alkalinity and aquatic plant communities. It is recommended that the level of impact on water quality by carp be determined and a plan developed to control their numbers, which should include a long-term monitoring program.

2.1.2.3 Native Wildlife Management

Under Alternative 1, wildlife at Burlington Bottoms would be managed for a diversity of species associated with the native plant communities. If any emphasis were placed on certain wildlife species, it would be for species listed under ESA and only under the guidelines of a recovery plan. Appendix A identifies native listed species that may occur at Burlington Bottoms. A complete inventory of wildlife species would be conducted prior to any management activities, to help determine what action(s) should be taken. Long-term monitoring would occur to evaluate the success of management activities.

The potential exists for several species, such as black-tailed deer, raccoons, and coyotes to become so numerous that they cause habitat alteration or adverse effects on other wildlife species. Causes for this potential increase include habitat alteration by man adjacent to Burlington Bottoms, the lack of higher predators such as bears and cougars, and the result of altered hydrologic conditions.

Recreational hunting of wildlife would not be permitted at Burlington Bottoms. Hunting regulations are prepared and enforced by the Oregon Department of Fish and Wildlife and any changes must be approved by the Oregon Fish and Wildlife Commission. Non-recreational hunting could be allowed to control populations of certain species to maintain a population balance or to prevent habitat degradation by overabundant wildlife. Hunting would then be permitted only in a manner compatible with other management plan objectives and carried out so as to not cause adverse impacts on other species.

Recreational trapping for wildlife at Burlington Bottoms would not be permitted. Non-recreational snare trapping or species specific trapping that would not affect non-target species could be permitted for population control of some wildlife species, especially non-natives, if native wildlife species populations or habitat are threatened. Trapping of predators would not be permitted unless needed to protect native wildlife populations or listed species. Predation is to be considered the preferred means of population control.

Wildlife at Burlington Bottoms could be captured, marked and released onsite as part of an approved and permitted (by ODFW and/or Federal agencies depending on the species) scientific research project. Projects would be permitted only upon demonstration of a need to manage the species or habitats. Recreational or educational capture and banding of wildlife would be discouraged. Scientific collection of wildlife species from Burlington Bottoms would not be permitted unless it could be demonstrated to improve management of the species.

Injured or sick wildlife would not be captured, treated or killed unless they pose a threat to humans, other wildlife populations, or listed species. Sick or injured wildlife would not be rehabilitated. These wildlife form an important part of the ecosystem as food for other wildlife and as a source of nutrients for the system.

Injured, sick, or rehabilitated wildlife would not be released into Burlington Bottoms. Any such introductions should be considered an unnecessary outside influence on the dynamics of fish and wildlife populations in Burlington Bottoms. Illegally introduced, rehabilitated (or incompletely rehabilitated by a good Samaritan) wildlife should be trapped and relocated or humanely killed.

Natural disasters or catastrophic events such as floods and fire should not be prevented or suppressed if they were part of the historic environment. Naturally occurring fires should not be suppressed unless certain structures or areas are determined to be critical or invaluable. Fire suppression would be permitted to prevent spread of fire to adjacent lands.

2.1.2.4 Non-native Wildlife Management

Under Alternative 1, non-native wildlife should be controlled or eliminated from the area if possible. No non-native wildlife should be released on Burlington Bottoms. Non-native wildlife should be removed in a manner that will not harm native wildlife populations and is legal and humane. Methods to remove non-native species could include trapping and netting.

Due to their competition with native wildlife and adverse effects on plant communities, some non-native species of concern are the Virginia opossum, nutria, European Starling, bullfrog, rock doves, house sparrow and Norway rats. A complete inventory of non-native populations would be conducted prior to any management activities. Long-term monitoring would occur to evaluate the success of management activities for non-native wildlife populations.

2.1.3 Hydrologic Resources Management

Proposed management of the hydrological resources on Burlington Bottoms under Alternative 1 includes the following:

1. Beaver dams - Both of the beaver dams would be monitored periodically. The beaver dam located on the outlet channel, northeast of Horseshoe Lake, is the principal flow control for the lower lake system. Failure of the dam, whether human caused or natural, could cause the lower lake system to drain in a few days. The second dam, located just north of the timber bridge, is the principal water surface control for the southern lake system (referred to in the Hydrology Report as Deep Lake and Upper Lake). This dam may raise the permanent pool elevation of these lakes by an estimated 0.62 meters (2 feet) or more.

Should the failure of the dam(s) occur, one management option is the placement of a water control structure in the outlet channel and/or near the timber bridge to control water flow and level.

2. Regulation of water levels - Regulation of water levels at Burlington Bottoms could be used to control non-native plant and fish species, such as Reed canary grass and carp. It could also be used to enhance fish and wildlife habitat, including wetlands.

Reed canary grass is present on the edges of the wetlands and is encroaching into the ponds and lakes in some areas.

As time progresses, this grass forms large mats; which as it decays, results in a high loading of organic matter and accelerated anaerobic conditions. Over the long-term, this may cause the lake system at Burlington Bottoms to transition to a wet marsh and eventually to a bog.

Historically, some of the ponds and lakes have dried up in the summer. If control of water levels is used as a management tool, it may be desirable to allow some ponds to dry up periodically. This could be beneficial to waterfowl, shorebirds (e.g. spotted sandpiper), and other species that use the exposed mud banks for foraging.

Should the failure of the beaver dam(s) occur, one management tool is the placement of a water control structure in the outlet channel and/or near the timber bridge (depending on whether one or both dams failed), to control water flow and level. A water control structure could also be installed in the backwater slough on the northeast portion of Upper Lake. Prior to construction of the rail line along the east side of Burlington Bottoms, this slough may have connected to Multnomah Channel and served as the outlet for all of the upper lakes area.

There would be long-term monitoring of water quality (including turbidity, total suspended solids, pH levels, and heavy metals) at Burlington Bottoms. Monitoring would provide a basis for identifying trends in water quality and quantity at Burlington Bottoms, and would also provide important information for guiding future wildlife habitat maintenance and enhancement activities.

There would be monitoring of off-site activities, such as logging and mining in the adjacent watershed. Though sediment transported to Burlington Bottoms from the contributing off-site watershed does not appear to be a problem at the present time, it may be in the future. Vegetative buffer strips exist between the watershed and the lower lakes, and should be maintained and/or enhanced for sediment control to help prevent potential problems.

3. River banks - An estimated 30 to 50 percent of the bank adjacent to the Multnomah Channel shows some degree of erosion. Riprap in the form of old timber piles and crib walls is present due to past human activities along the Multnomah Channel. In some areas this riprap is helping to protect the bank from erosion.

Long-term monitoring of the river bank would indicate whether action(s) should be taken to prevent further erosion and bank slouging.

2.1.4 Public Access/Recreation Management

Under Alternative 1, a recreation plan (Appendix C) would be implemented that would allow for passive wildlife oriented recreation, while providing protection for and minimizing disturbance to wildlife, with special emphasis on protection of sensitive wildlife areas. Sensitive wildlife areas (such as the heron colony) were identified and mapped on the Site Analysis Plan (Appendix C), prior to the development of alternatives.

This recreation plan can be altered for future needs (e.g. close a trail), in order to protect wildlife and wildlife habitat. Planned facilities, trails, etc., would meet full American Disabilities Act accessibility requirements.

The proposed recreation plan for Burlington Bottoms includes the following:

1) Trails would be located in the northeast, east, and central portions of Burlington Bottoms on what was the old road system for the site. Trails would be located away from sensitive wildlife areas, such as the heron colony and waterfowl breeding areas.

2) The trails could have designated wildlife viewing areas; these areas would be designed as blinds, using the surrounding vegetation and/or adding native vegetation, to minimize disturbance to wildlife while still providing public viewing opportunities.

3) Interpretive signs would be located adjacent to the viewing areas to provide visitors information on wildlife and plant species, habitat, cultural resources, etc.

4) An off-site visitor/interpretive center would be designed to introduce visitors to Burlington Bottoms and its resources. Parking and restroom facilities could be available. An off-site center would be preferred in order to minimize conflicts with habitat restoration/enhancement efforts at Burlington Bottoms and because of problems accessing the area on foot or by vehicle. However, no site has yet been identified.

At the present time the only way to access the area is across Burlington Northern railroad tracks. Due to potential liability and the high costs of installing a crossing gate, access at this point has not been resolved.

Because of its diverse array of wildlife and habitats, Burlington Bottoms offers many opportunities to the public for environmental education and research opportunities. Under Alternative 1, opportunities that would be available include research, education, and wildlife related tours.

All research and educational opportunities would be evaluated for their appropriateness in relation to the purposes of the proposed action.

Several dump sites exist (left over from a logging operation on the east side) at Burlington Bottoms. The sites have abandoned cars, cables, tires, and other trash that is a potential safety hazard, and also visually unattractive. These sites would be cleaned up as soon as practical.

Future garbage removal and methods to control trash dumping would be addressed in the Final Management Plan. Security would also need to be addressed, including whether to have someone on-site at all times. Seasonal restrictions and visitor days would also be addressed upon resolution of ownership. Seasonal public access restrictions may be used to protect wildlife and wildlife habitat and this would coincide with regulation of visitor days.

2.1.5 Cultural Resources Management

An overview survey for cultural/archaeological resources would be conducted at Burlington Bottoms under Alternative 1. Any sites found would be protected and managed according to State Historic Preservation Office (SHPO) regulations. Visitor access would be directed away from cultural sites in order to prevent compaction, collection, or erosion.

2.1.6 Operation and Maintenance

Under Alternative 1, Burlington Bottoms would be maintained at a level to prevent the loss of native wildlife populations and native wildlife habitat. Maintenance activities could include cutting back blackberries along the road and trail to keep them open for maintaining the property, removing the garbage, and the periodic monitoring of the area by authorized personnel.

2.2 ALTERNATIVE 2
(Maintenance and Enhancement/Closed to the Public)

All management activities proposed under Alternative 2 would be the same as those as proposed under Alternative 1, with the exception of public access/recreation management.

Under this alternative, the area would be closed to the public. Access to the site would be for authorized personnel only for custodial purposes such as the repair of gates. An on-site custodian may be necessary.

2.3 ALTERNATIVE 3 (No-Action)

Under the No-Action Alternative, BPA would not implement and fund habitat enhancement projects at Burlington Bottoms.

However, as long as BPA owned the property, baseline habitat conditions established by the HEP would be maintained. If the No-Action Alternative is selected, the following environmental effects would be anticipated:

2.3.1 Fish and Wildlife Habitat Management (Status Quo Maintained)

Under the No-Action Alternative, habitat succession would occur without human interference. Manipulation of native and non-native plants or plant communities (e.g. control of noxious weeds) would occur only to maintain the baseline habitat units determined by the Habitat Evaluation Procedure (HEP) in 1993. Long-term monitoring and evaluation of the habitat would occur.

2.3.2 Fish and Wildlife Management

No active management of fish and wildlife would take place.

2.3.3 Hydrologic Resources Management

There would be no management of the hydrology at Burlington Bottoms under the No-Action Alternative. Monitoring of hydrological conditions, such as water quality, would not occur.

2.3.4 Public Access/Recreation Management

Under Alternative 3, Burlington Bottoms would be closed to the public, and there would be no recreational or educational use of the area. The only human access would be for maintenance of the infrastructure, such as repairing gates, removal of noxious weeds, etc.

2.3.5 Cultural Resources Management

Under the No-Action Alternative, cultural resources identified, if any, would not be affected because no ground disturbing activities would occur.

2.3.6 Operation and Maintenance

Under the No Action Alternative, Burlington Bottoms would be maintained at a level to prevent the loss of native wildlife populations and native wildlife habitat. Maintenance activities could include cutting back blackberries along the road running through the site in order to keep this open for maintenance of the infrastructure, and the periodic monitoring of the area by authorized personnel.

CHAPTER 3: THE AFFECTED ENVIRONMENT

3.1 BACKGROUND

- Geography

Located approximately 1/2 mile north of the Sauvie Island Bridge (T2N R1W Sections 20,21), Burlington Bottoms is bordered on the east side by Multnomah Channel and on the west side by the Burlington Northern Railroad right-of-way and U.S. Highway 30 (see Figure 1). The area was first described in surveys conducted by the General Land Office in November 1853, and again in August 1854 (see Appendix D, Historical Survey Notes of 1853 and 1854). In these surveys, Burlington Bottoms was characterized as being "level and wet, sparsely timbered with ash, willow, balmgilead (cottonwood), oak, etc.," and containing areas of "open prairie." The 1853 description also describes the area as being "alternately wet prairie and low narrow ridges of timber and brush very much cut up with sloughs, lakes, ponds, marshes etc."

Burlington Bottoms today appears as a mosaic of wetland and riparian communities. A series of lakes, ponds and channels covers a large portion of the site, interspersed with groves of Oregon ash and cottonwood and open areas (historically wet prairie) previously grazed by cattle. Human activities have altered some of the natural features of the area; these include the operation of a logdump and maintenance facility up until the early 1960s, grazing of cattle until 1991, and the construction of a fill embankment along the eastern side of the site and across the wetlands in the south.

- Topography and Soils

Historically, Burlington Bottoms was described as being "level" and "land low." The area is currently relatively level and low, except for the elevated railroad right-of-way and the road that runs through the middle of the site and along the east side adjacent to the Multnomah Channel.

Reference was made in the 1853 survey to a 6.1 m (20 feet) high bank on the shore of Multnomah Channel, indicating that some of the banks were tall, and had built up as natural levees during floods. Most of the bank along Multnomah Channel today is approximately 7.6 m (25 feet) in height, due to the construction of a fill embankment along the east side adjacent to Multnomah Channel. Elevation ranges from approximately 3.0 to 10.8 m (10.0 to 35.5 feet).

The soils in Burlington Bottoms are predominantly Rafton and Sauvie silt loams. Both types of soils are considered poorly drained. These soils are typical of areas that have been repeatedly flooded.

3.2 AFFECTED ENVIRONMENT

3.2.1 Fish and Wildlife Habitat Resources

Burlington Bottoms is a mosaic of wetland, riparian, and pasture (formerly wet prairie) communities, and is a remnant of a more prevalent system that once existed along the Willamette and Columbia Rivers. The HEP characterized the area as having six major habitat types: riparian tree, riparian shrub, forested wetland, seasonally flooded pasture, emergent wetland, and open water.

Oregon ash (Fraxinus latifolia) and Black cottonwood (Populus trichocarpa) dominate the riparian tree habitat, and appear to be filling in open pasture habitat or what were historically "wet prairie" areas. This is evident when a comparison is made between photos taken in 1993 to those of the late 1930s and 1940s (see Appendix E).

Two areas in the central and northern portions of the site contain large ash trees, perhaps remnants of the "groves of ash trees" described in the 1854 survey. Two of the trees measured in 1993 had a diameter-breast-height (d.b.h.) of 125.7 cm (49.5 inches).

Native herbaceous plant species found at Burlington Bottoms include populations of Wapato (Sagittaria latifolia) in the ponds and marshes. The wetlands in the southern portion of the site have been referred to historically as "Wapato Marsh."

Approximately 5.7 ha (14 acres) of habitat at Burlington Bottoms have been characterized as "disturbed," due to human-related activities. These areas are found under the powerline, along the embankment next to Multnomah Channel, along the road running through the middle of the site, and along the Burlington Northern Railroad right-of-way.

Vegetation in the "disturbed" areas consists of predominantly non-native species such as Himalaya blackberry (Rubus discolor), Scot's broom (Cytisus scoparius), Reed canary grass (Phalaris arundinacea), Tansy ragwort (Senecio jacobea), Canada thistle (Cirsium arvense), and Bull thistle (Cirsium vulgare). Native plants found in these areas include Oregon white oak (Quercus garryana), Scouler willow (Salix scouleriana), Douglas spiraea (Spiraea douglasii), and Giant horsetail (Equisetum telmateia).

Non-native species have also invaded the wet pasture areas and portions of the wetlands. Until 1991, grazing of cattle and swine occurred in the pasture areas. Reed canary grass, Canada thistle, and Bull thistle are the predominant plants in the seasonally wet pasture habitat. Portions of the wetlands, particularly the edges of the ponds and lakes, contain large populations of Reed canary grass.

3.2.2 Fish and Wildlife Resources

Wildlife diversity at Burlington Bottoms is high and includes many species of fish, waterfowl, songbirds, raptors, mammals, reptiles, and amphibians. The extensive wetland system provides year-round habitat for such species as wood duck, beaver, great blue heron, and western painted turtle. Species listed by the U.S. Fish and Wildlife Service as threatened or endangered that may occur at Burlington Bottoms include the peregrine falcon and bald eagle; sightings of the red-legged frog, listed as a sensitive species by the State of Oregon have been documented (Appendix A).

Surveys for fish were conducted in May 1993 in several of the channels and lakes at Burlington Bottoms and included the following species: brown bullhead, redside shiner, white crappie, chinook salmon, peamouth, mosquitofish, and common carp. Native fish species, such as the chinook salmon, appear to be using the channels at Burlington Bottoms for feeding and cover areas.

Non-native species at Burlington Bottoms include the bullfrog, nutria, and carp. Bullfrogs are found throughout the site and are believed to be a major factor in the decline of native amphibian populations in the Northwest. Carp are present in most of the ponds, lakes and channels in the project site.

3.2.3 Hydrologic Resources

The hydrology of Burlington Bottoms is both complex and dynamic, and is influenced by both natural and human-related factors. A series of interconnected lakes, marshes and backwater channels makes up the wetlands system. A beaver dam on the outlet channel, which connects the large central lake to Multnomah Channel, is the most significant control feature of the lake system.

Prior to completion of flood-control dams in the 1960s, the annual spring freshet of the Columbia and Willamette Rivers inundated portions of Burlington Bottoms. Historical photos from the Vanport flood of 1948 show the entire Burlington Bottoms area being under water (see Appendix E for historical photos of the site). The survey of 1853 noted that a large portion of the site was "subject to annual inundation varying from one to fifteen feet deep."

Runoff from the surrounding hillsides and from U.S. Highway 30, on the western edge of the site, also contributes flows to Burlington Bottoms through a series of culverts. The survey of 1853 referred to three major streams that fed the site with runoff from the Tualatin Mountains. Human-related activities such as the construction of the railroad and U.S. Hwy. 30, logging and quarry mining have decreased the amount of flow and diverted the direction of flow into the Bottoms in some instances.

Other human activities that have influenced the hydrology of the site include the operation of a logdump along the eastern side adjacent to Multnomah Channel, from approximately the late 1930s to the early 1960s. To access the logdump and adjacent maintenance facility by railroad, a fill embankment was constructed along Multnomah Channel and across the southern portion of the site, from what may have been locally excavated material or dredge fill. An access road to the logdump was constructed across the middle of the site (dividing the lower lake system) from U.S. Hwy. 30 east to the Multnomah Channel.

3.2.4 Air Quality

The existing air quality in the Burlington Bottoms area is considered good to excellent, and air quality measurements fall within National Ambient Air Quality standards. The Department of Environmental Quality is responsible for air quality management in the State of Oregon
OAR 340-23-035 (3)).

3.2.5 Cultural Resources

Occupation by Native American cultures along the Columbia River dates back as far as 11,000 years ago (Aikens 1986). Some of the excavated sites in the lower Columbia (on Sauvie Island) have been dated to 500 B.C. (Minor et al. 1980). In their journey along the Columbia River, Lewis and Clark noted that they were seldom out of site of Chinook villages.

Because of Burlington Bottom's location and close proximity to Sauvie Island, there is a high potential for the occurrence of cultural resources at Burlington Bottoms. Sauvie Island was intensively occupied by indigenous people, with one of the highest population densities in the Pacific Northwest. Wapato, a native plant used by Native Americans for food, can be found in many of the lakes and ponds on the site. According to the Oregon State Historic Preservation Office (SHPO), no record of archaeological or historical surveys exist for Burlington Bottoms (Gilsen 1993).

CHAPTER 4: ENVIRONMENTAL CONSEQUENCES

4.1 POTENTIAL ENVIRONMENTAL IMPACTS OF ALTERNATIVE 1

4.1.1 Impacts Upon Fish and Wildlife Habitat

Control or eradication of non-native invasive plant species, such as Reed canary grass and Himalaya blackberry, would benefit fish and wildlife habitat by allowing native plant species to become reestablished, and by reducing the competition for resources (air, light, and water) with non-native plant species. Resulting benefits could include an increase in the quality and quantity of fish and wildlife habitat, and an increase in the biological diversity of native species.

Reestablishing or enhancing native plant communities would improve the quality of the habitat for many wildlife species. In the pasture habitat it would provide higher quality foraging for such species as the red-tailed hawk, and could improve the quality and quantity of available nesting habitat for the western painted turtle. Protection and enhancement of native plant species would also improve the food source for many species of waterfowl and other wildlife.

The placement of bat boxes and nest boxes for waterfowl and songbirds, would increase the available habitat for native wildlife species and could improve the chances for successful reproduction. Turtle basking habitat would be improved with the addition of logs and other refugia where such structures are missing.

Fish and wildlife habitat may be adversely affected by recreational activities if visitors to the area do not stay on designated trails and away from sensitive wildlife habitat. To avoid adverse impacts, management of recreation and public access may include the use of interpretive signs to educate visitors on the need to stay in designated areas, using vegetation as a natural barrier to prevent off-trail use, and/or having seasonal restrictions on visitor access.

4.1.2 Impacts Upon Fish and Wildlife Resources

Control of non-native fish and wildlife populations (carp and bullfrog) through trapping and netting would be beneficial by reducing competition with native species for resources. Native species such as the western painted turtle could benefit by control or eradication of non-native species such as the bullfrog.

Control of non-native plant populations such as Reed canary grass, and the enhancement of existing native communities, could benefit native fish and wildlife by improving existing habitat conditions. These benefits would include the enhancement of wetland plant communities, which provide cover and food for a variety of waterfowl, wading birds, shorebirds, fish, and other species.

Timing and location of management activities (burning of Reed canary grass, mechanical removal of blackberries, and trapping of bullfrogs) would occur in such a manner as to minimize disturbance to native fish and wildlife, especially during such critical periods as the breeding season for waterfowl. Buffers would be placed around sensitive wildlife areas (heron colony), in order to minimize disturbance.

To minimize potential adverse effects on native fish and wildlife resources, public access and recreation would only be allowed in locations away from sensitive wildlife and habitat areas (e.g. heron colony). The use of viewing blinds would afford visitors the opportunity to observe wildlife while at the same time minimizing disturbance to wildlife. Seasonal restrictions for recreation and public access would be implemented if it was determined that these restrictions would be necessary for native fish and wildlife protection.

4.1.3 Impacts Upon Hydrologic Resources

Under Alternative 1, the regulation of water levels to control non-native plant, fish, and wildlife populations should improve water quality and quantity over the long term. Non-native species such as carp and Reed canary grass can negatively affect water quality and quantity; removal of carp should decrease turbidity, removal of Reed canary grass should prevent wetlands from transitioning to a marsh and should reduce competition for resources with native plants.

By restricting public access to the road and trail which presently exist, negative impacts to water quality and quantity should be minimal. The use of interpretive signs and an on-site custodian could help to minimize any negative impacts.

4.1.4 Impacts Upon Air Quality

Control of non-native invasive plant species at Burlington Bottoms may include the burning of vegetation (Reed canary grass) in certain areas (pasture habitat) and at certain times of the year. This may cause, for the short term, an increase in carbon monoxide and smoke particulates. Burning would be coordinated with the Oregon DEQ to ensure that impacts to air quality would be minimal.

4.1.5 Impacts Upon Cultural Resources

Adverse impacts to cultural resources could occur due to public access to Burlington Bottoms, possibly resulting in compaction, collection, or erosion of sites (deliberate or unintended). Adverse impacts could be prevented or reduced by 1) keeping public access away from identified cultural resource sites; 2) educating visitors about the significance and need for protection of any known sites; and/or 3) having a guide or custodian on site during visitor hours.

4.1.6 Impacts Upon Wetlands and Floodplains

In accordance with the Department of Energy regulations on Compliance with Floodplain/Wetlands Environmental Review Requirements (10 CFR 1022.12), BPA has prepared the following assessment of the impacts of the Burlington Bottoms Wildlife Management Plan on floodplains and wetlands. A notice of floodplain/wetlands involvement for this project was published in the FEDERAL REGISTER on July 29, 1994.

Impacts to wetlands and floodplains could occur as a result of maintenance and enhancement activities to control non-native vegetation and non-native fish (Reed canary grass and carp). Control of Reed canary grass in the wetlands would be beneficial to native plant species by reducing competition with non-native populations for resources. Other beneficial impacts could include an increase in both plant diversity and structure in the wetlands and floodplains.

4.2 POTENTIAL ENVIRONMENTAL IMPACTS OF ALTERNATIVE 2

4.2.1 Impacts Upon Fish and Wildlife Habitat

Impacts to fish and wildlife habitat under Alternative 2 would be the same as those listed under Alternative 1 (see Alternative 1, 4.1.1), with the following changes:

Since the area would have no public access under this alternative, impacts to fish and wildlife from human disturbance would be minimal. Adverse impacts may occur due to unauthorized human presence, but this could be minimized by having authorized personnel monitor the area, or by having an on-site custodian.

4.2.2 Impacts Upon Fish and Wildlife Resources

Impacts to fish and wildlife resources under Alternative 2 would be the same as those listed under Alternative 1 (see 4.1.2 under Alternative 1) with the following changes:

Because the area would be closed the public, adverse impacts to fish and wildlife should be minimal. Adverse impacts may occur due to unauthorized human presence, but this could be minimized by having authorized personnel monitor the area, or by having an on-site custodian.

4.2.3 Impacts Upon Hydrologic Resources

Impacts to water quality and quantity would be the same as under Alternative 1, see 4.1.3.

4.2.4 Impacts Upon Air Quality

Under Alternative 2, impacts to air quality would be the same as under Alternative 1, see 4.1.4.

4.2.5 Impacts Upon Cultural Resources

Cultural resource surveys conducted under Alternative 2 would allow for the protection of any potential sites, and would add to the knowledge of local Native American cultures. Adverse impacts to cultural resources would be reduced since there would be no public access to the area. A potential for disturbance due to illegal human access could occur. This could be minimized by having periodic monitoring of the area by authorized personnel, or by having an on-site custodian.

4.2.6 Impacts Upon Wetlands and Floodplains

Impacts to wetlands and floodplains would be the same as under Alternative 1, see 4.1.6.

4.3 POTENTIAL ENVIRONMENTAL IMPACTS OF ALTERNATIVE 3

4.3.1 Impacts Upon Fish and Wildlife Habitat

Under the No-Action Alternative, the existing fish and wildlife habitat would be maintained. Since no enhancement activities would occur, opportunities for improving fish and wildlife habitat would be lost.

Adverse impacts on plant communities that could occur due to the lack of enhancement activities include the altered course of plant succession due to an increasing dominance by non-native invasive plant species, such as Reed canary grass. Prior disturbances to Burlington Bottoms by humans that resulted in the disruption of soils and topography created optimal conditions for invasion by non-native plants. Lack of management would not improve this situation.

4.3.2 Impacts Upon Fish and Wildlife Resources

Because of the lack of enhancement activities, potential adverse impacts of the No-Action Alternative on fish and wildlife could include the potential loss of various native wildlife species due to competition with non-native species. For example, European Starlings competing with native cavity nesting songbirds for limited cavities; Bullfrogs and predatory non-native fish such as Largemouth bass consuming native amphibians. Other adverse impacts include the potential for unlimited or uncontrolled population growth of a native species such as raccoon, with potential deleterious effects on other wildlife species such as ground nesting western pond turtles.

Without public access, adverse impacts to fish and wildlife from human disturbance would be minimal. Adverse impacts that could occur due to illegal human presence, include harassment or disturbance to wildlife, such as nesting birds, with a resulting decline in reproduction. These adverse impacts could be reduced by periodic monitoring of the area by authorized personnel, or by having an on-site custodian.

4.3.3 Impacts Upon Hydrologic Resources

Maintenance of the present baseline habitat conditions would occur under Alternative 3. Since no enhancement activities would occur, opportunities to improve water quality (such as regulation of water levels to reduce Reed canary grass) would be lost.

No adverse impacts from human presence would be expected, since the area would be closed to public access.

4.3.4 Impacts Upon Air Quality

Since no enhancement activities would occur under this alternative, there should be no impacts upon air quality.

4.3.5 Impacts Upon Cultural Resources

Beneficial impacts to cultural resources under Alternative 3 include the protection of any sites that may be found upon completion of surveys. Information from cultural resource surveys would add to the existing knowledge of local Native American cultures.

Adverse impacts could include the potential for disturbance (collection, compaction, etc.) due to illegal human presence. Methods to reduce potential disturbance may include periodic monitoring by authorized personnel, or by having an on-site custodian.

4.3.6 Impacts Upon Wetlands and Floodplains

Baseline habitat conditions established by the HEP in 1993 would be maintained in the wetlands and floodplains under Alternative 3. Beneficial impacts from maintenance of the wetlands include the protection of existing wetland habitat for wildlife.

Since no enhancement activities would occur under this Alternative, opportunities would be lost to improve habitat conditions in the wetlands and floodplains. This would include lost opportunities to reestablish native plant species and remove non-native invasive species.

CHAPTER 5: MONITORING AND EVALUATION

5.1 OBJECTIVES

Long-term monitoring and evaluation of management activities would occur 1) to determine if the objectives of the Proposed Action are met, and 2) to evaluate the success of the Management Plan. Included in the monitoring and evaluation program would be:

1) Monitoring and evaluation of habitat through the use of a quantifiable method to analyze change in Habitat Units (as determined by the HEP conducted in 1993) in response to habitat maintenance and enhancement activities.

2) Monitoring of species presence and occurrence both before, during, and after project implementation in response to habitat maintenance and enhancement activities.

3) Cost effectiveness of comparative methodologies during the development of project proposals and implementation.

5.2 ADAPTIVE MANAGEMENT

An adaptive management approach for Burlington Bottoms would give BPA the opportunity to alter management activities over time, in response to the success or failure of management actions. The information obtained from monitoring and evaluation (as stated under 5.1) would be used to develop and analyze management activities including:

1) Effectiveness of habitat maintenance and restoration activities.

2) Species occurrence and response to management actions.

CHAPTER 6: STATUTORY AND REGULATORY REQUIREMENTS

Nothing in this document is intended to be or should be perceived to be a permit to perform fish and wildlife habitat management activities in lieu of necessary State and Federal permits. Any action involving regulation of game and fish laws, or capture or control of fish and wildlife is under the jurisdiction of the Oregon Department of Fish and Wildlife. Some species of fish and wildlife are under the jurisdiction of the United States Fish and Wildlife Service and the National Marine Fisheries Service. Habitat manipulations for uplands or wetlands will likely require permits from the county and several State and Federal agencies.

CHAPTER 7: CONSULTATION AND COORDINATION

The following agencies participated in the planning and writing of the Draft Management Plan for Burlington Bottoms: BPA, The Nature Conservancy, Metro Parks and Greenspaces Dept., U.S. Fish & Wildlife Service, and Oregon Dept. of Fish and Wildlife.

The following groups, public agencies, and individual participants provided input on management issues at the June 1993 public meeting for Burlington Bottoms:

Gordon Howard - Multnomah County Planning
Chris Wrench - Friends of Forest Park
Chris Foster - local resident
Susan Foster - ODFW Commissioner
Jack Broome - The Wetlands Conservancy
Ellen Lanier-Phelps - Metro Greenspaces
Emily Roth - OR Division of State Lands
Allison Stenger and Chuck Hibbs - Inst. for Archeological Studies
Michael Jones - Cascade Geographic Society
Skip Anderson - Angell Brothers, Inc.
Dale Archibald - OR Historical Society
Ester Lev - Urban Streams Council
Donna Matrazzo - Sauvie Island Conservancy

CHAPTER 8: REFERENCES and BIBLIOGRAPHY

Aikens, M.C. 1986. **Archeology of Oregon.** 2nd edition. USDI, Bureau of Land Management, Oregon State Office, Portland, Oregon.

Cowardin, L.M. 1979. **Classification of Wetlands and Deepwater Habitats of the United States.** U.S. Fish and Wildlife Service. FWS/OBS-79/31. 103pp.

Gilsen, L. 1993. November 1 letter from Oregon State Historic Preservation Office to Carlene Fleskes, Bonneville Power Administration.

Ingles, LG. 1965. **Mammals of the Pacific States.** 3rd ed. Stanford University Press, Calif. 506pp.

Martin, A.C., Zim, H.S. and Nelson, A.L. 1951. **American Wildlife & Plants - A Guide To Wildlife Food Habits.** New York, Dover Publications, Inc. 500pp.

Northwest Power Planning Council. 1993. **Resident Fish and Wildlife Amendments to the Columbia River Basin Fish and Wildlife Program (Phase 4).**

Oregon Department of Fish and Wildlife. 1993. **Burlington Bottoms Habitat Evaluation.** Prepared for the Bonneville Power Administration. 43pp.

Oregon Department of Fish and Wildlife. 1993. **Sauvie Island Wildlife Area Management Plan.**

Oregon Natural Heritage Data Base. 1993. **Rare, Threatened, and Endangered Plants and Animals of Oregon.** The Nature Conservancy, Portland, Oregon.

Oregon Statewide Planning Program. 1973. ORS 197.225-.245. Adopted as administrative rules (OAR 660 Div. 15).

Short, H.L. and R.J. Cooper. 1985. **Habitat suitability index models: Great Blue Heron.** U.S. Fish and Wildlife Service. FWS/OBS-82/10.43. 27pp.

Sousa, P.J. and A.H. Farmer. 1983. **Habitat suitability index models: Wood Duck.** U.S. Fish and Wildlife Service. FWS/OBS-82/10.43. 27pp.

U.S. Army Corps of Engineers, Seattle District. 1984. **Wetlands Plants of the Pacific Northwest.** 85pp.

U.S. Fish and Wildlife Service. 1980. **Habitat suitability index models: Red-tailed Hawk.** Draft.

W & H Pacific. 1993. **Final Report - Burlington Bottoms Hydrology and Hydraulics Assessment.** Prepared for Oregon Dept. of Fish and Wildlife. 44pp.

CHAPTER 9: SCHEDULING OF IMPLEMENTATION

The implementation of the Management Plan for Burlington Bottoms would begin upon conclusion of the environmental review pursuant to the National environmental Policy Act of 1969 and subject to budget availability.

APPENDIX A

FISH AND WILDLIFE SPECIES AT BURLINGTON BOTTOMS

10/93

BIRDS OF BURLINGTON BOTTOMS

KNOWN OR BELIEVED TO BE PRESENT

LOONS, GREBES	Sp	Su	F	W	N
Red-throated Loon......	u		u	u	
Pacific Loon...........			r	r	
Common Loon............				r	
Pied-billed Grebe......	u	u	u	u	*
Horned Grebe...........	r			u	
Red-necked Grebe.......	r			r	
Eared Grebe............	r			r	
Western Grebe..........				u	
Clark's Grebe..........			u		

CORMORANTS	Sp	Su	F	W	N
Double-crested Cormorant.............	u	u	c	c	

SWANS, DUCKS, GEESE	Sp	Su	F	W	N
Tundra Swan............	r	r	r	r	
Trumpeter Swan.........	r			r	
Greater White-fronted Goose.................	u	r	u	u	
Snow Goose.............		r	u		
Ross' Goose............			r	r	
Emperor Goose..........				r	
Brant..................	r		r	r	
Canada Goose...........	a	c	a	a	*
Wood Duck..............	c	c	c	c	*
Green-winged Teal......	c	u	c	c	
American Black Duck....				r	
Mallard................	a	c	a	a	*
Northern Pintail.......	a	u	a	a	
Blue-winged Teal.......	u	u	c	r	
Cinnamon Teal..........	c	c	c	r	*
Northern Shoveler......	c	u	c	c	*
Gadwall................	r	r	u	u	
Eurasian Wigeon........	u		u	u	
American Wigeon........	a	r	a	a	
Canvasback.............			u	u	
Redhead................				r	
Ring-necked Duck.......	u	r	u	u	
Greater Scaup..........			r	r	
Lesser Scaup...........	r	r	r	u	

	Sp	Su	F	W	N
Black Scoter...........				r	
Surf Scoter............			r	r	
White-winged Scoter....			r	r	
Common Goldeneye.......	r		r	r	
Barrow's Goldeneye.....				r	
Bufflehead.............	r	r	c	c	
Hooded Merganser.......	u	u	u	u	*
Common Merganser.......	u	u	c	c	
Red-breasted Merganser.				r	
Ruddy Duck.............	u		u	u	*
Oldsquaw...............			r		

GULLS, TERNS, PELICANS	Sp	Su	F	W	N
Parasitic Jaeger.......			r		
Franklin's Gull........	r	r	r	r	
Bonaparte's Gull.......	u	r	u	u	
Mew Gull...............	u		c	a	
Ring-billed Gull.......	c	c	a	a	
California Gull........	u	c	c	c	
Herring Gull...........	u		u	u	
Thayer's Gull..........	u		u	u	
Western Gull...........			r	r	
Glaucous-winged Gull...	u	u	c	a	
Glaucous Gull..........	r		r	r	
Caspian Tern...........	r	u	u		
Common Tern............		r	r		
Forster's Tern.........			r		
Black Tern.............	r				
American White Pelican.		r	r		
Brown Pelican..........	r	r	r		

HERONS, BITTERNS IBIS	Sp	Su	F	W	N
Great Blue Heron.......	c	c	c	c	*
Green-backed Heron.....	u	u	r	r	*
Black-crowned Night Heron.................	r	r	r	r	
American Bittern.......	u	u	r	r	
Great Egret............	r	r	u	r	
Snowy Egret............			r		
Cattle Egret...........			r	r	
White-faced Ibis.......				r	

Sp = Mar-May
Su = Jun-Aug
F = Sept-Nov
W = Dec-Feb
N = Nests Locally*
a = Abundant
c = Common
u = Uncommon
r = Rare
ac = Accidental

BIRDS OF BURLINGTON BOTTOMS

KNOWN OR BELIEVED TO BE PRESENT

STORKS, CRANES	Sp	Su	F	W	N
Wood Stork.............				ac	
Sandhill Crane.........	c	r	c	u	

RAILS, COOT	Sp	Su	F	W	N
Virginia Rail..........	c	c	c	u	*
Sora...................	c	c	c		*
American Coot..........	u	u	c	c	*

SHOREBIRDS	Sp	Su	F	W	N
Black-bellied Plover...			u	r	
Lesser Golden Plover...			u		
Semipalmated Plover....		u	u		
Spotted Sandpiper......	u	u	u	u	*
Killdeer...............	c	c	c	c	*
American Avocet........	u	c	c	r	
Greater Yellowlegs.....	u	c	c	r	
Lesser Yellowlegs......	r	u	u	r	
Solitary Sandpiper.....	u	u	u	r	
Whimbrel...............	r	r	r		
Long-billed Curlew.....		r			
Marbled Godwit.........		r	r		
Sanderling.............		r	r	r	
Semipalmated Sandpiper.	r	r	r		
Western Sandpiper......	c	c	a	r	
Least Sandpiper........	c	c	c	u	
Bairds Sandpiper.......	r	r	u		
Pectoral Sandpiper.....		r	u		
Sharp-tailed Sandpiper..			ac		
Buff-breasted Sandpiper.............		r	r		
Short-billed Dowitcher.		r	r		
Long-billed Dowitcher..	u	c	c	r	
Common Snipe...........	u	r	u	u	
Wilson's Phalarope.....	r	r	r		
Red-necked Phalarope...		r	u		
Red Phalarope..........			r	r	

GROUSE, PHEASANT,	Sp	Su	F	W	N
Ruffed Grouse..........	u	u	u	u	*
Ring-necked Pheasant...	c	c	c	c	*
Northern Bobwhite......	u	u	u	u	*
California Quail.......	c	c	c	c	*

HAWKS, EAGLES, VULTURE	Sp	Su	F	W	N
Northern Harrier.......	c	u	c	c	*
Sharp-shinned Hawk.....	u	u	u	u	*
Cooper's Hawk..........	u	u	u	u	*
Northern Goshawk.......			r		
Red-shouldered Hawk....	r		r		
Swainson's Hawk........	r		r		
Red-tailed Hawk........	c	c	c	c	*
Ferruginous Hawk.......	r			r	
Rough-legged Hawk......	u		u	u	
Bald Eagle.............	u	r	u	c	*
Golden Eagle...........				r	
Turkey Vulture.........	c	c	c		
Osprey.................	u	u	u	r	
Black-shouldered Kite..	r		r	r	
American Kestrel.......	c	c	c	c	*
Merlin.................	r		r	r	
Peregrine Falcon.......	r		r	r	
Gyrfalcon..............				r	
Prairie Falcon.........			r		

OWLS	Sp	Su	F	W	N
Barn Owl...............	c	c	c	c	*
Northern Pygmy Owl.....	u	u	u	u	*
Western Screech Owl....	u	u	u	u	*
Great Horned Owl.......	c	c	c	c	*
Snowy Owl..............				ac	
Long-eared Owl.........	r	r	r	r	
Short-eared Owl........	r	r	u	u	
Northern Saw-whet Owl..	u	u	u	u	*

Sp = Mar-May	F = Sept-Nov	N = Nests Locally*	a = Abundant	u = Uncommon	ac = Accidental
Su = Jun-Aug	W = Dec-Feb		c = Common	r = Rare	

BIRDS OF BURLINGTON BOTTOMS

KNOWN OR BELIEVED TO BE PRESENT

KINGFISHER	Sp	Su	F	W	N
Belted Kingfisher......	c	c	c	c	*

PIGEONS, DOVES	Sp	Su	F	W	N
Band-tailed Pigeon.....	u	u	u	r	
Rock Dove..............	c	c	c	c	*
Mourning Dove..........	c	c	c	c	*

NIGHTHAWK, HUMMINGBIRD	Sp	Su	F	W	N
Common Nighthawk.......		r	r		
Anna's Hummingbird.....	r	r	r	r	
Rufous Hummingbird.....	u	c	c		*

SWIFTS	Sp	Su	F	W	N
Vaux's Swift...........		u	u		*

WOODPECKERS	Sp	Su	F	W	N
Lewis Woodpecker.......	r		r		
Acorn Woodpecker.......	r		r		
Red-breasted Sapsucker.	r	r	r	r	*
Downy Woodpecker.......	c	c	c	c	*
Hairy Woodpecker.......	u	u	u	u	*
Northern Flicker.......	c	c	c	c	*
Pileated Woodpecker....	u	u	u	u	*

FLYCATCHERS, SWALLOWS	Sp	Su	F	W	N
Olive-sided Flycatcher.	u	u			
Western Wood Pewee.....	u	c			*
Willow Flycatcher......	u	u	u		*
Hammond's Flycatcher...			r		
Dusky Flycatcher.......	r				
Pacific Slope Flycatcher............	u	u	u		*
Say's Phoebe...........	r				
Western Kingbird.......	r	r	r		*
Purple Martin..........	u	u	u		*
Tree Swallow...........	a	a	c	u	*
Violet-green Swallow...	a	a	c	u	*
Northern Rough-winged Swallow...............	u	r	u		*
Bank Swallow...........	r	r	r		
Cliff Swallow..........	a	a	u		*
Barn Swallow...........	a	a	a		*

LARKS	Sp	Su	F	W	N
Horned Lark............	r		r	r	

JAYS, CROWS	Sp	Su	F	W	N
Steller's Jay..........	u	u	u	u	*
Scrub Jay..............	c	c	c	c	*
Black-billed Magpie....			r	r	
American Crow..........	a	c	c	a	*
Common Raven...........				r	

CHICKADEES, BUSHTIT	Sp	Su	F	W	N
Black-capped Chickadee.	c	c	c	c	*
Mountain Chickadee.....				r	
Chestnut-backed Chickadee............	u	u	u	u	
Bushtit................	c	c	c	c	*

NUTHATCHES	Sp	Su	F	W	N
Red-breasted Nuthatch..	u	u	u	u	*
White-breasted Nuthatch..............	c	c	c	c	*
Brown Creeper..........	u	u	u	u	

WRENS	Sp	Su	F	W	N
Bewick's Wren..........	c	c	c	c	*
House Wren.............	c	c	c		*
Winter Wren............	u		u	u	
Marsh Wren.............	c	c	u	u	*

Sp = Mar-May   F = Sept-Nov   N = Nests Locally*   a = Abundant   u = Uncommon   ac = Accidental
Su = Jun-Aug   W = Dec-Feb   c = Common   r = Rare

BIRDS OF BURLINGTON BOTTOMS

KNOWN OR BELIEVED TO BE PRESENT

KINGLETS	Sp	Su	F	W	N
Golden-crowned Kinglet.	r	r	c	c	*
Ruby-crowned Kinglet...	c	r	c	c	

THRUSHES	Sp	Su	F	W	N
Western Bluebird.......	r	r	r		
Swainson's Thrush......	u	c	c		*
Hermit Thrush..........	u		u	u	
American Robin.........	a	a	c	c	*
Varied Thrush..........	u		u	u	

PIPIT, WAXWING	Sp	Su	F	W	N
American Pipit.........	u		a	r	
Cedar Waxwing..........	u	u	u	u	

SHRIKES, STARLING	Sp	Su	F	W	N
Northern Shrike........			r	r	
Loggerhead Shrike......	r		r		
uropean Starling......	a	a	a	a	*

VIREOS	Sp	Su	F	W	N
Solitary Vireo.........	u		u		
Hutton's Vireo.........	r	r	r	r	*
Warbling Vireo.........	c	c	c		
Red-eyed Vireo.........	u	u	u		*

WOOD WARBLERS	Sp	Su	F	W	N
Orange-crowned Warbler.	c	c	u	u	*
Nashville Warbler......	u	r	u		
Yellow Warbler.........	u	u	u		*
Yellow-rumped Warbler..	a	u	c	u	*
Black-throated Gray Warbler...............	c	u	c		
Townsend's Warbler.....	u	u	u	r	
MacGillivray's Warbler.	u	u	u		*
Common Yellowthroat....	c	c	u		*

	Sp	Su	F	W	N
Wilson's Warbler.......	c	c	u		*
Yellow-breasted Chat...	r	r			*

TANAGER, GROSBEAKS	Sp	Su	F	W	N
Western Tanager........	u	u			
Black-headed Grosbeak..	c	c	u		*

BLACKBIRDS, ORIOLES	Sp	Su	F	W	N
Red-winged Blackbird...	c	c	a	a	*
Tricolored Blackbird...	r	r	r	r	
Western Meadowlark.....	u	u	u	u	
Yellow-headed Blackbird.............	u	u	r	r	*
Rusty Blackbird........				r	
Brewer's Blackbird.....	c	c	c	c	*
Brown-headed Cowbird...	c	c	c	u	*
Northern Oriole........	c	c	r		*

TOWHEE, SPARROWS	Sp	Su	F	W	N
Rufous-sided Towhee....	c	c	c	c	*
Chipping Sparrow.......	r	u	r	r	*
Clay-colored Sparrow...				r	
Vesper Sparrow.........	r	r	r	r	
Lark Sparrow...........	r		r		
Tree Sparrow...........	c	c	c	r	*
Savannah Sparrow.......	c	c	c	r	*
Fox Sparrow............	r		u	r	
Song Sparrow...........	c	c	c	c	*
Lincoln Sparrow........	u		u	u	
Swamp Sparrow..........	r		r	r	
White-throated Sparrow.	r		r	r	
Golden-crowned Sparrow...............	c		c	a	
White-crowned Sparrow...............	u	u	u	c	*
Harris Sparrow.........	r			r	
Dark-eyed Junco........	u	r	c	c	*
Lapland Longspur.......	r		r		

Sp = Mar-May F = Sept-Nov N = Nests Locally* a = Abundant u = Uncommon ac = Accidental
Su = Jun-Aug W = Dec-Feb c = Common r = Rare

BIRDS OF BURLINGTON BOTTOMS

KNOWN OR BELIEVED TO BE PRESENT

FINCHES, WEAVER FINCH	Sp	Su	F	W	N
Purple Finch...........	u	u	u	u	*
House Finch............	c	c	c	c	*
Pine Siskin............	u	u	u	u	
Lesser Goldfinch.......	r	r			

	Sp	Su	F	W	N
American Goldfinch.....	c	c	a	c	*
Evening Grosbeak.......	r		r		
Red Crossbill..........			r	r	
House Sparrow..........	c	c	c	c	*

Sp = Mar-May	F = Sept-Nov	N = Nests Locally*	a = Abundant	u = Uncommon	ac = Accidental
Su = Jun-Aug	W = Dec-Feb		c = Common	r = Rare	

FISH OF BURLINGTON BOTTOMS

KNOWN OR BELIEVED TO BE PRESENT

WARMWATER FISH

White crappie
Black crappie
Brown bullhead
Yellow bullhead
Black bullhead
Channel catfish
Yellow perch
Large mouth bass
Smallmouth bass
Bluegill
Pumpkinseed
sunfish
Common Carp
Goldfish
Warmouth
Gambusia
Chiselmouth
Peamouth
Northern squawfish
Longnose dace
Redside shiner

COLDWATER FISH

Cottid
American shad
Peamouth
Largescale sucker
Mountain sucker
Walleye
Chiselmouth
Stickleback
Sturgeon
Western brook
lamprey
Pacific lamprey
Coho salmon
Chinook salmon
Sockeye salmon
Rainbow trout
Cutthroat trout
Steelhead trout
Kokanee
Prickley sculpin
Reticulate sculpin
Mountain whitefish
Sand roller

MARINE FISH

Starry flounder

REPTILES AND AMPHIBIANS OF BURLINGTON BOTTOMS

KNOWN OR BELIEVED TO BE PRESENT

REPTILES	C	U	R	T&E	SS
Western pond turtle...			x		x
Western painted turtle...............	x				x
Western fence lizard..		x			
Northern alligator lizard...............		x			
Western skink.........		x			
Rubber boa...........		x			
Ringneck snake........		x			
Racer.................		x			
Gopher snake..........		x			
Common garter snake...	x				
Northwestern garter snake.................	x				
Western terrestrial garter snake.........	x				

AMPHIBIANS	C	U	R	T&E	SS
Pacific tree frog.....	x				
Red-legged frog.......		x			x
Western toad..........			x		
Bullfrog..............	x				
Northwestern salamander...........		x			
Western red-backed salamander...........		x			
Long-toed salamander..	x				
Ensatina..............	x				
Dunn salamander.......		x			
Clouded salamander....			x		x
Rough-skinned newt....	x				

C = Common U = Uncommon R = Rare T&E = Threatened & Endangered SS = State sensitive

MAMMALS OF BURLINGTON BOTTOMS

Known or Believed to be Present

OPOSSUM	C	U	R	T&E	SS
Opossum	x				

SHREWS	C	U	R	T&E	SS
Dusky shrew	x				
Trowbridge shrew		x			
Vagrant shrew	x				
Pacific water shrew		x			

MOLES	C	U	R	T&E	SS
Shrew-mole			x		
Townsend mole	x				
Pacific mole	x				

BATS	C	U	R	T&E	SS
Little brown myotis	x				
Fringed myotis			x		x
California myotis		x			
Yuma myotis		x			
Long-eared myotis		x			
Silver-haired bat		x			
Red bat		x			
Big brown bat	x				
Hoary bat		x			
Western big-eared bat			x		x

CARNIVORES	C	U	R	T&E	SS
Black bear			x		
Raccoon	x				
Shorttail weasel		x			
Longtail weasel	x				
Mink	x				
River otter	x				
Spotted skunk	x				
Striped skunk	x				

CARNIVORES	C	U	R	T&E	SS
Red fox	x				
Grey fox		x			
Mountain lion			x		
Bobcat		x			
California sea lion		x			
Harbor seal		x			
Coyote	x				

RODENTS	C	U	R	T&E	SS
California ground squirrel	x				
Townsend's chipmunk		x			
Chickaree		x			
Fox squirrel		x			
Northern flying squirrel		x			
Bushytail woodrat	x				
Dusky footed woodrat		x			
Deer mouse	x				
Townsend vole	x				
Longtail vole	x				
Oregon vole	x				
Pacific jumping mouse		x			
House mouse	x				
Norway rat	x				
Black rat	x				
Brush rabbit		x			
Blacktail jackrabbit			x		
Eastern cottontail	x				
Beaver	x				
Muskrat	x				
Nutria	x				
Porcupine			x		

CERVIDS	C	U	R	T&E	SS
Black-tailed deer	x				
Elk			x		

C = Common U = Uncommon R = Rare T&E = Threatened & Endangered SS = State sensitive

APPENDIX B

PLANT SPECIES AT BURLINGTON BOTTOMS

Plants of Burlington Bottoms Natural Area, Multnomah County, Oregon

Oregon Natural Heritage Program

LAKES, POOLS AND PONDS - emergent marsh and aquatic beds

Herbs

Callitriche heterophylla	Different-leaved water-starwort
Callitriche stagnalis	Pond water-starwort
Ceratophyllum demersum	Coontail
Elodea canadensis	Canadian waterweed
Gratiola neglecta	American hedge-hyssop
Lemna minor	Duckweed
Ludwigia palustris	Water purslane
Myriophyllum hippuroides	Western water-milfoil
Myriophyllum spicatum	Spiked water-milfoil
Navarretia sp.	Navarretia
Polygonum amphibium	Water smartweed
Polygonum hydropiperoides	Waterpepper
Potamogeton epihydrus	Ribbon-leaf pondweed
Potamogeton crispus	Curled pondweed
Potamogeton pectinatus	Fennel-leaved pondweed
Sagittaria latifolia	Wapato
Sparganium emersum	Simplestem bur-reed
Spirodela polyrhiza	Great duckweed
Typha latifolia	Broad-leaved cattail

Grasses and sedges

Cyperus erythrorhizos	Red-rooted flatsedge
Eleocharis ovata	Ovoid spikerush
Eleocharis palustris	Creeping spikerush
Glyceria borealis	Northern mannagrass
Juncus bufonius	Toad rush
Juncus effusus	Soft rush
Juncus oxymeris	Pointed rush
Juncus tenuis	Slender rush
Phalaris arundinacea	Reed canary grass

SEASONALLY WET PASTURE

Shrubs

Rubus discolor	Himalaya blackberry

Herbs

Chrysanthemum leucanthemum	Oxe-eye daisy
Cirsium arvense	Canada thistle
Cirsium vulgare	Bull thistle
Geum macrophyllum	Broad-leaved avens

Grasses and sedges

Alopecurus aequalis	Shortawn foxtail
Alopecurus pratensis	Meadow foxtail
Anthoxanthum odoratum	Sweet vernal grass
Carex sp.	Sedge
Carex aperta	Columbia sedge
Festuca arundinacea	Tall fescue
Holcus lanatus	Velvet grass
Hordeum brachyantherum	Meadow barley
Phalaris arundinacea	Reed canary grass

BOTTOMLAND/RIPARIAN FOREST AND SHRUB-SWAMP

Trees

Alnus rubra	Red alder
Fraxinus latifolia	Oregon ash
Populus trichocarpa	Black cottonwood

Shrubs

Cornus stolonifera	Creek dogwood
Crataegus douglasii	Douglas hawthorn
Pyrus fusca	Crabapple
Rhamnus purshiana	Cascara
Ribes sp.	Gooseberry
Rosa nutkana	Nootka rose
Rubus discolor	Himalayan blackberry
Rubus parviflorus	Thimbleberry
Rubus ursinus	Trailing blackberry
Salix lasiandra	Pacific willow
Salix sitchensis	Sitka willow
Sambucus racemosa	Red elderberry
Spiraea douglasii	Douglas spiraea
Symphoricarpos albus	Snowberry

Herbs and ferns

Aruncus sylvester	Goatsbeard
Athyrium filix-femina	Lady fern
Bidens frondosa	Beggars tick
Equisetum arvense	Common horsetail
Galium aparine	Bedstraw
Glecoma hederacea	Ground ivy
Impatiens capensis	Jewelweed
Lysimachia nummularia	Moneywort
Polypodium glycyrrhiza	Licorice fern
Polystichum munitum	Sword fern
Ranunculus repens	Creeping buttercup
Rumex occidentalis	Western dock
Solanum dulcamara	Bittersweet nightshade
Tellima grandiflora	Fringe-cup
Urtica dioica	Stinging nettle

Grasses and sedges

Carex deweyana	Dewey's sedge
Phalaris arundinacea	Reed canary grass

UPLANDS - wooded margins and disturbed areas

Trees

Acer macrophyllum	Bigleaf maple
Fraxinus latifolia	Oregon ash
Prunus sp.	Cherry (cultivar)
Prunus sp.	Plum (cultivar)
Prunus emarginata	Bitter cherry
Quercus garryana	Oregon white oak

Shrubs

Corylus sp.	Filbert (cultivar)
Crataegus douglasii	Douglas hawthorn
Cytisus scoparius	Scots broom
Holodiscus discolor	Ocean spray
Rosa multiflora	Multiflora rose
Rubus discolor	Himalayan blackberry
Salix scouleriana	Scouler willow

Herbs and ferns

Artemisia douglasiana	Douglas sagewort
Barbarea orthoceras	American wintercress
Borago officinalis	Borage
Cerastium arvense	Chickweed
Chrysanthemum leucanthemum	Oxe-eye daisy

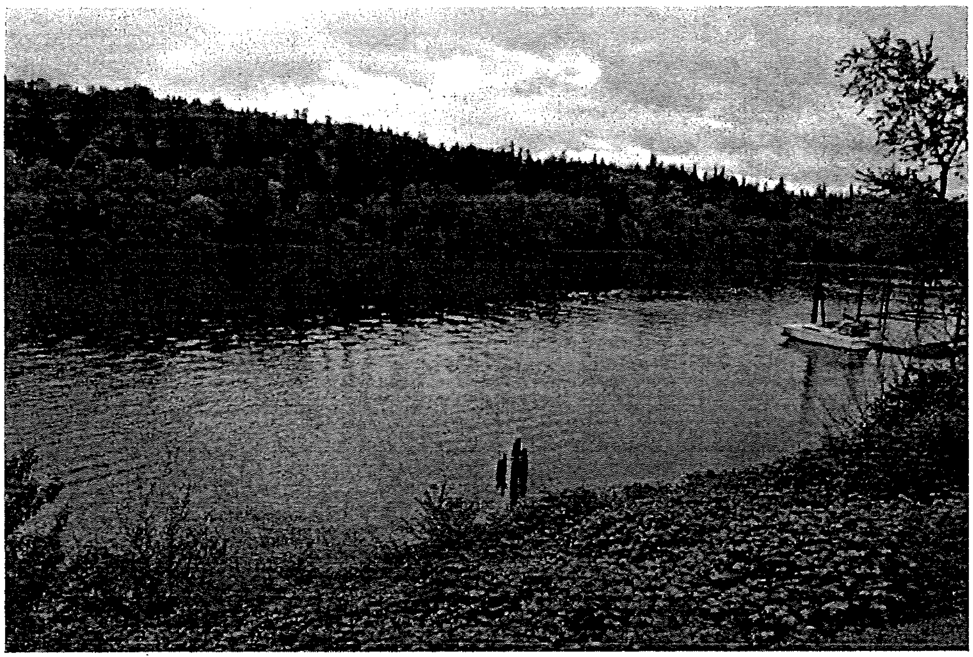
Cirsium arvense	Canada thistle
Cirsium vulgare	Bull thistle
Conium maculatum	Poison hemlock
Convolvulus sepium	Bindweed
Crepis sp.	Hawksbeard
Daucus carota	Wild carrot
Digitalis purpurea	Foxglove
Epilobium watsonii	Watson's willow-herb
Equisetum telmateia	Giant horsetail
Galium aparine	Bedstraw
Geranium molle	Dovefoot geranium
Hypericum perforatum	St. Johnswort
Hypochaeris radicata	False dandelion
Lactuca serriola	Prickly lettuce
Lapsana communis	Nipplewort
Lotus cornicultatus	Bird-foot trefoil
Medicago lupulina	Black medic
Plantago major	Common plantain
Pteridium aquilinum	Bracken fern
Rumex acetosella	Sheep sorrel
Rumex crispus	Curly dock
Senecio jacobea	Tansy ragwort
Sherardia arvensis	Blue field-madder
Solidago canadensis	Goldenrod
Tanacetum vulgare	Tansy
Trifolium arvense	Hare's-foot
Vicia villosa	Hairy vetch

Grasses and sedges

Agropyron repens	Quack grass
Aira caryophyllea	Silver hairgrass
Agrostis sp.	Bentgrass
Alopecurus pratensis	Meadow foxtail
Anthoxanthum odoratum	Sweet vernal grass
Bromus mollis	Soft brome
Bromus rigidus	Ripgut
Festuca arundinacea	Tall fescue
Holcus lanatus	Velvet grass
Phalaris arundinacea	Reed canary grass

Exhibit 22

Portland officials ban mountain bikers from longtime turf at River View Natural Area



The Portland City Council used $6 million collected from utility ratepayers to help buy 146 forested acres in Southwest Portland, now known as River View Natural Area. City officials issued notice Monday that the land is off-limits to mountain bikers starting March 16. *(Benjamin Brink/The Oregonian)*

By **Kelly House | The Oregonian/OregonLive**
Email the author
on March 03, 2015 at 4:36 PM, updated March 05, 2015 at 12:13 PM

Note: *This story has been updated to correct the amount of mountain biking trail in Forest Park.*

Charlie Sponsel bristled when he heard the news that March 16, he'll be kicked out of the mountain biking grounds he helped build.

Sponsel, a 26-year-old professional mountain biker, began practicing at the River View Cemetery Association's undeveloped 146-acre property in Southwest Portland years before the city bought the land and renamed it **River View Natural Area.**

"I'm there three to four times a week," Sponsel said. "The quality of trail in River View far exceeds anything else within an hour's drive away."

He and other Portland area mountain biking advocates had hoped city officials would preserve their access once the land became a park. On Monday, city commissioners Amanda Fritz and Nick Fish notified them **in a letter**, "mountain bikers will no longer be allowed," due to environmental concerns.

Fritz followed with a second on the River View web page clarifying the closure doesn't mean mountain bikers will never be allowed there, "just not now."

Instead, Fritz and Fish said, they would seek $350,000 in the city parks department's 2015-16 budget to fund a citywide off-road cycling plan.

"A comprehensive bicycling plan will identify the most appropriate biking opportunities within our City park system, while protecting the conservation values of our natural areas and the enjoyment and safety of all park users," Fritz and Fish wrote.

Mountain bikers say the decision eliminates one of their few options in a city whose bike-friendly reputation doesn't always extend to the off-road crowd. They're frustrated Fritz and Fish made the decision without a public process.

"They took great pains to bring the public in" to the planning process for River View, said Sponsel, who sits on the city's advisory committee for the property. "Then they seem to have thrown the process completely out the window."

Portland's mountain biking community has been clamoring for more access for years. An **attempt to add more trails to Forest Park** several years ago failed amid backlash from neighborhood associations and environmental groups.

Aside from several miles of trails at River View, Portland's mountain biking infrastructure is limited to nearly 30 miles of shared trails but less than a mile of single-track in Forest Park, along with a few miles at Powell Butte and Mt. Tabor in Southeast Portland. For longer and better trails, bicyclists must leave town, traveling to private land near Scappoose or to Sandy Ridge, A Bureau of Land Management property 40 miles east of Portland.

By contrast, Seattle has a designated city mountain biking park. Bellingham's bike trail network is also expansive.

City officials acknowledge their decision puts the squeeze on mountain bikers, but they contend keeping the trails open creates environmental hazards that could put the entire property in jeopardy.

River View was **one of multiple city projects called into question** in a 2011 lawsuit alleging the city improperly used utility ratepayer money on items that didn't qualify for the funds. A judge ruled the property's ecological importance makes it an appropriate purchase.

City attorneys warned Bureau of Environmental Services leaders that allowing "active recreation" like mountain biking at River View could jeopardize that ruling, said Jim Blackwood, Fish's policy director.

"If we allow mountain biking, the judge could change his mind," Blackwood said.

Hiking would still be allowed under the latest plan, Blackwood said, because city scientists have fewer concerns about hikers' potential to damage habitat in River View. Multiple streams run through the property, providing cold-water refuge for salmon.

"Scientists see the existing bike trails in there that go right through the streams and the watershed, and they say that's more invasive than passive recreation," he said.

Bikers take issue with that characterization. They defend their hobby as no more harmful to wildlife than off-leash dogs and errant hikers who stray from designated trails - **a stance backed up by River View's technical advisory committee**. The committee ranked dogs as the primary threat to the park's habitat, with off-trail bikers and hikers tying for second.

Mark Ross, a spokesman for the parks bureau, said River View's public advisory committee has been discussing whether dogs should continue to be allowed on the property.

By alienating mountain bikers, city officials lose a community of allies with a vested interest in maintaining the trails, said Barry O'Connor, manager of Fat Tire Farms mountain bike shop.

"When it comes down to it, mountain bikers are looking for the exact same thing walkers, runners and equestrians are looking for," O'Connor said. "They're looking to get out in the woods and have a peaceful time."

Fritz acknowledged Portland has a dearth of mountain biking opportunities given the size of its biking community, but said it's just one of a host of deficiencies to be addressed within the parks system. Finding alternative turf for mountain bikers hinges upon a Portland City Council vote to approve the Portland Parks Bureau's request for money to conduct their off-road cycling plan.

"If the advocates want more mountain biking opportunities, the right place to put their energy is in advocating for that budget ask," Fritz said.

Blackwood said Gateway Green, a 25- acre former Multnomah County jail site **the city acquired last year with biking in mind**, could be an option.

--Kelly House

Exh. 23

Environment (/News/Topic/Environment/)

Unauthorized Forest Park Bike Trail Seen As Vandalism

by **Rob Manning** (/contributor/rob-manning/) (Follow) **By Rob Manning** OPB Feb. 23, 2010 10 p.m. | Updated: April 3, 2017 9:32 a.m. | Portland, OR

Portland officials are currently on the hunt for a group of mountain bikers. The allegation? Cutting a mile-long bike trail through a roadless section of Forest Park.

OPB's Rob Manning recently walked the trail - with the biologist who found it.

Portland's Forest Park has miles of trails for hikers, bikers, and horseback riders. But Portland officials just learned about one more, in Forest Park's roadless north end.

John Deshler is the Portland biologist who found it.

John Deshler: "It's an access point I use to find pygmy owls, and find their nests in this large off-trail area."

The trail is about a mile-and-a-half long, and cuts through some of the park's best habitat.

Among the first people Deshler told about the damage was OPB's Oregon Field Guide producer, Vince Patton.

Patton took a television camera to the trail over the weekend and came across two men who were moving plant debris near the trail.

Vince Patton: "Are you putting in a legal trail? Do you have permission to be here?"

That's Patton. The men declined to identify themselves and contended they weren't building a trail – but were modifying it.

In the course of preparing a story on Forest Park for Oregon Field Guide, producer Vince Patton encountered bicyclists creating a new trail to bypass deep damage caused by another unsanctioned trail. He captured the encounter on video.

Man: "Oh, I'm not putting in anything."

Vince Patton: "Sounded like you said you were trying to clear this spot."

Man: "Well, that's a problem."

Vince Patton: "So you can ride over here instead, right?"

Man: “So people who want to use the trail can avoid those puddles. There are obvious drainage issues.”

Biologist John Deshler points out clear evidence of damage on the rogue trail.

John Deshler: “Now we’re getting to things that were cut.”

Deshler grabs one of numerous western red cedars that were cut down

John Deshler: “So, we’re mostly standing in a forest of alder and big-leaf maple, overwhelmingly so, and the western red cedar were just starting to get a foothold. And at least this small stand has been cut.”

He also points to a Douglas fir.

John Deshler: “This one actually looks to have been dead, even though it’s about six inches in diameter. But this one was alive, and this one is probably, 25 to 30 feet tall, that Doug fir.”

As the trail descends more sharply, whoever worked on the trail began using the cut trees to reinforce the trail's edges.

Park.
Watch Vince Patton's report for Oregon Field Guide. (http://www.opb.org/programs/ofg/segments/view/1741)

John Deshler: "This is where they got into some trail-building, where they started adding some supports in. There's sort of a nice jump, with some elk scat there are the bottom of it."

Deshler says he's dismayed, because elk are known to live in these relatively large and intact wild parts of Forest Park. But the large animals tend to avoid roads, and other signs of human activity.

City officials say they are particularly concerned about the bottom of the trail - where builders put rocks into a stream, so that bikes could get across it.

Dan Moeller is a parks' supervisor for the area that includes Forest Park.

Dan Moeller: "It's really a pristine area, it's really wonderful. You know, Forest Park is an extremely healthy and vibrant and wonderful park, as a whole. And within that whole, this area is one of the gems of the park."

Moeller says he's in conversations right now with other parks' officials and conservationists about what it will take to restore the area.

The discovery of the rogue trail comes at a sensitive time for the city, because a parks' committee is trying to find legitimate places to add mountain bike trails in Forest Park.

Parks' commissioner Nick Fish condemned the trail.

Nick Fish: "This kind of vandalism to our natural areas will not be tolerated. Our director of security is investigating. We will cooperate with law enforcement – we're going to find out who did this. This was a significant act of vandalism."

The lead mountain bike group on Fish's mountain bike committee, the Northwest Trail Alliance, has put up signs at the trail, to discourage people from using it. And the group echoes Fish's condemnation.

Frank Selker is a mountain bike enthusiast on Fish's committee. He agrees that the bike trail shouldn't have been built. But he says it underscores the need for trails.

Frank Selker: "Finding this trail just highlights that mountain bikers don't have access to trails, or single-track, and much like skateboarders didn't have anything ten years ago, there are mountain bikers who are frustrated and it leads to this kind of problem."

But members of the conservation community say there is no excuse for the way this trail was built.

The Impacts of Mountain Biking on Amphibians and Reptiles

Michael J. Vandeman, Ph.D.

Exh. 24

October 22, 2005

ABSTRACT: Although there have so far been no systematic studies of the impacts of mountain biking on amphibians and reptiles, there is plenty of evidence that mountain biking is a major threat to those amphibians and reptiles that cross trails, follow ruts as the path of least resistance, or lay their eggs in creeks crossed by trails or in the soft dirt that tends to be generated on or next to trails. The nature of mountain biking suggests several ways in which we would expect mountain biking to harm small animals: the long distances travelled by mountain bikers, their speed, their wide tires, their habit of riding through creeks, etc. The nature of amphibians leads them into conflict with bikers: their relatively slow movements, their cryptic coloration, and their habit of laying eggs in creeks. Snakes often lie crosswise on trails while sunning themselves. Thus it is not surprising that the Museum of Vertebrate Zoology of the University of California at Berkeley has two specimens of snakes killed by mountain bikers.

"Cities should be built on one side of the street." Bob Kaufman, 1959, p.60

"Mountain bikes' impacts on the land are large and getting worse. … The aggressive push of mountain bike organizations to build ever-growing webs of trails poses serious problems of habitat fragmentation, increased erosion, and wildlife conflicts. As interest in extreme riding continues to grow, as trail networks burgeon, and as new technology makes it possible for ever-more mountain bicyclists to participate, even the most remote wild landscapes may become trammeled -- and trampled -- by knobby tires. … The destruction of wilderness and the fragmentation of habitats and ecosystems is death by a thousand cuts. Will introduction of mountain bikes -- and their penetration farther into wilderness -- promote additional fragmentation and human conflicts with the natural world? Yes." O'Donnell and Carroll, 2003.

"Some things are obvious: mountain bikes do more damage to the land than hikers. To think otherwise ignores the story told by the ground." Dave Foreman, 2003

The sport of mountain biking is expanding rapidly, fueled partly by the mountain bike and tourism industries, the Olympics, and other competitive events (e.g., "adventure racing"). ("Trail use in the last ten years has seen a dramatic increase in off-road bicycles" (Wilson and Seney, 1994, p.86). "Mountain biking in particular is one of the fastest-growing outdoor activities, with 43.3 million persons participating at least once in 2000" (Taylor and Knight, 1993, p.952). "An estimated 13.5 million mountain bicyclists visit public lands each year" (U.S. Bureau of Land Management)(Lathrop, 2003).) It is putting intense pressure on wildlife habitat, worldwide, as well as inhibiting efforts to protect additional lands. There is strong pressure to find places to ride that are convenient -- not too far from home or work. This brings bikers in direct conflict with other urban and near-urban recreationists, who want to use the same parks.

Most of the studies on mountain biking impacts attempt to compare hiking and mountain biking, and conclude that their impacts are essentially the same. However, they all ignore speed and distance travelled, and nearly all ignore impacts on wildlife; they also make no attempt to test mountain biking under realistic conditions (e.g. normal speeds). A more accurate conclusion from the data presented would be that the impacts of mountain biking are actually from two to six times those of hiking, due in part to the greater speed and distance travelled by mountain bikers. No published statistics are available, but I collected 72 mountain bikers' ride announcements, which advertise one-day rides of a minimum of 8 miles, an average of 27 miles, and a maximum of 112 miles -- much greater distances than hikers travel. (Vandeman, 2004). "Because bicyclists are capable of and, in most areas, typically do travel much farther than hikers, it is reasonable to conclude that they will create a somewhat higher total number of encounters [with animals] and flushings" (Lathrop, 2003).

Some of the other important characteristics of mountain biking that have been ignored are: the direct killing of small animals, the increase in number of visitors that bikes allow; increased trail-building, with its attendant habitat destruction; the displacement of soil (other than downhill); the killing of roots and soil organisms; most effects on wildlife; the manner of riding (skidding, braking, acceleration, turning, and whether the mountain biking tested is representative of typical mountain biking); tire tread; and noise.

Braking, accelerating, and turning all create horizontal forces that accelerate erosion. Whereas shoes tend to flatten trails, bike tires create V-shaped ruts (Chiu and Kriwoken, 2003), which channel water and further increase erosion (as well as making the trails difficult and dangerous to walk on). Bikes also throw dirt to the outside on turns, crush small plants and animals on and under the trail, facilitate increased levels of human access into wildlife habitat, and drive other trail users (many of whom are seeking the tranquility and primitiveness of natural surroundings) out of the parks.

Amphibians and reptiles that lay their eggs in the soft dirt next to the trail (e.g. fence lizards and turtles -- Gary Beeman, personal communication) or in creeks (e.g. California newts), sun themselves in the trail (e.g. fence and alligator lizards and rattlesnakes), or migrate across trails (e.g. California newts), can be expected to incur an increase in mortality wherever mountain bikes are ridden. "Mountain bikes are a significant threat to turtles as the heavily used trails can act as death traps, tempting nesting females to lay their eggs in the eroded soils in high-traffic areas. … A newly emerged hatchling was found … on a mountain bike trail" (SaintOurs, 2000). The killing of plants on and next to the trail can deprive amphibians and reptiles of food (for example, box turtles eat berries -- SaintOurs, 2000).

Besides increasing the presence of humans in wildlife habitat (Vandeman, 1997), mountain biking causes direct mortality and morbidity of small animals and plants ("Anecdotal evidence suggests … that small mammals are vulnerable to impact and are not uncommonly killed" -- Lathrop, 2003). Even on foot, it is hard to avoid stepping on a well-camouflaged California newt! Mountain bikers are higher off the ground, are travelling much faster than a hiker, and, if they don't devote most of their attention to negotiating the trail, will crash. To get an idea of what mountain biking is like, and how fast mountain bikers ride, all you have to do is watch one of their videos (search for "mountain bike video" in Google, e.g. www.petefagerlin.com). It is impossible to mountain bike and look out for small critters [EDITOR: this is the most appropriate word, since it includes animals and plants and conveys the appropriate emotion; but if you must change it, I suggest using "creatures"] on the trail. While hikers try to avoid getting their feet wet when crossing streams, by stepping on stones or logs, mountain bikers generally ride through the stream, crushing animals and eggs that may be there ("Most amphibians lay their eggs in fresh water" -- Stebbins, 1995, p.166). Bikes also create deep ruts in the trail. According to Robert Stebbins (personal communication), lizards and salamanders often get stuck in these ruts, following them for a long distance.

In Black Diamond Mines Regional Preserve (in the San Francisco Bay Area), one of the largest Alameda whipsnakes (Masticophis lateralis euryxanthus, a federally Threatened species) ever seen was apparently killed by a mountain biker (Figure 1). In Claremont Canyon Regional Preserve, a ringneck snake (Diadophis punctatus) was apparently killed by a mountain biker riding where bikes are not allowed (Figure 2). In both cases, the snakes were killed on unpaved roads with no visibility problems, showing that bikers are not able to avoid killing wildlife. The width of the wounds matched the width of a mountain bike tire. This also calls into question the notion current in some park systems (e.g. East Bay Regional Park District (EBRPD), in the San Francisco Bay Area) that, while it may be dangerous for bikers to share narrow trails with hikers, they are okay on wide trails. In fact, the bikes may be more dangerous on wide trails, since they can go faster.

Recently there has been a large increase in night riding. This has the potential to further increase threats to amphibians and reptiles, if the animals are on or near a trail. If mountain bikers can't avoid crushing snakes on a wide trail in broad daylight, I hate to think what they will do at night! Amphibians that could be most impacted by night riding include those that migrate across trails at night (e.g. California newts and other seasonal pool breeders). EBRPD closes a road to automobile traffic for five months during the newt migration. However, bicycles are still allowed on the road!

Another disturbing trend is the increasing popularity of "freeriding": riding on trails doesn't provide enough challenge or enough thrills, so bikers are riding off-trail. This can only increase the threat to wildlife. Finally, Wisdom et al (2004) found that elk's avoidance of an area extended beyond the period when recreationists were actually present. When mountain bikers came within 1,640 yards, elk responded by fleeing the area. If a similar effect holds for amphibians and reptiles, I would expect a significant loss of (usable) habitat and increased energy costs due to wide-ranging mountain bikers.

It is clear that the addition of bicycles to natural areas is a serious threat to amphibians and reptiles, especially in the heavily populated urban environment.

Literature Cited

Chiu, L. and L. Kriwoken. 2003. Managing Recreational Mountain Biking in Wellington Park, Tasmania, Australia. Annals of Leisure Research, 6(4):339-361.

Foreman, D. 2003. A modest proposal. Wild Earth 13(1):34-5.

Kaufman, Bob. 1959. Solitudes Crowded with Loneliness. New Directions Publishing Corporation, New York.

Lathrop, J. 2003. Ecological impacts of mountain biking: a critical literature review. http://www.wildlandscpr.org/resourcelibrary/reports/mountainbikingreport.htm.

O'Donnell, B. and M. Carroll. 2003. Don't tread here. Wild Earth 13(1):31-33.

SaintOurs, F. H. 2000. Turtle conservation in rapidly developing suburban areas: An example from Plymouth County, Massachusetts. http://www.nescb.org/epublications/october2000/saintours.html.

Stebbins, R. C. and N. W. Cohen. 1995. A Natural History of Amphibians. Princeton University Press, Princeton, NJ.

Taylor, A. and R. L. Knight. 2003. Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13(4):951-63.

Vandeman, M. J. 1997. Wildlife Need Habitat Off-Limits to Humans! Presented at the Society for Conservation Biology meeting, University of Montana, Missoula, Montana, June 10, 2000, http://mjvande.info/india3.htm.

----- 2004. The Impacts of Mountain Biking on Wildlife and People -- A Review of the Literature. Presented at the Society for Conservation Biology meeting, Columbia University, New York, NY, August 2, 2004, http://mjvande.info/scb7.htm.

Wilson, J. P. and J. Seney. 1994. Erosional impact of hikers, horses, motorcycles, and off-road bicycles on mountain trails in Montana. Mountain Research and Development 14(1):77-88.

Wisdom, M. J., A. A. Ager, H. K. Preisler, N. J. Cimon, and B. K. Johnson. 2004. Effects of off-road recreation on mule deer and elk. Transactions of the North American Wildlife and Natural Resources Conference 69, pp. 531-550.

Figure 1. Alameda whipsnake, apparently killed by a mountain biker. Photo: Christopher Conroy, Museum of Vertebrate Zoology, University of California, Berkeley

Figure 2. Ringneck snake, apparently killed by a mountain biker. Photo: Christopher Conroy, Museum of Vertebrate Zoology, University of California, Berkeley

Reviewers:

Harry W. Greene, Professor and Curator

Department of Ecology and Evolutionary Biology

Corson Hall

Cornell University

Ithaca, NY 14853-2701

office phone: 607-254-4265

FAX: 607-255-8088

e-mail: hwg5@cornell.edu

Steven C. Anderson

Department of Biological Sciences

University of the Pacific

Stockton, California 95211 USA

Phone: (209) 464-2048

Fax: (209) 946-3022

E-mail: asaccus@aol.com

Exh. 25

www.oregon**metro.gov**

Wildlife corridors and permeability

A literature review

April 2010

Metro | *People places. Open spaces.*

About Metro

Clean air and clean water do not stop at city limits or county lines. Neither does the need for jobs, a thriving economy and good transportation choices for people and businesses in our region. Voters have asked Metro to help with the challenges that cross those lines and affect the 25 cities and three counties in the Portland metropolitan area.

A regional approach simply makes sense when it comes to protecting open space, caring for parks, planning for the best use of land, managing garbage disposal and increasing recycling. Metro oversees world-class facilities such as the Oregon Zoo, which contributes to conservation and education, and the Oregon Convention Center, which benefits the region's economy.

Metro representatives

Metro Council President – David Bragdon
District 1 – Rod Park
District 2 – Carlotta Collette
District 3 – Carl Hosticka
District 4 – Kathryn Harrington
District 5 – Rex Burkholder
District 6 – Robert Liberty
Auditor – Suzanne Flynn

www.oregonmetro.gov

Prepared by

Lori Hennings
Senior Natural Resource Scientist
lori.hennings@oregonmetro.gov
503-797-1940

Jonathan Soll
Science and Stewardship Manager

Metro Sustainability Center
600 NE Grand Avenue
Portland, OR 97232-2736

Metro thanks the following people for providing peer review of this document:

Leslie Bliss-Ketchum, Portland State University

Catherine de Rivera, Portland State University

Kate Holleran, Metro

John Marshall, US Fish and Wildlife Service

Anita Morzillo, Oregon State University

Nathan Poage, Clackamas Stewardship Partners

Claire Puchy, City of Portland

Kerry Rappold, City of Wilsonville

Elaine Stewart, Metro

Jennifer Thompson, US Fish and Wildlife Service

Melinda Trask, Oregon Department of Transportation

Jennifer Vanderhoof, King County, Washington

Brian Vaughn, Metro

Katy Weil, Metro

Curt Zonick, Metro

CONTENTS

EXECUTIVE SUMMARY 1

FUNDAMENTAL CONCEPTS IN WILDLIFE CONNECTIVITY 2

Introduction and study area 2

Habitat fragmentation 4

Metapopulation theory: A theoretical framework for understanding minimum population size 5

Theory of Island Biogeography: A theoretical framework for understanding community composition 6

Edge effects and habitat patch size and shape 7

Habitat patch size in the Portland-Vancouver region 9

Matrix: What lies between habitat patches 10

Urbanization and disturbance issues 12

Roads and road effects 13

Noise 14

Artificial light 15

Trails 16

Invasive species 18

Climate change 19

OVERVIEW OF THE REGION'S HABITAT AND WILDLIFE 20

Historic and current habitat 20

Fish 22

Amphibians 23

Reptiles 24

Birds 25

Mammals 27

Summary: What does wildlife need? 29

MORE ABOUT CORRIDORS 30

Different types of corridors and connectivity 30

Corridor width, length and shape 31

Corridor risks 33
Spatial scale 34
CONNECTING HABITAT: HOW IT'S DONE 35
Getting started....... 37
Assembling the working group 37
Establishing goals, criteria and selecting methodologies 37
Initial inventory....... 39
Identifying potential core habitat areas 39
Identifying focal species 39
Stakeholder outreach – locals know more 42
Final inventory 43
Selecting preferred alternatives (core habitats, focal species) 43
Identifying corridors 43
Barriers and gaps 45
Selecting preferred corridors and creating final maps 46
Implementing the strategy 47
Conducting broader outreach 47
Conservation tools for wildlife connectivity....... 48
Research, monitoring and adaptive management 49
Related efforts....... 51
SUMMARY – WHERE DO WE GO FROM HERE? 52
APPENDICES....... 53
Appendix 1. Literature relating to corridor widths....... 54
Appendix 2. Literature relating to species' habitat area requirements 61
Appendix 3. Literature relating to species' gap-crossing abilities 63
Appendix 4. Models and assessment techniques....... 64
Appendix 5. Vertebrate species known to use region habitats at least once every year....... 68
Appendix 6. Literature cited 80

EXECUTIVE SUMMARY

The purpose of this paper is to review the science of how and why wildlife species need to move across a landscape, including suggested methods to map and improve connectivity. The information will be used to create a regional wildlife connectivity map and strategy for the greater Portland-Vancouver metropolitan region, and will be incorporated into a regional conservation framework.

Connectivity can be difficult or impossible to regain after urbanization, yet it is critically important to the Portland-Vancouver region's wildlife. Habitat loss and fragmentation have partially or fully isolated many of the remaining habitat patches, and the matrix between patches may be too harsh for many species to navigate. Over time, isolated habitat patches tend to lose wildlife species, and without connectivity, these species cannot repopulate an area. Improving connectivity will help maintain the region's biodiversity by allowing species to move as needed to fulfill their life history requirements.

The amount and placement of a few key landscape features, especially trees, shrubs and hard surfaces, significantly influence the types of wildlife that can survive in urban areas. The size and shape of a habitat patch, as well as the relationship with surrounding habitats, play key roles in habitat quality and wildlife communities. Disturbance also plays a key role, and impacts may be species-specific. Roads, trails and development impose a variety of disturbances deriving from noise, sound, light, and human and pet impacts. However, the overall amount of habitat and the degree to which it is interconnected likely exert the most profound influence on urban wildlife.

This literature review consists of four sections plus appendices. The first section, *"Fundamental Concepts in Wildlife Connectivity,"* presents concepts and information about the ecology of connectivity, including the consequences of habitat fragmentation, ecological issues relating to urbanization and disturbance, invasive species and climate change. The second section, *"Overview of the Region's Habitat and Wildlife,"* describes historic and current habitat and discusses species groups and specific issues relating to each group. The third section, *"More about Corridors,"* reviews connectivity issues such as corridor shape, risks and spatial scale. The final section, *"Connecting habitats: How it's Done,"* provides a practical approach to creating a regional wildlife corridors map. The appendices include tables reviewing literature recommendations on corridor widths, patch size requirements and gap-crossing abilities for selected species, and a review of models and assessment techniques to identify wildlife connectivity. A regional vertebrate species list and literature cited are also provided in appendices.

Creating a wildlife connectivity strategy may range from relatively simple drawings on a map to complex modeling processes. At its best, it is a collaborative and iterative process. At its worst, the process becomes mired in arguments about specifics and takes too long, perhaps forever, to complete, even as population increases and more houses and roads are built. The movement strategy can identify opportunities to strategically invest in connectivity and initiate a process relying on long-range planning, restoration, acquisition, easements and other tools. Monitoring and adaptive management approaches, along with leadership, collaboration and public support, will be needed to ensure the strategy is effective. The long-term benefits for the region's biodiversity will be worth the effort.

FUNDAMENTAL CONCEPTS IN WILDLIFE CONNECTIVITY

INTRODUCTION AND STUDY AREA

The purpose of this paper is to review the science of how and why wildlife needs to move across our urban landscape. It is intended for the audience of people working on natural resources and in particular, wildlife connectivity in the Portland-Vancouver region. The goal is to provide the scientific foundation needed to map the region's most important habitat areas and develop a collaborative strategy to facilitate wildlife movement among these habitats. The results will be incorporated into a regional conservation framework.

The greater Portland-Vancouver region is at the northern end of the Willamette Valley ecoregion, the latter which encompasses 5,308 square miles (13,748 square kilometers) and includes the Willamette Valley and adjacent foothills [284]. Current vegetation in the region has changed substantially from historic patterns. Key factors include urban development, agricultural cultivation, livestock grazing, exotic species introduction, suppression of natural fires, logging, drainage of wetlands, and channelization of streams and rivers [6]. In the Willamette Valley, native prairie and oak savannah has been reduced to about one percent of historic land coverage; over 70 percent of the bottomland hardwood forests have been lost, as well as substantial wetland and surface stream loss [6;206;283;284].

The Portland-Vancouver metropolitan region ("region") provides homes for a diverse assemblage of native fish and wildlife including at least 26 fish, 16 amphibian, 13 reptile, 209 bird and 54 mammal species. These animals must be able to navigate the intricate network of roads, parking lots, backyards and barriers to survive and thrive. The region is expecting significant population growth in coming decades – about a million more people by 2025. Further, anticipated changes in temperature and weather patterns will impact habitat and wildlife in ways that are not yet known. Developing and implementing a strategic plan for wildlife movement now, that encompasses the region and connects to important habitats outside the region, can help preserve the region's biodiversity.

For geographic context, Figure 1 shows the region's urban areas (light green) and surrounding landscapes.

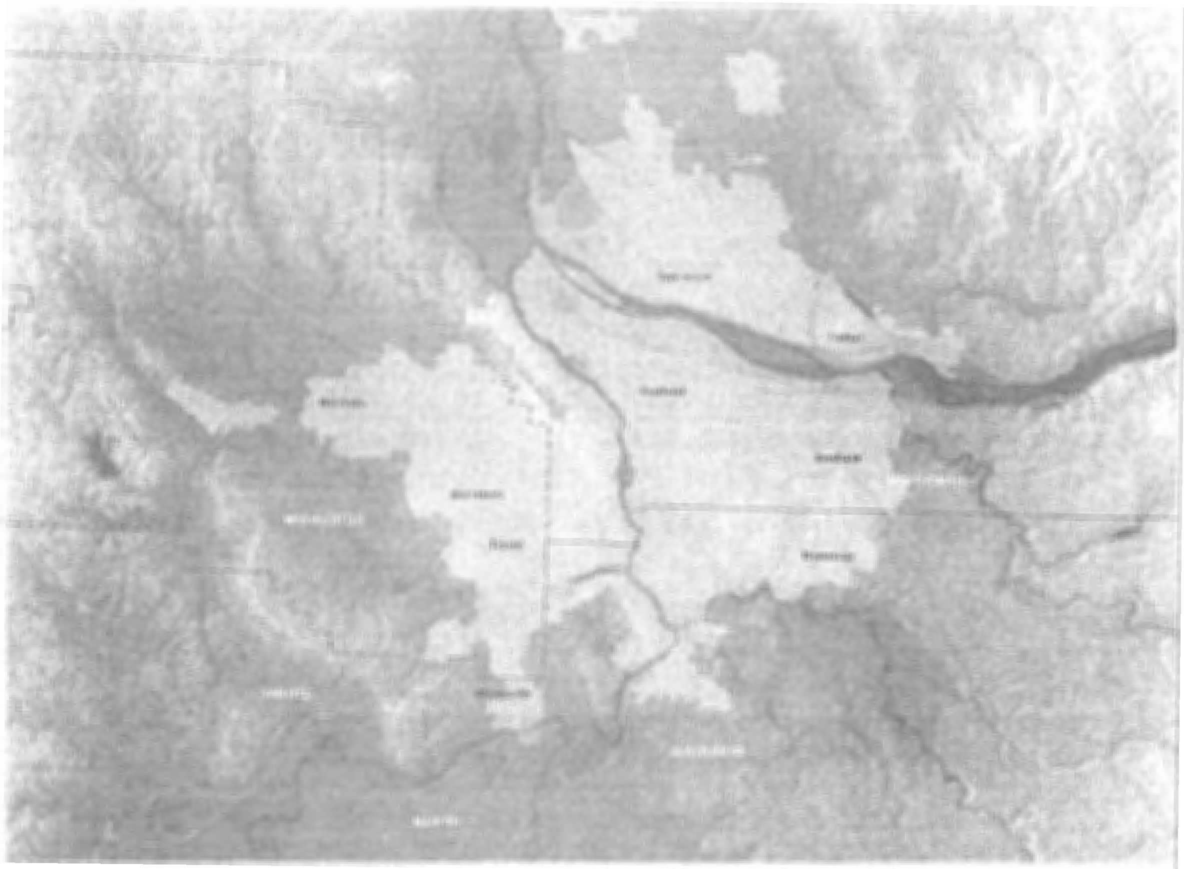


Figure 1. General study area location of the Portland, Oregon-Vancouver, Washington region. Areas in light green indicate urban areas.

Maps can be powerful. A regional wildlife corridors strategy and map, supported by key stakeholders and widely recognized as a set of long-term natural resource goals, can help marshal public will and resources to improve biodiversity. It is not meant to be used in a regulatory sense; it will not be perfect the first time, and conditions change continually. Rather, it provides a way to strategically incorporate natural resource goals into restoration efforts, land use planning, transportation and development projects, and the back yards of the people who live here. It can help focus efforts and funding on actions most likely to benefit wildlife and habitat.

The following sections review the science of how and why wildlife species need to move across a landscape, including suggested methods to map and improve connectivity. Several appendices provide species-specific information, including Appendix 1 (corridor widths), Appendix 2 (minimum habitat patch size), and Appendix 3 (gap-crossing abilities). Appendix 4 reviews selected methods in modeling wildlife connectivity. Appendix 5 provides a regional vertebrate species list, followed by literature cited in Appendix 6.

HABITAT FRAGMENTATION

Habitat fragmentation is the process of breaking apart large areas of habitat into multiple smaller unconnected patches. It is generally used in the context of forested areas, but also applies to other habitat types, such as wetland, shrub or grassland habitats [79;121;343].

Wildlife corridors and landscape permeability are separate but related concepts. A permeable landscape is one where wildlife can move relatively freely from one area to another. Fragmentation reduces permeability and may result in areas connected only by one or two corridors, or in completely isolated habitats where animals are essentially trapped or in danger if they leave the habitat patch.

Fragmentation is widely recognized as an over-arching threat to wildlife and ecosystem health [152;368] and is closely linked to habitat loss and invasive species, two other major threats [369]. Identifying important wildlife movement corridors and providing viable connectivity between remaining habitat patches can help reduce many of the ecological impacts of habitat fragmentation [34;223;343;370].

Habitat fragmentation diminishes the landscape's capacity to sustain healthy native wildlife populations primarily through habitat loss, reduced habitat patch size, increased edge habitat, increased isolation of patches and modification of disturbance regimes. Fragmentation can benefit some native species, but is generally detrimental to more sensitive wildlife. Fragmentation reduces the amount of and access to habitats needed to meet species' requirements, thereby lowering the number of individuals of a given species that can be supported, reducing population sizes and increasing the likelihood of local extinctions.

Over time, habitat isolation can lead to cascading effects that may disrupt ecological processes. Ecological processes play an essential part in maintaining ecosystem integrity, and include the cycling of water and nutrients, the flow of energy, and maintaining biodiversity [123]. These processes occur at many different spatial scales and are present in every ecosystem, but are often severely compromised in urban ecosystems [3;61;88;249;272]. The capacities of urban greenspaces to support biodiversity, mitigate climate extremes, and facilitate storm water infiltration are well recognized contributors to sustaining ecological processes [61].

Two theories are especially useful in understanding how fragmentation affects wildlife populations: metapopulation theory and island biogeography. Metapopulation theory helps to explain the population dynamics of species in a fragmented yet connected habitat, whereas island biogeography provides a useful framework for considering habitat patch size, configuration, and connectivity for groups of species at the landscape scale. Both theories apply to urban habitats. Both can be used to consider best approaches to improving wildlife connectivity.

METAPOPULATION THEORY: A THEORETICAL FRAMEWORK FOR UNDERSTANDING MINIMUM POPULATION SIZE

Wildlife corridors serve as conduits for animal movement and provide habitat, but an important additional function is genetic exchange between populations [316]. A population is a group of individuals of the same species that live within a particular area and interact with one another. A metapopulation is a group of populations within a landscape connected by migrating or dispersing individuals [310]. Interactions between these populations can be beneficial by increasing genetic interchange and animal health, and reducing the risk of local population, and potentially metapopulation, extinction. It can also mitigate some of the effects of small habitat patch size.

In addition to extinction risk, isolated populations can become unbalanced and negatively affect other species. An isolated habitat patch may lose large predator species, leading to deer overpopulation; deer overpopulation leads to widespread vegetation loss, affecting other wildlife through habitat loss and simplification. The impacts from deer overpopulation are currently a noteworthy problem in some parts of the U.S. [170;196;199]. These imbalances can result in cascading ecological effects. For example, loss of large predators can also lead to overabundant smaller mammals such as raccoons, squirrels and mice, further impacting songbirds through direct predation and nest predation [20;66;263]. Because songbirds disperse seeds, aid in pollination and control insect populations, habitat is altered even more [383].

Physical isolation can lead to genetic isolation. Gene flow is a combination of breeding population number and the rate of migration among populations [207]. Gene flow may be particularly important to small populations or those isolated for long periods of time because individuals in such populations may become increasingly genetically similar. Habitat connectivity or isolation affects gene flow in different ways for different species. For mobile species such as some birds, metapopulations and gene flow occur at a larger spatial scale than for less mobile species such as salamanders or frogs [80;261]. Therefore, it is easier for frogs and salamanders to become isolated, and genetically inbred, than it is for birds, which can travel greater distances to interact.

For example, researchers at Western Washington University found a sharp decline in gene flow among Cascade frog populations separated by more than 6 miles (10 kilometers) [261]. In urban areas, effective isolation distances may be much shorter for many species because roads, buildings, and paved areas between habitat patches may be difficult or impossible to cross. Genetic isolation can increase inherited diseases and reduce a species' ability to adapt to its environment, sometimes leading to local or total extinction [214;343].

A minimum viable population size depends largely on how much suitable habitat area is available combined with how connected each population is to others. With no connectivity, a much greater population size would be needed for viability and extinction risk for a given species increases. Improving connectivity helps maintain and can increase biodiversity of inter-connected patches.

THEORY OF ISLAND BIOGEOGRAPHY: A THEORETICAL FRAMEWORK FOR UNDERSTANDING COMMUNITY COMPOSITION

The theory of island biogeography has been applied to urban environments to further understand how habitat fragments function and as a basis for developing habitat protection plans [102]. MacArthur and Wilson first proposed the theory to explain the number of species (species richness) on islands in the Pacific Ocean [2;222]. It explains species richness on various islands based on a four fundamental concepts:

1. Larger islands (in the region, habitat patches) host more species than small ones because they have more kinds of habitats. Larger islands are also easier to find by migrating animals. (species-area relationship)
2. Smaller habitat patches closer to large patches host more species due to greater ease of immigration from the species-rich "mainland." (distance effect)
3. Smaller habitat patches lose more species more quickly than large patches because their populations are likely small to begin with (area effect). Small populations are more vulnerable to extinction due to disturbance and chance.
4. The risk of extinctions in any patch closer to a large patch is lower than those further away due to increased chances of re-colonization. (rescue effect)

According to the theory of island biogeography, when populations become isolated from one another, disturbance or chance may lead to local extinctions. Once a species becomes locally extinct in an isolated habitat island, the likelihood of reintroduction of the species is very low.

While this theory was created [222] and first tested for island biota [335;336], it has since gained support for land-based habitat islands as well [81;88;310], although land systems are more complex [208]. One key difference is that isolated oceanic islands accumulate species slowly until richness stabilizes with constant background introduction and extinction rates, whereas terrestrial habitats that become isolated will over time tend to harbor a decreasing number of species (the effect of time since isolation) [42].

Scientists observed island biogeography effects in a fragmented chaparral habitat system in California, where in a span of 20-80 years since isolation all native rodents had disappeared in over half the habitat patches studied [42]. Researchers in the same area [344] found that patch size and time since isolation explained most of the variation in the number of bird species found within a given habitat patch.

In contrast, in connected habitats a population in one patch may become temporarily extinct, but as long as the patch is connected to another patch populated with that species, it could be re-colonized. This rescue effect is crucial in the maintenance of small populations with limited habitat areas [310]. The rescue effect provides a compelling argument to maintain, improve and even restore lost wildlife connectivity: without connectivity, the number of wildlife species in the region's greenspaces will dwindle over time.

The theory of island biogeography provides a straightforward way to think about the composition of wildlife communities. However, fragmented terrestrial systems are more complex than islands and the theory does not account for edge effects, the matrix surrounding the habitat fragments, and human-caused changes and disturbances [208]. The next sections will discuss these issues.

EDGE EFFECTS AND HABITAT PATCH SIZE AND SHAPE

In addition to the important effects of habitat patch size (see Appendix 2) and proximity to other habitat patches key to the theory of island biogeography, the shape of a patch is also important to determining community diversity and composition [208]. Patch size and shape dictate the relative amount of edge and interior habitat. Edge habitat occurs where one habitat type, such as a forest, meets a meadow, road, or other natural or artificial habitat type [126;214]. Habitat fragmentation increases the amount and proportion of edge habitat, increasing the ecological effects associated with edges (edge effects). Edge effects derive from changes in conditions such as light, temperature, wind, humidity, and disturbances. Because of the increased habitat diversity and complexity of ecotones – the area of interface between two habitat types – edges often have greater species richness. Edge effects, however, also have negative impacts, especially when due to habitat fragmentation. Examples of negative edge effects include increased chance of establishment by invasive species, changes in vegetation structure and altered microclimate (for example, increased temperature and decreased humidity).

Although an increase in edge habitat may benefit some species, it can also reduce native biodiversity [13;187]. Invasive plant and animal species are much more prevalent in edge than in interior habitats. The number of species is sometimes higher in edge habitats, but the number of habitat specialists, which tend to be more sensitive or at-risk species, decreases [273;343]. Some species rely on large areas of relatively undisturbed interior habitat, and many sensitive species such as migratory songbirds avoid edges [164;169;216;216;359]. Nest parasitism – that is, egg-dumping by one species into another's nest – by Brown-headed Cowbirds is also typically higher in species nesting in edge habitats, reducing the host species' reproductive success [134;229;262].

Some urban predators such as foxes, skunks, coyotes, raccoons and jays hunt along edge habitats and trails where birds, bird and turtle nests, and small mammals are easier to find [51;107;375]. While benefitting certain predators, this can result in higher mortality for edge dwelling prey species or species moving through narrow corridors [235]. A study in Washington state found that 95 percent of Steller's Jay nest predations occurred within 50 meters of edges [374]. On the other hand, urban predators play a crucial role in maintaining a functioning ecosystem [35;343]. Larger predators such as coyotes help to maintain biodiversity by suppressing smaller predators such as raccoons and feral cats, and nest predators such as squirrels and mice. Small predators can be extremely destructive to wildlife, especially to ground and shrub nesting birds, when their populations increase above natural levels [343].

Edge effects can penetrate far into the interior habitat necessary for certain species, and the response of wildlife movement to and through edge habitat varies by species [214]. Some studies have shown that certain impacts such as invasion by exotic plants and predation can penetrate up to 1,640 feet (500 meters) into the forest [386]. California researchers found that the abundance of interior habitat bird species was reduced within 656-1,640 feet (200-500 meters) of an edge [43]. In Ontario, Ovenbirds, an interior habitat thrush species, select nest sites more than 820 feet (250 meters) from the forest edge, rendering smaller habitat patches unusable for breeding [58]. Researchers in Pacific Northwest old growth forests found that changes in relative humidity could be measured 98-141 feet (30-240 meters) into the forest interior from the edge of a clear-cut, while changes in soil temperature extended 197 feet (60 meters) into the interior [67]. In the Portland area, one study documented a marked reduction in invasive plant and animal species approximately 200 feet (61 meters) from the edge of forested riparian habitat patches [164].

The size and shape of a patch, as well as the relationship with surrounding habitats, determines the edge effects on wildlife populations [161;289]. For example, the Streaked Horned Lark, a grassland species that has declined severely in the region, uses a relatively small breeding territory but selects territories within much larger areas lacking tall structures such as trees or buildings [296;297]. A large round or square patch has less edge habitat and more interior habitat than a long narrow patch [343], provides fewer movement barriers and allows for increased foraging efficiency [126]. Several studies showed increased insect abundance in large urban and rural habitat patches, benefitting bats [18] and insectivorous birds [58;216;237].

Some studies suggest that the following breeding bird species occurring in the region may be sensitive to habitat patch size during the breeding season (see Appendix 2):

- Forested habitats: Black-capped Chickadee [133], Black-headed Grosbeak [164], Brown Creeper [14;137;164;244], Cassin's Vireo [137], Downy Woodpecker [133;228], Golden-crowned Kinglet [87], Hairy Woodpecker [89;133], Hermit Thrush [14;161;194;244], Pacific-slope Flycatcher [137], Pileated Woodpecker [77;89;137], Red-breasted Nuthatch [161;244], Red-eyed Vireo [89;133;161;228], Ruby-crowned Kinglet [194;244], Steller's Jay [137], Swainson's Thrush [164;194], Varied Thrush [137], Winter Wren [137;164], Yellow-billed Cuckoo [77], Yellow-breasted Chat [133;194], and several small mammal species, including: short-tail weasel, Oregon vole, Northern flying squirrel, shrew-mole, white-footed mouse, Trowbridge's shrew, vagrant shrew, Douglas squirrel, Western gray squirrel and Townsend chipmunk [267]
- Grassland / savannah / oak habitats: Northern Harrier [6], Short-eared Owl [6], Western Meadowlark [6], Streaked Horned Lark [6], White-breasted Nuthatch (also need large oaks) [89;133]

The definition of a large habitat patch depends on many factors including species in question, habitat type, setting (for example, urban, agriculture, rural), geographic region or other factors. Only a few empirical studies have been conducted to determine the appropriate patch size for various species, especially in an urban landscape [179]. In the northeastern U.S., 5-acre (2-hectare) patches provided sufficient small mammal diversity to reduce Lyme disease incidence [4]. Several studies in different regions documented reduced insect/arthropod abundance near edges and in habitat patches less than 37-124 acres (15-50 hectares) [58;82;107;315]. Numerous studies in a variety of areas indicate that larger habitat patches are better for the survival and diversity of native species [42;43;107;386]. These findings support the underpinnings of the theories of metapopulation and island biogeography.

In fragmented habitats, edge effects are generally much more negative than positive [16;90;109;141;154;193;229]. To minimize edge effects, land use planners should to try to maximize the ecological effectiveness of large or scarce habitats by: 1) protecting or expanding existing patches, 2) limiting the area of edge habitat through strategic restoration (for example, strive for more round or rectangular shapes), and 3) connecting habitat patches with well designed and strategically located corridors.

HABITAT PATCH SIZE IN THE PORTLAND-VANCOUVER REGION

Research suggests the importance of habitat patch size in the region. A study conducted in Portland examined 17 ecological variables associated with prevalence of the directly transmitted hantavirus in its wildlife host, the deer mouse (*Peromyscus maniculatus*) [96]. Only species diversity was statistically linked to infection prevalence: as species diversity decreased, infection prevalence increased. Larger habitat patches hosted higher small mammal species diversity. The results suggest that patch size affects species diversity, and species diversity affects disease emergence.

Two local studies suggest a minimum size at which "large" habitat patch characteristics begin to emerge. Metro staff collaborated with Dr. Michael Murphy at Portland State University (PSU) to compare results of his graduate students' fragmentation studies [267] and a Metro field study assessing wildlife habitat quality related to habitat patch size [165]. The two data sets were analyzed separately and the findings compared.

The results were surprisingly similar. The Murphy lab's research indicated that the following small mammals may need habitat patches of about 25 acres (10 hectares) or greater: short-tail weasel, Oregon vole, Northern flying squirrel, shrew-mole, white-footed mouse, Trowbridge's shrew, vagrant shrew, Douglas squirrel, Western gray squirrel, and Townsend chipmunk. Conversely, non-native mammals tended to decrease in abundance in larger patches. Put another way, as habitat patches become smaller, the mammalian population shifts from one dominated by native species to one dominated by non-native species. Dr. Murphy's students also found that avian species richness and abundance tended to increase with natural area size up to approximately 25 acres (10 hectares), and then declined somewhat in larger areas, possibly due to loss of early successional habitat in larger and older greenspaces [267;268]. Neotropical migratory songbird species continued to increase with greenspace size beyond 25 acres. According to Metro's region-wide habitat study, Wildlife Habitat Assessment scores were highly variable up to approximately 30-acre (12-hectare) patches, after which habitat conditions seemed to stabilize at relatively high scores.

Thirty acres (12 hectares) seems to be an appropriate starting point for "large" habitat patches in this region – that is, where area-sensitive small mammal species, bird species richness and better habitat conditions relating to forest structure, native vegetation and increased key habitat elements such as snags and woody debris, begin to appear. This 30-acre size is probably close to a minimum "large" patch, with some species requiring much larger habitat patches.

Several other studies, scattered throughout a variety of forested regions, indicate that 25 to 30 acres (10-12 hectares) may constitute a significant habitat patch threshold for some species [133;244]. This general threshold appeared significant for birds in eastern England [175], understory insectivorous birds in the Amazon [351], birds across multiple seasons in Georgia [244], and potentially for headwater-associated amphibians in northwestern California [378]. On the other hand, some grassland birds may require 500 acres (200 hectares) or more, although species such as Savannah Sparrows may only require about 25 acres [372]. Note that most studies focus on abundance or likelihood of occurrence, which may not be comparable to pairing or breeding success [58;59].

There are benefits to preserving smaller or edge-dominated habitat patches [171]. Although wider is clearly better, long narrow habitats may provide key connecting corridors, and small patches may be sufficient to preserve some plants or vegetation communities [343]. Small patches interspersed between larger patches provide important stepping stones for wildlife movement. However, the effectiveness of such stepping stones may be lower in more hostile matrix areas (see next section) such as roads, buildings or those lacking vegetation [24]. Further, although small, isolated patches may have diminished habitat value, they may also become increasingly important because they begin to serve more of an "oasis" function and are the last remaining indicators of where the "ecological dots" can be logistically reconnected. Small patches near other patches also provide important functions for some wildlife species not dependent on interior habitat. Some species may be able to use small habitat patches that are individually too small by composing a home range made up of multiple habitat fragments [104;179;277]. Other species may survive in urban areas if they have a series of relatively small patches connected by movement corridors [42]. Proximity of small patches to stream corridors and wetlands undoubtedly elevates their significance for wildlife.

Large habitat patches benefit many of the region's sensitive species, but small habitat patches increase the permeability of a landscape to wildlife. Urban areas with trees and shrubs scattered throughout, combined with larger natural areas connected by corridors, are likely to hold more species and more animals than large patches and corridors embedded within an entirely urban matrix. Back yards, street trees, right-of-ways and green roofs can all provide valuable opportunities to increase permeability.

MATRIX: WHAT LIES BETWEEN HABITAT PATCHES

The area that surrounds a habitat patch but that differs in terms of land use, physical and biotic conditions is called the matrix [174;295]. Island biogeography effectively explains concepts such as area and distance effects, but the theory was developed for islands and the seawater matrix surrounding islands is consistent. This simple scenario is not the case for land-based systems, where the matrix can affect a habitat patch's wildlife and habitat in a variety of ways.

Different matrix conditions affect species differently, and may change or increase ecological effects [121]. Some types of matrices, such as urban areas where human disturbance is high and busy roads can form an absolute barrier to wildlife passage, may exert stronger influences than others. The transition from a forested habitat to a densely populated urban area can be quite abrupt. In such cases, edge effects can be stronger and extend further into a habitat patch.

This effect is not always negative, and seasonality can play a role. An Ohio winter riparian bird study revealed a positive relationship between the amount of urban development within 0.6 mile (1 kilometer) and species richness, total abundance, and numbers of nine of ten native bird species [15]. A winter-spring bird study in the Portland, Oregon area found more non-native birds but also more species overall in winter urban residential habitats compared to more rural habitats, and highlighted the importance of conifers to winter birds [166]. In spring, Neotropical migrants were associated with low urbanization and more native shrub cover, but there were more birds overall, native and non-native, in urban habitats. Increasing native tree and shrub cover, and decreasing non-native shrub cover, appear to increase habitat value for Neotropical migratory songbird communities, and also appear to control non-native birds in this region.

Researchers in Ontario, Canada found that the edge effects of residential development impacted migratory songbirds in forested habitat patches regardless of patch size, from patches of 10-62 acres (4-25 hectares) [131]. In Pennsylvania, spring bird species richness and abundance generally decreased with distance from the stream in urban watersheds, but remained relatively constant in agriculture-dominated watersheds [82]. In Rhode Island, human-intolerant species predominated in less developed areas (below 12 percent residential development and 3 percent impervious surface), whereas human-tolerant species predominated above these levels, at several spatial scales [219]. A study conducted near Ottowa, Canada found that agricultural matrices tended to affect bird species at broad scales (within 3.1 miles, or 5 kilometers), whereas urban matrices tended to affect birds at narrow (1.1 miles, or 1.8 kilometers) as well as broad scales [103]; these researchers suggested that limiting urban land use within approximately 656-5,906 feet (200 – 1,800 meters) of forest patches would benefit Neotropical migratory birds.

Changing environmental conditions can also influence matrix effects. A controlled experiment in western Oregon tested the relative movements of Ensatina salamanders along two different (vegetated versus non-vegetated) 10 x 131-foot (3 x 40-meter) pathways between small plots [316]. Under normal weather conditions, the salamanders selected vegetated pathways more often but moved more quickly through non-vegetated pathways, thus the immigration rate resulting from each corridor type was similar. In drought conditions, the animals still preferred and moved more slowly along vegetated corridors, however, the rate of movement along non-vegetated pathways increased and these animals experienced weight loss and increased mortality. Therefore, fewer Ensatinas arrived at the next patch and they arrived in poorer condition compared to vegetated corridors. This study suggests the increased importance of high-quality corridors to mitigate climate change impacts on wildlife.

The effects of the matrix surrounding a patch are often species-dependent. For example, starlings thrive in edge habitats and easily cross wide matrix areas to visit another habitat patch. Both starlings and Brown-headed Cowbirds are associated with low tree cover in this region [164;169]. In contrast, many migratory songbirds are sensitive to disturbance and tend to avoid edge habitat except when migrating. For these species, edge habitat essentially becomes another type of matrix that must be navigated to move between patches; effective patch size shrinks, the matrix area expands, and species unwilling to cross gaps larger than a certain distance are blocked (see Appendix 3). Nonetheless, many birds can readily cross areas that are barriers to other species. Some wildlife species, such as amphibians and turtles, cannot move very fast or very far, particularly on dry land. These types of species are most vulnerable to matrix effects.

Environmental conditions, habitat selection, life-history requirements and mobility help determine matrix effects and what connectivity means to a species. Many matrix habitats do offer some degree of connectivity. The characteristics unique to each species provide important clues to help identify key habitat patches and provide connectivity between them. Roads, residential and industrial areas, which are common in urban matrix areas, can impose a variety of disturbances including noise, sound, light, and human and pet impacts. These are discussed in the next section. In addition, there are many ways to improve the matrix quality in our urban landscape, such as retaining and adding street and yard trees, green roofs, and "feathering" habitat edges with native shrubs and plants.

URBANIZATION AND DISTURBANCE ISSUES

More than half of the world's people live in metropolitan areas, and the proportion is expected to increase [252]. Scientists recognize urban areas as a unique type of ecosystem, with similar characteristics worldwide. A relatively large body of scientific literature documents effects due to urbanization that are similar regardless of geographic location. For wildlife, urban areas typically mean fewer specialized species and more generalist and invasive species [1;32;233]. However, some species appear able to adapt to urban areas by modifying their life-history traits [95].

Most of urbanization's adverse impacts originate from changes in the amount and timing of water runoff, loss and fragmentation of native habitat, increased edge effects, invasive species and disturbance [45;61;302]. Structural simplification is another hallmark of urban habitats, and structural complexity and total vegetation volume are well-known contributors to wildlife species richness in forested areas [12;32;130;145;205;232;258;326]. These systemic alterations harm water quality, wildlife habitat and sensitive species [1;32;166;250].

In general, species best adapted to urban environments are those not limited to a single habitat type, those with populations easily maintained by outside recruitment, and those that can exploit the urban matrix [88;290;324;361]. For example, in this region, habitat generalists such as Scrub Jays, American Robins and European Starlings are abundant, and Vaux's Swifts, which will nest in chimneys, are increasing [167;169;325]. Backyard bird feeders and other supplemental feeding may increase bird, feral cat and raccoon density [15;135;305;355]. The overall and species-specific impacts from supplemental feedings are not well known, and pose an interesting research question in the region [22].

Development patterns and the quantity, environmental conditions and location of undeveloped land strongly affect urban wildlife and habitat [220]. The amount and placement of a few key landscape features, especially trees, shrubs and hard surfaces, significantly influence the types of wildlife that can survive in urban areas. Habitat type, quality and human behavior also influence wildlife.

The next section discusses some of the impacts of roads, noise, light and trails on wildlife and habitat.

ROADS AND ROAD EFFECTS

The ecological footprint of a road can extend far beyond the road itself [125]. There are nearly 4 million miles of roads in the United States [28], and about one-fifth of the U.S. land area is directly ecologically affected by the public road system [125]. The issues reviewed below are covered in more detail in Metro's Wildlife Crossings Guidebook, and the book also offers a variety of solutions to wildlife movement barriers [91]. In brief, key road effects include:

- barriers to wildlife movement and wildlife killed by traffic
- habitat loss and fragmentation, increased edge habitat and edge effects
- changes in plant and wildlife composition; invasive species spread and establishment
- wildlife-vehicle collisions resulting in human injury, death and economic damages
- wildlife avoidance or behavioral changes due to noise, air quality, light and activity levels
- reduced air and water quality affecting aquatic and terrestrial ecosystems

A review of 79 studies found that negative effects of roads on wildlife outnumbered positive effects by a factor of five [110]. The review indicated that amphibians and reptiles tended to show negative effects. Birds primarily showed negative or no effects, small mammals generally showed either positive effects or no effect, mid-sized mammals showed either negative effects or no effect, and large mammals showed predominantly negative effects. The findings indicated that roads most negatively impact certain groups of species, including species that are attracted to or do not avoid roads and are unable to avoid individual cars (for example, amphibians) and species with large movement ranges, low reproductive rates, and low natural densities (for example, large carnivores).

Reptiles and amphibians are particularly vulnerable to road effects, and some species may experience high mortality when migrating to or from breeding areas [75;140;144;204;241], and such casualties do occur in this region. Observant residents who walk or bicycle in such circumstances have probably seen major rough-skinned newt or red-legged frog kills, all in the same short section of road. Road-kill was a major source of amphibian mortality in Indiana, where water, forest habitat, and urban/residential areas were the variables that best predicted mortality [144]. Turtle research across the U.S. indicates that sex ratios have become more male-dominated, presumably because females need to travel further overland to nest and suffer higher road mortality [11;51;140;348;349]. Researchers studying snakes in South Carolina found that smaller species tended to avoid roads altogether, some species immobilized in response to approaching vehicles, and some could not cross roads with high traffic densities [9].

Birds are frequently killed by vehicles, and mortality may be influenced by a variety of factors including species, habitat and road design. One literature review stated that birds often killed from highway-related causes include non-flying birds such as gallinaceous birds and ducklings; waterbirds such as terns; owls; ground-nesters; scavengers; Neotropical over-water migrants; and fruit-eating birds [183]. The review also offers several mitigation suggestions. In Virginia, researchers found a close association between a median planted with fruit-bearing shrubs and Cedar Waxwing mortality, and collected 459 dead birds along a 500 meter highway section in a 7-week period [379].

A recent estimate indicates there are between one and two million collisions between large animals and vehicles in the United States annually, and that collisions between animals and vehicles comprise five percent of all reported motor vehicle collisions [180]. Although reported vehicle-vehicle collisions have remained relatively steady from 1990 to 2004, reported animal-vehicle collisions have increased by 50 percent, a likely result of more people driving more miles and increases in deer populations in the United States [180].

Roads may also impact wildlife through noise and artificial light, as discussed in the following sections.

NOISE

Excessive noise, or noise pollution, can affect wildlife in a variety of ways including mortality, altered habitat use and activity patterns, increased stress response, decreased immune response, reduced - or sometimes increased - reproductive success, increased predation risk, degraded same-species communication, and damaged hearing if the noise is sufficiently loud [97;105;128;132;291;292;311-313;337;338]. Traffic volume and distance from road appear to play key roles in noise effects [105;107;132;291].

The loudest road noise occurs at lower pitches and can influence wildlife communication. Various studies, including one in Portland [393], show that some bird and frog species change the pitch of their songs to higher frequency near noisy roads [105;291;292;311;338]. This may represent a potential tradeoff between audibility and attractiveness to potential mates or territory defense. Densities of such species are often reduced near roads [313].

Animals may avoid or select noisy environments, disproportionately affecting some species. Researchers in Ontario [105] found thresholds of at least 250-1,000 meters within a busy highway where frog abundance was significantly reduced. In Arizona, researchers studying elk use of underpasses found that traffic over the crossings, particularly semi trucks, caused flight behavior [132]. On the other hand, a Utah study suggested neutral or positive effects for the majority of small mammal species captured near a noisy interstate highway [39]. Some species, such as deer, may become habituated to noisy environments [99].

Noise pollution appears to reduce reproductive success in some species [97;128;189]. However, other species may selectively and more successfully nest near noisy sites to avoid nest predators such as jays [128;338], potentially contributing to their increased reproductive success in urban areas.

Several noise mitigation measures can be employed, including noise barriers and reducing the source of noise [183;313;338]. Changing road elevation, such as elevating roads above habitat level, may help because most of the noise derives from the road surface. Sound walls can be effective noise barriers, but can also block wildlife passage; vegetation can help block noise without blocking wildlife movement, but if the vegetation attracts wildlife to road areas then crossings or other measures should be considered. Smoother road surfaces and road design can reduce noise.

ARTIFICIAL LIGHT

Longcore and Rich provide an extensive review of the consequences of ecological light pollution, which alters natural light regimes in terrestrial and aquatic ecosystems [217]. Light pollution includes chronic or periodically increased illumination, unexpected changes in illumination, and glare. The effects of ecological light pollution have been studied for some species, but the more subtle influences of artificial night lighting on the behavior and community ecology of species are less well recognized, and constitute a new focus for research in ecology as well as a pressing conservation challenge [26;269].

Some impacts of artificial light pollution arise from changes in orientation, disorientation, and attraction or repulsion of various wildlife species. Orientation and disorientation are species' navigational responses to the amount of light falling on objects in the environment, whereas attraction and repulsion derive from species' behavioral responses to the actual light sources and brightness.

Nocturnal animals accustomed to navigating in darkness can become disoriented in artificial light. Rapid increases in light may temporarily blind and disorient certain species, including some frogs, making them vulnerable to predation or traffic [26;217]. Researchers have documented that night lighting can interfere with the ability of moths and other nocturnal insects to navigate [129]. Some animals navigate at night by stars, and light pollution can cause disorientation by making stars less visible [183].

Artificial light attracts some species and repels others. Migratory birds seem to be attracted to buildings lighted at night, causing significant mortality [217]. Many migratory songbirds are attracted to lights and are killed at lighted towers; the U.S. Fish and Wildlife Service estimates that the number of birds killed after being attracted to tall lighted towers ranges from at least 4-50 million per year [230]. Large carnivores may avoid artificial light, creating an unintentional barrier effect for lighted areas [25]. Insects and other arthropods may be attracted or repelled by light, and certain bird and reptile species typically active only during daylight hours will forage under artificial light, potentially benefiting those species but not their prey [173].

Artificial night light may change animal behavior, inducing diurnal birds to sing territorially at night or earlier in the morning, wasting valuable energy [217;255]. Light pollution can negatively impact the migratory and breeding behavior of frogs and salamanders [217;321;392]. It can also change the duration and timing of bat foraging, with unknown consequences [41]. A European study of house-dwelling bats found that juveniles were smaller in night-lit houses than in those that were not lit [41].

In certain situations, artificial lighting may provide a conservation tool. For instance, lighting, in combination with other mitigation measures such as fencing and modifications to bridges, can reduce wildlife-vehicle collisions [243]. Night lights are sometimes used to attract fish to ladders near dams [217]. However, the majority of the science points to negative or at best, unknown effects for wildlife.

Light pollution can be mitigated, including using newer designs that meet the Illuminating Engineering Society of North America's standards and also reduce light pollution [183]. Directing light downward or away from habitat, reducing glare and using lower wattage flat lens fixtures on highways and city streets reduces light pollution, and increasing reflectivity of signs and road striping in appropriate areas may increase driver visibility while reducing the need for artificial lighting. One easy solution is to turn off unnecessary lights at night. Some urban areas are making strides toward reducing night lighting, as with the City of Chicago's "Lights out for Birds" campaign [71]. This has the added benefit of reducing cost and energy use.

TRAILS

Trails create edge habitat and may cause a variety of ecological impacts including trampling, soil compaction, erosion, pollution, fragmentation and edge effects, and introduction or spread of invasive plant species [188]. Some wildlife species may be particularly susceptible to predation, noise and motion disturbances near trails. Trail disturbances sometimes parallel road effects relating to light, noise and disturbance in that higher traffic volume tends to exert a stronger influence [114].

Several studies examined the influence of trails on wildlife, most notably on bird species [253;257;353]. Trails introduce human disturbance, causing a flight response in birds at various distances from people (the "flush distance"). Nearly all bird species will flush if approached too closely by humans, and larger species or those species active near the ground tend to be less disturbance-tolerant [107;116;148]. Energy that could be used for critical activities such as feeding, territory maintenance and breeding may be spent on avoidance behavior. Trail planning efforts should consider these factors if species of conservation concern are known or suspected to inhabit the study area.

Trails may reduce nest success [188]. However, species, habitat, disturbance types, and study methods sometimes show apparently opposite trends. For example, a Portland, Oregon study revealed increased Spotted Towhee reproductive success for nests within 33 feet (10 meters) of a trail [22]. A Colorado artificial nest study in lowland riparian areas showed lower predation rates closer to trails [253]; birds attacked more clay eggs in artificial nests near trails than away from trails, whereas mammals appeared to avoid nests near trails to some extent. However, artificial nest studies do not necessarily reflect reality [215;227;293;388]. Another researcher in Colorado studied real bird nests in grassland and forest ecosystems and found proportionately more generalist species near trails, fewer birds nesting near trails in grasslands, and reduced nest success near trails in both habitats [257]. Trails did not appear to affect cowbird parasitism. In northeastern California, one study showed greater bird nest desertion and abandonment – but reduced predation – on shrub nests less than 328 feet (100 meters) from off-highway vehicle trails compared to nests further from trails [21]; two of 18 bird species were less abundant at sites near trails than at sites 820 feet (250 meters) from trails, and no species were more abundant closest to trails.

Researchers in Spain found that 16 of 17 bird species were negatively affected by increasing pedestrian rates [113]. In Boulder, Colorado some species occurring in this region, including Western Meadowlarks, Chipping Sparrows and Western Wood-peewees, were significantly more abundant in areas away from trails, whereas American Robins and House Finches were more abundant near trails; nest failure for most species and cowbird parasitism on forest-dwelling species were more common near trails [257]. This study identified a trail "zone of influence" of about 246 feet (75 meters) from the trail for most species. As with roads, some species seem able to habituate to trails, including some habitat generalists and urban-associated species [107;114]. A southern California study suggests that deer, bobcats and coyotes become less active during the day in recreation areas, and effects were stronger in areas with heavy recreation [136].

One researcher [188] reviewed literature pertaining to trails and wildlife, in which studies indicated several key points:

- direct approaches cause greater wildlife disturbance than tangential approaches*
- rapid movement by joggers is more disturbing than slower hikers (no studies specifically addressing bicycles were found)**
- children and photographers are especially disturbing to birds
- passing or stopping vehicles are less disturbing than people on foot
- trails are associated with invasive plants, with more effect on higher-use trails (emphasizes the importance of cleaning boots and shoes between sites)
  *Note: We located one study in Spain in which numerous bird species were substantially more sensitive to tangential than direct approaches [117]
  **We located two studies demonstrating significant negative effects of bicycling activities on elk and waterfowl [270;298]

Research indicates that dogs on or near trails have negative impacts on wildlife beyond that of humans alone. This has been demonstrated for small mammals, mule deer, grassland bird species and bobcats [211;256]. A Colorado study showed reduced deer activity within 164 feet (50 meters) of trails where dogs were prohibited, but the distance doubled to 328 feet (100 meters) for trails that allowed dogs, with similar effects on a variety of small mammals [211]. Dog walking in Australian woodlands led to a 35 percent reduction in bird diversity and 41 percent reduction in abundance [19]. Off-leash dogs may be particularly detrimental, because some wildlife species can habituate to predictable disturbances but the behavior of off-leash dogs is unpredictable [95;211].

In South America, trail-wildlife researchers note that implementing restricted use buffer zones can moderate the effects of cars and pedestrian traffic, but can also conflict with recreational activities. They recommend re-distributing human disturbance by varying the number of visitors and area of visitation according to the spatial requirements of differently sized species [116]. This type of approach could be used in this region by determining what kinds of trails to install based on habitat and target species, and where and how to build them.

Despite the potential for negative wildlife impacts, trails can provide opportunities to increase wildlife connectivity. If humans can walk or bike along a natural area trail, most wildlife species can as well, although behavioral responses may limit passage depending on factors such as species, traffic volume, region, etc. A crossing structure may be incorporated into the design of bicycle/pedestrian facilities or recreational trails, but target wildlife species and their sensitivity to human disturbance must be considered. Metro's *Green Trails Guidebook* offers general recommendations on planning and implementation for trails in sensitive habitat areas. More studies on this topic are needed in this region.

INVASIVE SPECIES

Native plants are preferred for native wildlife because they tend to control non-native wildlife, support more insect prey, require little maintenance once established, and provide habitat diversity [32;57;66;166;169;245;267;299;299;395]. There are, however, species- or habitat-specific exceptions to this generality [162;317].

A Pennsylvania study comparing wildlife using native versus non-native suburban landscaping found that native properties supported significantly more caterpillars and caterpillar species and significantly greater bird abundance, diversity, species richness, biomass, and breeding pairs of native species; bird species of regional conservation concern were eight times more abundant and significantly more diverse on native properties [57]. Caterpillars are large and slow moving, and are particularly important to Pacific Northwest breeding birds [7]. Planting certain native caterpillar host plants, such as ocean spray (*Holodiscus discolor*), can significantly enhance habitat value for wildlife.

Habitat fragmentation, edge effects and climate change tend to increase invasive species. Invasive species are recognized as a major threat to ecosystems worldwide, but urban areas are particularly vulnerable due to high levels of habitat disturbance and the many routes through which such species can be introduced [100;265;278;299;304;373]. By one estimate, damage and loss from invasive species in the U.S. is at least $120 billion per year [304].

The Oregon Invasive Species Council defines invasive species as those species not native to the region which out-compete native species for available resources, reproduce prolifically and can dominate habitats, regions or ecosystems [278]. The group notes invasive species' lack of natural predators and potential to transform entire ecosystems, as native species and wildlife that depend on them for food, shelter and habitat disappear. Oregon Department of Fish and Wildlife (ODFW) developed the Oregon Invasive Species Council Action Plan in 2005 [278]. The plan states that exclusion, early detection and rapid response are by far the most cost-effective ways of dealing with undesirable invaders. The Action Plan's goal is to facilitate efforts to keep invasive species out of the state, find invasions before they establish permanent footholds and do whatever it takes to eradicate incipient populations of undesirable species. Education and cooperation are key components to an effective strategy.

The region has formed a collaborative effort to control invasive plant species. The Clackamas, Clark, Multnomah, and Washington County Cooperative Weed Management Area (CWMA) was formed to create and support collaborative weed management among land managers and owners in the region [127]. The CWMA coordinates weed management activities across multiple boundaries and ownerships, enhances funding opportunities, and promotes weed education/outreach, weed inventory and prevention and weed control activities. The management plan and other valuable information, such as weed control methods, are available online (www.4countycwma.org).

CLIMATE CHANGE

Urbanization as land use conversion is likely to have stronger and more rapid effects on the local habitat than global climate change [323]. Nonetheless, climate change is an important ecological driver to consider as (a) it will likely trigger migration of animals and elevate the need for connectivity for wildlife and plant species as ranges shift; and (b) restoration and structural elements added now may be in place for decades, therefore anticipating species' ranges and habitat needs now may facilitate their future survival.

The institute for Sustainable Environment issued a climate change report in 2009 for the upper Willamette Basin, where annual average temperatures are likely to increase from 8 to 12 degrees Fahrenheit (4 to 6 degrees Celsius) by around 2080 [98]. The report on the lower Willamette Basin is currently under revision, but projected impacts appear to be similar.

The region will see significant changes [98]. Storm events will be more severe and the region will have more water when it is not desirable, and less when it is needed. The result will be significantly altered hydrology from historic or current conditions. Existing habitat stressors including fragmentation, habitat loss and invasive species encroachment, will likely worsen; some rare habitats may decline and coniferous trees may be replaced by deciduous trees in certain areas, especially in lowlands. Some vegetation may become drought-stressed. Invasive species, disease and pests may increase and some new ones will likely emerge. The rate of change is expected to exceed species' ability to adapt. If they cannot adapt, the next best option is moving to appropriate habitat.

Scientists believe that corridors facilitating wildlife movement will be necessary for some species' survival [143]. The Institute for Sustainable Environment provides a series of recommendations that emphasize the need to maintain and restore ecosystem function and connectivity. Connectivity ensures that species can move to new areas, and "should become a priority of land management practices" [98]. In this region, wildlife that must undergo range shifts will need connectivity between important habitats within the urban area, to the Coast and Cascade mountain ranges, and north-south connections through the valley, including habitat on each side of major rivers.

Although climate change predictions have been made for some species, the overall changes expected in wildlife communities are not fully known [143;182;306]. Changes in some bird species' ranges attributable to climate change have been documented in Massachusetts and Maine [367;390], and for the majority of species wintering throughout North America [274]. Some species, such as habitat specialists or species already declining, will be more at risk. Intact ecosystems, best represented by large habitat patches, and associated species are less at risk.

The National Wildlife Federation reviewed the scientific literature pertaining to climate change adaptation and found that adaptation measures identified in the literature generally address the following five overarching principles (from [143]):

1. **Reduce other, non-climate stressors.** Addressing other conservation challenges, such as habitat destruction and fragmentation, pollution, and invasive species, will be critical for improving the

ability of natural systems to withstand or adapt to climate change. Reducing these stressors will increase the resilience of the systems, referring to the ability of a system to recover from a disturbance and return to a functional state.

2. **Manage for ecological function and protection of biological diversity.** Healthy, biologically diverse ecosystems will be better able to withstand some of the impacts of climate change. Ecosystem resilience can be enhanced by protecting biodiversity among different functional groups, among species within functional groups, and variations within species and populations, in addition to species richness itself.
3. **Establish habitat buffer zones and wildlife corridors.** Improving habitat connectivity to facilitate species migration and range shifts in response to changing climate condition is an important adaptation strategy.
4. **Implement proactive management and restoration strategies.** Efforts that actively facilitate the ability of species, habitats and ecosystems to accommodate climate change – for example, planting climate-resistant species and trans-locating species – may be necessary to protect highly valued species or ecosystems when other options are insufficient.
5. **Increase monitoring and facilitate management under uncertainty.** Because there will always be some uncertainty about future climate change impacts and the effectiveness of proposed management strategies, careful monitoring of ecosystem health coupled with management approaches that accommodate uncertainty will be required.

A new report by the Association of Fish and Wildlife Agencies provides a detailed approach for agencies wanting to incorporate the impacts of climate change into state Wildlife Action Plans and other wildlife and habitat management plans [74].

Habitat loss, fragmentation, invasive species and human disturbance already stress the region's fish and wildlife communities. Climate change will add to those stressors, but connectivity can help alleviate some of climate change's detrimental effects on the region's biodiversity.

OVERVIEW OF THE REGION'S HABITAT AND WILDLIFE

HISTORIC AND CURRENT HABITAT

Prior to European settlement the Willamette Valley consisted of a mosaic of large patches of riparian forests and wetlands, open white oak savannas and prairies, and hills of oak, Ponderosa pine and Douglas-fir [206]. Native Americans historically set controlled fires that maintained the prairies, savannas, and oak woodlands throughout much of the valley for many years [283;284].

Using data from land surveys for the General Land Office between 1851 and 1895, the Oregon Natural Heritage Program (now called the Oregon Natural Heritage Information Center) created a historical vegetation map for Oregon [69]. The map shows that this region was covered predominantly by closed and open canopy forest interspersed with prairie and savanna habitats.

Table 1 provides the estimated percentage breakdown for the types of vegetation that once covered the region compared to more recent land cover data. Forest canopy covered more than three fourths of the Clackamas, Sandy, Tualatin, and Willamette River basins within this region. The area inside the Portland area's urban growth boundary is currently comprised of about 30 percent tree cover [168]. The Columbia River and Multnomah Channel contained significant amounts of riparian forest, wetland, dry prairie and savanna, and open water. The Tualatin River basin contained a significant amount of dry prairie and savanna habitat.

Table 1. Percentage of vegetation cover within the urban growth boundary of the Portland, Oregon area: estimated historical versus recent.

Vegetation Type	WATERSHED						
	Clackamas River	**Columbia River**	**Multnomah Channel**	**Sandy River**	**Tualatin River**	**Willamette River**	**All**
	Percent historic/current	*Percent historic/current*	*Percent historic/current*	*Percent historic/current*	*Percent historic/current*	*Percent historic/current*	*Percent historic/current*
Barren/Urban	<1 / 27	<1 / 52	0 / 3	0 / 45	<1 / 17	<1 / 29	<1 / 24
Upland closed forest canopy	68 / 28	40 / 3	53 / 32	82 / 8	47 / 23	52 / 25	49 / 22
Upland open forest canopy	16 / 9	4 / 10	1 / 3	0 / 16	28 / 8	30 / 15	25 / 10
Riparian/ wetland forest	11 / 2	16 / 2	10 / 2	12 / 4	6 / 1	3 / 2	6 / 1
Wetlands and wet prairies	<1 / <1	4 / 2	8 / 2	<1 / 1	3 / 1	<1 / <1	2 / <1
Dry prairie, savanna, and shrubland	2 / 6	14 / 10	21 / 17	0 / 10	16 / 6	10 / 5	14 / 6
Ag riparian/ wetland	0 / <1	0 / <1	0 / 2	0 / <1	0 / 1	0 / <1	0 / <1
Ag Upland	0 / 25	0 / 2	0 / 35	0 / 10	0 / 43	0 / 19	0 / 31
Water	2 / 2	22 / 19	7 / 3	6 / 6	<1 / <1	4 / 4	4 / 4
Total Acres	14,053	47,252	22,481	6,892	289,985	166,356	547,017

Source: Christy 1993, Metro 1998 land cover data [69;250].

Notes:

1) The Urban category underestimates the amount of land covered with urban development because it excludes urban uses that are also intermingled with open and closed forest canopy cover.
2) The table shows a 43 percent decline in forest cover from historic levels. Forest composition has also changed due to loss of conifers, old growth forests and white oak woodlands.
3) Current riparian/wetland forest is only 17 percent of historic levels. However, the difference is probably much greater due to the assumptions used to calculate current riparian/wetland forest cover. This cover type was estimated using 200-foot buffers along streams and wetlands. This significantly overestimates the actual amount of riparian forest given existing land use patterns.
4) Historic dry prairie, savanna, and shrubland have been largely converted to non-native grasslands and shrublands.
5) Agriculture and urban categories comprise 55 percent of the land area in the region, representing a total conversion from the original land cover.

Changes in the types and amount of habitat lead to changes in wildlife communities. Although comprehensive survey data, both past and present, do not exist, consultations with some of the region's leading wildlife experts helped compile the following species information currently living in the region [250].

There are nearly 300 native vertebrate species in the region, including 16 amphibian, 13 reptile, 209 bird, and 54 mammal species (Appendix 5) [250]. A variety of native upland and riparian habitats is necessary to maintain the region's existing wildlife diversity. Ninety-three percent of the region's wildlife species use riparian areas at some point, with 45 percent regularly dependent on those areas. Eighty-nine percent of the region's terrestrial species are associated with upland habitats, with at least 28 percent regularly depending on these habitats.

Local Breeding Bird Survey data document declines in species specializing on habitats such as native oak, grassland, and riparian, and studies suggest that riparian areas, native shrubs, tree cover, woody debris and habitat patches greater than 30 acres (12 hectares) are particularly important to the region's wildlife in forested habitats [164-169;267;268;300].

The sections below provide a brief description of the region's wildlife by taxonomic group. Metro's 2005 Vertebrate Species List is included in Appendix 5, and Metro's 2006 State of the Watersheds report includes an appendix cross-walk of the region's sensitive species with Oregon Department of Fish and Wildlife's Strategy Species, including brief information on these species' needs, threats and conservation recommendations [167].

FISH

Although this paper focuses on terrestrial wildlife, the riparian areas that provide wildlife corridors are also key elements of fish habitat, as are all fish-negotiable streams and rivers.

The Metro region provides habitat for at least 26 native fish species, plus at least one extirpated species. Fifteen more species (37 percent) are non-native. Seven anadromous Pacific salmonid species (all members of the scientific genus *Oncorhynchus*) are native to Oregon. They include chinook, chum, coho, sockeye, steelhead and cutthroat trout [52;65]. Salmon survival depends on high-quality, stable environments from mountain streams, through major rivers to the ocean. As such, salmon habitat requirements serve as an indicator of the conditions needed for other fish species. Thirteen salmon runs are federally ESA-listed, with two of these also state Threatened or Endangered. Another run is listed as Endangered only at the state level. Out of the entire genus, only resident rainbow trout are not considered to be at risk.

The adverse effects of urbanization on salmon habitat include increased temperatures, low dissolved oxygen, increased turbidity and sedimentation, changes in streamflow patterns and floodplain connectivity, loss of physical habitat (pools, riffles, gravel beds, off-channel habitats, hyporheic flow), and loss of invertebrate prey. Woody debris is the preferred cover [239;342], and its documented loss in urban streams degrades fish habitat quality [23].

Currently, the *Lower Columbia River Conservation and Recovery Plan* is in draft form, scheduled for public outreach during the first half of 2010 (see www.dfw.state.or.us). In 2006, the Oregon Department of Environmental Quality (DEQ) issued the Willamette Total Maximum Daily Load (TDML), citing water temperature as a key, overarching pollution problem in the region [282]. The DEQ states that remedies to the region's TMDL issues include planting vegetation to reduce erosion and keep water cool; changing habits at home, at work, and at play to prevent or reduce pollutants entering waterways; improving fish passage and opening habitat that was blocked by past practices; and reducing erosion and sediment entering streams. These restoration activities will clearly benefit wildlife as well. Fish passage improvement projects can offer excellent, and sometimes inexpensive, ways to improve connectivity, sometimes as simple as installing a shelf or boulders to allow small animal passage through a culvert in high water periods.

AMPHIBIANS

At least 16 native amphibian species live in the region, including 12 salamander and four frog species (Appendix 5) [250]. Bullfrogs are introduced and biologists suspect they place considerable pressure on native species [138;260;286;309]. Eleven of these species rely exclusively on stream or wetland related riparian habitat for foraging, cover, reproduction sites and habitat for aquatic larvae [250]. Two species rely almost solely on uplands, although most species (94 percent) use upland habitats during their life cycles [250]. Six Metro-region amphibian species are state-listed species at risk; four species are considered at risk at the federal level.

This group of animals may be the vertebrates most vulnerable to extinction due to habitat isolation and climate change [281]. Amphibians have small home ranges and cannot travel as freely as other animals. Most of the region's amphibians require both aquatic habitats and terrestrial habitats close to water to complete their life cycle; most require ample woody debris. It may be difficult or impossible for these species to navigate the urban matrix. Amphibians are also particularly vulnerable to water pollution, in part because toxins may be absorbed through their skin [112].

Amphibians have suffered worldwide declines over the past several decades, with nearly a third of all species red-listed (threatened with extinction) under the International Union for the Conservation of Nature, or IUCN [352]. This group is highly sensitive to habitat loss and alteration such as microclimate changes [281]. For example, habitat fragmentation creates edge habitat and edge habitats tend to have elevated temperatures and reduced humidity. Unlike other species groups, amphibians' skin and eggs are not waterproof, and such microclimate changes may be lethal [112;198;281].

Many amphibians rely on stream connectivity and small stepping stone wetlands between larger habitat areas to move and disperse. Storm water detention facilities are emerging as a key factor in the region's wetland connectivity and provide regular feeding and breeding habitat for a variety of native amphibians. A Portland study of 59 wetlands found no difference in amphibian presence between natural and created wetlands [178]. In Gresham, 52 of 138 (38 percent) sites surveyed hosted native breeding amphibians. Of those 52 sites, more than half were constructed storm water ponds and swales [147]. These studies document the importance of small wetlands, often overlooked in conservation planning as well as regulation, to the region's connectivity and biodiversity. Recent court decisions removed isolated wetlands from federal wetland protection [139;209;210;385], further emphasizing the potential importance of storm water detention facilities and small wetland conservation to amphibians.

Research suggests that amphibians in urban areas are susceptible to direct mortality, road noise, fragmentation and barriers [75;110;144;204;241;328]. Particularly affected species include those that require short hydroperiods (timing and amount of water in the wetland), early breeding activity, and substantial upland habitat use [303]. Because they require moisture and have limited mobility, habitat connectivity for amphibians will likely depend on stream corridors and natural and created wetlands in close proximity to one another. Passage between such habitats can be enhanced through appropriate wildlife under-crossings and by augmenting cover – for example, planting native herbaceous and low shrub cover and placing arrays of large woody debris between key areas.

REPTILES

Thirteen native reptile species live in the region, including two turtle, four lizard and seven snake species (Appendix 5) [250]. Two more turtle species, snapping turtles and red-eared sliders, are non-native and invasive. Reptiles depend more on upland habitats than other species groups, with 100 percent of species using upland habitat during their life cycles [250]. However, both native turtle species require riparian-wetland as well as upland habitats. These two species are listed as at risk at state and/or federal levels.

Reptiles are heterothermic (cold-blooded) and some species have special behaviors and habitat requirements in order to collect the sun's energy. Many lizard and snake species rely on upland cliffs and rocky outcrops to gather heat during cool periods. Crevices within these structures also provide important refuge during hot spells. However, some reptiles prefer riparian areas, fulfilling complex life history needs through the structural and functional diversity provided by riparian forests. For example, the common garter snake forages for amphibians, small fish and earthworms, and needs riparian denning sites with good cover, such as downed wood and good shrub and understory. Downed wood is also important in upland reptile habitat [55;294].

Western pond turtles and painted turtles are the two native turtle species living in the region, and they are both listed as Critical on Oregon Department of Fish and Wildlife's Sensitive Species list [285]. These species eat a variety of foods such as plants, insects and tadpoles, need basking logs or structures in the water, and require both riparian and upland areas for feeding and nesting [284]. Pond turtles are in jeopardy due to habitat loss, isolation and predation on eggs and hatchlings by predators such as raccoons, non-native turtles and fish [286]. Western pond turtles have dangerously restricted gene pools due to geographic isolation of populations [284].

Although no local studies have been conducted, studies elsewhere in the country demonstrate that turtle sex ratios have become skewed towards males [11;51;140;271;348;349] (see also roads section). A Texas study suggested similar difficulties with snakes [318]. Local pond turtle populations sometimes contain only large older turtles, indicating unsuccessful reproduction, possibly due either to lack of or isolation from breeding habitat [286].

Providing safe connectivity between important habitat patches, including appropriate crossings, such as the Rivergate undercrossing created by the Port of Portland to connect two wetlands used by painted turtles, can increase the breeding populations of the two native turtle species. Conserving, restoring and creating wetlands and important nearby upland habitat will also benefit turtles and many other species.

BIRDS

Birds often represent a majority of vertebrate diversity in a region, and indeed the 209 native bird species comprise about two-thirds of the region's native vertebrate species (Appendix 5) [250]. Four more non-native species have established breeding populations in the area, and Barred Owls appear to be establishing a breeding presence. Birds are probably the most researched vertebrate group in the country, and thus provide much of the research cited in this report.

There are many upland-associated bird species - 61 species, or 29 percent, depend on uplands and 86 percent use uplands at some point - although about half of the region's native bird species depend on riparian habitats for their daily needs and most species use riparian habitats at various times during their lives [250]. Twenty-two bird species on Metro's list are state or federal species at risk; 19 of these are riparian obligates or regularly use water-based habitats. An additional riparian obligate, the Yellow-billed Cuckoo, was extirpated in the region; however, a single bird was observed in 2009 in the Sandy River Delta – a very hopeful sign and a good reason to continue restoring contiguous bottomland hardwood habitat. This species does an excellent job controlling tent caterpillar infestations and unlike European cuckoos, is not a nest parasite.

Urban bird communities are typically less diverse compared to those in undisturbed habitats, but contain higher numbers of birds due to domination by a few non-native and urban-associated species. Richness of urban bird species, particularly of habitat specialists, tends to decrease over time [1-3;142;166;167;169]. Long-distance migratory species that breed here and winter south of the U.S.-Mexico border (Neotropical migrants) appear to respond negatively to urbanization here and elsewhere [131;164;169;299], perhaps related to noise, fragmentation, food or nesting resources, or predation. However, the region still hosts a substantial number of bird species, as demonstrated by several local field surveys [38;166;169;267;268].

The European Starling, an abundant and highly edge-associated non-native species, is closely associated with the region's riparian habitats during breeding season and can comprise 50 percent or more of total birds in the region's narrow riparian forests [166;169]. Starlings aggressively out-compete natives for food and breeding habitat [181;192;301]. Neotropical migrants rely heavily on riparian areas for breeding and migration, therefore widening narrow riparian corridors will reduce starlings and benefit migratory songbirds.

Some bird species, such as the Rufous Hummingbird, Swainson's Thrush, Winter Wren, Brown Creeper and Pacific-slope Flycatcher, may be particularly sensitive to habitat fragmentation or disturbance in this region and appear to require large habitat patches during the breeding season [165;169]. Species that tend to be edge-associated, utilize urban habitats, or are habitat generalists may thrive in urban areas (for example, House Sparrows, European Starlings, Scrub Jays, American Crows and House Finches) [38;165;169]. Some cavity-nesting species such as swifts, swallows and Bewick's Wrens appear to be faring well in the region [167;325] and in other urban areas [40], possibly because cavity nesters are less vulnerable to small predators. Open-cup nesting species that nest lower to the ground are disproportionately declining, seeming to bolster the small predator theory [167].

It is likely that simplified vegetation structure associated with edge habitat and urbanization in the region, including lack of native shrubs, reduces the amount and quality of breeding habitat available for forest-dwelling songbirds [165;166]. Research suggests that birds respond to vegetation composition and structure, and urban areas with more native vegetation retain more native species [66;299]. Primary stressors for area-sensitive forest breeding birds in urban environments may include disruption of ecosystem processes, urban- and edge-associated predators, disturbance, connectivity barriers, habitat alteration (for example, invasives; loss of large wood) and outright habitat loss [43;107]. A local study suggested that conifers may be especially important to native wintering birds and that native shrubs are important to both breeding and wintering native birds [166].

The effects of habitat fragmentation are not limited to forest habitats. Grassland-dependent bird species are declining disproportionately in the region [5;6;167;325;371]. Many of these species require large habitat areas, and most of the region's native meadows and grasslands have vanished [5;6;314;372].

The effects of climate change are already being seen for some wildlife, including birds. Bird ranges are shifting and some species are migrating earlier [367;390]. For example, analysis of 40 years' of Christmas Bird Count data revealed significant northward range shifts by 68 percent of observed species, with an average distance moved by all bird species of 35 miles (56 kilometers) northward, but grassland species did not appear to be shifting ranges and the average distance was larger when the latter were excluded [274]. The National Wildlife Federation and the American Bird Conservancy modeled predicted U.S. bird changes due to climate change [306]. According to these models, 32 percent of Pacific Northwest neotropical migratory songbird species may disappear. New species will also appear as they undergo range expansions, for a predicted net loss of 16 percent. *The Birdwatcher's Guide to Global Warming* includes a CD (also available online at www.abcbirds.org) predicting bird species changes by state. These potential changes are summarized for the region (species not typically present here during summer are excluded in lists 1-4).

1. **Species whose future range may exclude Oregon in summer:** Black-capped Chickadee, Red-eyed Vireo, Townsend's Warbler, Savannah Sparrow, Dark-eyed Junco, Red Crossbill and Evening Grosbeak.
2. **Species whose summer ranges in Oregon might contract:** Olive-sided Flycatcher, Willow Flycatcher, Hammond's Flycatcher, Streaked Horned Lark, Tree Swallow, Cliff Swallow, Red-breasted Nuthatch, House Wren, Winter Wren, Marsh Wren, Cassin's Vireo, Warbling Vireo, Nashville Warbler, Yellow Warbler, Yellow-rumped Warbler, MacGillivray's Warbler, Common Yellowthroat, Wilson's Warbler, Western Tanager, Lazuli Bunting, Chipping Sparrow, Fox

Sparrow, Song Sparrow, White-crowned Sparrow, Western Meadowlark, Yellow-headed Blackbird, Bullock's Oriole, House Finch, Pine Siskin and American Goldfinch.

3. **Species whose climatic summer ranges in Oregon might undergo little change:** Western Wood-Pewee, Pacific-slope Flycatcher, Say's Phoebe, Western Kingbird, Violet-green Swallow, Northern Rough-winged Swallow, Barn Swallow, White-breasted Nuthatch, Hutton's Vireo, Orange-crowned Warbler, Black-throated Gray Warbler, Hermit Warbler, Black-headed Grosbeak, Spotted Towhee, Red-winged Blackbird, Brewer's Blackbird, Brown-headed Cowbird, Purple Finch and House Sparrow.
4. **Species whose climatic summer ranges in Oregon might expand:** Black Phoebe, Ash-throated Flycatcher, Purple Martin, Chestnut-backed Chickadee, Oak Titmouse, Bewick's Wren, Northern Mockingbird, Loggerhead Shrike, Yellow-breasted Chat, California Towhee and Lesser Goldfinch.
5. **Species whose future climatic summer ranges might include Oregon:** Phainopepla, Bell's Vireo, Blue Grosbeak, Dickcissel and Cassin's Sparrow.

This type of species modeling can help focus conservation interest on certain species that are not yet, but may become, at risk. In contrast, species that are unlikely to persist in the region over the long term may not be good conservation candidates.

MAMMALS

Mammals are another diverse group of species in the region, with at least 54 native species (Appendix 5). Mammals are not as strongly associated with riparian habitats as amphibians and birds: 28 percent are closely associated with riparian habitats, with another 64 percent using these habitats at various points during their lives. Eighteen of the region's mammal species (33 percent) depend on upland habitats, and nearly all species (92 percent) use upland habitat at some point in their life cycles [250]. Six out of nine bat species are state or federal species at risk. Three native rodent species are similarly listed.

The region harbors at least eight non-native species; most are rodents. Nutria are the primary non-native mammals using the region's streams and can be detrimental to wildlife, inflict wetland and agricultural damage and compete with beaver and muskrat for resources [202]. Introduced fox and eastern gray squirrels are abundant in the region, and squirrels frequently plunder bird nests [47;225;253;263]. Domestic cats and dogs are disruptive and often lethal to smaller native wildlife, as described in the Trails section [19;211;256].

Mammals are a diverse group, but many require some of the same habitat characteristics important to amphibians: complex habitat structure, woody debris, (particularly small mammals), good connectivity and access to water. A Washington state forest study indicated that multispecies canopies, coarse woody debris, and well-developed native understories are important to small mammal biodiversity across a broad suite of spatial scales [63]. Other studies in western Oregon and the Pacific Northwest show increased small mammal abundance or diversity with increasing coarse woody debris [60;242;389]. Riparian forests often contain high amounts of coarse woody debris, and this may help explain why some studies document higher small mammal abundance in riparian habitats than in uplands [33;101;247].

Mammals can profoundly influence habitat conditions. For example, the beaver, a keystone riparian species, plays a critical role in the creation and maintenance of wetlands and stream complexity and may have broad effects on physical, chemical and biological characteristics within a watershed [70;327;341].

Forest management practices can reduce the habitat characteristics important to mammals. In urban areas, dead or dying trees are often removed for safety and aesthetic purposes and local studies document simplified structure and reduced wood debris in small forest patches or narrow riparian areas compared to larger or wider areas [165;169].

In the Pacific Northwest, bats are both more abundant and diverse in habitats with increased roost availability including a variety of tree, cliff and cave roosts. Bats often roost in artificial structures and bat-friendly habitats may be provided in both new and existing bridges and other structures at little or no extra cost. Canopy cover and structural complexity are very important to this sensitive group, in part because these attributes provide roost sites and are also associated with insect abundance [18;279;300].

A study in the Oregon Coast Range suggests that vegetation at the local scale is closely correlated with bat foraging activity and that shrub- and forest-association is species-dependent – larger species may prefer more open stream channels for mobility reasons; the researchers recommended creating a diversity of riparian structure to accommodate the variety of western Oregon bat species [279]. Studies in northwestern California and Arkansas indicate that bats preferentially forage over seasonal streams compared to upland sites during the dry season, suggesting that even dry streams support increased insect abundance compared to uplands [72].

A Portland, Oregon study found weak but significant correlations between bat abundance and natural area park size; the weak results may be attributable to three of the natural area parks showing lower than expected abundance, possibly due to lack of daytime roost sites because of the young age of dominant trees [300]. The researcher noted that the species richness was unusually high for an urban area, and commented on the importance of native shrubs and riparian areas to insects and therefore bats. A study in Mexico found overall bat activity was significantly higher in large urban parks than in smaller parks [18].

Graduate level research at Portland State University suggests that the following small mammals may need habitat patches of 25 acres (10 hectares) or greater: short-tail weasel, Oregon vole, Northern flying squirrel, shrew-mole, white-footed mouse, Trowbridge's shrew, vagrant shrew, Douglas squirrel, Western gray squirrel and Townsend chipmunk [267] (see also Edge effects and habitat patch size section). The study also found that non-native mammal abundance decreased in larger patches.

Loss of habitat, connectivity, forest structural diversity and large woody debris commonly seen in urban areas alter the region's mammal populations and may lead to local extinctions over time [2;42;55;165]. Restoring these elements will improve the region's diversity and persistence of native mammal species.

In general, research suggests that larger habitat patches, connectivity and woody debris significantly improve habitat conditions for many mammal species. For homeowners, leaving the property somewhat "messy," with leaves, woody debris and snags when possible, can improve wildlife habitat. As discussed in the road impacts section, roads can be a major cause of mortality for many mammal species. Within identified corridors or where road-kill is an identified issue, installing appropriate wildlife crossings can help maintain mammal diversity in the region.

SUMMARY: WHAT DOES WILDLIFE NEED?

The preceding literature described issues relating to habitat fragmentation, urbanization and disturbance issues, and the region's habitat and wildlife, with emphasis on the role of connectivity in maintaining or restoring the region's substantial existing biodiversity.

The region's wildlife habitats – native oak, prairie, wetlands, riparian, upland and various forests types, as well as agriculture and urban – host nearly 300 native, terrestrial wildlife species. This wide variety of species translates to an unimaginably complex suite of life-history requirements. Existing and future threats to these species are equally complex. Local wildlife studies, particularly population and genetic studies, are lacking. It is not feasible, nor is it necessary, to conserve each species individually. Conservation efforts focused on sensitive, keystone or representative species, declining and high-quality habitats, threat reduction and connectivity may also conserve most of the region's native species.

However, an ecosystem approach to habitat and wildlife conservation is bound to be more effective than managing for a single or a few species. While it is not feasible to explicitly plan connectivity for every species, most of the current at-risk species would not be in trouble if their habitats and life history needs had been proactively considered earlier; focusing solely on at-risk species could jeopardize the future of other species not currently at risk. Paul Beier, in his introductory remarks at a recent Portland-Vancouver ecology symposium, offered his principle for wildlife connectivity: "No species left behind" [27].

General suggestions from Environment Canada can help guide conservation of the region's habitat system (adapted from [107]):

- Increase native vegetation structural diversity (ground cover, shrub, understory, canopy)
- Maintain native vegetation and dead wood
- Provide adequate functional habitat corridors, which can include parts of the matrix such as back yards and street trees; make the urban matrix more like the forest fragments
- Manage edge effects; soften the edges with greener matrix habitat
- Recognize that human intrusion may not be compatible with interior habitat conditions
- Discourage open lawns (which attract starlings – [164;166;169]) and encourage back yard habitat
- Realize that habitat fragments may not support all target species
- Develop monitoring programs that focus on reproduction, survival, migration and dispersal
- Practice adaptive management

This region's conservation efforts fit into the broader, statewide strategy and the statewide strategy should be used as a guiding document for regional and sub-regional plans. The goals of the statewide Conservation Strategy are to "maintain healthy fish and wildlife populations by maintaining and restoring functioning habitats, prevent declines of at-risk species, and reverse any declines in these resources where possible" [284]. The Conservation Strategy outlines six key statewide conservation issues – land use changes, invasive species, altered disturbance regimes, barriers to fish and wildlife movement, water quality and quantity, and institutional barriers to voluntary conservation – and lists actions that can be taken to prevent wildlife and habitat declines. The statewide Conservation Strategy provides a big-picture approach, and smaller-scale efforts such as a regional wildlife corridors plan can be knit together to better integrate natural resource work in the state and increase efficiency and effectiveness. Local plans provide the details needed to step down and implement the work on the ground. For example, the statewide strategy identifies key Conservation Opportunity Areas, but does not include mapping of connectivity between them, nor does it identify habitat areas that are very important at smaller spatial scales. That is our job.

Connectivity is one of the key elements needed for a regional conservation framework. Previous sections provided background information about connectivity, wildlife and habitat, including regionally specific information. The following sections delve more deeply into the process of creating a wildlife movement strategy, including methods to identify, enhance and create the connectivity needed to maintain the region's biodiversity. To aid in identifying focal species and their needs, appendices to this document include species-specific information about species' needs relating to corridor width, area requirements and gap-crossing abilities, as well as a review of some of the methodologies used to model wildlife connectivity.

MORE ABOUT CORRIDORS

DIFFERENT TYPES OF CORRIDORS AND CONNECTIVITY

Connectivity is the degree to which the landscape facilitates or impedes the movement of organisms among patches [320]. Wildlife corridors are key landscape elements that serve to provide and increase connectivity between habitat patches, especially in urban areas where the permeability of the surrounding matrix is relatively low [31;152;214]. They often follow stream corridors but may also consist of upland connections, greenways, windbreaks, wooded streets, field margins or hedgerows [36;37;113;174;185;231]. Corridors are not necessarily continuous and are best defined by functionality; for example, a well-placed linear sequence of "stepping stones" or a traversable matrix may provide effective connectivity for some species [174].

Corridors can also encompass complete home ranges to some animals, particularly edge-dwellers and species with small home ranges such as small mammals [316]. Thus, corridors serve as both movement pathways and as habitat for some animals.

The general scientific consensus is that connections between habitat fragments are crucial to the persistence of many species and populations, and that well designed corridors can play a key role in maintaining ecosystem functions [2;2;28;29;31;56;76;86;90;113;118;160;186;214;248;316;343-345;354;356;385;394]. Corridors provide the opportunity for many species to traverse through habitat that is not suitable for permanent residency to locate better habitat, find a mate, disperse from natal areas, escape predation or other dangers, and access habitats needed seasonally or at different life history stages [25;34;139;214].

In addition to corridors, there are other ways to improve connectivity for certain species, particularly some birds and invertebrates. For example, recent studies reveal opportunities to improve habitat quality in the intervening matrix by increasing spatial heterogeneity through semi-natural features such as vegetated buffers, storm water treatment facilities and edible gardens [147;178;218]. Green roofs and street trees are an emerging but potentially important connectivity element [64;113;280;361]. Residential yards can comprise a significant percentage of the "green" in an urban area [234;319], and the recent partnership between Portland Audubon Society and the Three Rivers Land Conservancy – the Backyard Habitat Certification Program – provides excellent opportunities to increase habitat and connectivity, as well as ways to soften the edge effects around habitat patches. Many other organizations, such as Soil and Water Conservation Districts, nonprofits and various cities and counties in the region, continue to work hard to restore habitat and connectivity. However, some species, such as many migratory songbirds, may be unwilling or unable to traverse developed areas [166;219;360]. Developing a regional map of core wildlife habitats and existing or desired connectivity provides a way for such programs to target specific species and areas to yield the highest ecological return for dollars spent.

CORRIDOR WIDTH, LENGTH AND SHAPE

The size and shape of a corridor can directly impact the effectiveness of the corridor for wildlife movement [118;177;186;223;330;345]. There are no hard-and-fast rules, but certain concepts can aid in corridor design. The key questions are: what habitat areas are we trying to connect, and which species do we want to use the corridor? Answering these questions through spatially explicit, species-specific analyses can help identify optimal corridor designs to best address a landscape's opportunities and constraints [122].

In general, corridors tend to be most effective if they are not overly long relative to species' movement abilities, there are few gaps and blockages, the width is sufficient to meet species' needs, and the corridor does not harbor an excessive number of predators [214]. Habitat quality is a very important corridor attribute and can be the determining factor in corridor functionality [8;120;122]. Other attributes such as surrounding matrix and topographic position in the landscape can also significantly influence corridor value [108].

The most effective way for wildlife to move is generally via the shortest route, or the one that most effectively minimizes the amount of travel time or risk to the animal [122;343]. In addition, animals need to be able to find the entrance to the corridor, and this can be harder for smaller and slow-moving animals. An effective corridor is one that "costs" the animal the least in terms of effort and risk. Multiple corridor options are more effective than a single corridor because more animals are likely to find it and if something disrupts one corridor, another is available.

Studies and models suggest that wider corridors direct and increase animals' movement rates between patches, acting a bit like drift fences or funnels guiding animals toward habitat patches [150]. Some researchers suggest that larger habitat patches require larger movement corridors [201]. Wider corridors are obviously preferred, but land use and cost constraints favor narrower corridors [28]. The key goal should be to provide connectivity between populations and prevent reproductive isolation. There are no hard-and-fast rules for corridor width design; educated but subjective decisions must be made. Some species- or guild-specific corridor width studies have been conducted, as summarized in Appendix 1.

Connectivity research varies widely by geographic area and species or guild, but it is clear that narrow corridors, hedgerows, field margins, fencerows, and street trees can improve connectivity for some songbirds, small mammals and other species during various life cycle stages [37;113;119;185;231;332;377]. Researchers studying urbanized California chaparral habitat report that for some species, extremely narrow wildlife corridors can function quite well [344]. Their studies showed that Spotted Towhees traveled along habitat strips just three feet (1 meter) wide, and three other species of chaparral birds used strips only 33 feet (10 meters) wide. These findings argue that even a narrow corridor will conserve at least some biodiversity. However, many of the region's species are likely to require wider movement corridors.

Most wildlife corridor studies focus on forest and woody vegetation or aquatic connectivity. It may also be important in this region to consider species that need open habitat such as farm fields and meadows to live and move. A large-scale study in South Carolina demonstrated that for a diverse range of open habitat species, 32 meter wide corridors between forested patches directed animals' movement to the next appropriate habitat patch [152]. Interestingly, the same number of animals left a given patch with or without corridors, but corridors increased their arrival at the next patch by more than 68 percent for each of 10 species. Moving to other appropriate habitat rather than landing in unsuitable (or less suitable) habitat increases animals' odds of survival and reproduction.

The scientific literature shows a remarkable range of recommended movement corridor widths, ranging from a few to thousands of feet, depending on species or guild (see Appendix 1). Small mammals and less sensitive songbirds seem to lean toward the narrow end of this range [44;48;78;113;196;332] whereas carnivores, area-sensitive breeding birds and other sensitive species or those requiring large home ranges tend to need wider corridors [77;82;87;93;196;224;240;299;345;350]. Amphibian requirements are highly variable but often seem to fall somewhere in between, depending on whether these species' rather complex requirements are met – for example, interspersed wetlands and uplands, with relatively short distances between wetlands or other key habitat [56;62;163;322;329]. Several studies and synthesis reports suggest corridors should be at least 328 feet (100 meters) wide to provide for most wildlife movement and habitat functions [56;108;146;224;350].

Few studies are long-term, multi-season, conducted in urban areas or conducted in this region, therefore most of the reported or recommended corridor widths must be taken within context. For many species, corridors link different habitat types (for example, aquatic and terrestrial) important to species' life-history requirements. This highlights the critical importance of ascertaining the seasonal life history requirements of species of conservation interest.

For example, area-sensitive species are unlikely to breed within most corridors, but often use them for dispersal or migration. For some edge-dwelling species, short corridors may not provide sufficient home range sizes but will facilitate inter-patch movement; increasing shrub cover, a characteristic component of forest edge habitats, may particularly benefit these species. Some species may be highly susceptible to human disturbance, and corridors for these species should limit or exclude trails and be placed away from busy roadways as much as possible. Some species of conservation interest, such as butterflies and bluebirds, depend on open habitat and may be best accommodated by early successional corridors embedded within a forested matrix [149;151;153].

CORRIDOR RISKS

The benefits of habitat corridors have been heavily debated in the scientific literature, as demonstrated by the unusually high number of published responses to corridor articles – some of them rather heated [2;172;214;276;277;333;334;343]. There are some potential disadvantages to corridors, often specific to a given situation, although they have not been well quantified [334]. Problems may be more pronounced in narrow corridors and where human disturbance is high, such as along trails or busy roadways. However, even scientists speculating that wildlife corridors may cause some problems also consistently comment about corridors' known or likely conservation values [31;158;172;275;276;307;334].

Scientists theorize that corridors may promote the spread of invasive species and serve as reservoirs of such species, as well as changing seed predation and pollination dynamics [333;334]. This is certainly possible simply due to edge effects associated with relatively long, narrow habitats. A study in South Carolina found that seed predation for two early successional plant species, the latter which are often weedy, was higher in connected patches because more rodents were present [288]. Predation rates differed among the two plant species, depending on the key predator – rodents or invertebrates. The same experimental study area showed that butterflies moved more between connected patches, thus influencing pollination in both patches [149]. This could be good news or bad, depending on whether the plant is desirable, how seeds are dispersed, and whether seeds germinate after passing through animals' digestive tracts. The point is that in areas where corridors successfully enable inter-patch travel, there may be unanticipated effects and the effects may be positive, neutral or negative. That is one reason why ongoing corridor studies are useful.

Corridors may allow for easier transmission of disease and faster predator movement or more effective predation [2;102;334]. On the other hand, lack of corridors may block predator movement and substantially change ecosystem dynamics, including herbivore overpopulation and resulting habitat loss [25;35]. If disease causes a species to go extinct in one patch, the species will stay extinct without connectivity. Many of the potential disadvantages of corridors could be avoided or mitigated by enlarging corridor width [277].

Corridors may create population sinks – that is, lower quality habitat in which a species' reproductive output is insufficient to maintain the population, necessitating immigration for long-term species persistence [174]. The sink may be due to habitat within the corridor, or because the corridor provides connectivity that actually diminishes wildlife populations.

For example, corridors may create colonization routes to habitat patches where species will breed unsuccessfully, such as male Ovenbirds - a species related to Swainson's and Hermit thrushes - selecting small habitat patches that lack sufficient insect prey and which females avoid [58]. Corridors may facilitate population sinks where significant barriers, such as roads, cause mortality. In a Florida study, 95 percent of turtles were killed attempting to cross a 4-lane highway prior to construction of an undercrossing and associated drift fences to guide turtles, whereas only 84 of 8,475 turtles climbed or penetrated the drift fences after construction [10]. In such a case, without the crossing an absolute barrier may be preferable over access to the roadway. Finally, habitat within the corridor may increase threat of direct predation due to increased prey vulnerability in narrow or less than ideal habitats and elevate nest predation or nest parasitism due to increased edge effects [174;213;236;381]. These effects are not always readily apparent; bird counts may show increased abundance for some species, but they may not be breeding successfully.

Beier and Noss reviewed scientific studies on the benefits and negative aspects of corridors [31]. While the overall conclusion was that the literature is not yet sufficient to declare the positive value of corridors, several studies showed that corridors function as travel connections for wildlife in real life, and no studies provided empirical evidence of negative impacts from corridors. The literature appears to indicate that the benefits of a connected landscape typically outweigh the potential negative effects of corridors, especially in urban environments where the matrix may be too harsh for many species to navigate [31;344].

SPATIAL SCALE

The spatial scale of conservation is an oft-debated topic among ecologists. Are sites, areas, or broad landscapes most important?

Researchers attempted to answer this question by systematically assessing the appropriate spatial scales of conservation for 4,239 threatened vertebrate species based on a literature review [46]. The answer, not surprisingly, was that all scales are important, but different animals respond to different scales. Neither site scale nor broad-scale approaches alone can prevent extinctions. "Spatial plans and systematic conservation exercises," state the authors, "must look beyond sites to include the additional area and connectivity requirements of these threatened species" [46].

Spatial scale is a key consideration in improving wildlife connectivity. Which habitat patches are most important? The patches are the region's "sites," within which the finest scale analyses generally occur. How should these patches be connected? Watersheds or jurisdictions may be used to sub-divide the region for mid-scale analyses. The region is the broader scale – patches, corridors and matrix. How can we expand those connections to important habitat areas outside the region? This is the largest (landscape) scale, and it can extend as far as is deemed important.

Applying metapopulation theory may be quite useful at broader scales. What are the target species for specific habitat patches? If local populations go extinct, how could they be repopulated? Elk provide a good example. Elk move back and forth between the region and specific habitat areas near the Coast range, from the north, and from the eastern forested hills leading to Mt. Hood. Are there habitat patches in the region, such as Forest Park and the East Buttes, where elk might be a conservation target species? If so, it will be important to identify population sources outside the region and provide connectivity appropriate for this species. Is there an area near the selected habitat patches, for example urban Gresham, where elk are undesirable?

In all cases, consider each conservation target species when designing corridors. Wildlife corridors can provide elk passage between elk habitat patches within and outside the region. Wildlife corridors and crossings can be designed to exclude large mammals but provide passage for other species. In this case at least five spatial scales are important: landscape scale, region, general area such as a watershed, habitat patch, and essentially a point on the map – the wildlife crossing. Metro's *"Wildlife Crossings Guidebook"* provides a wide variety of examples and solutions relating to mitigating movement barriers [251].

CONNECTING HABITAT: HOW IT'S DONE

Connectivity can be difficult or impossible to regain after urbanization, and whenever possible, should be considered early in planning processes. Without specific yet broad-scale planning, connectivity will be haphazard, sometimes accidental, or absent. What can be done?

The first important activity is to create and agree upon a map depicting potential core habitats and corridors, as described in previous sections. Planners and key stakeholders should be involved. The draft map should identify all potential habitat patches and corridors that meet the group's criteria. When this stakeholder group agrees on a final product, politicians and decision-makers and potentially a broader public audience, all who were preferably kept in the loop during the mapping process, can support the map and facilitate integration of the results into planning, acquisition and conservation efforts.

The following sections describe the general steps needed to create a wildlife movement strategy, as summarized in Figure 2 below. The steps are outlined as a linear process for clarity, but the actual process is likely to be more organic, and include overlap and revisiting of some of these steps along the way. In some cases it may be appropriate or necessary to simplify the process, such as omitting the focal species concept or reducing outreach efforts. The most important outcome is to produce an agreed-upon map for planners, restoration practitioners and others to focus some of their activities. If the tradeoffs of a more complex process are too steep - for example, if it adds a year or more to the project during a period of rapid land use change - it may be preferable to simplify the process and get the job done before more connectivity is lost.

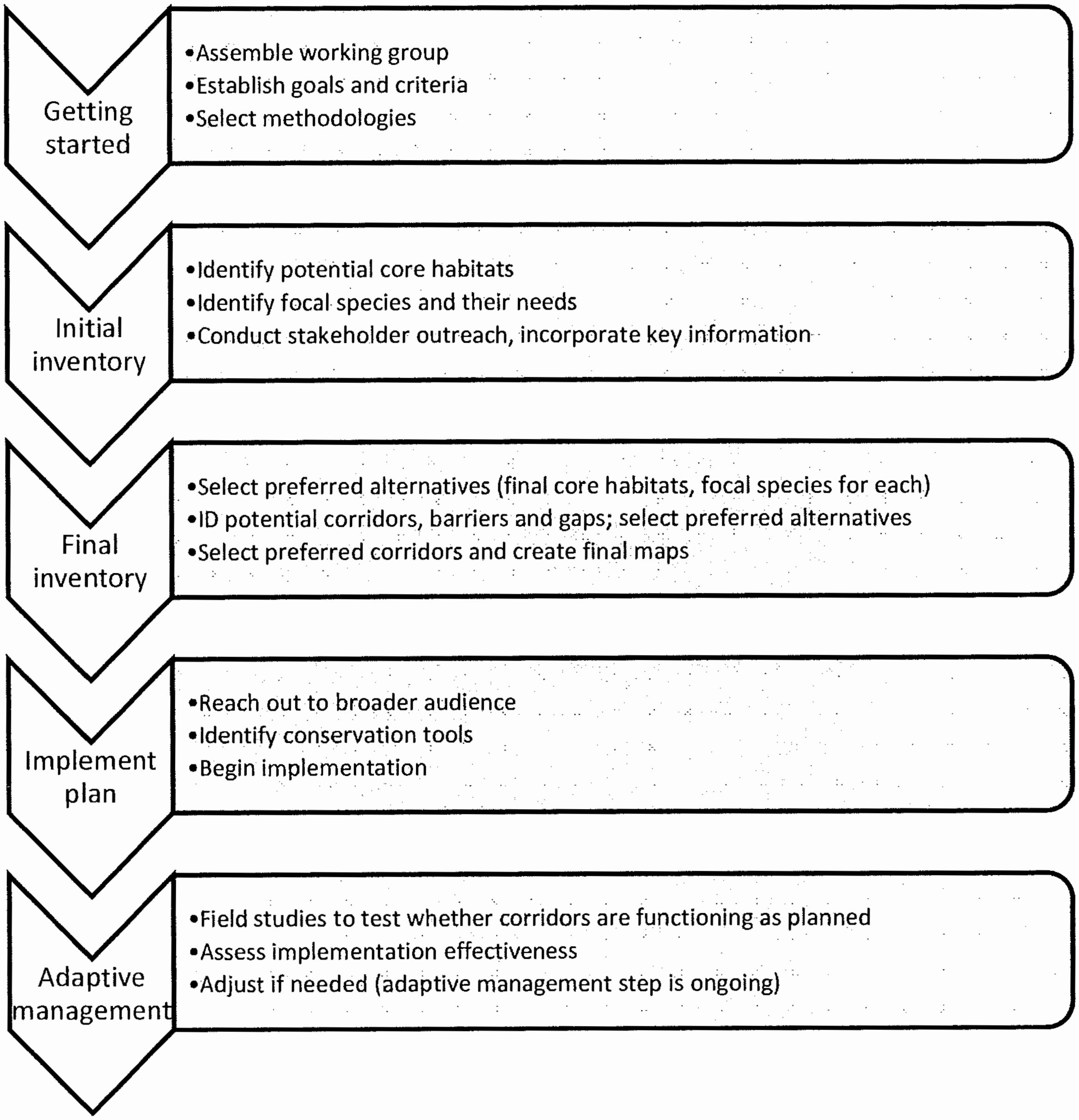


Figure 2. General steps involved with creating a wildlife movement strategy.

GETTING STARTED

ASSEMBLING THE WORKING GROUP

The first step in developing a wildlife movement strategy is to assemble a working group. This step is crucial to the success of the project, and may require some background research to identify the key players.

Beier et al.'s wildlife corridor design website, *Conceptual steps for designing corridors*, concisely summarizes the "big picture" [28]:

> "We have contributed to over 30 linkage designs in California and Arizona. We failed at this task when we tried to tell managers what to do. We succeeded when we asked management agencies and conservation organizations how we could help them identify wildlife linkages at risk and develop plans to conserve them. We share four lessons.
>
> - It is more exciting and rewarding to work for connectivity than against fragmentation.
> - Be a team player on everything—and that means involving non-scientists in science.
> - Corridors must be designed for multiple species.
> - The connectivity design plan must be comprehensive. It must address land conservation and roads and management practices and involving landowners as stewards. It's not just about getting the animal across the road."

The region can benefit from the experience of local biologists, natural resource planners and land managers. Some local governments and conservation groups have already identified the most important habitats in their jurisdiction, although few directly address connectivity, and local conservation groups may have conducted similar work. Locals usually know more about the land than people working at broader scales. Considering these efforts can add key information and reduce the amount of time and resources needed; failing to consider them may alienate the people who will ultimately influence whether and how well the plan is implemented. Spend the time to find out who should be involved.

ESTABLISHING GOALS, CRITERIA AND SELECTING METHODOLOGIES

Developing a draft set of goals and criteria before the working group first meets can save time. It is easier to revise something than to create it to begin with, and giving the group something with which to start can produce tangible results quickly. Another good pre-meeting task is to ask invited members to come prepared with any habitat inventory and associated guidelines already established under their own work. An early part of the process includes identifying the study area, or the overall area of interest (see the following *Identifying potential core habitat areas* section).

Criteria can include specific "rules" for selecting core habitats. They might also include rules of engagement; for example, are identified, local high-priority habitats automatically included as core habitat? If not, how should the information be used? Determine how final decisions will be made if general agreement is not apparent, such as by group vote. A skilled meeting facilitator can help limit digression from stated goals and ensure that quieter members' voices are heard.

Important core habitat characteristics may include habitat type(s), current and desired future conditions, species known or suspected to live within the core habitats and habitat suitability for those species (see section on focal species). Core habitats should represent unique or unusually important habitats, including very large habitat patches, at the study area scale. Otherwise, efforts and funding may be too diffuse to be effective, and the process and strategy may also lose credibility.

Specific criteria will help focus attention on the most important habitats. For example, criteria for selecting core forested habitats in the region might include:

- Size - minimum of 30 acres unless another qualifying criterion supersedes size, although not all 30-acre patches may be core habitats; for example, a 30-acre patch in a habitat-sparse area may be more important to wildlife than in a habitat-rich area
- Habitat quality, including current restoration efforts or plans
- Particularly unique areas or features that provide irreplaceable structures or functions for wildlife
- Habitats of concern such as native oak, native prairie, wetlands, bottomland hardwood forest, and river islands
- Protection level and risk to the resource
- Documented presence of species of critical conservation concern, such as native turtles or threatened or endangered plant species, could constitute a reason for adding a core habitat that doesn't meet any of the other criteria

To be included as a candidate core area, perhaps an area would need to meet at least two or three of these criteria. Key habitat areas already identified by local and regional governments in the Willamette Valley and statewide provide a starting point.

Once criteria are established, how are habitat areas meeting these criteria identified? It is important to develop a framework early in the process for how information will be collected. This will speed up the process with which potential core habitats, focal species and corridors can be identified and facilitate a reasonable estimate of time and resource costs.

This part of the process involves reconnaissance on available data sources. For example, it may include identifying existing data sets of important habitat areas, high quality vegetation, sensitive species locations, special or declining habitat areas, road-kill hotspots, development and conservation plans, tax lot size, and publicly-owned or protected lands. Local jurisdictions, watershed councils, and the section on "related efforts" below can provide foundation information with which to move forward.

The project's goals should drive the data collection. It is a common mistake to let available information shape a project. Focusing on the goals will help identify whether available data sets are sufficient for the project and if not, pinpoint the critical missing pieces to ensure that the data answer the key questions. This is often an iterative process - for example, key pieces may be in place to identify core habitats and corridors, but information on barriers and gaps may be lacking and will require future fieldwork. Identifying and addressing such issues can be part of a longer term plan.

After the desired data sets are collected, what methods are most appropriate to identify specific core habitat areas on the ground? This may include the knowledge of local experts, Geographic Information Systems-based modeling, or a combination of both. These methods will be applied in the next step to identify the initial inventory.

INITIAL INVENTORY

IDENTIFYING POTENTIAL CORE HABITAT AREAS

As discussed in the Spatial Scale section, the study area is the overall area of interest. In the region, this includes the Metro Urban Growth Boundary, City of Vancouver and portions of Clark County, and adjacent or nearby areas that are either being conserved on behalf of the region or that could directly contribute to metapopulation dynamics (see Figure 1). For example, the latter may include portions of the Mt. Hood National Forest, the Coast Range, the Sandy River gorge and delta, and other major habitat areas outside but near the region, depicted in a more general way than the region's core habitat areas.

By now the working group has established criteria, collected existing or created new data sets, selected appropriate methods and is ready to create a draft map of core habitat areas.

This may involve a one-time mapping process, in which case the initial map is also the final core habitat inventory. It could also be an iterative exercise, depending on the criteria established by the group and the results of the first map. For example, the initial map may reveal an unrealistically large amount of "core" habitat that reflects more than just the most important habitat areas, or the map may reveal tiers of priority habitat areas, where some habitats meet all of the criteria. At this point, refining criteria and conducting stakeholder outreach may help in the map refinement processes.

IDENTIFYING FOCAL SPECIES

Metapopulation theory is frequently used to plan natural area systems in a conceptual sense, with good reason. However, in actuality we are limited by lack of population data. Even with such data, we are often unsure what constitutes a viable population.

To partially overcome these limitations, experts recommend working with biologists who know the analysis area to select 10 or more focal (target) species, or groups of species such as guilds, that collectively will serve as an umbrella for all native species and ecological processes [28;30;156;203]. Select a subset of these focal species for each core habitat. Focusing on providing habitat and passage for these specialized species will, in theory, provide for the more generalist species as well. Species with the following traits should be included:

- area-sensitive
- habitat specialists
- dispersal limited
- sensitive to barriers
- sensitive to climate change
- otherwise ecologically important, including at-risk species

It may also be appropriate to select focal species that evoke strong public interest or for which long-term or extensive survey data are available. Once a subset of focal species for each core habitat is selected, ascertain species-habitat relationships, including known movement requirements, and conservation potential based on existing habitat, then use the information to selectively conserve or restore connectivity. Species-habitat relationships may be documented through a variety of sources, including local studies and knowledge; published studies; published habitat suitability indices (HSI) or software to develop them [94;365]; on-the-ground habitat evaluation procedures (HEP) or similar habitat assessment tools [362]; and various GIS-based modeling techniques.

The U.S. Fish and Wildlife Service uses habitat-based focal species to represent conservation targets – that is, species, species groups, or communities of particular interest for a refuge [364]. U.S. Fish and Wildlife's Willamette Valley focal species include invertebrates, fish, turtles, birds, and plants. These species help the agency define the specific habitat and environmental attributes to be maintained or achieved for each conservation target. The Nature Conservancy uses a similar focal species approach [357], as does Partners in Flight [6].

Several questions arise for focal species. How large are the species' home ranges? Where do they occur, and where could they occur? How sensitive are they to disturbance, what types of disturbance, and what are their movement needs? Do these issues vary by season? What are the key habitat features - the "must-haves" - for corridor habitat? These questions might be answered in part through literature and professional knowledge (see Appendices 1, 2, 3).

Because most bird species fly, they are not as hindered by terrestrial barriers as other wildlife species. Although this would suggest that improving connectivity for a particular bird species may be easier than for species in other wildlife groups, the great diversity of bird species poses a challenge to designing wildlife corridors. There are over 200 species of birds in the region, each with unique life history requirements. For this reason, biologists often separate birds into guilds - groups of species with certain similar functional requirements or shared life history traits - and plan according to guild needs [53;68;82;114;330]. This approach, for birds and other species groups, can also be used for focal species in planning wildlife corridors. Season and location must be accounted for when considering research findings. Some examples of potential guilds in the region could include:

- Area- and disturbance-sensitive species for patch size and shape consideration
- Species requiring movement corridors of a certain minimum width (for example, amphibians; selected bird species with similar requirements; native turtles)

- Road avoiders or species that change behavior near roads (for example, Neotropical migratory songbirds, frogs, snakes)
- Urban-adapted native species (for example, Song Sparrow, American Robin, deer)
- Birds adapted to specific habitats such as native grassland, shrub or coniferous habitat (for example, Savannah Sparrow, White-crowned Sparrow and Common Yellowthroat for grasslands; Spotted Towhee, Willow Flycatcher for shrub; Western Tanager, Golden-crowned Kinglet and certain warbler species for conifer)
- Riparian specialists such as Willow Flycatcher, Black-headed Grosbeak, beaver and otter
- Larger species with shorter flush distances, especially when considering where to put trails (for example, quail, sensitive waterfowl species, Northern Flicker, Pileated Woodpecker)
- Species reluctant to cross gaps of a certain size (for example, Red- and White-breasted Nuthatch or Downy Woodpecker);
- Migratory songbirds during migration

The Oregon Department of Fish and Wildlife and a number of agency partners hosted a series of wildlife linkage workshops in 2007 to support the Oregon Wildlife Movement Strategy [160]. Workshop participants identified linkage areas for three groups of focal species, including large game mammals, small mammals, and amphibians and reptiles. The three groups, essentially large guilds, were selected to encompass a broad array of animal movement needs.

Focal species may also be used to evaluate connectivity under alternative scenarios for disturbances such as climate change, urban development, and new trails and roads. The key is to know what questions need to be answered, and select the species that can help answer them. Some information about focal species' needs may be derived from literature (see Appendices 1, 2, 3). However, these studies were usually conducted in different geographic regions and in non-urban areas, and may have limited applicability in the region. Combining information from available studies with local wildlife knowledge can help guide development of focal species' requirements for habitat and connectivity.

Wildlife-vehicle collision and road-kill data may help with connectivity planning. Metro and the Oregon Department of Transportation (ODOT) have selected information on wildlife-vehicle collisions and road kills, but at present no comprehensive data set exists for the region. In addition, existing data is heavily weighted towards large mammals due to human risk, and also because they are more visible than smaller animals. ODOT's data is for the state-owned road system, constituting a fraction of the region's roads, and Metro's data is incomplete and somewhat outdated. To effectively use this type of data, the region would need a more up-to-date and comprehensive data set. Wildlife-vehicle collision or road-kill data sets do not account for absolute wildlife barriers, where animals do not even enter the roadway. In addition, such data fail to account for connectivity issues not related to roads. Wildlife-vehicle collision data is retrospective and not necessarily relevant in newly urbanizing areas or those with increasing populations. Nonetheless, such data can provide important supplemental information, particularly to identify some areas within a corridor where wildlife crossings are needed.

Indicator species and guild approaches are time tested and valid approaches to ecological assessment and problem solving, but there are other approaches as well. For example, simply identifying and conserving the best remaining corridors, along with addressing gaps and barriers over time, may successfully facilitate higher fish and wildlife permeability. These might be used as reference corridors to inform protection and restoration decisions in other corridors that are threatened by new development.

STAKEHOLDER OUTREACH – LOCALS KNOW MORE

It is important to include the public in natural resource management, from pre-planning through implementation. Local residents usually know what wildlife uses their lands. In addition, without support from the public and private landowners, little meaningful conservation beyond acquisition can be accomplished. Public participation costs money, time, and may yield unanticipated or even unwanted results; it means involving non-scientists in science. But it can also bring about surprisingly creative and effective solutions.

Lyman and others reviewed tools for incorporating community knowledge, preferences and values into natural resource decisions [221]. Such tools can be clustered into three general groups: (a) extractive use, in which knowledge, values or preferences are synthesized by the lead group (for example, scientists) and the preferred solution(s) referred to a decision-making process; (b) co-learning, in which syntheses are developed jointly and the implications are passed to a decision-making process; and (c) co-management, in which the participants perform the syntheses and include them in the joint decision-making process. Generally, the time and level of effort required increase from extractive use to co-management processes. However, an important trade-off is the extent to which citizens become involved, invested, and gain a sense of ownership of the project, which may increase project implementation and success, particularly on private lands.

In a corridor proposed by NGOs and academic institutions linking southern Ontario and Adirondack Park in New York, much of the land was private property [50]. A random survey of households within the proposed corridor zone revealed that landowners knew little of the proposal and had no contact with its advocates, placed high value on conserving biological diversity, and were worried about restrictions being placed on their land. Without private landowner buy-in and participation, any plan would be likely to fail. More work to disseminate information and engage citizens in formulating the corridor plan could allay fears, create corridor advocates and instill a sense of pride and community rather than creating resentment.

During the concept planning process for the City of Damascus, Oregon, planners held a series of community forums to keep the public informed and ask for input. One forum was laid out in a series of stations, including a natural resource station with draft inventory maps and aerial photos where residents could find their property and identify habitat areas for deer, elk, coyotes, owls, herons and other wildlife they considered important, as well as road-kill problem areas. They also pointed out important habitat features such as older forest, oak habitat, unmapped wetlands, etc. These features provided background for core habitat areas and were used to help refine the draft wildlife corridors map.

If public participation is invited, allow the residents to document anything they think is important. The criteria established by the working group will help sort out which new areas identified by the public should be added to the inventory, if any. This type of information can be very useful in documenting the importance of potential core areas, and can also be used to think about focal species for different habitat areas.

FINAL INVENTORY

SELECTING PREFERRED ALTERNATIVES (CORE HABITATS, FOCAL SPECIES)

At this point the working group has established goals and implemented methods to identify potential core habitat areas. Public outreach has revealed more about the wildlife using habitat areas and places that are special to local residents. Now is the time to document in detail why each core habitat area is important, what wildlife species are known or likely to use it, and incorporate new areas identified by the public if needed.

The documentation should focus on and revisit the criteria established by the working group early in the process. Determine which and how many criteria each core habitat area meets. Information from the public can help this process - for example, known sensitive species locations - and may alter the results. On the other hand, residents have likely advocated for the inclusion of areas that do not meet the criteria, and this part of the process helps explain why such areas were excluded from the final inventory.

The working group now decides which draft core habitat areas are to remain in the final inventory. The next step is to identify a final set of focal species for each core habitat area. This will provide the key information for the subsequent step: identifying corridors appropriate for moving focal species between their core habitat areas.

IDENTIFYING CORRIDORS

As is often the case with natural resource planning, identifying priority wildlife corridors in an urban environment is a blend of science and professional judgment. There is no one formula to use, especially in urban areas, where the complexity of analysis increases significantly due to the number of factors and issues to consider.

After identifying potential core habitats, focal species, and the needs of these species, the next step is to delineate potential wildlife corridors. There are several ways to accomplish this, from looking at maps and aerials and simply drawing lines - although this will not explicitly address focal species' needs - to complex models. Models can be used to identify potential movement corridors, assess or validate corridors identified by ecologists, identify gaps or constrictions or help decide which of several corridors may provide the best alternative. A combination of published empirical data, local professional knowledge and modeling methods can be effective [73] (see Appendix 4).

One or more of the modeling approaches described in Appendix 4 could increase technical rigor, but modeling is not necessarily the best way to identify corridors. Identifying existing connectivity by drawing lines on a map, then using focal species to delineate where corridors are adequate and where restoration may be needed, can be simple and effective. In urban areas, sometimes existing connectivity is obvious and often lies along stream corridors. In such cases, modeling efforts may be unnecessary, but the needs of focal species including corridor widths, barriers and gaps must be addressed. Regardless of whether modeling is used, some of the decisions will likely be judgment calls based on the established criteria for selected focal species and group consensus. For this purpose we reviewed the scientific literature for research-based recommendations about species' corridor needs in Appendix 1.

Recapping the information reviewed regarding corridor width and shape: in general, corridors should be as wide and short as possible, barriers or breaks in the corridor should be minimized, and width and corridor conditions should be based on the requirements of focal species. Keep in mind that although forests benefit many species, there are other habitat types, such as oak savannah, wetlands and grasslands, to which similar principles may be applied.

There may be cases where there is no clear corridor or there are several potential corridors, and some sort of permeability analysis, modeled or otherwise, may be useful. In any case, a consistent algorithm - a step-by-step problem-solving procedure - can help determine the best existing or potential route(s). The next few paragraphs describe one common modeling approach for situations of uncertainty, the "cost-distance" approach (Figure 3) [28].

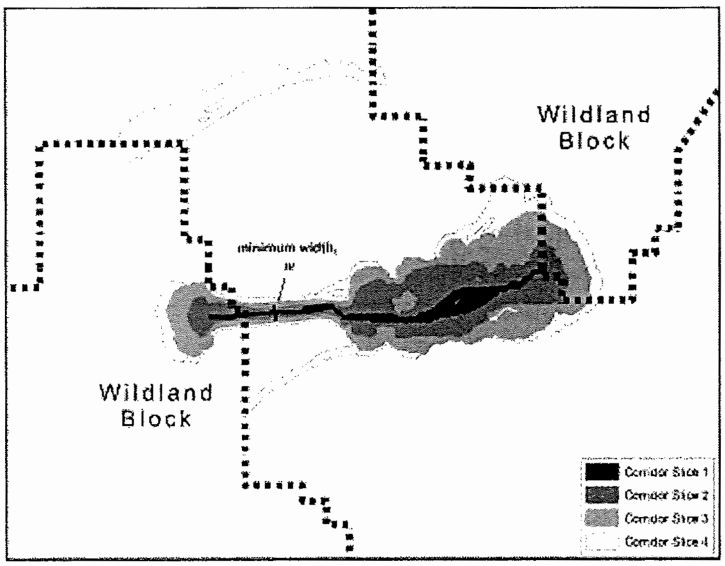


Figure 3. Example of a graded cost-distance map (also called an effective distance or cost-weighted distance map), used with permission from Beier and colleagues' web site [28].

Cost-distance modeling is a raster-based GIS exercise in which resistance to wildlife movement is identified, and the pathway with least resistance is a potential corridor. Resistance is the cost of travel for an animal through a given area in terms of energy expenditure or risk of dying. If an animal can easily travel through an area, that area has good permeability, or is suitable habitat for focal species [28]. These two concepts represent polar ends of a gradient:

100% resistance ⟶	100% permeability
(patch is an island, or there is no patch)	(focal species move freely)

Cost-distance modeling involves three steps to modeling corridors, briefly summarized here. The first step is to use the inverse of the focal species' habitat suitability as a measure of resistance. This can be represented on a scale of 1-100 on the resistance-permeability gradient.

The second step is to select "terminals" in each core habitat as the start and end points for corridor modeling. These can be points, lines, or polygons. Often there are several terminals in each core habitat.

The third step is to calculate a cost-distance for each pixel. This produces a "graded cost map" revealing where the best connectivity lies, followed by next-best and so on (Figure 1). The results are limited by data quality.

BARRIERS AND GAPS

Regardless of how they are created, maps are an artificial depiction of reality. A corridor that looks good on a map might actually contain numerous unseen barriers and gaps, or field surveys might find that a focal species actually moves through the corner of a field not within a mapped corridor. Perhaps what seemed appropriate based on the scientific literature does not, in fact, accommodate focal species movement in the region. That is one reason field-based studies are important to successfully implement a wildlife connectivity strategy (see *Monitoring and research* section). If implementation is not working, a new approach is needed and we cannot know whether it is working without looking on the ground.

Barriers are natural or man-made structures or situations that prevent an organism from moving through a corridor. They can be physical or behavioral. For example, if a bird species will not cross an unvegetated gap of 50 meters, that gap becomes a barrier. However, not all gaps are barriers; if an otherwise forested corridor has a gap in vegetation, some species may be willing to cross the gap, but these animals may be exposed to elevated risk of predation or other hazards. On the other hand, species such as bluebirds are more willing to travel through open areas than forested areas; for bluebirds, corridors are comprised of openings, whereas forest patches may act as gaps or barriers [212]. Habitat conditions in the gap (matrix) - for example, a busy road - may influence species' behavior, and the gap can become a barrier. Other types of barriers may arise from artificial light, noise and disturbance, steep inclines, unsuitable substrate, etc.

Barriers and gaps are species-dependent [251]. A deer can jump over a fence that might block a coyote. A coyote can traverse a much longer corridor than a frog, and in much more varied conditions. The barriers or gaps in corridors connecting core areas should be addressed based on the needs of the focal species with greatest requirements, but the specialized needs of each focal species must be considered. Appendix 3 provides species-specific gap information identified during the literature review.

Interestingly, the definition of a "gap" for one species may sometimes depend on the presence of another species. A study in Florida found that more individuals and more species of winter songbirds crossed forest gaps to mob Eastern Screech-owls (using recorded vocalizations) when more titmice were present, and the effect was additive [331].

Producing a regional plan to address physical and behavioral barriers and gaps within corridors will be an essential element of a functional system of core habitats and corridors [111]. Barriers and gaps can be identified through a variety of means including road-kill surveys, anecdotal evidence from area residents and field studies to identify physical barriers to focal species' movement. Aerial photos and GIS-based analyses help, but at some point, on-the-ground studies will be necessary to identify, assess and address barriers and gaps within a corridor, then to ensure that corrective measures are successful.

In 2009, researchers at Portland State University collaborated with ODOT and others to develop a mobile GIS tool to characterize wildlife passage conditions at intersections of potential wildlife corridors and road crossings [191]. Applying such tools in field studies can help determine the level of effort, investment and time that may be needed to make corridors fully functional.

SELECTING PREFERRED CORRIDORS AND CREATING FINAL MAPS

Between the draft map of potential corridors and the final map, an important filtering step is needed. Political realities, financial limitations and land ownership necessitate focusing efforts on the most important, achievable goals first. The draft map may have too many corridors for realistic implementation, and may need revision. Analyzing land ownership, zoning and future plans can help.

Land ownership is an important consideration for maintaining and improving wildlife connectivity. It influences what conservation tools may be used and may help or hinder conservation efforts. For example, ODOT evaluated connectivity between several large habitat patches in the proposed Sunrise Corridor alignment area leading to Damascus [360]. Using migratory songbirds and larger mammals as focal species, ODOT identified several movement corridors. Based on current zoning and land use ordinances, about half of the existing habitat patches and movement corridors are vulnerable to development.

Many of the region's jurisdictions provide for natural areas and open spaces, but planning for wildlife connectivity between such areas is often overlooked and can be greatly influenced by ownership and zoning. Most land use planners are not wildlife biologists, may not be familiar with wildlife or their needs, and tend to consider smaller spatial scales than are necessary to maintain many wildlife populations over time.

Consider a hypothetical case study. Three potential corridors, all along streams, are drawn on the draft map between two core habitats. The group wants to select two of the three for the final map. An analysis of land ownership reveals that:

1. Eighty percent of the first corridor lies within protected natural areas, and the areas between are already developed around a 150-foot wide protected stream corridor. This is the shortest distance between the two core habitats.
2. The second corridor is 50 percent protected, and a new highway alignment is proposed in 15 percent of the unprotected area, which currently constitutes a gap in the corridor. The remainder runs through large privately owned parcels, including residential and industrial areas.

Part of the residential area is outside the urban growth boundary but could become urban in the future. This corridor is the longest distance between the two core habitats.

3. In the third corridor, 75 percent is protected but most of the remainder is very constricted, with high-density development within 50 feet (15 meters) of the stream channel.

After analyzing land use and risk, the group's first selection (corridor #1) is easy. The second selection is more difficult, but corridor #3's constriction would be hard to repair, whereas #2 has potential if the right tools are employed. The highway alignment presents key wildlife passage opportunities - for example, a widened bridge and fencing to guide animals to the vegetated undercrossing - that may help the road builders, such as Oregon Department of Transportation, mitigate environmental damage, gain required permits and secure additional funds to help with the crossing project. Local jurisdictions and conservation groups can work with landowners to secure conservation easements and remove wildlife barriers.

Of course, sometimes this works and sometimes it doesn't, which argues for redundancy in movement corridors. The region will need to take a long-term approach and if necessary, shift strategies. For this reason, the wildlife corridor map will always remain a draft; conditions, land use, and wildlife change over time. However, consistently moving forward with a deliberate but adaptive strategy will ensure continued progress.

The preceding sections describe ways to identify potential core habitats and connecting corridors, link species' needs to each, refine the details and decide on the preferred alternative(s). Now the working group is ready to create final maps consisting of existing core habitat areas, corridors and in some cases, desired conditions for corridors that are not yet sufficient for focal species. An implementation plan will include these maps and identify ways to preserve or improve core habitats and corridors. The next section highlights some conservation tools to help achieve these goals.

IMPLEMENTING THE STRATEGY

CONDUCTING BROADER OUTREACH

A toolkit of approaches will be needed to successfully implement a wildlife movement strategy. Now is the time to identify these tools and conduct broad outreach to the agencies, organizations and citizens who can use the tools. These are the people who can implement the plan successfully, or cause it to fail.

A marketing strategy can be helpful, and consulting marketing and outreach professionals within the working group's organizations can be quite useful. Before reaching out to stakeholders and the public, identify in a general way the tools that may be most useful in a given situation based on variables such as habitats and species' needs, land use and likely future scenarios. Use this early reconnaissance to help identify approaches to various stakeholder groups.

The next section briefly describes some commonly used conservation tools.

CONSERVATION TOOLS FOR WILDLIFE CONNECTIVITY

Protection and restoration are critical components of an effective fish and wildlife habitat conservation program. In addition, a variety of non-regulatory tools comprise an important part of the strategy to conserve and enhance the region's wildlife corridor system. Some examples of non-regulatory tools are described below, and the Oregon Conservation Strategy describes selected tools in more detail [284]. These can all be important tools depending on the situation, and are not listed in order of priority.

Acquisition programs such as those currently funded through regional and local bond measures provide the most reliable means of conserving core habitats and corridors between habitats that meet the program's goals, although restoration and maintenance should accompany natural area acquisition.

Conservation easements are deed restriction contracts under which a landowner voluntarily gives up the right to conduct certain activities on the property but continues to own and sometimes, manage the land. Conservation easements are donated to or purchased by an agency or conservation organization. The landowner typically agrees not to subdivide, harvest timber, remove native vegetation, alter streams and floodplains, or otherwise engage in activities that may degrade the resource value.

Stewardship and recognition programs publicly acknowledge landowners, businesses and other entities for conserving open space, protecting or restoring habitat areas, making financial contributions or carrying out good stewardship practices. These include certification programs, such as the Audubon Society and Three Rivers Land Conservancy's Backyard Habitat program.

Financial incentives may include direct funding such as grants, incentives for specific activities in targeted areas, or property and income tax reductions.

Outreach can include technical assistance, targeted messaging, signage ("You are passing through an important wildlife corridor"), working with local schools and universities, habitat improvement workshops and other educational activities.

Volunteer activities including restoration, site steward programs and citizen monitoring can improve habitat and educate and engage citizens.

Transfer of development rights (TDR) programs allow landowners to transfer the right to develop one parcel of land to a different parcel of land. TDRs are often accomplished through zoning, and are meant to shift development from undesirable areas such as important wildlife habitat, to areas more suitable for development. TDRs can help address landowner equity and property rights issues.

Transportation and trail improvement projects can provide opportunities to improve connectivity through wildlife crossings (see [251]).

New urban area planning that explicitly identifies and protects or enhances core habitats and movement corridors can help retain biodiversity [234]. Providing a variety of types and arrangements of open space in new developments will meet the needs of more species.

Significant opportunities exist to combine multiple objectives to achieve wildlife connectivity. For example, replacing or retrofitting culverts and/or bridges can be planned to allow both fish and wildlife passage, and in fact some federally funded projects are now required to consider wildlife in new or retrofitted projects [251]. Trail construction or improvements, often tied to transportation funding sources, can offer similar opportunities. Where and how roads and trails are built can have profound influences - positive or negative - on the ability of wildlife to move across a landscape.

RESEARCH, MONITORING AND ADAPTIVE MANAGEMENT

Research and monitoring can help determine which habitats are most important, locate appropriate movement corridors, and determine whether corridors are functioning properly. Effective monitoring is necessary to inform adaptive management, leading to ongoing refinement and enhancement of wildlife connectivity efforts. Some research and monitoring ideas are discussed below. Many more are likely to emerge as the region continues to develop a wildlife connectivity program.

Research attention might be particularly important to assess high-value species - threatened, declining, or perhaps keystone species that influence many other species in an ecosystem. Such species studies could include population trends, presence/absence, abundance, species-habitat relationships, and research related to metapopulations and genetics. Another interesting question involves the overall and species-specific impacts from supplemental feedings.

Biological monitoring is notoriously difficult to fund, yet it is such a critical component for success. Resources are limited and species' needs vary by season, geography and other factors. Acknowledge and identify the most important research needs in initial project planning, and fund accordingly.

The Western Governors' Association established a Wildlife Habitat Council to deal, in part, with wildlife corridors [382]. The associated report states:

> "...creating the scientific information base for wildlife corridor conservation is not a one-time project, but an ongoing effort that supports current and future decision-making in a dynamic landscape. Thus it is critical to establish funding streams for the continued development of information about crucial habitats and important wildlife corridors as land and water uses change. Funding is also needed to monitor the sensitivity of these resources to disruption, their responses to management activities, and to cover the cost of coordination among the many key players from both the public and private sectors."

In an ideal world, long-term monitoring data would be available for each species and habitat of interest throughout the region. In fact, almost none of these data exist. Because research and monitoring are expensive and difficult to fund, it is important to spend resources where they will most effectively answer key research questions.

The first question is: what are the questions? Whether research is utilized to help answer key questions depends on resource availability (time and money), urgency of the question, level of uncertainty, and whether information can reasonably be obtained through other means, such as the scientific literature.

Once core habitats and focal species are identified, the region can begin to sort out what really needs to be accomplished through field studies.

Monitoring corridors is very important and in fact, often necessary for success. For example, field studies will certainly be needed along corridors to determine on-the-ground barriers and other issues that cannot be assessed using GIS or aerial photos. It is necessary to find out which species do and do not use the area and why, to inform corridor planning and implementation. Wildlife-vehicle collision and road-kill surveys can help inform this process, but are not by themselves sufficient. Patch-based monitoring combined with nearest-neighbor distance is often used to measure connectivity between populations (for example, [268]), but matrix conditions need to be considered as well.

When solutions such as wildlife crossings are installed to address barriers, conduct baseline monitoring before installation whenever possible, and collect at least three years' data after installation. Some species will not use crossings immediately but begin using them after two or three years [251]. In addition, it will not necessarily be clear that focal species are actually using corridors. Monitoring corridor use by focal species allows for adaptive management; if they are not using the corridors, more research will be needed to determine and correct the reasons.

We need more information about likely impacts of climate change on wildlife and habitat, and some of this could be acquired through literature searches and the knowledge of experts. How might habitats change, and how will those changes affect wildlife? How quickly will these changes occur? Are we likely to lose or gain some species, no matter what we do? Which wildlife species are most at risk, and how can we improve their chances? Amphibians are likely to fall in the latter category. Exploring questions like these as soon as possible can help guide selection of core habitats, corridors and restoration activities, including which plant species should be planted.

The basic process to develop a research and monitoring strategy looks something like this:

1. Identify objectives, goals and specific targets, and establish check-in dates to determine whether targets are being met.
2. Engage key agencies, such as Oregon Department of Fish and Wildlife, for technical advice.
3. Identify and prioritize key research questions and decide how they should be answered.
4. Identify available data, including field, electronic and other types, and assess their value to the process.
5. Identify information gaps.
6. Create a research and monitoring work plan.
7. Foster collaborative monitoring programs and secure resources and funding.
8. Implement work plan and document the results of studies.
9. Use the results to inform #1 and integrate research into ongoing activities and decision-making.

Find and use the information already available, such as local studies. Consult with biologists when developing a monitoring plan to ensure rigor and statistical validity of research projects. Partnering with academic institutions for short- and long-term monitoring programs is an excellent approach; students often need research projects and want their studies to be useful in the real world. For example, Masters' of Environmental Management (MEM) students can conduct topical literature reviews as well as certain types of modeling processes, and research-oriented programs can address questions requiring field research. Capstone and GIS-based classes can take on specific research needs.

RELATED EFFORTS

Several regional or statewide efforts are linked to mapping core habitats and wildlife corridors in the region and should be integrated with the work being done here as appropriate.

The Western Governors' Association approved a resolution in 2007 to identify key wildlife migration corridors and crucial habitat in the West and recommends policy options and tools for preservation [382]. In response, the association launched the Wildlife Corridor Initiative to promote best practices for development, reduce harmful impacts on wildlife and integrate migratory and crucial habitat into planning decisions.

The Oregon Conservation Strategy articulates a vision for healthy fish and wildlife populations in Oregon by maintaining and restoring functioning habitats, preventing declines of at-risk species, and reversing any declines in these resources, where possible. The Strategy further articulates six key conservation issues that threaten wildlife and habitat, including barriers and lack of connectivity [284]. The Strategy provides a "Conservation Opportunity Areas" map and associated shapefile which should help inform the region's efforts, but note that it was conducted at a state-wide scale and will not include some of the region's core habitat areas. The current Strategy does not delineate wildlife corridors.

The Willamette Basin Synthesis Project combines results from five major Willamette conservation assessments: Pacific Northwest Ecosystem Research Consortium, ODFW's Conservation Strategy, The Nature Conservancy's Willamette Valley – Puget Trough Georgia Basin Lowlands (WPG) Ecoregional Assessment, Wetland Conservancy priority wetlands and the Oregon Biodiversity Project [287]. The synthesis delineates priority land and freshwater sites where investment in conservation or restoration would most improve the health of historically significant and functional habitats, survival or recovery of imperiled plants and wildlife dependent on those habitats, floodplain connections to benefit water quality for aquatic biodiversity, and overall watershed health. The project is a partnership between Oregon Department of Fish and Wildlife, The Nature Conservancy, The Wetlands Conservancy, the Willamette Partnership, Oregon Parks & Recreation Department, Defenders of Wildlife, Oregon Natural Heritage Information Center, Oregon Department of Environmental Quality, the Oregon Biodiversity Project and Metro. The Willamette Synthesis will be adopted as an update of both the ODFW Conservation Strategy and The Nature Conservancy's ecoregional assessment.

The Oregon Wildlife Movement Strategy is an interagency partnership to inventory and prioritize wildlife movement barriers on the state highway system, and directly implements the Oregon Conservation Strategy by addressing barriers to and landscape permeability for animal movement [284]. The goals are to: maintain and improve existing conditions suitable for natural movement of animals across the landscape, improve safety for the traveling public, provide a venue for interagency cooperation and collaboration on wildlife movement issues in Oregon, and develop guidance and recommendations for stakeholders to address wildlife movement. The strategy identifies and prioritizes wildlife linkage opportunities to enable better decisions regarding transportation planning, design and mitigation. Data on wildlife linkages and collision hot spots can be used to help reduce animal-vehicle collisions and enhance landscape permeability for wildlife. However, while these data may be useful to the current effort they are at a state-wide scale, based on the state highway system and are not sufficient for the region's needs.

Two other related initiatives are taking place in the region now. First, the Intertwine Alliance is an initiative to create the world's greatest systems of parks, trails, and natural areas - the Intertwine - in the region. The Intertwine Alliance is a collaborative effort between non-profits, state and local agencies, businesses and citizens from across the region. The alliance includes a core organizing group and five key focus areas: conservation, natural area acquisition, trails, environmental education, and a regional system component. For more information or to get involved, e-mail info@theintertwine.org.

The other local initiative, currently under development, is a Regional Conservation Framework. The framework will be based on the Oregon Conservation Strategy, but with emphasis on local goals and opportunities, including improving wildlife corridors and connectivity for current and future climatic conditions. The framework and the Intertwine are likely to be linked. The current task of identifying core habitats and wildlife corridors will be linked to both.

SUMMARY – WHERE DO WE GO FROM HERE?

The region's existing habitat system is fragmented, often poorly connected and complex, yet the region holds many species representing substantial biodiversity. Connectivity has not been entirely lost; stream corridors, areas to be brought into the urban growth boundary, or those that are not yet fully developed offer key opportunities to plan ahead for wildlife connectivity.

Corridor ecology requires both science and creative thinking. Identifying wildlife connectivity may range from relatively simple drawings on a map to complex modeling processes. At its best, it is a collaborative and iterative process. Creating a wildlife movement strategy lays the initial foundation, but this is just the starting place for what may well be a long-term process relying on long-range planning, restoration, acquisition, easements and other tools. Leadership and public support will be important to the success of a wildlife movement strategy. Monitoring and adaptive management will help ensure success. There are plenty of examples from which to draw. Initiating a connectivity strategy simply requires selecting appropriate tools and approaches and moving forward.

The body of literature reviewed in this document highlights a few key considerations:

- Maps can be important tools to point resources in the right direction
- Species matter - different animals may have very different needs, and in different seasons

- Corridor habitat quality matters
- Matrix matters - probably less for birds, more for terrestrial animals, and most for amphibians
- More native vegetation in more places equals higher biodiversity
- A narrow corridor is usually better than none
- More than one corridor is best
- Formal modeling may not be necessary, but could prove useful
- Use focal species to identify and address habitat suitability, widths, gaps and barriers

It would be easy to become mired in arguments about specifics and take too long, perhaps forever, to complete a movement strategy, even as population increases and more houses and roads are built. Without a plan, there is no organized way to recognize or take advantage of key opportunities to strategically invest in habitat and connectivity.

In theory, however, this is a simple process that requires answering three questions:

1. What do we have?
2. What do we want?
3. How do we get there?

To answer these questions, the first step is to convene a group of key stakeholders and agree on the process. Next, identify potential core habitat patches, target species for each patch, and determine species' needs based on best available science and professional judgment. After that, evaluate existing connectivity and identify risks and alternatives, select preferred alternatives, and create a roadmap to achieve this combination of planning and reality over the long term. Vet the results to a broader audience to gain public support and assistance. And finally, implement the strategy, assess whether it is working, and adapt as needed.

The process will require a great degree of collaboration, communication and compromise. However, the long-term benefits for the region's biodiversity may be well worth the effort.

APPENDICES

- **Appendix 1**: Literature relating to corridor widths
- **Appendix 2**: Literature relating to species' habitat area requirements
- **Appendix 3**: Literature relating to species' gap-crossing abilities
- **Appendix 4:** Models and assessment techniques
- **Appendix 5:** Vertebrate species known to use region habitats at least once every year.
- **Appendix 6:** Literature cited.

APPENDIX 1. LITERATURE RELATING TO CORRIDOR WIDTHS

Research suggesting movement corridor widths (in feet and meters) required by various North American wildlife species. Widths are total corridor widths, including both sides of streams unless noted.

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Best [37]	Birds in Iowa agricultural lands May-November and March-April	• N/A – study relating to 3 types of fencerows (all narrow, width not quantified) • More species in fencerows with more woody vegetation	In every season studied (spring, summer, fall), increase in species was substantial along hedgerows from herbaceous to scattered trees/shrubs to continuous trees/shrubs. Abundance trended in same direction, except summer (scattered trees/shrubs more abundant than continuous).
Brudvig et al. [54]	Experimental connectivity study at Savannah River site, South Carolina. Patches and corridors were early successional habitat within a pine forest matrix. Experimental forest setting. Vascular plants, not season-specific.	• 105-foot (32-meter) corridors enhances biodiversity "spillover" effect	Corridors facilitate movement of organisms between patches, increasing species richness within patches. In patches connected by corridors vs. isolated patches, corridors created a biodiversity "spillover" effect extending approx. 30% of the width of the 1-hectare connected patches, resulting in 10-18% more vascular plant species around connected patches.
Burbrink et al. [56]	Reptiles and amphibians in Illinois	• 328 feet (100 meters) or more; depends greatly on patch characteristics and corridor conditions	Wide (> 3,281 feet or 1,000 meters) riparian corridors did not support more species than narrow (<320 feet or 100 meters). Instead, proximity to core area and local habitat heterogeneity best explained species richness. Other literature suggested that lack of upland habitats and fishless pools, and hydroperiod inhibited many species from consistently occurring in corridor. Demonstrates importance of local conditions and natural history.
Calhoun and Clemens [62]	Amphibians	• 98-755 feet (30-230 meters); salamanders at lower end of range, frogs at upper end.	Recommend 3 management zones: the wetland depression, the wetland envelope (i.e., land within 98 feet or 30 meters of the wetland), and the critical terrestrial habitat (i.e., 98-755 feet or 30–230 meters from the wetland).
Conner et al. [77]	Riparian (intermittent stream) forest breeding bird communities in eastern Texas; used 3 widths: narrow (16-82 feet, or 5-25 meters), medium (98-131 feet, or 30-40 meters) and wide (164-328 feet, or 50-100 meters). Young pine plantations in rural setting.	(extracted species occurring in W OR) • Steadily increased with increasing width: downy woodpecker • 197-230 feet (60-70 meters): abruptly increased after threshold reached: pileated woodpecker, yellow-billed cuckoo • Steadily decreased with forest width: yellow-breasted chat • Not associated with forest width: hairy woodpecker, brown-headed cowbird	Detected many Neotropical migrant species in narrower widths, suggesting these zones do have some value. Shrub-breeding birds more associated with narrow widths.
Constantine et al. 2005 [78]	Small mammal study conducted in mature loblolly pine stands in South Carolina. Considered edge effects of 328-foot (100-meter) wide mature pine corridors through clear cuts.	• In some areas, 328-foot (100-meter) forested movement corridors may be sufficient to provide passage for some small mammal species (e.g., shrews). • Some small mammals may use corridor as their entire home ranges.	Live-trapped small mammals in three regenerating stands following clear-cuts. Harvested stands were bisected by 100-m corridors.

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Croonquist and Brooks [82]	Bird species in central Pennsylvania riparian corridors, spring-summer	• At least 164 feet (50 meters); wider to support sensitive species; 820 feet (250 meters) to support full complement of bird communities • 13 feet (4 meters) woody vegetation for bird community in disturbed areas	Undisturbed (reference) vs. disturbed (agricultural / residential) corridors – species richness, abundance generally decrease with distance from stream in disturbed, but not undisturbed, watersheds. Specialist neotropical migrants used disturbed corridors primarily for migration. Disturbance-sensitive species occurred only in undisturbed corridor 82 feet (25 meters) or greater.
Damschen et al. [86] Damschen et al. [85]	Experimental connectivity study at Savannah River site, South Carolina. Experimental forest setting. Patches and corridors were early successional habitat within a pine forest matrix. Two patch types: edgy and not edgy. Vascular plants, not season-specific.	• 105-foot (32-meter) corridors	1 - Habitat patches connected by corridors retained more native plant species than do isolated patches, this difference increased over time, and the corridors did not promote invasion by exotic species. 2 – Looking at plant dispersal, found that dispersal vectors (birds vs. wind dispersed) and habitat features (edge, corridors) affected species colonization. Bird-dispersed plant species showed positive connectivity effects increasing then stabilizing over time, but no edge effects. Wind-dispersed plant species richness showed steadily accumulating edge and connectivity effects.
Darveau et al. (1995) [87]	Spring songbirds in riparian boreal forests in Canada. Studied corridors 66, 131, 197 feet (20, 40, 60 meters) and control (984 feet, or 300 meters) wide, effects over time due to logging.	• 197-foot (60-meter) wide corridors	To maintain forest breeding birds. Bird densities increased in buffer strips immediately after logging ("packing" effect), then decreased in all strip widths thereafter. By third year after clear-cutting, forest-dwelling species less abundant than generalists in 66-foot (20-meter) strips; Golden-crowned Kinglet and Swainson's Thrush became essentially absent in 66-foot (20-meter) strips after 3 years. Moderate thinning had a more moderate, but similar, effect.
Dickson et al. [93]	Breeding birds in 3 riparian widths in eastern Texas	• 49-82 feet (15-25 meters) (narrow – not recommended) • 98-131 feet (30-40 meters) (medium – minimum recommended) • 164-312 feet (50-95 meters) (wide, recommended) *Species-specific corridor width associations:* • Cowbird, Common Yellowthroat, Mourning Dove: no association • Yellow-breasted Chat: narrow • Red-eyed Vireo, Yellow-billed Cuckoo: increased with width • Downy woodpecker, American Crow: medium/wide	Narrow width (49-82 feet, or 15-25 meters) contained many shrub and edge associates. Medium width (98-131 feet, or 30-40 meters) contained a mix of species associated with narrow and wide widths. Widest width (164-312 feet, or 50-95 meters) contained species primarily associated with mature pine-hardwood and bottomland hardwood.
Environment Canada 1998 [106]	Minimum to allow for interior habitat species movement Sufficient to allow for generalist species movement	• 328 feet (100 meters) • 164 feet (50 meters)	Connectivity width will vary depending on the objectives of the project and the attributes of the nodes that will be connected. Corridors designed to facilitate species movement should be a minimum of 164-328 feet (50-100 meters) wide. Corridors designed to accommodate breeding habitat for specialist species need to be designed to meet habitat requirements of those target species.
Fahrig and Merriam (1985) (from 244)	White-footed mice (Peromyscus leucopus)	• "a few meters"	To reduce probability of extinction in woodlots
Fernandez-Juricic [113]	Urban birds in Madrid, Spain	• Wooded streets increase habitat connectivity to parks	Streets with trees that connected parks positively influenced the number of species in parks

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Fernandez-Juricic and Jokimaki [115]	Review two comprehensive urban bird studies in Spain and Finland parks	• N/A - surrounding urban streets.	Wooded streets increase habitat connectivity to parks
Haddad [149]	2 butterfly species in experimentally designed landscape, South Carolina. Patches and corridors were early successional habitat within a pine forest matrix.	• 105 feet (32 meters) corridor	Corridors increased inter-patch movement rates; movement rate was significantly, negatively related to inter-patch distance. Corridor effects were stronger for males than for females.
Haddad and Baum [151]	4 butterfly species in experimentally designed landscape, South Carolina. Patches and corridors were early successional habitat within a pine forest matrix.	• 105 feet (32 meters) corridor	Three out of four butterfly species reached higher densities in patches connected by corridors than in similar, isolated patches.
Haddad et al. [152]	Variety of invertebrate and vertebrate species (10 spps) in experimentally designed landscape, South Carolina. Patches and corridors were early successional habitat within a pine forest matrix.	• 105 feet (32 meters) corridor	This width was sufficient (and was the only width tested) to successfully direct movement of animals to the next patch. Interestingly, the same number of animals left a given patch with or without corridors, but corridors increased their arrival at the next patch by more than 68 percent for each of 10 species, acting as a sort of "drift fence."
Hagar 1999 [155]	Western Oregon study of logged and unlogged riparian areas. Study conducted May-July in Coast Range.	These species' numbers increased with increasing buffer width (40-70m 1-sided buffers): • Pacific-slope Flycatcher, Brown Creeper, Chestnut-backed Chickadee, Winter Wren 1-sided, 70-m buffer may be too narrow for these species: • Hammond's Flycatcher, Golden-crowned Kinglet, Varied Thrush, Hermit Warbler	
Helferty 2002 [163]	Review of needs for amphibian upland corridors in Toronto area	• Up to 0.62 mile (1 kilometer) traveled between wetland and terrestrial habitats.	Maintenance of natural hydrology regimes is critical to maintaining amphibian biodiversity.
Hodges and Krementz 1996 [177]	Riparian forests in Georgia during breeding season. Minimum distance needed to support area-sensitive Neotropical migratory birds	• 328 feet (100 meters) or more, 1-sided width • Red-eyed Vireo probably needs more	Sufficient to maintain the six most common species of breeding Neotropical migrant birds.

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Keller, Robbins & Hatfield 1993 [190]	Birds in riparian corridors (117) in agricultural setting in Maryland and Delaware, 25-800 m wide.	• Probablility of area-sensitive Neotropical migrants increased most dramatically between 25-100m • Recommended minimum 100-m corridors Significant probability of detecting these species continued to increase to maximum width: • Red-eyed Vireo, Wood Thrush, Eastern Wood-peewee • Noted Red-eyed Vireo, Wood Thrush, Hairy Woodpecker as area-sensitive species with maximum probability of detection in minimum 100-ha patches. These species were significantly associated with narrow corridors: • Purple Martin, Mourning Dove, Red-winged Blackbird, European Starling, Turkey Vulture, House Sparrow, American Robin	Brown-headed Cowbird came close to significance (P =0.07) for wider corridors. This makes sense in light of other studies showing correlation not necessarily with hard edges, but particularly with streamside edges.
Kilgo et al. 1998 [195]	Compared breeding bird abundance, species richness among S. Carolina bottomland hardwood stands ranging in width from <50 m to >1,000 m and enclosed by forested habitat. Also compared avian abundance and richness among stands enclosed by pine (Pinus spp.) forest and stands enclosed by field-scrub habitats.	• Neotrop and total species richness was positively associated with stand width. • Total abundances were generally greatest in width classes <50m and >1000m. • Probability of occurrence was + associated with stand width for 12 species, - for one. • Even narrow riparian zones can support diverse avifauna, but 500-m zones are needed to maintain complete avian community characteristics.	Because these bottomland forests were embedded within other forest or vegetation types, relevance to the Metro region may not be high.
Kinley & Newhouse 1997 [197]	SE British Columbia breeding bird surveys examining riparian reserve zone width and bird density, diversity. Three zones: 70, 37 or 14 m wide.	These species seem to prefer the widest corridors (70 m or more): • Golden-crowned Kinglet, Gray Jay , Townsend's Warbler, Varied Thrush, Warbling Vireo (P<0.07), Winter Wren • Density of all species and all riparian-associated species > with increasing width.	See pages 81-82 for species-habitat relationships.
Cross et al. 1985 [200]	Downy woodpecker	• 98 feet (30 meters)	Minimum mean width supporting breeding populations of downy woodpeckers
Knutson and Naef 1997 [200]	Black-capped chickadee	• 98 feet (30 meters)	Minimum mean width supporting breeding populations of black-capped chickadees
Mudd 1975 [264]	Mourning doves	• 98 feet (30 meters)	Sufficient width for mourning doves
Stauffer and Best 1980 [347]	White-breasted nuthatch	• 112 feet (34 meters)	Minimum mean width supporting breeding populations of white-breasted nuthatch

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Stauffer and Best 1980 [347]	Minimum needed to support Rufous-sided Towhee breeding populations	• 1,310 feet (400 meters)	Rufous-sided Towhees were subsequently split between Spotted and Eastern towhees.
Mudd 1975 [264]	Pheasant, quail and deer	• 150 feet (46 meters)	
Machtans et al. 1996 [224]	Bird movements through riparian (lakeside) buffer strips before and after harvest in Alberta, Canada May-August, 3 years	• At least 328 feet (100 meters) buffer along 1 edge of lake	Resident juvenile birds (dispersal). Number of mist-net captures for all ages/species increased logarithmically closer to lake.
Margui 2007 [266]	Valencia, Spain street tree study over several seasons.	• Tree species richness, abundance, height were primary factors affecting bird metrics. • Siberian elm, box elder, white poplar were bird favorites. • Use varied by bird species and season. • Winter: 25% of all wintering bird species in the area used street trees; breeding = 19%	Author concludes that street trees provide poor habitat, in sharp contrast to two other studies examining street trees as corridors in Madrid, Spain and Melbourne, Australia [113;384]. The Valencia study sites were purposely selected such that there were no natural areas nearby, unlike the other street tree studies, which were connected to natural areas. Madrid and Melbourne also had larger, more mature street trees. For more sensitive species, it seems likely that street trees may be quite valuable for connectivity but less valuable as habitat.
May 2000 [238]	General wildlife habitat	• 328 feet (100 meters)	Wildlife needs summarized from May's literature review.
Merriam	Eastern chipmunk	• *Note this deals with length, not width.* • 66-1,509 feet (20-460 meters); most frequent usage in the 66-131-foot (20-40-meter) range	Range of distances traveled between isolated upland forests; 90% via wooded linkages.
Peak and Thompson 2004 [295]	Nest success of songbirds in riparian forests of different widths (agricultural setting) in Missouri	• Wider than 1312-1739 feet (400-530 meters) for most area-sensitive species. • 180 feet (55 meters) may be sufficient for generalist species such as catbirds and cardinals.	This study was for breeding habitat, not corridor movement; applies to birds attempting to nest within corridors.
Pennington et al. 2008 [299]	Neotropical migratory birds in Ohio – breeding and migration	• 1640 feet (500 meter) wide corridor or patch without buildings for breeding • 820 feet (250 meters) for migrating, buildings okay	Hard to disentangle native vegetation from corridor width (true also here); both bird measures also positively related to native vegetation and mature trees. Recommend adding high native tree cover in urban areas for stopover habitat.
Rudolph and Dickson 1990 [322]	Full complement of herpetofauna and other vertebrate species	• > 197 feet (60 meters)	Corridor should have mature trees.

landscape, improve safety for the traveling public, provide a venue for interagency cooperation and collaboration on wildlife movement issues in Oregon, and develop guidance and recommendations for stakeholders to address wildlife movement. The strategy identifies and prioritizes wildlife linkage opportunities to enable better decisions regarding transportation planning, design and mitigation. Data on wildlife linkages and collision hot spots can be used to help reduce animal-vehicle collisions and enhance landscape permeability for wildlife. However, while these data may be useful to the current effort they are at a state-wide scale, based on the state highway system and are not sufficient for the region's needs.

Two other related initiatives are taking place in the region now. First, the Intertwine Alliance is an initiative to create the world's greatest systems of parks, trails, and natural areas - the Intertwine - in the region. The Intertwine Alliance is a collaborative effort between non-profits, state and local agencies, businesses and citizens from across the region. The alliance includes a core organizing group and five key focus areas: conservation, natural area acquisition, trails, environmental education, and a regional system component. For more information or to get involved, e-mail info@theintertwine.org.

The other local initiative, currently under development, is a Regional Conservation Framework. The framework will be based on the Oregon Conservation Strategy, but with emphasis on local goals and opportunities, including improving wildlife corridors and connectivity for current and future climatic conditions. The framework and the Intertwine are likely to be linked. The current task of identifying core habitats and wildlife corridors will be linked to both.

SUMMARY – WHERE DO WE GO FROM HERE?

The region's existing habitat system is fragmented, often poorly connected and complex, yet the region holds many species representing substantial biodiversity. Connectivity has not been entirely lost; stream corridors, areas to be brought into the urban growth boundary, or those that are not yet fully developed offer key opportunities to plan ahead for wildlife connectivity.

Corridor ecology requires both science and creative thinking. Identifying wildlife connectivity may range from relatively simple drawings on a map to complex modeling processes. At its best, it is a collaborative and iterative process. Creating a wildlife movement strategy lays the initial foundation, but this is just the starting place for what may well be a long-term process relying on long-range planning, restoration, acquisition, easements and other tools. Leadership and public support will be important to the success of a wildlife movement strategy. Monitoring and adaptive management will help ensure success. There are plenty of examples from which to draw. Initiating a connectivity strategy simply requires selecting appropriate tools and approaches and moving forward.

The body of literature reviewed in this document highlights a few key considerations:

- Maps can be important tools to point resources in the right direction
- Species matter - different animals may have very different needs, and in different seasons

- Corridor habitat quality matters
- Matrix matters - probably less for birds, more for terrestrial animals, and most for amphibians
- More native vegetation in more places equals higher biodiversity
- A narrow corridor is usually better than none
- More than one corridor is best
- Formal modeling may not be necessary, but could prove useful
- Use focal species to identify and address habitat suitability, widths, gaps and barriers

It would be easy to become mired in arguments about specifics and take too long, perhaps forever, to complete a movement strategy, even as population increases and more houses and roads are built. Without a plan, there is no organized way to recognize or take advantage of key opportunities to strategically invest in habitat and connectivity.

In theory, however, this is a simple process that requires answering three questions:

1. What do we have?
2. What do we want?
3. How do we get there?

To answer these questions, the first step is to convene a group of key stakeholders and agree on the process. Next, identify potential core habitat patches, target species for each patch, and determine species' needs based on best available science and professional judgment. After that, evaluate existing connectivity and identify risks and alternatives, select preferred alternatives, and create a roadmap to achieve this combination of planning and reality over the long term. Vet the results to a broader audience to gain public support and assistance. And finally, implement the strategy, assess whether it is working, and adapt as needed.

The process will require a great degree of collaboration, communication and compromise. However, the long-term benefits for the region's biodiversity may be well worth the effort.

APPENDICES

- **Appendix 1**: Literature relating to corridor widths
- **Appendix 2**: Literature relating to species' habitat area requirements
- **Appendix 3**: Literature relating to species' gap-crossing abilities
- **Appendix 4:** Models and assessment techniques
- **Appendix 5:** Vertebrate species known to use region habitats at least once every year.
- **Appendix 6:** Literature cited.

APPENDIX 1. LITERATURE RELATING TO CORRIDOR WIDTHS

Research suggesting movement corridor widths (in feet and meters) required by various North American wildlife species. Widths are total corridor widths, including both sides of streams unless noted.

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Best [37]	Birds in Iowa agricultural lands May-November and March-April	• N/A – study relating to 3 types of fencerows (all narrow, width not quantified) • More species in fencerows with more woody vegetation	In every season studied (spring, summer, fall), increase in species was substantial along hedgerows from herbaceous to scattered trees/shrubs to continuous trees/shrubs. Abundance trended in same direction, except summer (scattered trees/shrubs more abundant than continuous).
Brudvig et al. [54]	Experimental connectivity study at Savannah River site, South Carolina. Patches and corridors were early successional habitat within a pine forest matrix. Experimental forest setting. Vascular plants, not season-specific.	• 105-foot (32-meter) corridors enhances biodiversity "spillover" effect	Corridors facilitate movement of organisms between patches, increasing species richness within patches. In patches connected by corridors vs. isolated patches, corridors created a biodiversity "spillover" effect extending approx. 30% of the width of the 1-hectare connected patches, resulting in 10-18% more vascular plant species around connected patches.
Burbrink et al. [56]	Reptiles and amphibians in Illinois	• 328 feet (100 meters) or more; depends greatly on patch characteristics and corridor conditions	Wide (> 3,281 feet or 1,000 meters) riparian corridors did not support more species than narrow (<320 feet or 100 meters). Instead, proximity to core area and local habitat heterogeneity best explained species richness. Other literature suggested that lack of upland habitats and fishless pools, and hydroperiod inhibited many species from consistently occurring in corridor. Demonstrates importance of local conditions and natural history.
Calhoun and Clemens [62]	Amphibians	• 98-755 feet (30-230 meters); salamanders at lower end of range, frogs at upper end.	Recommend 3 management zones: the wetland depression, the wetland envelope (i.e., land within 98 feet or 30 meters of the wetland), and the critical terrestrial habitat (i.e., 98-755 feet or 30–230 meters from the wetland).
Conner et al. [77]	Riparian (intermittent stream) forest breeding bird communities in eastern Texas; used 3 widths: narrow (16-82 feet, or 5-25 meters), medium (98-131 feet, or 30-40 meters) and wide (164-328 feet, or 50-100 meters). Young pine plantations in rural setting.	(extracted species occurring in W OR) • Steadily increased with increasing width: downy woodpecker • 197-230 feet (60-70 meters): abruptly increased after threshold reached: pileated woodpecker, yellow-billed cuckoo • Steadily decreased with forest width: yellow-breasted chat • Not associated with forest width: hairy woodpecker, brown-headed cowbird	Detected many Neotropical migrant species in narrower widths, suggesting these zones do have some value. Shrub-breeding birds more associated with narrow widths.
Constantine et al. 2005 [78]	Small mammal study conducted in mature loblolly pine stands in South Carolina. Considered edge effects of 328-foot (100-meter) wide mature pine corridors through clear cuts.	• In some areas, 328-foot (100-meter) forested movement corridors may be sufficient to provide passage for some small mammal species (e.g., shrews). • Some small mammals may use corridor as their entire home ranges.	Live-trapped small mammals in three regenerating stands following clear-cuts. Harvested stands were bisected by 100-m corridors.

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Croonquist and Brooks [82]	Bird species in central Pennsylvania riparian corridors, spring-summer	• At least 164 feet (50 meters); wider to support sensitive species; 820 feet (250 meters) to support full complement of bird communities • 13 feet (4 meters) woody vegetation for bird community in disturbed areas	Undisturbed (reference) vs. disturbed (agricultural / residential) corridors – species richness, abundance generally decrease with distance from stream in disturbed, but not undisturbed, watersheds. Specialist neotropical migrants used disturbed corridors primarily for migration. Disturbance-sensitive species occurred only in undisturbed corridor 82 feet (25 meters) or greater.
Damschen et al. [86] Damschen et al. [85]	Experimental connectivity study at Savannah River site, South Carolina. Experimental forest setting. Patches and corridors were early successional habitat within a pine forest matrix. Two patch types: edgy and not edgy. Vascular plants, not season-specific.	• 105-foot (32-meter) corridors	1 - Habitat patches connected by corridors retained more native plant species than do isolated patches, this difference increased over time, and the corridors did not promote invasion by exotic species. 2 – Looking at plant dispersal, found that dispersal vectors (birds vs. wind dispersed) and habitat features (edge, corridors) affected species colonization. Bird-dispersed plant species showed positive connectivity effects increasing then stabilizing over time, but no edge effects. Wind-dispersed plant species richness showed steadily accumulating edge and connectivity effects.
Darveau et al. (1995) [87]	Spring songbirds in riparian boreal forests in Canada. Studied corridors 66, 131, 197 feet (20, 40, 60 meters) and control (984 feet, or 300 meters) wide, effects over time due to logging.	• 197-foot (60-meter) wide corridors	To maintain forest breeding birds. Bird densities increased in buffer strips immediately after logging ("packing" effect), then decreased in all strip widths thereafter. By third year after clear-cutting, forest-dwelling species less abundant than generalists in 66-foot (20-meter) strips; Golden-crowned Kinglet and Swainson's Thrush became essentially absent in 66-foot (20-meter) strips after 3 years. Moderate thinning had a more moderate, but similar, effect.
Dickson et al. [93]	Breeding birds in 3 riparian widths in eastern Texas	• 49-82 feet (15-25 meters) (narrow – not recommended) • 98-131 feet (30-40 meters) (medium – minimum recommended) • 164-312 feet (50-95 meters) (wide, recommended) *Species-specific corridor width associations:* • Cowbird, Common Yellowthroat, Mourning Dove: no association • Yellow-breasted Chat: narrow • Red-eyed Vireo, Yellow-billed Cuckoo: increased with width • Downy woodpecker, American Crow: medium/wide	Narrow width (49-82 feet, or 15-25 meters) contained many shrub and edge associates. Medium width (98-131 feet, or 30-40 meters) contained a mix of species associated with narrow and wide widths. Widest width (164-312 feet, or 50-95 meters) contained species primarily associated with mature pine-hardwood and bottomland hardwood.
Environment Canada 1998 [106]	Minimum to allow for interior habitat species movement Sufficient to allow for generalist species movement	• 328 feet (100 meters) • 164 feet (50 meters)	Connectivity width will vary depending on the objectives of the project and the attributes of the nodes that will be connected. Corridors designed to facilitate species movement should be a minimum of 164-328 feet (50-100 meters) wide. Corridors designed to accommodate breeding habitat for specialist species need to be designed to meet habitat requirements of those target species.
Fahrig and Merriam (1985) (from 244)	White-footed mice (Peromyscus leucopus)	• "a few meters"	To reduce probability of extinction in woodlots
Fernandez-Juricic [113]	Urban birds in Madrid, Spain	• Wooded streets increase habitat connectivity to parks	Streets with trees that connected parks positively influenced the number of species in parks

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Fernandez-Juricic and Jokimaki [115]	Review two comprehensive urban bird studies in Spain and Finland parks	• N/A - surrounding urban streets.	Wooded streets increase habitat connectivity to parks
Haddad [149]	2 butterfly species in experimentally designed landscape, South Carolina. Patches and corridors were early successional habitat within a pine forest matrix.	• 105 feet (32 meters) corridor	Corridors increased inter-patch movement rates; movement rate was significantly, negatively related to inter-patch distance. Corridor effects were stronger for males than for females.
Haddad and Baum [151]	4 butterfly species in experimentally designed landscape, South Carolina. Patches and corridors were early successional habitat within a pine forest matrix.	• 105 feet (32 meters) corridor	Three out of four butterfly species reached higher densities in patches connected by corridors than in similar, isolated patches.
Haddad et al. [152]	Variety of invertebrate and vertebrate species (10 spps) in experimentally designed landscape, South Carolina. Patches and corridors were early successional habitat within a pine forest matrix.	• 105 feet (32 meters) corridor	This width was sufficient (and was the only width tested) to successfully direct movement of animals to the next patch. Interestingly, the same number of animals left a given patch with or without corridors, but corridors increased their arrival at the next patch by more than 68 percent for each of 10 species, acting as a sort of "drift fence."
Hagar 1999 [155]	Western Oregon study of logged and unlogged riparian areas. Study conducted May-July in Coast Range.	These species' numbers increased with increasing buffer width (40-70m 1-sided buffers): • Pacific-slope Flycatcher, Brown Creeper, Chestnut-backed Chickadee, Winter Wren 1-sided, 70-m buffer may be too narrow for these species: • Hammond's Flycatcher, Golden-crowned Kinglet, Varied Thrush, Hermit Warbler	
Helferty 2002 [163]	Review of needs for amphibian upland corridors in Toronto area	• Up to 0.62 mile (1 kilometer) traveled between wetland and terrestrial habitats.	Maintenance of natural hydrology regimes is critical to maintaining amphibian biodiversity.
Hodges and Krementz 1996 [177]	Riparian forests in Georgia during breeding season. Minimum distance needed to support area-sensitive Neotropical migratory birds	• 328 feet (100 meters) or more, 1-sided width • Red-eyed Vireo probably needs more	Sufficient to maintain the six most common species of breeding Neotropical migrant birds.

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Keller, Robbins & Hatfield 1993 [190]	Birds in riparian corridors (117) in agricultural setting in Maryland and Delaware, 25-800 m wide.	• Probablility of area-sensitive Neotropical migrants increased most dramatically between 25-100m • Recommended minimum 100-m corridors Significant probability of detecting these species continued to increase to maximum width: • Red-eyed Vireo, Wood Thrush, Eastern Wood-peewee • Noted Red-eyed Vireo, Wood Thrush, Hairy Woodpecker as area-sensitive species with maximum probability of detection in minimum 100-ha patches. These species were significantly associated with narrow corridors: • Purple Martin, Mourning Dove, Red-winged Blackbird, European Starling, Turkey Vulture, House Sparrow, American Robin	Brown-headed Cowbird came close to significance (P =0.07) for wider corridors. This makes sense in light of other studies showing correlation not necessarily with hard edges, but particularly with streamside edges.
Kilgo et al. 1998 [195]	Compared breeding bird abundance, species richness among S. Carolina bottomland hardwood stands ranging in width from <50 m to >1,000 m and enclosed by forested habitat. Also compared avian abundance and richness among stands enclosed by pine (Pinus spp.) forest and stands enclosed by field-scrub habitats.	• Neotrop and total species richness was positively associated with stand width. • Total abundances were generally greatest in width classes <50m and >1000m. • Probability of occurrence was + associated with stand width for 12 species, - for one. • Even narrow riparian zones can support diverse avifauna, but 500-m zones are needed to maintain complete avian community characteristics.	Because these bottomland forests were embedded within other forest or vegetation types, relevance to the Metro region may not be high.
Kinley & Newhouse 1997 [197]	SE British Columbia breeding bird surveys examining riparian reserve zone width and bird density, diversity. Three zones: 70, 37 or 14 m wide.	These species seem to prefer the widest corridors (70 m or more): • Golden-crowned Kinglet, Gray Jay , Townsend's Warbler, Varied Thrush, Warbling Vireo (P<0.07), Winter Wren • Density of all species and all riparian-associated species > with increasing width.	See pages 81-82 for species-habitat relationships.
Cross et al. 1985 [200]	Downy woodpecker	• 98 feet (30 meters)	Minimum mean width supporting breeding populations of downy woodpeckers
Knutson and Naef 1997 [200]	Black-capped chickadee	• 98 feet (30 meters)	Minimum mean width supporting breeding populations of black-capped chickadees
Mudd 1975 [264]	Mourning doves	• 98 feet (30 meters)	Sufficient width for mourning doves
Stauffer and Best 1980 [347]	White-breasted nuthatch	• 112 feet (34 meters)	Minimum mean width supporting breeding populations of white-breasted nuthatch

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Stauffer and Best 1980 [347]	Minimum needed to support Rufous-sided Towhee breeding populations	• 1,310 feet (400 meters)	Rufous-sided Towhees were subsequently split between Spotted and Eastern towhees.
Mudd 1975 [264]	Pheasant, quail and deer	• 150 feet (46 meters)	
Machtans et al. 1996 [224]	Bird movements through riparian (lakeside) buffer strips before and after harvest in Alberta, Canada May-August, 3 years	• At least 328 feet (100 meters) buffer along 1 edge of lake	Resident juvenile birds (dispersal). Number of mist-net captures for all ages/species increased logarithmically closer to lake.
Margui 2007 [266]	Valencia, Spain street tree study over several seasons.	• Tree species richness, abundance, height were primary factors affecting bird metrics. • Siberian elm, box elder, white poplar were bird favorites. • Use varied by bird species and season. • Winter: 25% of all wintering bird species in the area used street trees; breeding = 19%	Author concludes that street trees provide poor habitat, in sharp contrast to two other studies examining street trees as corridors in Madrid, Spain and Melbourne, Australia [113;384]. The Valencia study sites were purposely selected such that there were no natural areas nearby, unlike the other street tree studies, which were connected to natural areas. Madrid and Melbourne also had larger, more mature street trees. For more sensitive species, it seems likely that street trees may be quite valuable for connectivity but less valuable as habitat.
May 2000 [238]	General wildlife habitat	• 328 feet (100 meters)	Wildlife needs summarized from May's literature review.
Merriam	Eastern chipmunk	• *Note this deals with length, not width.* • 66-1,509 feet (20-460 meters); most frequent usage in the 66-131-foot (20-40-meter) range	Range of distances traveled between isolated upland forests; 90% via wooded linkages.
Peak and Thompson 2004 [295]	Nest success of songbirds in riparian forests of different widths (agricultural setting) in Missouri	• Wider than 1312-1739 feet (400-S30 meters) for most area-sensitive species. • 180 feet (55 meters) may be sufficient for generalist species such as catbirds and cardinals.	This study was for breeding habitat, not corridor movement; applies to birds attempting to nest within corridors.
Pennington et al. 2008 [299]	Neotropical migratory birds in Ohio – breeding and migration	• 1640 feet (500 meter) wide corridor or patch without buildings for breeding • 820 feet (250 meters) for migrating, buildings okay	Hard to disentangle native vegetation from corridor width (true also here); both bird measures also positively related to native vegetation and mature trees. Recommend adding high native tree cover in urban areas for stopover habitat.
Rudolph and Dickson 1990 [322]	Full complement of herpetofauna and other vertebrate species	• > 197 feet (60 meters)	Corridor should have mature trees.

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Semlitsch and Bodie 2003 [329]	Literature review relating to wetland / riparian buffer requirements for reptiles and amphibians, so this is not strictly a corridor reference.	Group / range of recommended widths • Frogs / 673-1207 (205-368 meters) • Salamanders / 384-715 feet (117-218 meters) • Amphibians / 522-951 feet (159-290 meters) • Snakes / 551-997 feet (168-304 meters) • Turtles / 404-942 feet (123-287 meters) • Reptiles / 417-948 feet (127-289 meters) • Herpetofauna / 466-948 feet (142-289 meters) • Overall recommendation to cover most species: 98-197 feet (30-60 meters) aquatic buffer, 466-1276 feet (142-389 meters) core habitat (from stream), additional 164 feet (50 meters) beyond core for terrestrial buffer.	Mean minimum and maximum core terrestrial habitat for amphibians and reptiles. Values represent mean linear radii extending outward from the edge of aquatic habitats compiled from summary data in the authors' appendix (i.e., one-sided buffer). The review summarized terrestrial migration distances from aquatic sites for reptiles and amphibians, so the widths are more relevant to home range radii than corridors. However, provides information regarding both core habitat and corridor length requirements for a wide variety of species, including the following species occurring here: western toad, Pacific chorus frog (from 1956 OR study), bullfrog, OR spotted frog, rough-skinned newt (from 1960 OR study), snapping turtle, painted turtle, and northwestern pond turtle.
Silva and Prince 2008 [332]	Prince Edward Island, Canada Small mammals in agricultural landscape	• Hedgerows provided substantial connectivity for small mammals • Hedgerows narrow, but length and composition are important	Abundance of small mammals except eastern chipmunk increased in hedgerows longer than 225–250 m, but was independent of length in shorter hedgerows. Most small mammals appeared to benefit from hedgerows with high shrub diversity, ground cover and few gaps.
Small 1982 [339]	Pileated woodpecker nesting	• 328 feet (100 meters)	
Small 1982 [339]	Travel corridor for red fox and marten	• 328 feet (100 meters)	
Soulé et al. 1988 [344]	4 chaparral bird species, including Spotted Towhee	• 16 feet (5 meters)	chaparral strips running between habitat patches to reduce local extinctions in isolated patches
Spackman and Hughes 1995 [345]	Birds and vascular plants in Vermont Spring; rural setting.	• At least 492-1148 feet (150-350 meters) to retain 90% of bird species. • Small mammals traveled primarily below or just above high water mark.	Used "above high water mark" terminology to describe corridors, so assumed distances were 1-sided and doubled them. Corridors should be forested.
Thurmond et al. 1995 [359]	Forest interior and neotropical migrant birds in Georgia riparian areas	• Wider than 165 feet (50 meters)	Forest interior and neotropical migrants were essentially absent in widths less than this distance.
Todd 2000	General wildlife habitat	• 100-325 feet (30-99 meters)	From buffer width chart – wildlife needs

Reference	Location, species and context	Recommended or studied corridor width(s)	Notes
Tzilkowski, Wakely & Morris 1986 [361]	Relationships between street-tree characteristics, including habitat features, and use by urban birds were investigated from May-July in State College, PA. Bird presence or absence was sampled in 1278 individual street trees of 24 species.	• Analysis of tree species, height class and bird occurrence determined that pin oak, American elm and honey locust were used most frequently by birds. • There was a positive linear relationship between height class and bird occurrence. • Both native and non-native birds occurred more frequently in tall street trees where there was little other tree cover. • Natives were seen more often in residential areas with low vehicular traffic. • Non-natives were seen more often in business areas with high traffic volume.	Street tree species and structure vary in their attractiveness to bird species. This study does not specifically address connectivity but ties to three other street tree studies cited here [113;266;384].
Prose 1985 [308]	Belted Kingfisher roosts; this was a Habitat Suitability Model from USFWS, and this reference was from Maritime Provinces.	• 100-200 feet (30-61 meters) from water (note 1-sided width)	Kingfishers typically roosted among the leaves of deciduous trees and near the tips of small supple limbs, where they were safe from nocturnal predators.
White et al. 2005 [384]	Urban bird study in Melbourne, Australia.	• The transition from native to exotic streetscapes saw the progressive loss of insectivorous and nectivorous species reflecting a reliance by these species on structurally diverse and/or native vegetation for both shelter and food resources. More structurally diverse streetscapes provided habitat and movement corridors for more species.	The implementation of effective strategies and incentives which encourage the planting of structurally diverse native vegetation in streetscapes and gardens should be paramount if avian biodiversity is to be retained and enhanced in urban environments.
Hannon et al. 2002 [157]	Studied changes in terrestrial vertebrate communities from pre- to post-harvest over 3 years in experimentally created buffer strips (20, 100, 200, and 800 m wide) in a boreal mixed wood forest in Alberta, Canada.	• 656-foot (200-meter) buffer needed to conserve pre-harvest passerine bird community, at least up to 3 years post-harvest.	Forest-dependent bird species declined as buffer width narrowed from 200 to 100 m and narrower. Changes in small mammal or amphibian abundance were not detected for any treatment relative to controls; however, studied species are habitat generalists that used and even bred in clear cuts.

APPENDIX 2. LITERATURE RELATING TO SPECIES' HABITAT AREA REQUIREMENTS

Research suggesting minimum habitat patch size or noting area-sensitivity, for various species. Most species noted are present in the Metro region; others do not occur here but may have similar requirements to species occurring here (such as migratory thrushes).

Reference	Location and context	Recommended minimum habitat area	Notes
Askins, Philbrick & Segano 1987 [14]	Connecticut breeding bird study in forested landscape, testing importance of isolation and patch size.	• Hermit Thrush – 798 acres (323 hectares) • Brown Creeper – 124 acres (50 hectares)	Forest area was the best predictor for forest-interior species richness and density for small forest patches, but in large patches, isolation was the best predictor.
Burke & Nol 1998 [58]	Study of Ovenbird (Neotropical migrant) patch size needs in southern Ontario.	• Density, pairing success higher in larger patches • Prey biomass was 10-36 times higher in large versus small woodlots • 49 acre (20 hectare) core area, 198 acre (80 hectare) total forest area	• Distance to edge (623-984 feet, or 190-300 meters) most important predictor of pairing success
Dawson, Darr & Robbins 1993 [89]	Maryland birds studied May-July using point counts.	• Hairy Woodpecker: 178 acres (72 hectares) • Pileated Woodpecker: 1,147 acres (464 hectares) • White-breasted Nuthatch: 343 acres (139 hectares) • Red-eyed Vireo: 42 acres (17 hectares)	This study estimated probability of occurrence within patches of various sizes based on field data. The recommended areas shown here represent the size at which a given species is substantially more likely to occur.
Galli, Leck & Forman 1976 [133]	New Jersey bird study conducted between June-August in mixed oak forested habitat. Patch sizes studied from <2.5 acres (1 hectare) to 74 acres (30 hectares)	• Red-eyed Vireo: most in 25-59 acre patches (10-24 hectares) • Downy Woodpecker: some in 2-10 acre patches (1-4 hectares), most in 25-59 acre patches (10-24 hectares) • Eastern Wood-peewee: 5 acres (2 hectares) or more; most in 25-59 acre patches (10-24 hectares) • White-breasted Nuthatch: some in 5-20 acre patches (2-8 hectares); more in 25-59 acre patches (10-24 hectares) • Ovenbird: started at 10 acres (4 hectares); most in 25-59 acre patches (10-24 hectares) • Hairy Woodpecker: some in 5-25 acre patches (2-10 hectares); most in 25-59 acre patches (10-24 hectares) • Black-capped Chickadee: some in 5-20 acre patches (2-8 hectares); most in 25-59 acre patches (10-24 hectares) • Yellow-breasted Chat: some in 10-59 acre patches (4-24 hectares); most in ≥ 59 acres (24 hectares) • Red-shouldered Hawk: 25-59 acre patches (10-24 hectares)	This study estimated probability of occurrence within patches of various sizes based on field data. The recommended areas shown here represent the size at which a given species is substantially more likely to occur. All of the species noted at left are insectivorous except Red-shouldered Hawk (carnivore).
George & Brand 2002 [137]	Breeding bird study conducted in northern California redwood forests studying effects of fragmentation.	• These species appear to be area-sensitive: • Pileated woodpecker, Pacific-slope Flycatcher, Steller's Jay, Brown Creeper, Winter Wren, Varied Thrush	These bird species are sensitive to fragmentation possibly due to changes in microclimate along forest edges or to increased nest predation and subsequent avoidance of forest edges

Reference	Location and context	Recommended minimum habitat area	Notes
Hawrot & Niemi 1996 [161]	Birds studied via transects over two years during June in northwest Wisconsin. Study examined potential impacts of different types of edge and patch shape on species.	• Red-breasted Nuthatch, Hermit Thrush, Red-eyed Vireo and Ovenbird appear to be area-sensitive. • No specific area recommendations.	The types of (natural, not urban) edge matters and there may be differences in edge that appear subtle to the observer, yet make a big difference to bird species.
Hinsley et al. 1998 [176]	Review of European studies looking at woodland patch size, land cover, latitude and longitude in relation to breeding bird species in agricultural lands.	• No specific area recommendations (patches were generally less than 49 acres, or 20 hectares). • The number of species expected to breed decreased significantly with patch size decreases in several studies, revealing a linear relationship from 2-37 acres (1-15 hectares).	Species richness declined with increasing latitude.
Kilgo, Miller & Smith 1999 [194]	Fall bird study conducted in South Carolina, examining forest practices. Study looked at created gaps within forests gap size 33-, 66-, and 131-foot (10-, 20-, and 40-meter) radius. Mist-netting study in bottomland hardwood forests.	The following species were captured most often in the largest (131-foot radius, or about 5 acres; 40-meter radius, or about 2 hectares) gaps (in this case, gaps are patches): • Swainson's Thrush • Yellow-breasted Chat • Ruby-crowned Kinglet • Hermit Thrush • Eastern Towhee • White-throated Sparrow	Forest-dependent birds apparently shifted habitat preferences in fall to include forest gaps. (Lori's comment: newly emerging information suggests that migratory songbirds may have a life-history phase requirement for molting associated with migration, and that species' needs during this time may be entirely different from other life-history phases. Thus in this case, gap size represents "patch size.")
Mancke & Gavin 2000 [228]	This Pennsylvania study examined possible impacts of patch size and proximity to buildings on breeding bird communities in a forested area.	• Forest interior species: Wood Thrush, Red-eyed Vireo • Edge species: Common Yellowthroat, American Crow, American Robin, European Starling, Eastern Towhee, Song Sparrow, Red-winged Blackbird, Baltimore Oriole, House Finch, American Goldfinch, house Sparrow • Species preferring few buildings or present only in moderately deep and deep woodlots when buildings are nearby: Downy Woodpecker, Rose-breasted Grosbeak, Song Sparrow • Prefers no buildings nearby: Eastern Towhee	Species-habitat relationships on page 606 of this article.
McIntyre 1995 [244]	Georgia study on the effects of landscape patchiness on the diversity of birds. Examined birds from January-April in small (<8 acre, or <3 hectare) vs (25-32 acre, or 10-13 hectare) forested patches set within a non-forested agricultural landscape. Compared these two patch size classes to control patches >32 acres (13 hectares).	• Across seasons, f the two smaller size classes, the larger held an average of 52 species while the small held 39 species. • Species associated with the 25-32 acre (10-13 hectare) patches and larger included Red-breasted Nuthatch, Brown Creeper, Hermit Thrush, Ruby-crowned Kinglet and Wood Thrush. • Edge species include Cedar Waxwing, Dark-eyed Junco, Northern Rough-winged Swallow, Purple Martin and House Wren.	The study revealed significant differences in diversity between large and small woodlots and between contiguous and fragmented landscapes, especially in terms of the numbers of edge and interior species and winter-resident, summer resident, and year-round birds observed.
Small & Hunter 1998 [340]	Artificial nest study during breeding season, forested habitats in Maine. Patch sizes ranged from 7-2,570 acres (3-1,040 hectares).	• Predation rates were highest in small patches completely surrounded by land. • Predation rates were lowest in large habitat areas with at least one side bordered by water.	Results suggest an influx of predators from nearby habitats may be responsible for artificial nest predation in these fragments.
Weinberg & Roth 1998 [380]	Delaware Wood Thrush study on patch size. Mist-netting/banding study during May-August. "Control" patch was 37 acres (15 hectares).	• Small patches with the same cumulative size produced many fewer young and fewer birds/ha.	Helps address SLOSS (single large or several small patches) debate.

APPENDIX 3. LITERATURE RELATING TO SPECIES' GAP-CROSSING ABILITIES

Research suggesting gap distance (in feet and meters) that various wildlife species are willing to cross in wildlife movement corridors.

Reference	Species	Gap width (threshold distance), type	Notes
Desrochers and Hannon 2003 [92]	Quebec City, Canada Boreal forest and agricultural landscapes –	• Birds were twice as likely to travel through 164 feet (50 meters) of woodland than through 164 feet (50 meters) of open habitat. • Given choice of traveling through woodland or across a gap, most birds selected woodland routes, even when they were 3x longer than shortcuts in the open. • However, species differed greatly in their response to gaps.	Used chickadee mobbing calls to induce birds across forest gaps during post-fledging period.
Harris and Reed 2002 [159]	Red-breasted Nuthatch (*Sitta canadensis*)	• 164 feet (50 meters) • Clear cut, fields	Summer-fall
Harris and Reed 2002 [159]	White-breasted Nuthatch (*Sitta carolinensis*)	• 492 feet (150 meters) • Clear cut, fields	Fall-winter
Harris and Reed 2002 [159]	Downy Woodpecker (*Picoides pubescens*)	• 525 feet (160 meters) • Clear cut, fields	Fall-winter
Harris and Reed 2002 [159]	Hairy Woodpecker (*Picoides villosus*)	• 1312 feet (400 meters) • Clear cut, fields	Fall-winter
Harris and Reed 2002 [159]	Northern Flicker (*Colaptes auratus*)	• 1969 feet (600 meters) • Clear cut, fields	Fall-winter
Harris and Reed 2002 [159]	Golden-crowned Kinglet (*Regulus satrapa*) (2 different studies)	• 131 feet (40 meters) • Trails, dirt roads, clearcuts • 98 feet (30 meters) • Fields, clearcuts	Summer Summer-fall
Harris and Reed 2002 [159]	Swainson's Thrush (*Catharus ustulatus*)	• 164 feet (50 meters) • Trails, dirt roads, clearcuts	Summer
Harris and Reed 2002 [159]	Yellow-rumped Warbler (*Dendroica coronate*)	• 115-131 feet (35-40 meters) • Trails, dirt roads, clearcuts	Literature review
St. Claire et al. 1998 [346]	Black-capped chickadee (*Poecile atricapillus*) White-breasted Nuthatch (*Sitta carolinensis*) Hairy Woodpecker (*Picoides villosus*) Downy Woodpecker (*Picoides pubescens*)	• 656 feet (200 meters) – all species unlikely to cross. • Chickadees – 164 feet (50 meters), but if corridor more convoluted, more likely to cross (up to 656-foot, or 200-meter, gap). • Nuthatch and woodpecker – much less likely to cross gaps or use narrow corridors; corridor width may be important to these species.	Winter. Willingness to cross gaps of various distances when continuous forest along narrow corridors (fencerows) was present. Also looked at movement in forest patches.

APPENDIX 4. MODELS AND ASSESSMENT TECHNIQUES

Numerous models have been developed to identify core areas, landscape permeability and preferred movement corridors. Models often use variables such as forest canopy cover, edge, fragmentation metrics, land cover and land use, and road metrics. The U.S. Geological Survey offers descriptions of some GIS-based models and landscape analysis tools online at http://rmgsc.cr.usgs.gov/latp/tools.shtml. Beier and colleagues' corridor design web site offers downloadable corridor design tools for use with ArcCatalog software [28]. Some of the models seen in the literature, and their applied uses, are summarized in the table below.

Selected modeling methods used to identify core habitat areas, corridors and connectivity measures.

Reference	Model type / use	Setting	Model description
American Wildlands 2006 [8]	• HSI, cost surface, least cost paths	Montana to Canada	Used habitat suitability, complexity, and weighted road density to develop cost surface layer. Selected core habitat areas and identified least cost paths between cores. Final connectivity model developed by connectivity surface and threshold modeling.
Austin, Viani and Hammond 2006 [17]	• GIS-based exercise augmented w/road-kill data • Focused on roads	Vermont	Developed a centralized database of wildlife road mortality (bear, moose, deer, bobcat, amphibian, reptile), wildlife road crossing, and related habitat data for individual species for which data exists throughout the state of Vermont. Developed a relationship with VTran to gather the data. Developed a GIS-based Wildlife Linkage Habitat Analysis using landscape scale data to identify or predict the location of potentially significant Wildlife Linkage Habitats using (a) land use and land cover data; (b) development density data (E911 house sites); and (c) contiguous or "core" habitat data from the University of Vermont.
Beier et al. 2009 [28]	• Least cost path	General	The least cost path model is designed to identify the path between two points which has the lowest cost for wildlife to travel, where cost is a function of time, distance, or other user-defined factors. It is fairly widely used but has some drawbacks. Beier et al. see "no excuse for least cost paths instead of corridor swaths to define wildlife corridors," because such modeling exercises are raster-based, fail to consider matrix impacts, and are overly generalized and prone to classification errors. In addition, the "best" corridor identified through this method is not necessarily sufficient for focal species. They cite three useful tools to compare alternative linkage designs: 1. Frequency distribution of habitat quality for each target species 2. A graph depicting intensity and length of bottlenecks 3. A list of the longest inter-patch distances that animals of each focal species would have to cross Another researcher notes the same drawbacks regarding least cost modeling, but provides recommendations for "finding and filling the cracks" to enhance the methodology [320]. Cracks relate to thin but significant barriers, such as roads and railroad tracks, that aren't identified in raster-based analyses; these would be significant in any urban region. Another drawback she addresses is that least cost modeling can miss narrow but critical corridors, which are prevalent in the region.
Brooker, Brooker and Cale 1999 [49]	• Dispersal simulation models	Europe	Used a spatially explicit dispersal simulation to generate movement frequencies and distances for comparison with real dispersal frequencies collected in the field from two habitat-specific, sedentary bird species. The relationship between these two data sets allowed investigators to (1) test the hypothesis that the study species used corridor routes during dispersal; (2) measure the degree of reliance on corridor continuity; (3) estimate the rate of dispersal mortality with respect to distance traveled, and (4) give examples of how the model can be used to assess habitat connectivity with respect to similarly behaved species. Used two non-migratory bird species.

Reference	Model type / use	Setting	Model description
Clevenger et al. 2002 [73]	• Empirical habitat data • Best professional opinion • Literature-based	Black bear movement corridors in Banff across Trans-Canada Highway	Compared three models developed using GIS to an independent data set, the latter which was used for validation. One model was based on empirical habitat data, one was professional opinion-based, and one was literature-based. The literature-based model performed best, while the opinion-based model least resembled the actual situation. Expert opinion seemed to over-rate importance of riparian corridors. There were some issues with season (pre-berry) that may have influenced results.
Csuti et al. 1997 [83]	• Comparison of reserve selection algorithms	Oregon	Compared number of species represented and spatial pattern of reserve networks using five types of reserve selection algorithms on a set of vertebrate distribution data. Compared: richness-based heuristic algorithms (four variations), weighted rarity-based heuristic algorithms (two variations), progressive rarity-based heuristic algorithms (11 variations), simulated annealing, and a linear programming-based branch-and-bound algorithm. The latter method worked best.
Cushman, McKelvey and Schwartz 2008 [84]	• Landscape resistance mapping (empirical) • Least-cost path	Yellowstone and Canadian border	Used a method that combines empirically derived landscape-resistance maps (from genetic studies) and least-cost path analysis between multiple source and destination locations. Identifying corridors and barriers for black bear movement between Yellowstone and Canadian border.
Dijak et al. 2007 [94]	• HSI software including habitat and spatial components	General	Habitat suitability index (HSI) models are traditionally used to evaluate habitat quality for wildlife at a local scale. Rarely have such models incorporated spatial relationships of habitat components. We introduce Landscape HIS models, a new Microsoft Windows- (Microsoft, Redmond, WA)-based program that incorporates local habitat as well as landscape-scale attributes to evaluate habitats for 21 species of wildlife. Models for additional species can be constructed using the generic model option. At a landscape scale, attributes include edge effects, patch area, distance to resources, and habitat composition. A moving window approach is used to evaluate habitat composition and interspersion within areas typical of home ranges and territories or larger. The software and sample data are available free of charge from the United States Forest Service, Northern Research Station at http://www.nrs.fs.fed.us/hsi/.
Forest Landscape Ecology Lab, UW-Madison 2009 [124]	• APACK • Calculates 25 landscape metrics, including connectivity • Runs on C++	General	APACK is an analysis package designed to meet these needs. It is a standalone program written in C++ that calculates landscape metrics on raster files. It runs on the Windows 95/98/NT/2000/XP platforms. Data formats supported include ERDAS GIS files and ASCII files. Output data consists of a text file and a spreadsheet readable file that can be further analyzed. APACK can calculate 25 metrics useful for determining landscape characteristics such as basic measures (e.g., area), information theoretic measures (e.g., diversity), shape measures (e.g., fractal dimension), textural measures (e.g., lacunarity), probabilistic measures (e.g., electivity), and structural measures (e.g., connectivity). In tests versus other commonly used analysis packages APACK was able to calculate upon larger maps and was significantly faster. This is in part due to APACK only calculating those metrics specified by the user. APACK fills the need for an analysis package that can easily and efficiently calculate landscape metrics from large raster maps.
Jantz and Goetz 2008 [184]	• Fragstats • ArcRstats • Least cost pathways	Northeastern U.S.; multi-state.	Used geospatial data (roads, impervious surface, tree cover, protected areas, water features). Identified core areas by calculating road density in 250-m pixels, clustering similar pixels, setting a minimum core area size (2,000 ha). Calculated tree cover and removed anything <60%. Subsequently looked at ownership. Used Fragstats for core area metrics. Used ArcRstats, a graph theoretic approach (can identify more than one potential corridor), to identify least cost paths between habitat patches from which network connectivity metrics were calculated.
Majka et al. 2007 [226]	• HSI • ArcCatalog set of tools	General	The CorridorDesigner toolbox aids the user in 1) creating habitat suitability models & identifying potential habitat patches, 2) creating corridor models, and 3) transforming a DEM into a topographic slope position raster. The CorridorDesigner toolbox currently only works within ArcCatalog, not ArcMap, and requires all data to be in the same meters (UTM) projection.

Reference	Model type / use	Setting	Model description
McRae and Beier 2007 [246]	• Circuit theory	General	Circuit theory is a recent approach that borrows from electronic circuit theory to predict gene flow across complex landscapes. Incorporates potential effects of multiple pathways linking focal species' populations. "When applied to data from threatened mammal and tree species," state the authors, "the model consistently outperformed conventional gene flow models, revealing that barriers were less important in structuring populations than previously thought. Circuit theory now provides the best-justified method to bridge landscape and genetic data, and holds much promise in ecology, evolution, and conservation planning."
Miller et al. 2009 [254]	• Optimization modeling framework	Chicago area	Used an optimization modeling framework to devise spatially explicit habitat acquisition and restoration strategies for 19 remnant-dependent focal species (butterflies). This is a modeling approach that seeks the "best" or optimum solution - the process of making something as good or as effective as possible with given resources and constraints. Considered minimum patch size to support population, suitable undeveloped properties contiguous to prospective sites, and parcels in surrounding landscape that could provide additional habitat if restored. Assumed conservation value increased when near protected sites. Made assumptions about gap distance.
Minnesota Department of Natural Resources 2003 [259]	• GIS models	Minnesota	Four sets of models (forests, grasslands, wetlands/lakes, river corridors) were developed to map significant habitat. Literature reviews and expert opinion were used to select native animals that could serve as indicators of significant habitats. Describes general methodologies, including criteria and focal species, for each model.
Thorne et al. 2009 [358]	• MARXAN (reserve selection algorithm)	California	Compared integration of regional conservation designs, termed greenprints, with early multi-project mitigation assessment for two areas in CA. Used reserve-selection algorithm MARXAN to identify greenprint for each site and seek mitigation solutions through parcel acquisition that would contribute to the greenprint and meet agency obligations.
U.S. Fish and Wildlife Service 1980 [363] Beier et al. 2009 [28]	• Habitat Suitability Indices (HSI)	General	Identifying core habitat areas requires habitat assessment in relation to species of interest. Habitat suitability models are tools for predicting the suitability of habitat for a given species based on known affinities with environmental parameters. One such model is the Habitat Suitability Index (HSI), which involves identifying, weighting ad scoring key environmental factors. Habitat suitability models are most commonly based on literature review and expert opinion [28;363], and this is the method preferred by Beier et al. [28]. Scientific literature-based models have drawbacks such as varying geographic areas, but they do not require collecting field data and they make use of the work of previous scientists. For these reasons they are inexpensive and efficient.
U.S. Geological Survey 2009 [366]	• Species distribution software	Landscape Analysis Tools - USGS web site	DesktopGarp is a software package for biodiversity and ecologic research that allows the user to predict and analyze wild species distributions. Includes a GIS extension, "Boundary U-test Extension," that aids in analyses of boundaries and edges in ecology.
Walker and Craighead 1997 [376]	• ARC/GRID • Gap Analysis data • Least cost path	Northern Rockies	Delineated landscape routes offering the best chance of success for wildlife moving among the three large core protected areas. Using ARC/GRID and Montana Gap Analysis data, derived habitat suitability models for three umbrella species, then combined with road density information to create kilometer-scale cost surfaces of movement. For each of the three species (grizzly bear, elk, cougar) performed a least.cost.path analysis to locate broad potential corridor routes. From this first approximation, identified probable movement routes and as well as critical barriers, bottlenecks, and filters where corridor routes intersected with high-risk habitat. This analysis is being used to identify priority areas for wildlife management to improve the connectivity between the core protected ecosystems in the Northern Rockies.
Williams and Snyder 2005 [387]	• Shortest-path optimization • Nearest-neighbor rules • Restoration prioritization	General	Identifies where restoration should take place to efficiently reconnect habitat with a landscape-spanning corridor. Building upon findings in percolation theory, uses shortest-path optimization methodology for assessing the minimum amount of restoration needed to establish corridors. This methodology is applied to large numbers of simulated fragmented landscapes to generate mean and variance statistics for the amount of restoration needed. Provides information about the expected level of resources needed to realize different corridor configurations under different degrees of fragmentation and different characterizations of habitat connectivity ("neighbor rules").

Reference	Model type / use	Setting	Model description
Woess et al. 2002 [391]	• Landscape resistance model • Large mammals • Focuses on roads	Austria	Modeling connectivity for large mammals and carnivores. Examines road network permeability. An interdisciplinary project in Austria, titled Wildlife corridors, examined the applicability of remote sensing methods and terrestrial surveys to identify corridor structures at different landscape scales. With the collected data and information from aerial / satellite images and terrestrial surveys a resistance model for the investigation area and the indicator species red deer and wild boar could be developed. The most probable migration route between the floodplains of the Danube and the floodplains of the Leitha was detected. Both projects reveal explicit measurements of resource management, which ensure genetic exchange on the long term.

APPENDIX 5. VERTEBRATE SPECIES KNOWN TO USE REGION HABITATS AT LEAST ONCE EVERY YEAR.

Purpose and limitations

The purpose of Metro's species list is threefold:

1. To identify fish and wildlife species that occur in the Metro region.
2. To identify the relative importance of various types of habitat to fish and wildlife species.
3. To provide a biologically meaningful way in which to describe the biodiversity of the Metro region.

THE LIST IS NOT A STATEMENT OF POLICY. In keeping with Metro's Streamside CPR Vision Statement, the focus of the list is on native fish and wildlife species whose historic ranges include the metropolitan area and whose habitats are or can be provided for in urban habitats. Urban habitats may never be conducive to significant populations of some species, such as black bear and cougar. Further analysis and Metro Council deliberation will help determine (to the extent possible) the type, amount, and location of fish and wildlife habitats that should be protected and/or restored. For example, landowner incentives will be developed for conservation purposes.

This list contains:

- All known native vertebrate species that currently exist within the Metro region (the final version will include a map of area involved) for at least a portion of the year and could be found in the region through diligent search by a knowledgeable person. Vagrant species (those that do not typically occur every year) are not included on this list.
- Extirpated (locally extinct) native vertebrate species known to have inhabited the region in the past.
- Nonnative vertebrate species with established breeding populations in the region.

The species list is based on the opinion of more than two dozen local wildlife experts. The Oregon Natural Heritage Program (ORNHP), Endangered Species Act (ESA), and Oregon Department of Fish and Wildlife (ODFW) status categories were obtained from ORNHP's February, 2001 *Rare, Threatened and Endangered Plants and Animals of Oregon* publication. Habitat associations were obtained from Johnson and O'Neil's new book, *Wildlife Habitats and Relationships in Oregon and Washington*. The taxonomic standards for common and scientific names for birds is based on the American Ornithological Union Check-list. We are also developing a separate aquatic and terrestrial invertebrate list, but this will not be as comprehensive in scope as the vertebrate species list.

Key to notations

- Indicates species that are **non-native** (also known as alien or introduced) to Metro region.

( ) Indicates a species that was **historically present but was extirpated** from the Metro region within approximately the last century.

Code (type of animal)

A = Amphibians
B = Birds
F = Fish
M = Mammals
R = Reptiles

Migratory Status (indicates trend for the majority of a given species in the Metro region):

A = Anadromous (fish; lives in the ocean, spawns in fresh water)
C = Catadromous (fish; lives in fresh water, spawns in the ocean)
M = Migrates through area without stopping for long time periods

N = Neotropical migratory species (birds; majority of individuals breeding in the Metro region migrate south of U.S./Mexico border for winter)
R = Permanent resident (lives in the area year-round)
S = Short-distance migrant (from elevational to regional migration, e.g., across several states)
W = Winters in the Metro region

Federal Status is based on current Endangered Species Act listings. **E** = Endangered, **T** = Threatened. Endangered taxa are those which are in danger of becoming extinct within the foreseeable future throughout all or a significant portion of their range. Threatened taxa are those likely to become endangered within the foreseeable future.
LE = Listed Endangered. Taxa listed by the U.S. Fish and Wildlife Service (USFWS) or the National Marine Fisheries Service (NMFS) as Endangered under the Endangered Species Act (ESA), or by the Departments of Agriculture (ODA) and Fish and Wildlife (ODFW) of the state of Oregon under the Endangered Species Act of 1987 (OESA).
LT = Listed Threatened. Taxa listed by the USFWS, NMFS, ODA, or ODFW as Threatened.
PE = Proposed Endangered. Taxa proposed by the USFWS or NMFS to be listed as Endangered under the ESA or by ODFW or ODA under the OESA.
PT = Proposed Threatened. Taxa proposed by the USFWS or NMFS to be listed as Threatened under the ESA or by ODFW or ODA under the OESA.
C = Candidate taxa for which NMFS or USFWS have sufficient information to support a proposal to list under the ESA, or which is a candidate for listing by the ODA under the OESA.
SoC = Species of Concern. Former C2 candidates which need additional information in order to propose as Threatened or Endangered under the ESA. These are species which USFWS is reviewing for consideration as Candidates for listing under the ESA.

ODFW Status (state status) is based on current Oregon Department of Fish and Wildlife "Oregon Sensitive Species List," 2001. See Federal Status (above) for definitions of LT and LE.
SC (Critical) = Species for which listing as threatened or endangered is pending; or those for which listing as threatened or endangered may be appropriate if immediate conservation actions are not taken. Also considered critical are some peripheral species which are at risk throughout their range, and some disjunct populations.
SV (Vulnerable) = Species for which listing as threatened or endangered is not believed to be imminent and can be avoided through continued or expanded use of adequate protective measures and monitoring. In some cases the population is sustainable, and protective measures are being implemented; in others, the population may be declining and improved protective measures are needed to maintain sustainable populations over time.
SP (Peripheral or Naturally Rare) = Peripheral species refer to those whose Oregon populations are on the edge of their range. Naturally rare species are those which had low population numbers historically in Oregon because of naturally limiting factors. Maintaining the status quo for the habitats and populations of these species is a minimum requirement. Disjunct populations of several species which occur in Oregon should not be confused with peripheral.
SU (Undetermined Status): Animals in this category are species for which status is unclear. They may be susceptible to population decline of sufficient magnitude that they could qualify for endangered, threatened, critical or vulnerable status, but scientific study will be required before a judgment can be made.

ORNHP Rank (ABI – Natural Heritage Network Ranks): ORNHP participates in an international system for ranking rare, threatened and endangered species throughout the world. The system was developed by The Nature Conservancy and is maintained by The Association for Biodiversity Information (ABI) in cooperation with Heritage Programs or Conservation Data Centers (CDCs) in all 50 states, 4 Canadian provinces, and 13 Latin American countries. The ranking is a 1-5 scale, primarily based on the number of known occurrences, but also including threats, sensitivity, area occupied and other biological factors. On Metro's Species List the first ranking (**rank**/rank) is the Global Rank and begins with a "G". If the taxon has a trinomial (a subspecies, variety or recognized race), this is followed by a "T" rank indicator. A "Q" at the end of this ranking indicates the taxon has taxonomic questions. The second ranking (rank/**rank**) is the State Rank and begins with the letter "S". The ranks are summarized below.

1 = Critically imperiled because of extreme rarity or because it is somehow especially vulnerable to extinction or extirpation, typically with 5 or fewer occurrences
2 = Imperiled because of rarity or because other factors demonstrably make it very vulnerable to extinction (extirpation), typically with 6-20 occurrences
3 = Rare, uncommon or threatened, but not immediately imperiled, typically with 21-100 occurrences
4 = Not rare and apparently secure, but with cause for long-term concern, usually more than 100 occurrences
5 = Demonstrably widespread, abundant and secure
H = Historical Occurrence, formerly part of the native biota with the implied expectation that it may be rediscovered
X = Presumed extirpated or extinct
U = Unknown rank
? = Not yet ranked, or assigned rank is uncertain

ORNHP List is based on Oregon Natural Heritage Program data.
List 1 contains taxa that are threatened with extinction or presumed to be extinct throughout their entire range.
List 2 contains taxa that are threatened with extirpation or presumed to be extirpated from the state of Oregon. These are often peripheral or disjunct species which are of concern when considering species diversity within Oregon's borders. They can be very significant when protecting the genetic diversity of a taxon. ORNHP regards extreme rarity as a significant threat and has included species which are very rare in Oregon on this list.
List 3 contains species for which more information is needed before status can be determined, but which may be threatened or endangered in Oregon or throughout their range.
List 4 contains taxa which are of conservation concern but are not currently threatened or endangered. This includes taxa which are very rare but are currently secure, as well as taxa which are declining in numbers or habitat but are still too common to be proposed as threatened or endangered. While these taxa currently may not need the same active management attention as threatened or endangered taxa, they do require continued monitoring.

Riparian Association indicates use of any of the **4** water-based habitats. Single "X" in any habitat type (upland or water-associated) indicates general association; "XX" indicates close association, as per Johnson and O'Neil 2001.

Habitat Types based on Johnson and O'Neil (2001). These habitats are described more fully within the text of the upland and riparian chapters.
WLCH = Westside Lowlands Conifer-Hardwood Forest
WODF = Westside Oak and Dry Douglas-fir Forest and Woodlands
WEGR = Westside Grasslands
AGPA = Agriculture, Pasture and Mixed Environs
URBN = Urban and Mixed Environs
WATR = Open Water – Lakes, Rivers, Streams
HWET = Herbaceous Wetlands
RWET = Westside Riparian-Wetlands

Appendix 5. Species list and habitat associations for species normally occurring within the Metro region. Study area is the Metro jurisdictional boundary plus 1 mile buffer.

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8]							
									WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
F	River Lamprey	*Lampetra ayresi*	A	SoC	None	G4/S4	4	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Western Brook Lamprey	*Lampetra richardsoni*	A	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Pacific Lamprey	*Lampetra tridentata*	A	SoC	SV	G5/S3	2	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	White Sturgeon	*Acipenser transmontanus*	A	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	American Shad*	*Alosa sapidissima*	A	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chiselmouth	*Acrocheilus alutaceus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Goldfish*	*Carassius auratus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Common Carp*	*Cyprinus carpio*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Peamouth Chub	*Mylocheilus caurinus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
(F)	(Oregon Chub - extirpated from Metro area)	*Oregonichthys crameri*	R	LE	SC	G2/S2	1	(XX)	(XX)	(XX)	N/A	N/A	N/A	N/A	N/A	N/A
F	Northern Pikeminnow (Squawfish)	*Ptychocheilus oregonensis*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Longnose Dace	*Rhynichthys cataractae*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Leopard Dace	*Rhynichthys falcatus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Speckled Dace	*Rhynichthys osculus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Redside Shiner	*Richardsonius balteatus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Largescale Sucker	*Catostomus macrocheilus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Brown Bullhead*	*Ameiurus nebulosus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	N/A	N/A	N/A	N/A	N/A	N/A
F	Eulachon (Columbia River Smelt)	*Thaleichthys pacificus*	A	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Coastal Cutthroat Trout, SW WA/Col. R. ESU	*Oncorhynchus clarki clarki*	A	PT	SC	G4T2Q/S2	2	XX	XX	X	N/A	N/A	N/A	N/A	N/A	N/A
F	Coastal Cutthroat Trout, Upper Will. R. ESU	*Oncorhynchus clarki clarki*	A	SoC	None	G4T?Q/S3?	4	XX	XX	X	N/A	N/A	N/A	N/A	N/A	N/A
F	Chum Salmon, Columbia River ESU	*Oncorhynchus keta*	A	LT	SC	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Coho Salmon, Oregon Coast ESU	*Oncorhynchus kisutch*	A	LT	SC	G4T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Coho Salmon, Lower Columbia R./Southwest Washington ESU	*Oncorhynchus kisutch*	A	C	LE	G4T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Rainbow Trout (resident populations)	*Oncorhynchus mykiss*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead (anadromous Rainbow Trout), Oregon Coast ESU	*Oncorhynchus mykiss*	A	C	SV	G5T2T3Q/S2S3	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Lower Columbia River ESU	*Oncorhynchus mykiss*	A	LT	SC	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Upper Willamette River ESU, winter run	*Oncorhynchus mykiss*	A	LT	SC	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Middle Columbia River ESU	*Oncorhynchus mykiss*	A	LT	SC/SV	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Snake River Basin ESU	*Oncorhynchus mykiss*	A	LT	SV	G5T2T3Q/S2S3	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Upper Columbia River ESU	*Oncorhynchus mykiss*	A	LE	None	G5T2Q/SU	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Sockeye Salmon, Snake River ESU	*Oncorhynchus nerka*	A	LE	None	G5T1Q/SX	1 - ex	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Lower Columbia R. ESU	*Oncorhynchus tshawytscha*	A	LT	SC	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Upper Will. R spring run	*Oncorhynchus tshawytscha*	A	LT	None	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Snake River Fall-run ESU	*Oncorhynchus tshawytscha*	A	LT	LT	G5T1Q/S1	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Snake River Spr/Sum.run	*Oncorhynchus tshawytscha*	A	LT	LT	G5T1Q/S1	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Upper Col. R. Spring-run	*Oncorhynchus tshawytscha*	A	LE	None	G5T1Q/SU	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Mountain Whitefish	*Prosopium williamsoni*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Sand Roller	*Percopsis transmontanus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Mosquitofish*	*Gambusia affinis*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	N/A	N/A	N/A	N/A	N/A	N/A
F	Three-spined Stickleback	*Gasterosteus aculeatus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8]								
									WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
F	Prickly Sculpin	*Cottus asper*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Reticulate Sculpin	*Cottus perplexus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Green Sunfish*	*Lepomis cyanellus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Pumpkinseed Sunfish*	*Lepomis gibbosus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Warmouth*	*Lepomis gulosus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Bluegill*	*Lepomis macrochirus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Smallmouth Bass*	*Micropterus dolomieu*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Largemouth Bass*	*Micropterus salmoides*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	X	N/A	N/A	N/A	N/A	N/A	N/A
F*	White Crappie*	*Pomoxis annularis*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Black Crappie*	*Pomoxis nigromaculatus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Yellow Perch*	*Perca flavescens*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	X	N/A	N/A	N/A	N/A	N/A	N/A
F*	Walleye*	*Stizostedion vitreum vitreum*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Starry Flounder	*Platichthys stellatus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
A	Northwestern Salamander	*Ambystoma gracile*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
A	Long-toed Salamander	*Ambystoma macrodactylum*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
A	Pacific Giant Salamander	*Dicamptodon tenebrosus*	R	None	None	None	None	XX			XX	X	X	X		X
A	Cope's Giant Salamander	*Dicamptodon copei*	R	None	SU	G3/S2	2	XX	X		XX	X				
A	Columbia Torrent Salamander	*Rhyacotriton kezeri*	R	None	SC	G3/S3	2	XX			XX	X				
A	Cascade Torrent Salamander	*Rhyacotriton cascadae*	R	None	SV	G3/S3	2	XX			XX	X				
A	Rough-skinned Newt	*Taricha granulosa*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
A	Dunn's Salamander	*Plethodon dunni*	R	None	None	None	None	X			X	X	X			X
A	Western Red-backed Salamander	*Plethodon vehiculum*	R	None	None	None	None	X			X	X	X			X
A	Ensatina	*Ensatina eschscholtzii*	R	None	None	None	None	X			X	XX	X	X	X	X
A	Clouded Salamander	*Aneides ferreus*	R	None	SU	G3/S3	3					X	X		X	X
A	Oregon Slender Salamander	*Batrachoseps wrighti*	R	SoC	SU	G4/S3	1	X			X	X				
A	Western Toad	*Bufo boreas*	R	None	SV	G4/S4	4	XX	XX	XX	XX	X	X	X	X	X
A	Tailed Frog	*Ascaphus truei*	R	SoC	SV	G4/S3	2	XX			XX	X				
A	Pacific Chorus Frog (tree frog)	*Hyla regilla*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
A	Northern Red-legged Frog	*Rana aurora aurora*	R	SoC	SV/SU	G4T4/S3	2	XX	XX	XX	XX	XX	X	X	X	X
(A)	(Oregon Spotted Frog - extirpated)	*Rana pretiosa*	R	C	SC	G2G3/S2	1	(XX)	(XX)	(XX)	(XX)	(X)	(X)	(X)	(X)	
A*	Bullfrog*	*Rana catesbeiana*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	XX	X	X	X	X	X
R*	Common Snapping Turtle*	*Chelydra serpentina*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	X				X	X
R	Painted Turtle	*Chrysemys picta*	R	None	SC	G5/S2	2	XX	XX	XX	X		X		X	X
R	Northwestern Pond Turtle	*Clemmys marmorata marmorata*	R	SoC	SC	G3T3/S2	1	XX	XX	XX	XX	X	XX	X	X	X
R*	Red-eared Slider*	*Trachemys scripta elegans*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	X				X	X
R	Northern Alligator Lizard	*Elgaria coerulea*	R	None	None	None	None	X			X	X	X	X		X
R	Southern Alligator Lizard	*Elgaria multicarinata*	R	None	None	None	None	X			X	X	X	X	X	X
R	Western Fence Lizard	*Sceloporus occidentalis*	R	None	None	None	None					X	X	X	X	X
R	Western Skink	*Eumeces skiltonianus*	R	None	None	None	None					X	X	X	X	X
R	Rubber Boa	*Charina bottae*	R	None	None	None	None	X			X	X		X	X	X
R	Racer	*Coluber constrictor*	R	None	None	None	None						X	X	X	X
R	Sharptail Snake	*Contia tenuis*	R	None	SV	G5/S3	4	X			X	X	X	X	X	X
R	Ringneck Snake	*Diadophis punctatus*	R	None	None	None	None	X			X	X	X	X	X	X

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8]							
									WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
R	Gopher Snake	*Pituophis catenifer*	R	None	None	None	None						X	X	X	X
R	Western Terrestrial Garter Snake	*Thamnophis elegans*	R	None	None	None	None	X		X	X		X	X	X	X
R	Northwestern Garter Snake	*Thamnophis ordinoides*	R	None	None	None	None	X			X	X	X	X	X	X
R	Common Garter Snake	*Thamnophis sirtalis*	R	None	None	None	None	XX		XX	XX	X	X	X	X	X
B	Red-throated Loon	*Gavia stellata*	W / M	None	None	None	None	XX			XX					
B	Pacific Loon	*Gavia pacifica*	W / M	None	None	None	None	XX			XX					
B	Common Loon	*Gavia immer*	W / M	None	None	None	None	XX	X	XX						
B	Pied-billed Grebe	*Podilymbus podiceps*	S / N	None	None	None	None	XX	X	XX	X					
B	Horned Grebe	*Podiceps auritus*	W / M	None	SP	G5/S2B, S5N	2	XX	XX	XX						
B	Eared Grebe	*Podiceps nigricollis*	W	None	None	None	None	XX	XX	XX						
B	Western Grebe	*Aechmophorus occidentalis*	W	None	None	None	None	XX	XX	XX						
B	Clark's Grebe	*Aechmophorus clarkii*	W / M	None	None	None	None	XX	XX	XX						
B	Doubled-crested Cormorant	*Phalacrocorax auritus*	R / S	None	None	None	None	XX	XX	X	X					X
B	American Bittern	*Botaurus lentiginosus*	S / N	None	None	None	None	XX		XX					X	
B	Great Blue Heron	*Ardea herodias*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	XX	X
B	Great Egret	*Ardea alba*	W / M	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
B	Green Heron	*Butorides virescens*	N / S	None	None	None	None	XX	X	XX	XX					
B	Black-crowned Night Heron	*Nycticorax nycticorax*	S	None	None	None	None	XX	XX	XX	X					
(B)	(California Condor - extirpated)	*(Gymnogyps californianus)*	R	LE	None	G1SX	1-ex	(X)			(X)			(X)		
B	Turkey Vulture	*Cathartes aura*	N	None	None	None	None	X		X	X	X	X	X	X	X
B	Greater White-fronted Goose	*Anser albifrons*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Snow Goose	*Chen caerulescens*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Ross's Goose	*Chen rossii*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Canada Goose	*Branta canadensis*	VARIABLE	None	None	None	None	XX	XX	XX	X				XX	
B	Dusky Canada Goose	*Branta canadensis occidentalis*	W / M	None	None	G5T2T3/ S2N	4	XX	XX	XX	X				XX	
B	Aleutian Canada Goose (wintering)	*Branta canadensis leucopareia*	W / M	LT	LE	G5T3/S2N	1	XX	XX	XX	X				XX	
B	Trumpeter Swan	*Cygnus buccinator*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Tundra Swan	*Cygnus columbianus*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Wood Duck	*Aix sponsa*	S	None	None	None	None	XX	XX	X	XX	X			X	
B	Gadwall	*Anas strepera*	W / M	None	None	None	None	XX	XX	XX				X	X	
B	Mallard	*Anas platyrhynchos*	R	None	None	None	None	XX	X	XX	XX				X	X
B	Eurasian Wigeon	*Anas penelope*	W / M	None	None	None	None	XX	XX	X					X	
B	American Wigeon	*Anas americana*	W / M	None	None	None	None	XX	X	XX	X				XX	
B	Blue-winged Teal	*Anas discors*	W / M	None	None	None	None	XX	X	XX				X	XX	
B	Cinnamon Teal	*Anas cyanoptera*	N	None	None	None	None	XX	X	XX				X	XX	
B	Northern Shoveler	*Anas clypeata*	W / M	None	None	None	None	XX	XX	XX				X	X	
B	Northern Pintail	*Anas acuta*	W / M	None	None	None	None	XX	XX	XX					X	
B	Green-winged Teal	*Anas crecca*	S	None	None	None	None	XX	X	XX	X			X	X	
B	Canvasback	*Aythya valisineria*	W / M	None	None	None	None	XX	XX	XX						
B	Redhead	*Aythya americana*	W / M	None	None	None	None	XX	XX	XX						
B	Ring-necked Duck	*Aythya collaris*	W / M	None	None	None	None	XX	X	X	XX					
B	Greater Scaup	*Aythya marila*	W / M	None	None	None	None	XX	XX							
B	Lesser Scaup	*Aythya affinis*	W / M	None	None	None	None	XX	XX	XX						

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8]							
									WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
B	Surf Scoter	*Melanitta perspicillata*	W / M	None	None	None	None	X	X							
B	Harlequin Duck	*Histrionicus histrionicus*	W / M	SoC	SU	G4/S2B, S3N	2	XX	XX		XX					
B	Bufflehead	*Bucephala albeola*	W / M	None	SU	G5/S2B,S5N	4	XX	XX	XX	X					
B	Common Goldeneye	*Bucephala clangula*	M	None	None	None	None	XX	XX	X						
B	Barrow's Goldeneye	*Bucephala islandica*	W / M	None	SU	G5/S3B,S3N	4	XX	XX	X						
B	Hooded Merganser	*Lophodytes cucullatus*	W / M	None	None	None	None	XX	XX	X	XX	XX				
B	Common Merganser	*Mergus merganser*	W / M	None	None	None	None	XX	XX		XX	XX				
B	Red-breasted Merganser	*Mergus serrator*	W / M	None	None	None	None	X	X							
B	Ruddy Duck	*Oxyura jamaicensis*	W / M	None	None	None	None	XX	XX	XX						
B	Osprey	*Pandion haliaetus*	N	None	None	None	None	XX	XX		X	X	X		X	X
B	White-tailed Kite (appears to be undergoing range expansion)	*Elanus leucurus*	W / M	None	None	G5/S1B, S3N	2	X			X	X		X	XX	
B	Bald Eagle[a]	*Haliaeetus leucocephalus*	S	LT[a]	LT	G4/S3B, S4N	2	XX	XX	X	X	X	X	X	X	X
B	Northern Harrier	*Circus cyaneus*	N	None	None	None	None	X		X	X			X	X	X
B	Sharp-shinned Hawk	*Accipiter striatus*	N	None	None	None	None	X		X		X	X	X	X	X
B	Cooper's Hawk	*Accipiter cooperii*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Northern Goshawk	*Accipiter gentilis*	W / M	SoC	SC	G5/S3	2	X		X	X	X	X			
B	Red-shouldered Hawk (appears to be undergoing range expansion)	*Buteo lineatus*	?	None	None	None	None	X			X	X			X	
B	Red-tailed Hawk	*Buteo jamaicensis*	S / N	None	None	None	None	X		X	X	X	X	X	XX	X
B	Rough-legged Hawk	*Buteo lagopus*	W / M	None	None	None	None	X		X	X	X	X	X	X	X
B	American Kestrel	*Falco sparverius*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Merlin	*Falco columbarius*	W / M	None	None	G5/S1B	2	X	X	X	X	X	X	X	X	X
B	American Peregrine Falcon	*Falco peregrinus anatum*	N	None	LE	G4T3/S1B	2	X	X	X	X	X	X	X	X	X
B*	Ring-necked Pheasant*	*Phasianus colchicus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	X		X	X	X	X	XX	XX	X
B	Ruffed Grouse	*Bonasa umbellus*	R	None	None	None	None	XX			XX	XX	X		X	
B	Blue Grouse	*Dendragapus obscurus*	R	None	None	None	None	X			X	XX	X			
B*	Wild Turkey*	*Meleagris gallopavo*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	X			X	X	X	X	X	X
(B)	(Mountain Quail - extirpated)	*Oreortyx pictus*	R / S	SoC	SU	G5/S4?	4	(X)			(X)	(X)	(X)		(X)	(X)
B	California Quail	*Callipepla californica*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Virginia Rail	*Rallus limicola*	R / S	None	None	None	None	XX		XX					X	
B	Sora	*Porzana carolina*	S / N	None	None	None	None	XX		XX					X	
B	American Coot	*Fulica americana*	R / S	None	None	None	None	XX	XX	XX					X	X
B	Lesser Sandhill Crane	*Grus canadensis*	W / M	None	None	None	None	XX		XX					XX	
B	Black-bellied Plover	*Pluvialis squatarola*	M	None	None	None	None	X	X						XX	
B	American Golden-plover	*Pluvialis dominica*	W / M	None	None	None	None	X	X						XX	
B	Semipalmated Plover	*Charadrius semipalmatus*	M	None	None	None	None	XX	XX						X	
B	Killdeer	*Charadrius vociferus*	S / N	None	None	None	None	X		X	X	X	X	X	XX	X
B	Greater Yellowlegs	*Tringa melanoleuca*	W / M	None	None	None	None	XX	XX	XX	X			X	X	
B	Lesser Yellowlegs	*Tringa flavipes*	W / M	None	None	None	None	XX	XX	XX	X			X	X	
B	Solitary Sandpiper	*Tringa solitaria*	W / M	None	None	None	None	XX	XX	XX	XX			X	X	
B	Spotted Sandpiper	*Actitis macularia*	N	None	None	None	None	XX	X	X	XX				X	
B	Semipalmated Sandpiper	*Calidris pusilla*	W / M	None	None	None	None	XX	XX							

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8] WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
B	Western Sandpiper	*Calidris mauri*	W / M	None	None	None	None	XX	XX	XX					X	
B	Least Sandpiper	*Calidris minutilla*	W / M	None	None	None	None	XX	X	XX					X	
B	Baird's Sandpiper	*Calidris bairdii*	W / M	None	None	None	None	XX	X	XX					X	
B	Pectoral Sandpiper	*Calidris melanotos*	W / M	None	None	None	None	XX	X	XX					X	
B	Dunlin	*Calidris alpina*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Short-billed Dowitcher	*Limnodromus griseus*	W / M	None	None	None	None	X		X					X	
B	Long-billed Dowitcher	*Limnodromus scolopaceus*	W / M	None	None	None	None	XX	X	XX					XX	
B	Common Snipe	*Gallinago gallinago*	S / N	None	None	None	None	XX		XX				X	XX	
B	Wilson's Phalarope	*Phalaropus tricolor*	W / M	None	None	None	None	XX	X	X						
B	Red-necked Phalarope	*Phalaropus lobatus*	W / M	None	None	None	None	X	X							
B	Bonaparte's Gull	*Larus philadelphia*	M / W	None	None	None	None	XX	X						X	X
B	Mew Gull	*Larus canus*	W / M	None	None	None	None	XX	XX						X	X
B	Ring-billed Gull	*Larus delawarensis*	W / M	None	None	None	None	XX	XX	X					X	X
B	California Gull	*Larus californicus*	S	None	None	None	None	XX	XX	X					X	X
B	Herring Gull	*Larus agentatus*	W / M	None	None	None	None	XX	XX	X					X	X
B	Thayer's Gull	*Larus thayeri*	W / M	None	None	None	None	XX	XX	X					X	X
B	Western Gull	*Larus occidentalis*	R / S	None	None	None	None	X	X							XX
B	Glaucous Gull	*Larus hyperboreus*	W / M	None	None	None	None	XX	XX	X						X
B	Glaucous-winged Gull	*Larus glaucescens*	W / M	None	None	None	None	XX	X							XX
B	Caspian Tern	*Sterna caspia*	N	None	None	None	None	XX	XX	XX						
B	Forster's Tern	*Sterna forsteri*	M	None	None	None	None	XX	XX	XX						
B	Common Tern	*Sterna hirundo*	W / M	None	None	None	None	X	X							
B*	Rock Dove*	*Columba livia*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien							X	XX	XX
B	Band-tailed Pigeon	*Columba fasciata*	S	SoC	None	G5/S4	4	XX			XX	XX	XX		X	X
B	Mourning Dove	*Zenaida macroura*	S	None	None	None	None	XX			XX	X	X	X	XX	X
B	Barn Owl	*Tyto alba*	R / S	None	None	None	None	X		X	X		X	X	XX	X
B	Western Screech-Owl	*Otus kennicottii*	R	None	None	None	None	X		X	X	X	X		X	X
B	Great Horned Owl	*Bubo virginianus*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Northern Pygmy-Owl	*Glaucidium gnoma*	R	None	SC	G5/S4?	4	X		X	X	XX	X		X	X
(B)	(Northern Spotted Owl - extirpated from Metro region)	*(Strix occidentalis caurina)*	(S)	LT	LT	G3T3S3	1					(XX)	(X)			
B	Barred Owl	*Strix varia*	R	None	None	None	None	X			X	XX	X			X
B	Long-eared Owl	*Asio otus*	W / M	None	None	None	None	X		X		X	X	X	X	
B	Short-eared Owl	*Asio flammeus*	W / M	None	None	None	None	XX		XX				X	XX	
B	Northern Saw-whet Owl	*Aegolius acadicus*	R / S	None	None	None	None	X			X	XX	XX		X	X
B	Common Nighthawk (nearly extirpated)	*Chordeiles minor*	N	None	SC	G5/S5	4	X	X	X	X	X	X	X	X	X
B	Vaux's Swift	*Chaetura vauxi*	N	None	None	None	None	XX	XX	X	X	X	X	X		X
B	Anna's Hummingbird	*Calypte anna*	R	None	None	None	None	X			X	XX	X			X
B	Rufous Hummingbird	*Selasphorus rufus*	N	None	None	None	None	X		X	X	X	X	X	X	X
B	Belted Kingfisher	*Ceryle alcyon*	S	None	None	None	None	XX	XX		XX					
B	Lewis's Woodpecker (extirpated as breeding species)	*Melanerpes lewis*	W / M	SoC	SC	G5/S3B, S3N	4	X			X		XX	X	X	X
B	Acorn Woodpecker	*Melanerpes formicivorus*	R	SoC	None	G5/S3?	4						XX	X		X

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8] WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
B	Red-breasted Sapsucker	*Sphyrapicus ruber*	S	None	None	None	None	X			X	X	X	X	X	X
B	Downy Woodpecker	*Picoides pubescens*	R	None	None	None	None	XX			XX	X	X		X	X
B	Hairy Woodpecker	*Picoides villosus*	R	None	None	None	None	X			X	X	X	X	X	X
B	Northern Flicker	*Colaptes auratus*	R	None	None	None	None	X			X	X	X	X	X	X
B	Pileated Woodpecker	*Dryocopus pileatus*	R	None	SV	G5/S4?	4	X			X	X	X		X	X
B*	Monk Parakeet*	*Myiopsitta monachus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX			XX		X		X	XX
(B)	(Yellow-billed Cuckoo; extirpated)	*Coccyzus americanus*	N	SoC	SC	G5/S1B	2	(XX)			(XX)					
B	Olive-sided Flycatcher	*Contopus cooperi (= borealis)*	N	SoC	SV	G5/S4	4	X			X	XX				
B	Western Wood-Pewee	*Contopus sordidulus*	N	None	None	None	None	X			X	X	X		X	X
B	Willow Flycatcher (western OR race)	*Empidonax traillii brewsteri*	N	None	SV	G5TU/S1B	4	XX			XX	X	X		X	X
B	Hammond's Flycatcher	*Empidonax hammondii*	N	None	None	None	None					X	X			
B	Dusky Flycatcher	*Empidonax oberholseri*	M	None	None	None	None	X			X	X	X			
B	Pacific-slope Flycatcher	*Empidonax dificilus*	N	None	None	None	None	X			X	XX	X			
B	Say's Phoebe	*Sayornis saya*	N	None	None	None	None							X	X	X
B	Western Kingbird	*Tyrannus verticalis*	N	None	None	None	None						X	X	X	X
B	Northern Shrike	*Lanius excubitor*	W / M	None	None	None	None	X		X				X	XX	
B	Cassin's Vireo	*Vireo cassinii*	N	None	None	None	None					X	XX			X
B	Hutton's Vireo	*Vireo huttoni*	R / S	None	None	None	None	X			X	X	XX		X	X
B	Warbling Vireo	*Vireo gilvus*	N	None	None	None	None	XX			XX	XX	X		X	X
B	Red-eyed Vireo	*Vireo olivaceus*	N	None	None	None	None	XX			XX	X				
B	Steller's Jay	*Cyanocitta stelleri*	R	None	None	None	None	X			X	X	X		X	X
B	Western Scrub-Jay	*Aphelocoma californica*	R	None	None	None	None	X			X	X	XX	X	X	X
B	Gray Jay	*Perisoreus canadensis*	R	None	None	None	None	X			X	X	X			X
B	American Crow	*Corvus brachyrhynchos*	R	None	None	None	None	X		X	X	X	X	X	XX	XX
B	Common Raven	*Corvus corax*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Streaked Horned Lark	*Eremophila alpestris strigata*	S	SoC	SC	G5T2/S2?	2							XX	X	X
B	Purple Martin	*Progne subis*	N	SoC	SC	G5/S3B	2	XX	XX	X	X	X	X	X		X
B	Tree Swallow	*Tachycineta bicolor*	N	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
B	Violet-green Swallow	*Tachycineta thalassina*	N	None	None	None	None	X	X	X	X	X	X	X	X	X
B	Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	N	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
B	Cliff Swallow	*Petrochelidon pyrrhonota*	N	None	None	None	None	XX	XX	X	XX	X	X	X	X	X
B	Barn Swallow	*Hirundo rustica*	N	None	None	None	None	XX	XX	XX	XX	X	X	X	XX	X
B	Black-capped Chickadee	*Poecile atricapilla*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Mountain Chickadee	*Poecile gambeli*	W / M	None	None	None	None	X			X	X	X			X
B	Chestnut-backed Chickadee	*Poecile rufescens*	R	None	None	None	None	X			X	X	X		X	X
B	Bushtit	*Psaltriparus minimus*	R	None	None	None	None	X			X	X	X		X	X
B	Red-breasted Nuthatch	*Sitta canadensis*	R	None	None	None	None	X			X	X	X		X	X
B	White-breasted Nuthatch	*Sitta carolinensis*	R	None	None	None	None	X			X		X	X	X	X
B	Brown Creeper	*Certhia americana*	R	None	None	None	None	X			X	X	X	X	X	X
B	Bewick's Wren	*Thryomanes bewickii*	R	None	None	None	None	X		X	X	X	X		X	X
B	House Wren	*Troglodytes aedon*	N	None	None	None	None	X			X	X	X	X	X	X
B	Winter Wren	*Troglodytes troglodytes*	R	None	None	None	None	X			X	X	X			X
B	Marsh Wren	*Cistothorus palustris*	N	None	None	None	None	XX		XX						

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8]							
									WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
B	American Dipper	*Cinclus mexicanus*	R / S	None	None	None	None	XX	XX	X	XX					
B	Golden-crowned Kinglet	*Regulus satrapa*	R	None	None	None	None	X			X	XX	X			X
B	Ruby-crowned Kinglet	*Regulus calendula*	W / M	None	None	None	None	X		X	X	X	X	X	X	X
B	Western Bluebird	*Sialia mexicana*	S	None	SV	G5/S4B, S4N	4					XX	XX	X	X	X
B	Townsend's Solitaire	*Myadestes townsendi*	W / M	None	None	None	None	X			X	X	X		X	X
B	Swainson's Thrush	*Catharus ustulatus*	N	None	None	None	None	X			X	X	X		X	X
B	Hermit Thrush	*Catharus guttatus*	S	None	None	None	None	X			X	X	X		X	X
B	American Robin	*Turdus migratorius*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Varied Thrush	*Ixoreus naevius*	W / M	None	None	None	None					XX	X		X	X
B*	European Starling*	*Sturnus vulgaris*	R / S	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX		X	XX	X	X	X	X	XX
B	American Pipit	*Anthus rubescens*	W / M	None	None	None	None	X		X				X	XX	
B	Cedar Waxwing	*Bombycilla cedrorum*	S	None	None	None	None	X		X	X	X	X		X	X
B	Orange-crowned Warbler	*Vermivora celata*	N	None	None	None	None	X			X	X	X	X	X	X
B	Nashville Warbler	*Vermivora ruficapilla*	N	None	None	None	None	X			X	X	X		X	
B	Yellow Warbler	*Dendroica petechia*	N	None	None	None	None	XX			XX					
B	Yellow-rumped Warbler	*Dendroica coronata*	S	None	None	None	None	X		X	X	X	X		X	X
B	Black-throated Gray Warbler	*Dendroica nigrescens*	N	None	None	None	None	XX			XX	XX	XX		X	X
B	Townsend's Warbler	*Dendroica townsendi*	S / N	None	None	None	None	X			X	X	X		X	X
B	Hermit Warbler	*Dendroica occidentalis*	N	None	None	None	None	X			X	XX	X			
B	MacGillivray's Warbler	*Oporornis tolmiei*	N	None	None	None	None	X			X	X	X		X	
B	Common Yellowthroat	*Geothlypis trichas*	N	None	None	None	None	XX		XX	XX	X	X	X		X
B	Wilson's Warbler	*Wilsonia pusilla*	N	None	None	None	None	XX			XX	XX	X		X	X
B	Yellow-breasted Chat	*Icteria virens*	N	SoC	SC	G5/S4?	4	XX			XX	X	X		X	
B	Western Tanager	*Piranga ludoviciana*	N	None	None	None	None	X			X	XX	XX			X
B	Spotted Towhee	*Pipilo maculatus*	R	None	None	None	None	X			X	X	XX		X	X
B	Chipping Sparrow	*Spizella passerina*	N	None	None	None	None	X			X	X	X	X	X	X
B	Oregon Vesper Sparrow	*Pooecetes gramineus affinis*	S / N	SoC	SC	G5T3/S2B, S2N	2							XX	XX	
B	Savannah Sparrow	*Passerculus sandwichensis*	S / N	None	None	None	None	X		X	X			XX	XX	X
B	Fox Sparrow	*Passerella iliaca*	W / M	None	None	None	None	X			X	X	X		X	X
B	Song Sparrow	*Melospiza melodia*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Lincoln's Sparrow	*Melospiza lincolnii*	S / N	None	None	None	None	XX		XX	XX	X			X	
B	Swamp Sparrow	*Melospiza georgiana*	W / M	None	None	None	None	XX		XX	XX				X	
B	White-throated Sparrow	*Zonotrichia albicollis*	W / M	None	None	None	None								X	X
B	Harris's Sparrow	*Zonotrichia querula*	W / M	None	None	None	None								X	X
B	White-crowned Sparrow	*Zonotrichia leucophrys*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Golden-crowned Sparrow	*Zonotrichia atricapilla*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Dark-eyed Junco	*Junco hyemalis*	S	None	None	None	None	X			X	X	X		X	X
B	Black-headed Grosbeak	*Pheucticus melanocephalus*	N	None	None	None	None	X			X	X	X		X	X
B	Lazuli Bunting	*Passerina amoena*	N	None	None	None	None	X			X	X	X	X	XX	X
B	Red-winged Blackbird	*Agelaius phoeniceus*	S	None	None	None	None	XX		XX	X			X	X	X
B	Tricolored Blackbird	*Agelaius tricolor*	S	SoC	SP	G3/S2B	2	XX		XX					X	

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8] WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
B	Western Meadowlark (extirpated as breeding species)	*Sturnella neglecta*	W / M	None	SC	G5/S5	4	X		X				XX	XX	
B	Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	N	None	None	None	None	XX		XX					X	
B	Brewer's Blackbird	*Euphagus cyanocephalus*	S	None	None	None	None	X		X	X		X	X	XX	X
B	Brown-headed Cowbird	*Molothrus ater*	S / N	None	None	None	None	X		X		X	X	X	XX	X
B	Bullock's Oriole	*Icterus bullockii*	N	None	None	None	None	XX			XX		XX		X	X
B	Purple Finch	*Carpodacus purpureus*	S	None	None	None	None	XX			XX	X	XX		X	X
B	House Finch	*Carpodacus mexicanus*	R	None	None	None	None	X		X	X	X	X	X	XX	XX
B	Red Crossbill	*Loxia curvirostra*	R / S	None	None	None	None	X			X	X	X			X
B	Pine Siskin	*Carduelis pinus*	S	None	None	None	None	X		X	X	X	X		X	X
B	Lesser Goldfinch	*Carduelis psaltria*	S	None	None	None	None	XX			XX	X	XX	X	X	X
B	American Goldfinch	*Carduelis tristis*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Evening Grosbeak	*Coccothraustes vespertinus*	W / M	None	None	None	None	X			X	X	X			X
B*	House Sparrow*	*Passer domesticus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien								XX	XX
M*	Virginia Opossum*	*Didelphis virginiana*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	X			X	X	X	X	XX	XX
M	Vagrant Shrew	*Sorex vagrans*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Pacific Water Shrew	*Sorex bendirii*	R	None	None	None	None	XX		X	XX	X	X			
M	Water Shrew	*Sorex palustris*	R	None	None	None	None	XX			XX	X				
M	Trowbridge's Shrew	*Sorex trowbridgii*	R	None	None	None	None	X			X	XX	X		X	X
M	Shrew-mole	*Neurotrichus gibbsii*	R	None	None	None	None	X		X	X	XX	X		X	X
M	Townsend's Mole	*Scapanus townsendii*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Coast Mole	*Scapanus orarius*	R	None	None	None	None	X			X	XX	X	X	X	X
M	Yuma Myotis	*Myotis yumanensis*	R / S	SoC	None	G5/S3	4	XX	XX	XX	XX	X	X	X	X	X
M	Little Brown Myotis	*Myotis lucifugus*	R / S	None	None	None	None	X	X	X	X	X	X	X	X	X
M	Long-legged Myotis	*Myotis volans*	R / S	SoC	SU	G5/S3	4	X	X	X	X	XX	X	X	X	X
M	Fringed Myotis	*Myotis thysanodes*	R / S	SoC	SV	G4G5/S2?	2	X	X	X	X	X	X		X	X
M	Long-eared Myotis	*Myotis evotis*	R / S	SoC	SU	G5/S3	4	X	X	X	X	X	X	X	X	X
M	Silver-haired Bat	*Lasionycteris noctivagans*	L	SoC	SU	G5/S4?	4	X	X	X	X	XX	X	X	X	X
M	Big Brown Bat	*Eptesicus fuscus*	R / S	None	None	None	None	X	X	X	X	X	XX	X	XX	XX
M	Hoary Bat	*Lasiuris cinereus*	L	None	None	G5/S4?	4	X	X	X	X	X	X	X	X	X
M	Pacific Western Big-eared Bat	*Corynorhinus townsendii townsendii*	R / S	SoC	SC	G4T3T4/S2?	2	XX	XX	X	X	X	X	X	X	X
M	Brush Rabbit	*Sylvilagus bachmani*	R	None	None	None	None	X			X	X	X	X	X	X
M*	Eastern Cottontail*	*Sylvilagus floridanus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	X			X				X	X
M	Mountain Beaver	*Aplodontia rufa*	R	None	None	None	None	XX			XX	XX				
M	Townsend's Chipmunk	*Tamias townsendii*	R	None	None	None	None	X			X	XX	X			X
M	California Ground Squirrel	*Spermophilus beecheyi*	R	None	None	None	None					X	X	X	X	X
M*	Eastern Fox Squirrel*	*Sciurus niger*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien							XX	XX	XX
M*	Eastern Gray Squirrel*	*Sciurus carolinensis*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien						XX		X	XX
M	Western Gray Squirrel	*Sciurus griseus*	R	None	SU	G5/S4?	3					X	XX		X	X
M	Douglas' Squirrel	*Tamiasciurus douglasii*	R	None	None	None	None		XX	XX	X					
M	Northern Flying Squirrel	*Glaucomys sabrinus*	R	None	None	None	None	X			X	XX	XX			X
(M)	(Western pocket gopher)	*(Thomomys mazama)*	(R)	None	None	None	None					(XX)	(XX)	(X)	(X)	(X)
M	Camas Pocket Gopher	*Thomomys bulbivorus*	R	SoC	None	G3G4/S3 S4	3							XX	XX	X

Code[1]	Common Name	Genus/Species	Migratory Status[2]	Federal Status[3]	ODFW Status[4]	ORNHP Rank[5]	ORNHP List[6]	Riparian Assn.[7]	Habitat Type[8]							
									WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
M	American Beaver	*Castor canadensis*	R	None	None	None	None	XX	XX	XX	XX	X	X		X	X
M	Deer Mouse	*Peromyscus maniculatus*	R	None	None	None	None	XX		XX	XX	XX	XX	XX	XX	XX
M	Bushy-tailed Woodrat	*Neotoma cinerea*	R	None	None	None	None	X			X	XX	XX		XX	X
M	Western Red-backed Vole	*Clethrionomys californicus*	R	None	None	None	None	X			X	X				
M	Heather Vole	*Phenacomys intermedius*	R	None	None	None	None	X			X		X			
M	White-footed Vole	*Arborimus (= Phenacomys) albipes*	R	SoC	SU	G3G4/S3	4	XX			XX	XX				
M	Red Tree Vole	*Arborimus (= Phenacomys) longicaudus*	R	SoC	None	G3G4/S3S4	3	X			X	XX	XX			
M	Gray-tailed Vole	*Microtus canicaudus*	R	None	None	None	None							XX	XX	
M	Townsend's Vole	*Microtus townsendii*	R	None	None	None	None	XX		XX	X	X	X	X	X	
M	Long-tailed Vole	*Microtus longicaudus*	R	None	None	None	None	XX		XX	XX	X	X	X	X	
M	Creeping Vole	*Microtus oregoni*	R	None	None	None	None	X			X	X	X	X	X	X
M	Water Vole	*Microtus richardsoni*	R	None	None	None	None	X			X	X				
M	Common Muskrat	*Ondatra zibethicus*	R	None	None	None	None	XX	XX	XX	XX				X	X
M*	Black Rat*	*Rattus rattus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien								X	XX
M*	Norway Rat*	*Rattus norvegicus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien								X	XX
M*	House Mouse*	*Mus musculus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien								XX	XX
M	Pacific Jumping Mouse	*Zapus trinotatus*	R	None	None	None	None	XX		X	XX	X	X		X	
M	Common Porcupine	*Erethizon dorsatum*	R	None	None	None	None	XX		X	XX	XX	XX		X	X
M*	Nutria*	*Myocastor coypus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	XX				X	X
M	Coyote	*Canis latrans*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Red Fox	*Vulpes vulpes*	R	None	None	None	None	X			X	X	X	XX	X	X
M	Gray Fox	*Urocyon cinereoargenteus*	R	None	None	None	None	X			X	XX	X	X	X	
(M)	(Gray Wolf - extirpated)	*(Canis lupus)*	S	None	None	None	None	(X)			(X)	(X)	(X)	(X)		
M	Black Bear	*Ursus americanus*	S	None	None	None	None	X		X	X	X	X	X	X	X
(M)	(Grizzly Bear)	*(Ursus arctos)*	(R)	LT	None	G4/SX	2-ex	(X)			(X)	(X)		(X)		
M	Common Raccoon	*Procyon lotor*	R	None	None	None	None	XX	X	XX	XX	X	X	X	XX	XX
M	Ermine	*Mustela erminea*	R	None	None	None	None	X			X	X	X	X	X	
M	Long-tailed Weasel	*Mustela frenata*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Mink	*Mustela vison*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
M	Striped Skunk	*Mephitis mephitis*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Western Spotted Skunk	*Spilogale gracilis*	R	None	None	None	None	X			X	X	X	X	X	X
M	Northern River Otter	*Lontra canadensis*	R	None	None	None	None	XX	XX	XX	XX					X
M	Mountain Lion (Cougar)	*Puma concolor*	S	None	None	None	None	X		X	X	X	X		X	X
M	Bobcat	*Lynx rufus*	S	None	None	None	None	X		X	X	X	X	X	X	X
M*	Domestic Cat (feral)*	*Felis domesticus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
M	California Sea Lion	*Zalophus californianus*	S	None	None	None	None	XX	XX							
M	Roosevelt Elk	*Cervus elaphus roosevelti*	S	None	None	None	None	X		X	X	X	X	X	X	X
(M)	(Columbian White-tailed Deer)	*(Odocoileus virginiana leucurus)*	(R)	LE	SV	G5T2QS2	1	(X)		(X)	(X)	(X)	(XX)	(X)	(X)	(X)
M	Mule Deer	*Odocoileus hemionus*	R	None	None	None	None	X		X	X	X	X	X	X	X

[a] Bald eagle is currently proposed for de-listing at the federal level.

APPENDIX 6. LITERATURE CITED

1. Adams LW: Urban Wildlife Habitats: A Landscape Perspective. Minneapolis, MN, University of Minnesota Press, 1994.
2. Adams LW, Dove LE: Wildlife reserves and corridors in the urban environment. A guide to ecological landscape planning and resource conservation. Columbia, MD, National Institute for Urban Wildlife, 1989.
3. Alberti M, Marzluff JM: Ecological resilience in urban ecosystems: Linking urban patterns to human and ecological functions. Urban Ecosystems 2004;7:241-265.
4. Allan BF, Keesing F, Ostfeld RS: The effect of habitat fragmentation on Lyme disease risk. Conservation Biology 2003;17:267-272.
5. Altman B: Status and conservation of state sensitive grassland bird species in the Willamette Valley. 1-80. 1999. Corvallis, OR, Oregon Department of Fish and Wildlife. Ref Type: Report
6. Altman B: Conservation strategies for landbirds in lowlands and valleys of western Oregon and Washington. Version 1.0, March 2000, 1-138. 2000. Corvallis, OR, Oregon-Washington Partners in Flight and the American Bird Conservancy. Ref Type: Report
7. Altman B, Hagar J: Rainforest birds: A land manager's guide to breeding habitat in young conifer forests in the Pacific Northwest. Scientific Investigations Report 2006-5304, 1-60. 2006. Corvallis, OR, U.S. Geological Survey. Ref Type: Report
8. American Wildlands. Regional habitat connectivity analysis: Crown of the Continent ecosystem. 1-29. 2006. Bozeman, MT, American Wildlands. Ref Type: Report
9. Andrews KM, Gibbons JW, Reeder TW: How do highways influence snake movement? Behavioral responses to roads and vehicles. Copeia 2009;2005:772-782.
10. Aresco MJ: Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a north Florida lake. Journal of Wildlife Management 2005;69:549-560.
11. Aresco MJ: The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles. Biological Conservation 2009;123:37-44.
12. Artman VL: Effects of commercial thinning on breeding bird populations in western hemlock forests. American Midland Naturalist 2003;149:225-232.
13. Ås S: Invasion of matrix species in small habitat patches. Conservation Ecology [online] 1999;3:Article 1.
14. Askins RA, Philbrick MJ, Sugeno DS: Relationship between the regional abundance of forest and the composition of forest bird communities. Biological Conservation 1987;39:129-152.
15. Atchison KA, Rodewald AD: The value of urban forests to wintering birds. Natural Areas Journal 2006;26:280-288.
16. Austen MJW, Francis CM, Burke DM, Bradstreet MSW: Landscape context and fragmentation effects on forest birds in southern Ontario. The Condor 2001;103:701-714.
17. Austin JM, Viani K, Hammond F: Vermont wildlife linkage habitat analysis. A GIS-based, landscape-level identification of potentially significant wildlife linkage habitats associated with State of Vermont roadways. VTrans Research Advisory Council No. RSCH008-967, 1-24. 2006. Vermont Agency of Transportation. Ref Type: Report
18. Avila-Flores R, Fenton MB: Use of spatial features by foraging insectivorous bats in a large urban landscape. Journal of Mammalogy 2005;86:1193-1204.
19. Banks PB, Bryant JV: Four-legged friend or foe? Dog walking displaces native birds from natural areas. Biological Letters [online] 2007;1-4.
20. Barding EE, Nelson TA: Raccoons use habitat edges in northern Illinois. The American Midland Naturalist 2008;159:394-402.
21. Barton DC, Holmes AL: Off-highway vehicle trail impacts on breeding songbirds in northeastern California. Journal of Wildlife Management 2007;71:1617-1620.
22. Bartos Smith S, McKay JE, Murphy MT: Edges, trails, and reproductive performance of Spotted Towhees in urban greenspaces. 1-29. 2010. Portland, OR, Portland State University. Ref Type: Report

23. Bauer SB, Ralph SC: Strengthening the use of aquatic habitat indicators in Clean Water Act programs. Fisheries 2001;26:14-24.
24. Baum KA, Haynes KJ, Dillemuth FP, Cronin JT: The matrix enhances the effectiveness of corridors and stepping stones. Ecology 2004;85:2671-2676.
25. Beier P: Dispersal of juvenile cougars in fragmented habitat. Journal of Wildlife Management 1995;59:228-237.
26. Beier P: Effects of artificial night lighting on terrestrial mammals; in Rich C, Longcore T (eds): Ecological consequences of artificial night lighting. District of Columbia, U.S., Island Press, 2006, pp 19-42.
27. Beier P: An overview of science-based approaches to wildlife linkage design. Proceedings for the 8th Annual Urban Ecology and Conservation Symposium, 9. 2010. Portland, OR, Urban Ecosystem Research Consortium. Ref Type: Conference Proceeding
28. Beier P, Majka D, Jenness J: Conceptual steps for designing wildlife corridors. 1-86. 2009. Northern Arizona University, Flagstaff, AZ, Environmental Research, Development and Education for the New Economy. Ref Type: Report
29. Beier P, Majka D, Newell S, Garding E: Best management practices for wildlife corridors. 1-14. 2008. Northern Arizona University.
30. Beier P, Majka D, Spencer WD: Forks in the road: Choices in procedures for designing wildlife linkages. Conservation Biology 2008;22:836-851.
31. Beier P, Noss RF: Do habitat corridors provide connectivity? Conservation Biology 1998;12:1241-1252.
32. Beissinger SR, Osborne DR: Effects of urbanization on avian community organization. The Condor 1982;84:75-83.
33. Bellows AS, Mitchell JC: Small mammal communities in riparian and upland habitats on the upper coastal plain of Virginia. Virginia Journal of Science 2000;51:171-186.
34. Bennett G, Mulongoy KJ: Review of experience with ecological networks, corridors and buffer zones. 1-100. 2006. Montreal, Canada, Secretariat of the Convention on Biological Diversity. Technical Series No. 23. Ref Type: Report
35. Berger J, Stacey PB, Bellis L, Johnson MP: A mammalian predator-prey imbalance: Grizzly bear and wolf extinction affect avian neotropical migrants. Ecological Applications 2001;11:947-960.
36. Bernier-Leduc M, Vanesse A, Olivier A, Bussieres D, Maisonneuve C: Avian fauna in windbreaks integrating shrubs that produce non-timber forest products. Agriculture, Ecosystems and Environment 2009;131:16-24.
37. Best LB: Bird use of fencerows: Implications of contemporary fencerow management practices. Journal of the Iowa Agriculture and Home Economics Experiment Station 1983;343-347.
38. Biewener J, Gross WA: Portland Christmas Bird Count, 83-year summary, 1926-2008. 1-4. 2009. Portland, OR, Audubon Society of Portland. Ref Type: Report
39. Bissonette JA, Rosa SA: Road zone effects in small-mammal communities. Ecology and Society [online] 2009;14:Article 27.
40. Blewett CM, Marzluff JM: Effects of urban sprawl on snags and the abundance of productivity of cavity-nesting birds. The Condor 2005;107:678-693.
41. Boldogh S, Dobrosi D, Samu P: The effects of the illumination of buildings on house-dwelling bats and its conservation consequences. Acta Chiropterologica 2007;9:527-534.
42. Bolger DT, Alberts AC, Sauvajot RM, Potenza P, McCalvin C, Tran D, Mazzoni S, Soulé ME: Response of rodents to habitat fragmentation in coastal Southern California. Ecological Applications 1997;7:552-563.
43. Bolger DT, Scott TA, Rotenberry JT: Breeding bird abundance in an urbanizing landscape in coastal southern California. Conservation Biology 1997;11:406-421.
44. Bolton SM, Shellberg J: Ecological issues in floodplains and riparian corridors. WA-RD 524.1, 1-88. 2001. Olympia,WA, Research Office, Washington State Department of Transportation. Ref Type: Report
45. Booth DB, Karr JR, Schauman S, Konrad CP, Morley SA, Larson MG, Burges SJ: Reviving urban streams: Land use, hydrology, biology, and human behavior. Journal of the American Water Resources Association 2004;40:1351-1364.
46. Boyd C, Brooks TM, Butchart SHM, Edgar GJ, da Fonseca GAB, Hawkins F, Hoffmann M, Sechrest W, Stuart SN, van Dijk PP: Spatial scale and the conservation of threatened species. Conservation Letters [online] 2008;1:37-43.

47. Bradley JE, Marzluff JM, Thompson III FR: Rodents as nest predators: Influences on predatory behavior and consequences to nesting birds. The Auk 2003;120:1180-1187.
48. Brinkerhoff RJ, Haddad NM, Orrock JL: Corridors and olfactory predator cues affect small mammal behavior. Journal of Mammalogy 2005;86:662-669.
49. Brooker L, Brooker M, Cale P: Animal dispersal in fragmented habitat: Measuring habitat connectivity, corridor use, and dispersal mortality. Conservation Ecology [online] 1999;3:Article 4.
50. Brown R, Harris G: Comanagement of wildlife corridors: The case for citizen participation in the Algonquin to Adirondack proposal. Journal of Environmental Management 2005;74:97-106.
51. Browne CL, Hecnar SJ: Species loss and shifting population structure of freshwater turtles despite habitat protection. Biological Conservation 2007;138:421-429.
52. Brownell D: The six species of the salmon nation; Salmon Nation: People and Fish at the Edge. Portland, OR, Ecotrust, 1999, pp 45-47.
53. Bruce RC: Intraguild interactions and population regulation in Plethodontid salamanders. Herpetological Monographs 2008;31-53.
54. Brudvig LA, Damschen EI, Tewksbury JJ, Haddad NM, Levey DJ: Landscape connectivity promotes plant biodiversity spillover into non-target habitats. PNAS 2009;106:9328-9332.
55. Bull E: The value of coarse woody debris to vertebrates in the Pacific Northwest. General Technical Report PSW-GTR-181, 171-178. 2002. USDA Forest Service. Ref Type: Report
56. Burbrink FT, Phillips CA, Heske EJ: A riparian zone in southern Illinois as a potential dispersal corridor for reptiles and amphibians. Biological Conservation 1998;86:107-115.
57. Burghardt KT, Tallamy DW, Shriver WG: Impact of native plants on bird and butterfly biodiversity in suburban landscapes. Conservation Biology 2009;23:219-224.
58. Burke DM, Nol E: Influence of food abundance, nest-site habitat, and forest fragmentation on breeding Ovenbirds. The Auk 1998;115:96-104.
59. Butcher JA, Morrison ML, Ransom D, Slack RD, Wilkins RN: Evidence of a minimum patch size threshold of reproductive success in an endangered songbird. Journal of Wildlife Management 2009;74:133-139.
60. Butts SR, McComb WC: Associations of forest-floor vertebrates with coarse woody debris in managed forests of Western Oregon. Journal of Wildlife Management 2000;64:95-104.
61. Cadenasso ML, Pickett STA: Urban principles for ecological landscape design and management: Scientific fundamentals. Cities and the Environment [online] 2008;1:Article 4.
62. Calhoun AJK, Miller NA, Klemens MW: Conserving pool-breeding amphibians in human-dominated landscapes through local implementation of Best Development Practices. Wetlands Ecology and Management 2005;13:291-304.
63. Carey AB, Johnson ML: Small mammals in managed, naturally young, and oldgrowth forests. Ecological Applications 1995;5:336-352.
64. Carter T, Butler C: Ecological impacts of replacing traditional roofs with green roofs in two urban areas. Cities and the Environment [online] 2008;1:Article 9.
65. Cederholm CJ, Kunze MD, Murota T, Sibatani A: Pacific salmon carcasses: Essential contributions of nutrients and energy for aquatic and terrestrial systems. Fisheries 2000;24:6-15.
66. Chace JF, Walsh JJ: Urban effects on native avifauna: A review. Landscape and Urban Planning 2006;74:46-69.
67. Chen J, Franklin JF, Spies TA: Growing-season microclimatic gradients from clearcut edges into old-growth Douglas-fir forests. Ecological Applications 1995;5:74-86.
68. Chettri N, Deb DC, Sharma E, Jackson R: The relationship between bird communities and habitat. Mountain Research and Development 2005;25:235-243.
69. Christy J, Alverson ER, Dougherty MP, Kolar SC: Historical vegetation for Oregon. 1993. Oregon Natural Heritage Program,The Nature Conservancy of Oregon. Ref Type: Report
70. Cirmo CP, Driscoll CT: Beaver pond biogeochemistry: Acid neutralizing capacity generation in a headwater wetland. Wetlands 1993;13:277-292.
71. City of Chicago, IL. Lights Out Chicago! http://egov.cityofchicago.org/Environment/BirdMigration/sub/lights_out_chicago.html. 2010. City of Chicago, IL. Ref Type: Electronic Citation

72. Clark BS, Leslie DM, Jr., Carter TS: Foraging activity of adult female Ozark big-eared bats (*Plecotus townsendii ingens*) in summer. Journal of Mammalogy 1993;74:422-427.
73. Clevenger AP, Wierzchowski J, Chruszcz B, Gunson K: GIS-generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. Conservation Biology 2002;16:503-514.
74. Climate Change Wildlife Action Plan Work Group. Voluntary guidance for states to incorporate climate change into state wildlife action plans and other management plans. 1-53. 2009. Salem, OR, Association of Fish & Wildlife Agencies'Climate Change and Teaming With Wildlife Committees. Ref Type: Report
75. Coleman JL, Ford NB, Herriman K: A road survey of amphibians and reptiles in a bottomland hardwood forest. Southeastern Naturalist 2008;7:339-348.
76. Collinge SK: Spatial arrangement of habitat patches and corridors: Clues from ecological field experiments. Landscape and Urban Planning 1998;42:157-168.
77. Conner RN, Dickson JG, Williamson JH, Ortego B: Width of forest streamside zones and breeding bird abundance in eastern Texas. Southeastern Naturalist 2004;3:669-682.
78. Constantine NL, Campbell TA, Baughman WM, Harrington TB, Chapman BR, Miller KV: Small mammal distributions relative to corridor edges within intensively managed southern pine plantations. Southern Journal of Applied Forestry 2005;29:148-151.
79. Copenheaver CA, Predmore SA, Askamit DN: Conversion of rare grassy openings to forest: Have these areas lost their conservation value? Natural Areas Journal 2009;29:133-139.
80. Corlatti L, Hacklander K, Frey-Rous F: Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. Conservation Biology 2009;In press.
81. Cornelius C, Cofre H, Marquet PA: Effects of habitat fragmentation on bird species in a relict temperate forest in semiarid Chile. Conservation Biology 2000;14:534-543.
82. Croonquist MJ, Brooks RP: Effects of habitat disturbance on bird communities in riparian corridors. Journal of Soil and Water Conservation 1993;48:65-70.
83. Csuti B, Polasky S, Williams PH, Pressey RL, Camm JD, Kershaw M, Kiester AR, Downs B, Hamilton R, Huso M, Sahr K: A comparison of reserve selection algorithms using data on terrestrial vertebrates in Oregon. Biological Conservation 1997;80:83-97.
84. Cushman SA, McKelvey KS, Schwartz MK: Use of empirically derived source-destination models to map regional conservation corridors. Conservation Biology 2008; 368-376.
85. Damschen EI, Brudvig LA, Haddad NM, Levey DJ, Orrock JL, Tewksbury JJ: The movement ecology and dynamics of plant communities in fragmented landscapes. PNAS 2008;105:19078-19083.
86. Damschen EI, Haddad NM, Orrock JL, Tewksbury JJ, Levey DJ: Corridors increase plant species richness at large scales. Science 2006;313:1284-1286.
87. Darveau M, Beauchesne P, Belanger L, Huot J, Larue P: Riparian forest strips as habitat for breeding birds in boreal forest. Journal of Wildlife Management 1995;59:67-78.
88. Davis AM, Glick TF: Urban ecosystems and island biogeography. Environmental Conservation 1978;5:299-304.
89. Dawson DK, Darr LJ, Robbins CS: Predicting the distribution of breeding forest birds in a fragmented landscape. Transactions of the North American Wildlife Conference 1993;58:35-43.
90. Debinski DM, Hold RD: A survey and overview of habitat fragmentation experiments. Conservation Biology 2000;14:342-355.
91. Debruyckere L: Wildlife crossings: The state of the science. A literature review. 1-112. 2008. Portland, OR, Metro Regional Government. Ref Type: Report
92. Desrochers A, Hannon SJ: Gap crossing decisions by forest songbirds during the post-fledging period. Conservation Biology 2003;11:1204-1210.
93. Dickson JG, Williamson JH, Conner RN, Ortego B: Streamside zones and breeding birds in eastern Texas. Wildlife Society Bulletin 1995;23:750-755.
94. Dijak WD, Rittenhouse CD, Larson MA, Thompson FR, Millspaugh JJ: Landscape habitat suitability index software. Journal of Wildlife Management 2007;71:668-670.
95. Ditchkoff SS, Saalfeld ST, Gibson CJ: Animal behavior in urban ecosystems: Modifications due to human-induced stress. Urban Ecosystems 2006;9:5-12.
96. Dizney LJ, Ruedas LA: Increased host species diversity and decreased prevalence of Sin Nombre virus. Emerging Infectious Diseases 2009;15:1012-1018.

collectively will serve as an umbrella for all native species and ecological processes [28;30;156;203]. Select a subset of these focal species for each core habitat. Focusing on providing habitat and passage for these specialized species will, in theory, provide for the more generalist species as well. Species with the following traits should be included:

- area-sensitive
- habitat specialists
- dispersal limited
- sensitive to barriers
- sensitive to climate change
- otherwise ecologically important, including at-risk species

It may also be appropriate to select focal species that evoke strong public interest or for which long-term or extensive survey data are available. Once a subset of focal species for each core habitat is selected, ascertain species-habitat relationships, including known movement requirements, and conservation potential based on existing habitat, then use the information to selectively conserve or restore connectivity. Species-habitat relationships may be documented through a variety of sources, including local studies and knowledge; published studies; published habitat suitability indices (HSI) or software to develop them [94;365]; on-the-ground habitat evaluation procedures (HEP) or similar habitat assessment tools [362]; and various GIS-based modeling techniques.

The U.S. Fish and Wildlife Service uses habitat-based focal species to represent conservation targets – that is, species, species groups, or communities of particular interest for a refuge [364]. U.S. Fish and Wildlife's Willamette Valley focal species include invertebrates, fish, turtles, birds, and plants. These species help the agency define the specific habitat and environmental attributes to be maintained or achieved for each conservation target. The Nature Conservancy uses a similar focal species approach [357], as does Partners in Flight [6].

Several questions arise for focal species. How large are the species' home ranges? Where do they occur, and where could they occur? How sensitive are they to disturbance, what types of disturbance, and what are their movement needs? Do these issues vary by season? What are the key habitat features - the "must-haves" - for corridor habitat? These questions might be answered in part through literature and professional knowledge (see Appendices 1, 2, 3).

Because most bird species fly, they are not as hindered by terrestrial barriers as other wildlife species. Although this would suggest that improving connectivity for a particular bird species may be easier than for species in other wildlife groups, the great diversity of bird species poses a challenge to designing wildlife corridors. There are over 200 species of birds in the region, each with unique life history requirements. For this reason, biologists often separate birds into guilds - groups of species with certain similar functional requirements or shared life history traits - and plan according to guild needs [53;68;82;114;330]. This approach, for birds and other species groups, can also be used for focal species in planning wildlife corridors. Season and location must be accounted for when considering research findings. Some examples of potential guilds in the region could include:

- Area- and disturbance-sensitive species for patch size and shape consideration
- Species requiring movement corridors of a certain minimum width (for example, amphibians; selected bird species with similar requirements; native turtles)

- Road avoiders or species that change behavior near roads (for example, Neotropical migratory songbirds, frogs, snakes)
- Urban-adapted native species (for example, Song Sparrow, American Robin, deer)
- Birds adapted to specific habitats such as native grassland, shrub or coniferous habitat (for example, Savannah Sparrow, White-crowned Sparrow and Common Yellowthroat for grasslands; Spotted Towhee, Willow Flycatcher for shrub; Western Tanager, Golden-crowned Kinglet and certain warbler species for conifer)
- Riparian specialists such as Willow Flycatcher, Black-headed Grosbeak, beaver and otter
- Larger species with shorter flush distances, especially when considering where to put trails (for example, quail, sensitive waterfowl species, Northern Flicker, Pileated Woodpecker)
- Species reluctant to cross gaps of a certain size (for example, Red- and White-breasted Nuthatch or Downy Woodpecker);
- Migratory songbirds during migration

The Oregon Department of Fish and Wildlife and a number of agency partners hosted a series of wildlife linkage workshops in 2007 to support the Oregon Wildlife Movement Strategy [160]. Workshop participants identified linkage areas for three groups of focal species, including large game mammals, small mammals, and amphibians and reptiles. The three groups, essentially large guilds, were selected to encompass a broad array of animal movement needs.

Focal species may also be used to evaluate connectivity under alternative scenarios for disturbances such as climate change, urban development, and new trails and roads. The key is to know what questions need to be answered, and select the species that can help answer them. Some information about focal species' needs may be derived from literature (see Appendices 1, 2, 3). However, these studies were usually conducted in different geographic regions and in non-urban areas, and may have limited applicability in the region. Combining information from available studies with local wildlife knowledge can help guide development of focal species' requirements for habitat and connectivity.

Wildlife-vehicle collision and road-kill data may help with connectivity planning. Metro and the Oregon Department of Transportation (ODOT) have selected information on wildlife-vehicle collisions and road kills, but at present no comprehensive data set exists for the region. In addition, existing data is heavily weighted towards large mammals due to human risk, and also because they are more visible than smaller animals. ODOT's data is for the state-owned road system, constituting a fraction of the region's roads, and Metro's data is incomplete and somewhat outdated. To effectively use this type of data, the region would need a more up-to-date and comprehensive data set. Wildlife-vehicle collision or road-kill data sets do not account for absolute wildlife barriers, where animals do not even enter the roadway. In addition, such data fail to account for connectivity issues not related to roads. Wildlife-vehicle collision data is retrospective and not necessarily relevant in newly urbanizing areas or those with increasing populations. Nonetheless, such data can provide important supplemental information, particularly to identify some areas within a corridor where wildlife crossings are needed.

Indicator species and guild approaches are time tested and valid approaches to ecological assessment and problem solving, but there are other approaches as well. For example, simply identifying and conserving the best remaining corridors, along with addressing gaps and barriers over time, may successfully facilitate higher fish and wildlife permeability. These might be used as reference corridors to inform protection and restoration decisions in other corridors that are threatened by new development.

STAKEHOLDER OUTREACH – LOCALS KNOW MORE

It is important to include the public in natural resource management, from pre-planning through implementation. Local residents usually know what wildlife uses their lands. In addition, without support from the public and private landowners, little meaningful conservation beyond acquisition can be accomplished. Public participation costs money, time, and may yield unanticipated or even unwanted results; it means involving non-scientists in science. But it can also bring about surprisingly creative and effective solutions.

Lyman and others reviewed tools for incorporating community knowledge, preferences and values into natural resource decisions [221]. Such tools can be clustered into three general groups: (a) extractive use, in which knowledge, values or preferences are synthesized by the lead group (for example, scientists) and the preferred solution(s) referred to a decision-making process; (b) co-learning, in which syntheses are developed jointly and the implications are passed to a decision-making process; and (c) co-management, in which the participants perform the syntheses and include them in the joint decision-making process. Generally, the time and level of effort required increase from extractive use to co-management processes. However, an important trade-off is the extent to which citizens become involved, invested, and gain a sense of ownership of the project, which may increase project implementation and success, particularly on private lands.

In a corridor proposed by NGOs and academic institutions linking southern Ontario and Adirondack Park in New York, much of the land was private property [50]. A random survey of households within the proposed corridor zone revealed that landowners knew little of the proposal and had no contact with its advocates, placed high value on conserving biological diversity, and were worried about restrictions being placed on their land. Without private landowner buy-in and participation, any plan would be likely to fail. More work to disseminate information and engage citizens in formulating the corridor plan could allay fears, create corridor advocates and instill a sense of pride and community rather than creating resentment.

During the concept planning process for the City of Damascus, Oregon, planners held a series of community forums to keep the public informed and ask for input. One forum was laid out in a series of stations, including a natural resource station with draft inventory maps and aerial photos where residents could find their property and identify habitat areas for deer, elk, coyotes, owls, herons and other wildlife they considered important, as well as road-kill problem areas. They also pointed out

If public participation is invited, allow the residents to document anything they think is important. The criteria established by the working group will help sort out which new areas identified by the public should be added to the inventory, if any. This type of information can be very useful in documenting the importance of potential core areas, and can also be used to think about focal species for different habitat areas.

FINAL INVENTORY

SELECTING PREFERRED ALTERNATIVES (CORE HABITATS, FOCAL SPECIES)

At this point the working group has established goals and implemented methods to identify potential core habitat areas. Public outreach has revealed more about the wildlife using habitat areas and places that are special to local residents. Now is the time to document in detail why each core habitat area is important, what wildlife species are known or likely to use it, and incorporate new areas identified by the public if needed.

The documentation should focus on and revisit the criteria established by the working group early in the process. Determine which and how many criteria each core habitat area meets. Information from the public can help this process - for example, known sensitive species locations - and may alter the results. On the other hand, residents have likely advocated for the inclusion of areas that do not meet the criteria, and this part of the process helps explain why such areas were excluded from the final inventory.

The working group now decides which draft core habitat areas are to remain in the final inventory. The next step is to identify a final set of focal species for each core habitat area. This will provide the key information for the subsequent step: identifying corridors appropriate for moving focal species between their core habitat areas.

IDENTIFYING CORRIDORS

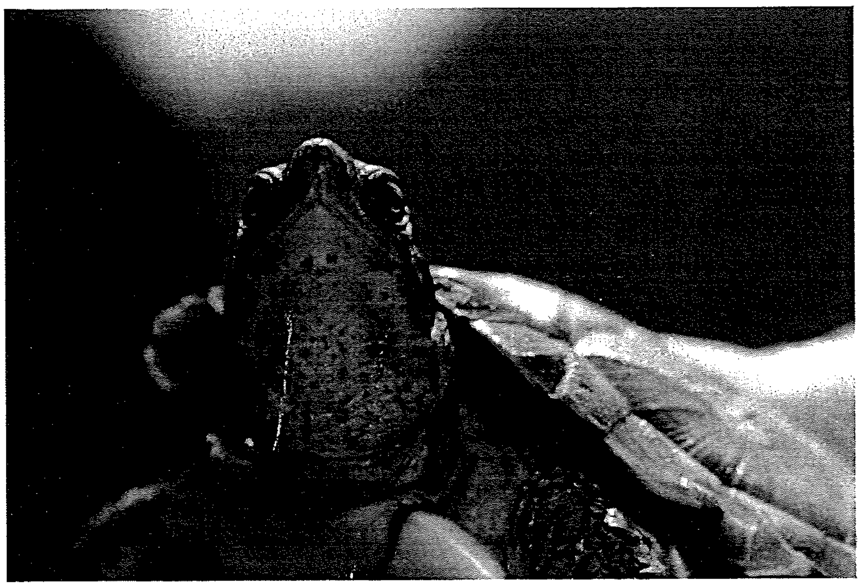
As is often the case with natural resource planning, identifying priority wildlife corridors in an urban environment is a blend of science and professional judgment. There is no one formula to use, especially in urban areas, where the complexity of analysis increases significantly due to the number of factors and issues to consider.

After identifying potential core habitats, focal species, and the needs of these species, the next step is to delineate potential wildlife corridors. There are several ways to accomplish this, from looking at maps and aerials and simply drawing lines - although this will not explicitly address focal species' needs - to complex models. Models can be used to identify potential movement corridors, assess or validate corridors identified by ecologists, identify gaps or constrictions or help decide which of several corridors may provide the best alternative. A combination of published empirical data, local professional knowledge and modeling methods can be effective [73] (see Appendix 4).

Today's hours: 9:30 a.m. to 4 p.m.

Exhibit 27

Western pond turtles



They survived the dinosaurs, but turtles worldwide are facing a modern extinction crisis, with half of all species at risk of disappearing.

Once common from Baja California to Puget Sound, the small, long-lived western pond turtle (Actinemys marmorata) is listed as endangered in Washington and threatened in Oregon. The Oregon Zoo works with Washington Department of Fish and Wildlife (WDFW) to help restore this shy reptile to its historic range through a unique head-starting program. As a result, Western pond turtle numbers are on the rise.

Adult turtles can live up to 70 years, nest on land and feed, breed and bask in water. They prefer streams, ponds, lakes and permanent wetlands, although their populations are much reduced and concentrated in a few locations.

Threats

Habitat loss
draining and filling of wetlands, dams and water diversion deprive these aquatic reptiles of critical habitat

Invasive predators
bullfrogs and largemouth bass prey on the vulnerable hatchlings

Shell disease
an emergent disease affecting the shell, which can lead to paralysis and death in advances stages

Invasive plants
when non-native plant species dominate, turtles can't excavate a nest, and the sun can't reach their nests

Western pond turtle recovery
In 1990, work started to recover Western pond turtles in Washington. The Oregon Zoo has been a collaborator since 1998.

What the recovery project looks like:

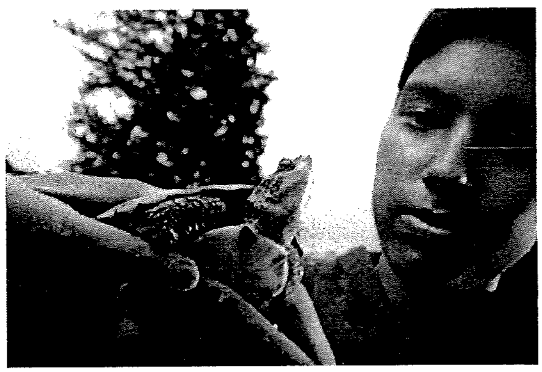
A "head-starting" project was initiated to protect the turtles during their most vulnerable stage of life and to accelerate their natural growth rates.

- Spring: WDFW biologists survey for adult female turtles.
- Summer: Female turtles dig a nest in dry, densely packed soil. She

deposits two to 11 eggs into the nest, which she then covers and abandons. Biologists locate and protect nests with wire exclosures to keep predators out. The eggs incubate naturally all summer.

- Fall: Biologists collect some of the quarter-sized hatchlings and move them to facilities such as the Oregon Zoo, where they grow and eat in a predator-free 'simulated summer' environment.
- Winter: In the wild, hatchlings become dormant in the cold. But the enhanced light and warmth at the zoo stimulates them to continue to eat and grow.
- Summer: About 10 months after their summertime hatch, zoo-reared juvenile turtles are nearly three times larger than if they had remained in the wild and survived. Now large enough to avoid being eaten by common non-native predators like bullfrogs, they are released at sites selected by WDFW.

Successes and ongoing recovery work


Show your commitment to the Oregon Zoo's local and global conservation efforts by becoming a Wildlife Partner today.

In 1990, only two pond turtle sites were left in Washington. Today, six populations have been established with two in Puget Sound and four in the Columbia River Gorge. During the same period, more than 1,800 turtles have been head-started and released to these sites. Studies have revealed that an estimated 95 percent of turtles released in the Columbia River Gorge survived their first year.

Currently, the Washington Department of Fish and Wildlife and partners are investigating causes and treatments for the shell disease that has affected some of Washington's western pond turtles.

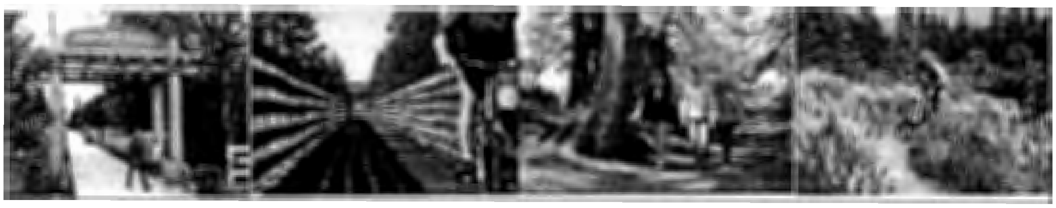
The Western pond turtle recovery program is a collaboration between the Oregon Zoo, Woodland Park Zoo and the WDFW. Other partners include Bonneville Power Administration, U.S. Forest Service, Washington State Parks, US Fish and Wildlife Service, Sustainability in Prisons Projects, Larch Corrections Center and others.

TAKE ACTION FOR NATIVE TURTLES

Both of Oregon's native turtles - the western pond turtle and the western painted turtle - are listed as "critical" on the state's sensitive species list. **Find out how to help protect** native turtles and report turtle sightings.

4001 SW Canyon Road
Portland, OR 97221
503-226-1561

Exhibit 31



Survey of Oregon Non-motorized Trail Providers

Final Report

Terry Bergerson

Oregon Parks and Recreation Department

September 2014

OREGON STATE PARKS

Nature
HISTORY
Discovery

EXECUTIVE SUMMARY

Objectives

This survey is part of the 2015 Oregon Statewide Trails Planning effort. Project objectives were to describe non-motorized trail funding priorities for the OPRD-administered Recreational Trails Grant Program (RTP) and identify top non-motorized trail management issues as part of the Statewide Trails Planning effort.

Methods

Data were obtained from an internet survey of 558 Oregon non-motorized trail providers between July 24 and August 14, 2014. The total number of completed questionnaires was n=232 with an estimated total response rate of 42%.

Results

Non-motorized Trail Management

- Most of the non-motorized trail provider respondents were from local park and recreation departments (41%), non-profit organizations (17%), state agencies (14%), and federal agencies (7%).
- Most survey respondents provide non-motorized trail opportunities in Region 2 (21%), Region 3 (17%), Region 4 (14%), and Region 1 (10%). Fewest respondents provide boating opportunities in Region 11 (1%).
- Most survey respondents provide non-motorized trail opportunities within Urban Growth Boundaries (UGBs; 54%), while 46% provide non-motorized trails in dispersed settings.
- The most serious non-motorized trail management issues were trail maintenance (88% rated the problem "slight" to "very" important), ability to experience the natural environment (86%), trail information on the internet (74%), trails connecting towns/public spaces (73%), trail surface quality (73%), and trail signs (directional and distance markers; 73%). The least serious issues were single-use trails to avoid user conflicts (20%), availability of benches (22%), availability of drinking water (22%), and controlling overcrowding on trails (23%).
- Other important management issues included the need for greater trail connectivity, lack of funding for non-motorized trail maintenance and repair, lack of funding for trail construction, and need for greater Americans with Disabilities (ADA) trail facility compliance.
- For non-motorized trails within UGBs, the most important issues were the ability to experience the natural environment (88% rated the problem "slight" to "very" important), trail maintenance (85%), trails connecting towns/public spaces (85%), trail surface quality (74%), and trail information on the internet (71%).
- For trails in dispersed settings, the most important issues were trail maintenance (91%), ability to experience the natural environment (83%), trail information on the internet (76%), trail signs (directional and distance markers; 75%), parking space at trailheads (72%), and trail surface quality (70%).
- Highest priority need for non-motorized trail opportunities within UGBs were for walking trails (93% rated the need "moderate" to "high priority"), running/jogging trails (85%), hard surfaced biking trails (75%), walking and running trails for those with a dog on-leash (69%), and singletrack biking trails (narrow natural/soft surface; 54%).

- In dispersed settings outside UGBs, highest priority trail opportunity need was for walking trails (85%), running/jogging trails (70%), singletrack biking trails (narrow natural/soft surface; 69%), hard surface biking trails (wider, dirt, gravel, or paved routes with little or no automobile use; 67%), and walking and running trails for those with a dog on-leash (60%)
- Other important non-motorized trail opportunity need within UGBs was greater trail connectivity, ADA accessible trails, and bike parks. For dispersed settings, most frequently mentioned other need was greater trail connectivity, mountain biking trails, and water trails.
- The most important funding need was for routine upkeep of the trails themselves (91% rated the priority "slight" to "high"), repair of major trail damage (84%), protection of natural features, including wildlife habitat (82%), connecting trails into larger trail systems (77%), and routine removal of litter/trash (65%).
- Other important funding need was for maintenance and upkeep of existing facilities; technical assistance for local governments, NGOs, and others for funding, facility development, and land acquisition; and need for additional trail funding in general.
- Most important funding need for non-motorized trail opportunities within UGBs were for routine upkeep of the trails themselves (91% rated the priority "slight" to "high"), repair of major trail damage (84%), protection of natural features, including wildlife habitat (81%), connecting trails into larger trail systems (80%), and routine removal of litter/trash (70%). In dispersed settings outside UGBs, top funding need was similar to that identified for trails within UGBs.

TABLE OF CONTENTS

Executive Summary .... *i*
Table of Contents .... *iii*
List of Tables .... *iii*
List of Figures .... *iv*
Introduction and Objectives 1
Methods 1
    Sample Sizes and Response Rates 1
Results 1
    Non-motorized Trail Management 1
        Agency/Organization 1
        Planning Region 2
        Recreation Setting Type 3
        Non-motorized Trail Issues 3
        Non-motorized Trail Opportunity Need 7
        Non-motorized Trail Funding Need 11
        Section Summary 14
Appendix A. Open-Ended Comments 16
Appendix B. Questionnaire 27
Appendix C. Uncollapsed Percentages 32

LIST OF TABLES

1 Sample sizes and response rates 1
2 Respondent provider type 2
3 Respondent planning region 3
4 Ratings of non-motorized trail management issues 4
5 Ratings of non-motorized trail management issues by trail setting type 5
6 Rankings of non-motorized trail management issues by trails planning region 6
7 Priority need for additional non-motorized trail opportunities by setting type 7
8 Priority ranking of need for additional non-motorized trail opportunities within UGBs by trails planning region 9

9	Priority ranking of need for additional non-motorized trail opportunities in dispersed areas outside UGBs by trails planning region	10
10	Ratings of non-motorized trail funding importance	11
11	Ratings of non-motorized trail funding importance by trail setting type	12
12	Rankings of non-motorized boating funding importance by trails planning region	13

LIST OF FIGURES

1	Oregon trails planning regions	2

INTRODUCTION AND OBJECTIVES

The Oregon Parks and Recreation Department (OPRD) was given responsibility for recreation trails planning in 1971 under the "State Trails Act" (ORS 390.950 to 390.990). The last Statewide Trails Plan for Oregon was completed in 2005. This survey is a part of an effort to update that plan. Project objectives were to describe non-motorized trail funding priorities for the OPRD-administered Recreational Trails Grant Program (RTP) and identify top non-motorized trail management issues as part of the Statewide Trails Planning effort.

METHODS

Data were obtained from an internet survey (see survey instrument in Appendix B) of 558 Oregon non-motorized trail providers between July 24 and August 14, 2014. A respondent was only allowed one opportunity to complete a questionnaire.

Sample Sizes and Response Rates

As shown in Table 1, the total number of completed questionnaires was n = 232 with an estimated total response rate of 42%.

Table 1. Sample sizes and response rates

	Initial contacts	Completed surveys (n)	Response rate (%)
Providers	558	232	42

RESULTS

Non-motorized Trail Management

Agency/Organization. The first question asked non-motorized trail providers to identify their type of agency/organization. Table 2 shows that most of the non-motorized trail provider respondents were from local park and recreation departments (41%), non-profit organizations (17%), state agencies (14%), and federal agencies (7%).

Table 2. Respondent provider type

Provider Type	Participation (%) [a]
Local park and recreation department	41
Non-profit organization	17
State agency	14
Federal agency	7
Special District	6
County parks department	6
Other	5
Port District	3
Tribal Government	1

[a] Cell entries are percentages (%) of respondents from each organization type.

Planning Region. Trail managers were asked to report the primary trails planning region in which they provide non-motorized trail opportunities in Oregon. Figure 1 shows the boundaries for the 11 planning regions in the state.

Figure 1. Oregon trails planning regions

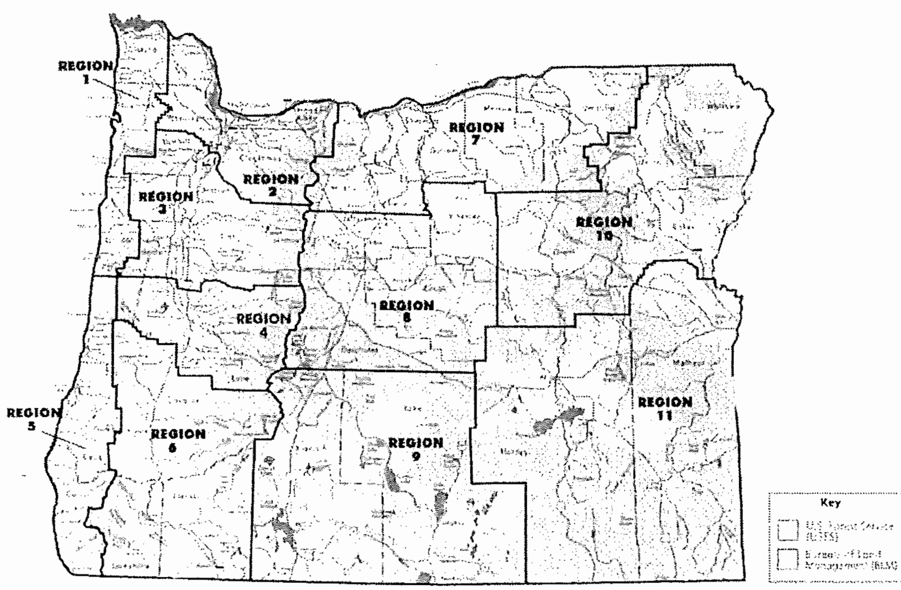


Table 3 shows that most survey respondents provide non-motorized trail opportunities in Region 2 (21%), Region 3 (17%), Region 4 (14%), and Region 1 (10%) Fewest respondents provide trail opportunities in Region 11 (1%).

Table 3. Respondent planning region [a]

Region 1	10
Region 2	21
Region 3	17
Region 4	14
Region 5	8
Region 6	7
Region 7	5
Region 8	9
Region 9	3
Region 10	6
Region 11	1

[a] Cell entries are percentages (%) of where respondents provide non-motorized trail opportunities in Oregon.

Recreation Setting Type. Next, survey respondents were asked to identify the primary setting type their non-motorized trails are located within. Choices included either within Urban Growth Boundaries (UGBs) or in dispersed settings outside of UGBs. Slightly over half of survey respondents provide non-motorized trails within UGBs (54%) while 46% provide non-motorized trails in dispersed settings.

Non-motorized Trail Issues. Several items in the questionnaire examined provider attitudes about non-motorized trail management issues in their trails planning region. Providers were asked, for example, the importance that listed issues posed to managers. Table 4 shows that the most important issues were trail maintenance (88% rated the problem "slight" to "very" important), ability to experience the natural environment (86%), trail information on the internet (74%), trails connecting towns/public spaces (73%), trail surface quality (73%), and trail signs (directional and distance markers; 70%). The least serious issues were single-use trails to avoid user conflicts (20%), availability of benches (22%), availability of drinking water (22%), and controlling overcrowding on trails (23%).

Table 4. Ratings of non-motorized trail management issues [a]

	Trail Providers (%) [a]
Trail maintenance	88
Ability to experience the natural environment	86
Trail information on the internet	74
Trails connecting towns/public spaces	73
Trail surface quality	73
Trail signs (directional and distance markers)	70
Information about getting to the trail	65
Parking space at trailheads	65
Trail maps at trailheads	60
Sense of safety at trailheads	59
Trash cans at trailheads	50
Enforcement of trail rules	47
Security at parking areas	46
Restroom facilities at trailheads	40
Pet litter bags and dispensers at trailheads	40
Nature/wildlife information at trailheads	37
Controlling overcrowding on trails	23
Availability of drinking water	22
Availability of benches	22
Single-use trails to avoid user conflicts	20

[a] Cell entries are percentages (%) of respondents who rated who rated the importance "slight" to "very."

Respondents were then asked to identify any other trail management issues that were important to them and their organization. Most frequently mentioned issues included the need for greater trail connectivity, lack of funding for non-motorized trail maintenance and repair, lack of funding for trail construction, and need for greater Americans with Disabilities (ADA) trail facility compliance.

Trail management issue priority is also presented by primary trail setting type (Table 5). For non-motorized trails within UGBs, the most important issues were the ability to experience the natural environment (88% rated the problem "slight" to "very" important), trail maintenance (85%), trails connecting towns/public spaces (85%), trail surface quality (74%), and trail information on the internet (71%). For trails in dispersed settings, the most important issues were trail maintenance (91%), ability to experience the natural environment (83%), trail information on the internet (76%), trail signs (directional and distance markers; 75%), parking space at trailheads (72%), and trail surface quality (70%).

Table 5. Ratings of non-motorized trail management issues by trail setting type [a]

Issues	Within UGBs (%) [a]	Dispersed (%) [a]
Ability to experience the natural environment	88	83
Trail maintenance	85	91
Trails connecting towns/public spaces	85	61
Trail surface quality	74	70
Trail information on the internet	71	76
Trash cans at trailheads	68	31
Trail signs (directional and distance markers)	66	75
Information about getting to the trail	66	64
Sense of safety at trailheads	64	53
Pet litter bags and dispensers at trailheads	62	16
Parking space at trailheads	58	72
Trail maps at trailheads	53	66
Restroom facilities at trailheads	46	33
Enforcement of trail rules	44	51
Security at parking areas	43	50
Nature/wildlife information at trailheads	40	34
Availability of benches	39	3
Availability of drinking water	26	17
Single-use trails to avoid user conflicts	14	27
Controlling overcrowding on trails	13	33

[a] Cell entries are percentages (%) of respondents who rated who rated the importance "slight" to "very."

Rankings of issues were also determined for each of the 11 trails planning regions based on percentages of respondents who rated the problem "slight" to "very important." Table 6 shows the ranking of each of the 20 issues by planning region.

Table 6. Rankings of non-motorized trail management issues by trails planning region [a]

	Trails Planning Region										
Issues	1	2	3	4	5	6	7	8	9	10	11
Controlling overcrowding on trails	17	16	17	16	20	19	20	13	19	20	20
Single-use trails to avoid user conflicts	20	17	20	14	19	20	19	16	20	17	19
Ability to experience the natural environment	4	4	4	2	1	1	4	1	3	1	1
Trails connecting towns/public places	10	2	3	6	3	5	1	7	4	5	2
Trail maintenance	1	1	2	1	2	2	2	6	1	2	8
Availability of drinking water	18	19	19	20	17	18	3	17	13	11	9
Availability of benches	19	20	16	19	13	17	18	19	18	18	18
Restroom facilities at trailheads	12	12	15	17	8	13	5	20	14	12	3
Trash cans at trailheads	15	9	10	15	10	14	7	9	5	13	4
Pet litter bags and dispensers at trailheads	16	13	13	18	14	15	13	14	9	14	17
Information about getting to the trail	2	8	6	10	12	4	6	12	2	8	5
Parking space at trailheads	7	5	11	7	11	12	12	2	10	9	12
Security of parking areas	13	14	14	8	9	16	8	18	11	15	16
Sense of safety at trailheads	9	7	8	11	5	7	9	11	15	16	15
Trail maps at trailheads	5	10	12	9	18	8	10	5	6	6	10
Trail information on the internet	6	11	1	3	6	9	14	3	7	3	6
Enforcement of trail rules	14	15	7	12	15	10	15	8	16	10	7
Trail surface quality	8	3	5	4	4	3	16	10	8	7	11
Nature/wildlife information at trailheads	11	18	18	13	16	11	11	15	17	19	13
Importance of trail signs (directional and distance markers)	3	6	9	5	7	6	17	4	12	4	14

[a] Cell entries are rankings of issues (#1-20) based on percentages (%) of respondents who rated the importance "slight" to "very."

Non-motorized Trail Opportunity Need. Trail managers were asked to prioritize the need for a number of types of additional non-motorized trail opportunities in their planning region. The question was asked separately for trail opportunities within UGBs and outside UGBs in dispersed settings. Table 7 shows highest priority need for non-motorized trail opportunities within UGBs were for walking trails (93% rated the need "moderate" to "high priority"), running/jogging trails (85%), hard surfaced biking trails (75%), walking and running trails for those with a dog on-leash (69%), and singletrack biking trails (narrow natural/soft surface; 54%). In dispersed settings outside UGBs, highest priority need was for walking trails (85%), running/jogging trails (70%), singletrack biking trails (narrow natural/soft surface; 69%), hard surface biking trails (wider, dirt, gravel, or paved routes with little or no automobile use; 67%), and walking and running trails for those with a dog on-leash (60%).

Table 7. Priority need for additional non-motorized trail opportunities by trail setting type [a]

Trail Opportunity	Within UGBs (%) [a]	Dispersed (%) [a]
Walking (includes hiking)	93	85
Running/jogging	85	70
Biking on hard surface trails (wider, dirt, gravel, or paved routes with little or no automobile use)	75	67
Walking & running specifically with a dog on-leash	69	60
Biking on singletrack trails (narrow natural/soft surface)	54	69
Other	32	26
Walking & running specifically with a dog off-leash	31	43
Horseback riding	23	48
Skateboarding	23	8
Backpacking (involves overnight along/near trail)	21	53
In-line skating (rollerblading), roller skating, or roller skiing	18	7
Cross-country skiing on groomed trails	14	27
Cross-country skiing on ungroomed trails	14	25
Snowshoeing	12	26

[a] Cell entries are percentages (%) of respondents who rated who rated the need a "moderate" to "high" priority.

Respondents were then asked to identify any other non-motorized trail opportunities that were needed within their region. Most frequently mentioned need within UGBs was greater trail connectivity, ADA accessible trails, and bike parks. For dispersed settings, most frequently mentioned need was greater trail connectivity, mountain biking trails, and water trails.

Rankings of trail opportunity need were also determined for each of the 11 trails planning regions based on percentages of respondents who rated the need a "moderate" to "high priority." Table 8 shows the ranking of each of the 14 trail opportunities within UGBs by planning region and Table 9 similar rankings for dispersed settings outside UGBs.

Table 8. Priority ranking of need for additional non-motorized trail opportunities within UGBs by trails planning region [a]

	Trails Planning Region										
Trail Opportunity	1	2	3	4	5	6	7	8	9	10	11
Walking (includes hiking)	1	1	1	1	1	1	1	1	1	1	1
Running/jogging	2	2	2	3	2	2	2	2	2	2	6
Walking & running specifically with a dog on-leash	3	4	4	4	4	4	3	4	3	4	2
Walking & running specifically with a dog off-leash	8	6	7	8	5	7	7	11	7	11	7
Backpacking (involves overnight along/near trail)	6	9	11	9	6	9	13	12	8	12	3
Biking on singletrack trails (narrow natural/soft surface)	5	5	5	5	8	5	6	3	9	5	4
Biking on hard surface trails (wider, dirt, gravel, or paved routes with little or no automobile use)	4	3	3	2	3	3	4	5	4	3	5
Horseback riding	9	8	10	6	9	8	8	13	10	9	8
In-line skating (rollerblading), roller skating, or roller skiing	10	11	8	13	7	13	11	14	13	13	9
Skateboarding	7	10	6	10	10	14	14	8	11	14	10
Cross-country skiing on groomed trails	12	12	12	14	13	10	12	6	5	7	11
Cross-country skiing on ungroomed trails	13	13	13	11	11	11	9	9	6	8	12
Snowshoeing	14	14	14	12	12	12	10	10	12	10	13
Other	11	7	9	7	14	6	5	7	14	6	14

[a] Cell entries are rankings of trail opportunity needs (#1-14) based on percentages (%) of respondents who rated the need a "moderate" to "high" priority.

Table 9. Priority ranking of need for additional non-motorized trail opportunities in dispersed areas outside UGBs by trails planning region [a]

	Trails Planning Region										
Trail Opportunity	1	2	3	4	5	6	7	8	9	10	11
Walking (includes hiking)	1	1	1	1	1	1	3	1	3	1	1
Running/jogging	2	2	3	5	2	6	4	3	4	2	7
Walking & running specifically with a dog on-leash	4	5	5	7	3	4	9	9	5	5	8
Walking & running specifically with a dog off-leash	8	8	8	9	5	11	5	11	6	10	2
Backpacking (involves overnight along/near trail)	5	6	6	6	6	5	6	8	7	11	3
Biking on singletrack trails (narrow natural/soft surface)	6	4	2	2	8	2	1	2	2	6	4
Biking on hard surface trails (wider, dirt, gravel, or paved routes with little or no automobile use)	3	3	4	4	4	3	2	10	1	3	5
Horseback riding	7	9	7	3	7	7	11	5	11	9	6
In-line skating (rollerblading), roller skating, or roller skiing	11	14	13	13	9	13	12	13	10	12	9
Skateboarding	9	13	12	14	10	14	13	12	12	13	10
Cross-country skiing on groomed trails	12	10	10	10	12	10	10	4	8	7	11
Cross-country skiing on ungroomed trails	13	11	9	11	13	12	7	6	13	8	12
Snowshoeing	14	12	11	12	11	9	8	7	9	4	13
Other	10	7	14	8	14	8	14	14	14	14	14

[a] Cell entries are rankings of trail opportunity needs (#1-14) based on percentages (%) of respondents who rated the need a "moderate" to "high" priority.

Non-motorized Trail Funding Need. Trail managers were asked to rate the importance of funding need for a number of types of non-motorized trail facilities and services in their planning region. Table 10 shows that the most important funding needs were for routine upkeep of the trails themselves (91% rated the priority "slight" to "high"), repair of major trail damage (84%), protection of natural features, including wildlife habitat (82%), connecting trails into larger trail systems (77%), and routine removal of litter/trash (65%).

Table 10. Ratings of non-motorized trail funding importance [a]

Facility/Service	Trail Providers (%) [a]
Routine upkeep of the trails themselves	91
Repair of major trail damage	84
Protection of natural features, including wildlife habitat	82
Connecting trails into larger trail systems	77
Routine removal of litter/trash	65
More trails for runners/general exercise	51
More soft surface walking trails	50
More trails for persons with disabilities	50
More trail maps/trail information	45
More hard-surface trails for bikers generally	43
More natural-surface trails for mountain bikers	42
More signs at trailheads	38
More signs along trails	38
More hard surface walking trails	38
More restrooms	24
More parking	24
More trails for horseback riders	22
More trails for off-leash dog recreationists	20
More information about required parking permits	11
More trails for cross-country skiers	9
More trails for snowshoers	9
More trails for in-line skaters (roller bladers), roller skaters, or roller skiers	6

[a] Cell entries are percentages (%) of respondents who rated the priority "slight" to "high."

Respondents were also asked to identify any other non-motorized trail resource needs that were important to their organization. Most frequently mentioned needs included funding for maintenance and upkeep of existing facilities; technical assistance for local governments, NGOs, and others for funding, facility development, and land acquisition; and need for additional trail funding in general.

Importance of funding need for a number of types of non-motorized trail facilities and services are also provided for trails by setting type. Table 11 shows that the most important funding need for trails within UGBs were for routine upkeep of the trails themselves (91% rated the priority "slight" to "high"), repair of major trail damage (84%), protection of natural features, including wildlife habitat (81%), connecting trails into larger trail systems (80%), and routine removal of litter/trash (70%). In dispersed settings outside UGBs, top funding need was similar to that identified for trails within UGBs.

Table 11. Ratings of non-motorized trail funding importance by trail setting type[a]

Facility/Service	Within UGBs (%) [a]	Dispersed (%) [a]
Routine upkeep of the trails themselves	91	91
Repair of major trail damage	84	84
Protection of natural features, including wildlife habitat	81	82
Connecting trails into larger trail systems	80	75
Routine removal of litter/trash	70	58
More hard surface walking trails	56	18
More trails for persons with disabilities	56	44
More trails for runners/general exercise	56	44
More hard-surface trails for bikers generally	52	33
More soft surface walking trails	50	51
More trail maps/trail information	42	48
More signs at trailheads	39	36
More signs along trails	34	41
More natural-surface trails for mountain bikers	34	51
More restrooms	30	17
More parking	18	30
More trails for off-leash dog recreationists	18	22
More trails for horseback riders	11	35
More information about required parking permits	8	13
More trails for in-line skaters (roller bladers), roller skaters, or roller skiers	8	2
More trails for snowshoers	2	17
More trails for cross-country skiers	1	18

[a] Cell entries are percentages (%) of respondents who rated the priority "slight" to "high."

Rankings of funding need was also determined for each of the 11 trails planning regions based on percentages of respondents who rated the priority "slight" to "high". Table 12 shows the ranking of each of the 22 facility/service funding need by planning region.

Table 12. Rankings of non-motorized trail funding importance by trails planning region [a]

	Trails Planning Region										
Facility/Service	1	2	3	4	5	6	7	8	9	10	11
Routine removal of litter/trash	6	5	4	7	9	5	2	3	4	5	3
Routine upkeep of the trails themselves	4	1	1	1	2	2	1	1	2	1	10
Repair of major trail damage	1	3	3	2	3	1	3	2	5	2	15
Connecting trails into larger trail systems	2	2	5	3	4	3	4	4	6	4	1
Protection of natural features, including wildlife habitat	3	4	2	4	1	4	6	5	1	3	2
More restrooms	18	16	14	20	13	17	5	17	9	20	4
More parking	11	15	17	18	17	18	11	11	10	21	11
More signs at trailheads	12	10	13	14	11	8	8	10	17	9	13
More signs along trails	14	8	15	12	14	13	9	9	11	10	14
More trail maps/trail information	5	11	10	10	18	9	12	7	12	6	5
More information about required parking permits	19	19	18	19	22	16	21	21	18	22	16
More soft surface walking trails	8	13	7	6	10	10	7	6	13	17	6
More hard surface walking trails	9	14	12	15	7	6	13	12	14	18	17
More trails for persons with disabilities	13	7	6	9	5	7	14	13	3	11	18
More natural-surface trails for mountain bikers	15	12	11	5	12	12	18	14	8	12	7
More hard-surface trails for bikers generally	10	9	9	11	8	14	15	16	15	13	8
More trails for runners/general exercise	7	6	8	8	6	11	19	8	7	7	12
More trails for in-line skaters (roller bladers), roller skaters, or roller skiers	20	20	22	22	19	20	22	22	21	19	19
More trails for horseback riders	16	18	19	13	15	21	20	15	19	15	9
More trails for off-leash dog recreationists	17	17	16	21	16	15	16	18	16	16	20
More trails for cross-country skiers	21	21	20	16	21	22	17	19	22	8	21
More trails for snowshoers	22	22	21	17	20	19	10	20	20	14	22

[a] Cell entries are rankings of funding importance (#1-22) based on percentages (%) of respondents who rated the priority "slight" to "high."

Section Summary. Taken together, survey results showed that:

- Most of the non-motorized trail provider respondents were from local park and recreation departments (41%), non-profit organizations (17%), state agencies (14%), and federal agencies (7%).
- Most survey respondents provide non-motorized trail opportunities in Region 2 (21%), Region 3 (17%), Region 4 (14%), and Region 1 (10%). Fewest respondents provide boating opportunities in Region 11 (1%).
- Most survey respondents provide non-motorized trail opportunities within Urban Growth Boundaries (UGBs; 54%), while 46% provide non-motorized trails in dispersed settings.
- The most serious non-motorized trail management issues were trail maintenance (88% rated the problem "slight" to "very" important), ability to experience the natural environment (86%), trail information on the internet (74%), trails connecting towns/public spaces (73%), trail surface quality (73%), and trail signs (directional and distance markers; 73%). The least serious issues were single-use trails to avoid user conflicts (20%), availability of benches (22%), availability of drinking water (22%), and controlling overcrowding on trails (23%).
- Other important management issues included the need for greater trail connectivity, lack of funding for non-motorized trail maintenance and repair, lack of funding for trail construction, and need for greater Americans with Disabilities (ADA) trail facility compliance.
- For non-motorized trails within UGBs, the most important issues were the ability to experience the natural environment (88% rated the problem "slight" to "very" important), trail maintenance (85%), trails connecting towns/public spaces (85%), trail surface quality (74%), and trail information on the internet (71%).
- For trails in dispersed settings, the most important issues were trail maintenance (91%), ability to experience the natural environment (83%), trail information on the internet (76%), trail signs (directional and distance markers; 75%), parking space at trailheads (72%), and trail surface quality (70%).

- Highest priority need for non-motorized trail opportunities within UGBs were for walking trails (93% rated the need "moderate" to "high priority"), running/jogging trails (85%), hard surfaced biking trails (75%), walking and running trails for those with a dog on-leash (69%), and singletrack biking trails (narrow natural/soft surface; 54%).

- In dispersed settings outside UGBs, highest priority trail opportunity need was for walking trails (85%), running/jogging trails (70%), singletrack biking trails (narrow natural/soft surface; 69%), hard surface biking trails (wider, dirt, gravel, or paved routes with little or no automobile use; 67%), and walking and running trails for those with a dog on-leash (60%)

- Other important non-motorized trail opportunity need within UGBs was greater trail connectivity, ADA accessible trails, and bike parks. For dispersed settings, most frequently mentioned other need was greater trail connectivity, mountain biking trails, and water trails.

- The most important funding need was for routine upkeep of the trails themselves (91% rated the priority "slight" to "high"), repair of major trail damage (84%), protection of natural features, including wildlife habitat (82%), connecting trails into larger trail systems (77%), and routine removal of litter/trash (65%).

- Other important funding need was for maintenance and upkeep of existing facilities; technical assistance for local governments, NGOs, and others for funding, facility development, and land acquisition; and need for additional trail funding in general.

- Most important funding need for non-motorized trail opportunities within UGBs were for routine upkeep of the trails themselves (91% rated the priority "slight" to "high"), repair of major trail damage (84%), protection of natural features, including wildlife habitat (81%), connecting trails into larger trail systems (80%), and routine removal of litter/trash (70%). In dispersed settings outside UGBs, top funding need was similar to that identified for trails within UGBs.

APPENDIX A: OPEN-ENDED COMMENTS

What other non-motorized trail issues are important to you and your organization?

- Accessibility
- Acquiring funding for toilet maintenance in non-motorized areas!
- ADA
- ADA accessibility
- ADA accessibility and availability for handicapped motorized scooters
- ADA Compliant
- Adequate space for large horse trailer parking and maneuvering at trail heads and parking areas.
- Aesthetic qualities of design; providing "trail-like" on-street connections; connecting trails to transit; providing mid-block crossings for trails, especially when trail crosses a busy roadway; lighting for trails, especially those used for commuting purposes; 24 hour access for trails that are used for transportation purposes; access points along the trail to improve access and safety; bicycle parking at trail heads; bicycle camping opportunities; how to deal with electric bicycles
- All horses, hiking, bikes.
- Appropriate surfacing; good trail design and siting.
- Availability and maintenance of a wide variety of trails in our area that appeal to and are appropriate for a range of user types and ability/experience levels. More appealing trails attract more visitors to our area, providing an opportunity for economic stability and growth in our communities.
- Availability of funding for construction and maintenance; Appropriate trail specifications for local environment and use; Developing fruitful partnerships with trail user groups; Managing conflicts between, and expectations of, mountain bikers and hikers.
- Avoiding user conflict.
- Building more! We have very few trails in Coquille.
- Capital and operational funding. Programming.
- Collaboration between user groups. Trail master planning.
- Completing trail connections to neighboring trails in adjacent communities.
- Conflict of various user groups, bikes, horses, etc.
- Connecting pedestrian pathways along the entire waterfront.
- Connections, obtaining easements.
- Connector trails throughout system.
- Control of animals.
- Control of multiple use conflicts.
- Cooperative planning with land managers of trail systems within a community. Common rules and management objectives for trail networks that cross jurisdictional boundaries More funding to maintain existing trails and build new ones We use a lot of volunteers and it would be great to have access to a pool of hand tools (grub hoes, McLeod, Pulaski, etc.) within the community for trail maintenance and building days. More information on the web re: water trails for kayaks and canoes (put in and pull out info).
- Coordination with Oregon Parks and Recreation Department on master planning trail segment identified in Coastal Trail System at the Tribal property at Coos Head leading to the town of Charleston about 2 miles away. It is the Tribes intent to develop and install

about 3 miles of trail from Bastendorff Beach on the Pacific Ocean through the Coos Property and Chicken Point and continue to connect with the Community of Charleston.
- Creating more.
- Defining the difference between a "trail" and a "path" is very important. To many planners the term "trail" encompasses both paved and natural surface trails where as in the trail building industry as well as recreational trail use (especially mountain biking and hiking) the term "trail" generally refers to single track (12"-36" tread), natural surface trail. For the purposes of this survey, my responses have been made as if the term "trail" is being used to refer to narrow, natural surface trail.
- Developing a riverfront trail and connecting trails to existing sidewalk infrastructure.
- Development of more trails
- Ease of communication between land managers, trail use groups and the public.
- Economic impact assessment of non-motorized, regional trails. Funding for trail interpretive guides.
- Educating new trail users on the rules for safety and etiquette.
- Education as to what weather/soil conditions are acceptable to be using trails. Avoiding muddy conditions.
- Enforcement is a big issue in Eugene. Dogs off-leash is a big issue and Park staff do not have the authority to enforce rules and have to rely on Eugene Police and Animal Control. Having separate trails for hikers and mountain bikes would be ideal, but currently not practical because of budget restraints. We currently have hiker trails, jogging trails, hard surface bike trails, and shared use trails.
- Enhancing wetland features where appropriate to increase habitat for wildlife.
- Etiquette between mountain bikers and equestrian trail users.
- Event management on trails, future trail easement acquisition, safe connections between trails.
- Funding
- Funding availability, or lack thereof, to build and maintain trails to the extent our community desires.
- Funding for new trail development
- Funding for trail development, maintenance and marketing.
- Funding opportunities.
- Funding reconstruction projects for structure repairs or replacement, and trail relocations to make the routes more sustainable and less impactful to natural resources.
- Funding sources for the above.
- Greater connectivity of the trail system: connecting existing trail segments with new trail segments to make a longer trail system with opportunities for loops.
- Horseback access, shared use trails for motorized and non-motorized users.
- Improving trail system connectivity. Adding diversity to the trail system in use type and difficulty levels. Creating loop trail opportunities to better disperse use and reduce the potential for conflict among trail users. Developing other funding opportunities for accomplishing trail maintenance and trail construction projects.
- Interpretive signage on trails.
- Interpretive/educational materials for hikers. Effective trail etiquette signs.
- Keeping hunters off.
- Lighting, connectivity to the trails.
- Limited noise issues.

- Litter control
- Maintaining wilderness characteristics
- More and more visitors are asking for non-motorized trail opportunities and they plan well in advance so putting information on the web is critical. Garbage cans, safety/security and restrooms all rank equally important at trail heads. Rule enforcement is necessary to ensure visitor safety.
- Mountain biking opportunities - ways to increase access.
- Need for new trails and funding for new trails.
- New access points.
- Not losing our traditional horse trails to new users, such as mountain bikers. Although many bikers are nice about sharing the trails, many bikers make the trails unsafe for horseback riders, as well as hikers.
- Off-leash dog rule enforcement, transient camping, fire potential, river crossing issues-need for new footbridges, water trail safe passage of low-head dams, joint use of irrigation district easements for public trail use, public perception of trails inducing/facilitating crime.
- Ongoing replacement of "no biking" signs in areas designated as pedestrian only once signs are vandalized and / or removed.
- Our biggest issue is trying to keep up with demand! People very much want more off-street trails. The time frame for planning & implementation is lengthy. Another issue: potential for conflict between bicycle commuters, who want to travel quickly, and pedestrians or looky-lou cyclists who are enjoying the trail as an experience. I have had cyclists comment to me that they can get places faster with on-street solutions and feel safer, rather than on trails where people walk down the middle, have dogs on leashes, scampering children whose movements are unpredictable, etc. We have not had collisions that I am aware of.... just that I know commuters can be frustrated with recreational trail users.
- Our service area covers three counties: Clackamas, Multnomah, and Washington.
- Proper use and respect of natural resources found along trails and in the immediate vicinity.
- Provide a range of difficulty, use and experience
- Providing ADA access where ever possible so that more of our mobility challenged citizens and visitors can experience the beauty of our Forests and waterways. In our specific area there is a big disconnect between the need for trail maintenance and rehabilitation and the agencies that are responsible for the work. All we hear is that the Forest Service does not have money, that's why we as a business are trying to rehabilitate our local trails with our own resources and we have just applied for an RTP grant to rehabilitate two miles of lake side trail in our recreation area.
- Providing diverse trail experiences from all access/beginner to technical/advanced, and creating new trails that provide a unique experience (i.e., flow trail for mountain bicyclists).
- Providing more multi-use natural trails for users.
- Providing recreational (hiking, running, etc.) opportunities that do not disturb wildlife.
- Quality trail experience for users.
- Reduction in the number of user created trails. Reduction in the amount of user created parking areas or access points. Collaboration and information sharing between agencies and especially with search and rescue.
- Regional planning with other governments.

- Renovation of aging trails, trail user safety (lighting, clear vision, transients, etc.), and user conflicts.
- Routine annual trail maintenance, deferred maintenance (primarily erosion control) and providing current information for over 1,400 miles of trail are our biggest issues. Primary visitor use is backcountry, although there is increasing interest in developing mountain bike trails.
- Safe access to natural areas; community trail use for health; alternate transportation; and impact on the local economy.
- Safe pedestrian crossing of major highways, including highway bridges that the PCT crossings.
- Safety for all users on the trail.
- Secure parking areas for overnight and extended backpacking trips along the Oregon Coast Trail. Enforcement of quiet hours at designated camping areas. Camping opportunities on state park lands for long-distance overnight backpackers doing extended trips/sections of the Oregon Coast Trail that would make doing the trail logistically possible. Cyclists can always get to the next official hiker-biker campsite, overnight backpackers at the very least need to have designated areas where primitive camping can be done safely (an hour before sunset and two hours after sunrise in existing day-use state parks, thereby not disrupting typical day-user activities.)
- Separate tracks for bicycles.
- Shared trail user courtesy
- Shared use trails access (esp. via public transportation) looping
- Signage and maps at trail junctions. Building more trails top meet increasing demand.
- Snowmobiles
- Trail connectivity and continuity.
- Trail design, so many of our trails are unmaintainable because they were developed with such horrible lines. We are planning to fix many of those poor lines but we need more money and a much larger work force to make it happen.
- Trail maintenance and connection to town.
- Trail structure quality (e.g. drainage, crib walls, etc.). Coordination with user groups/events (e.g. DOD, Obsidians, trail races, etc.).
- Trail work
- Training older volunteers to conduct safe, effective/efficient trail maintenance. Modifying trail design standards to better accommodate older or otherwise less able hikers (i.e., shorter stair heights, stair rails, less slope) when possible. Both financial and interpretive staff assistance for interpretive kiosks -- visitors really crave learning about the areas they hike in.
- Upgrading trails in city parks for ADA accessibility or at least making them more handicapped friendly.
- User conflicts on multi-use trails
- User safety on trails-EMT access.
- Using trail building and maintenance to build in structures to avoid multi-user conflicts. We and do recreate together. We need the trail providers to educate and develop a culture of mutual respect for each of our ways of recreating.
- Utilities such as lighting.
- Utilization and tracking- if no one uses the trail it becomes a maintenance issue and is it worth having it?
- Vandalism, homelessness/vagrancy issues

- Way finding once out on the trail system.
- We are considering adding some mountain biking trails when we develop additional trail networks.
- We are currently working on developing a trail system. We do not have one in place at this time.
- We cover three different planning regions 1, 2 and 3
- We do not have any trails.
- We have been concentrating on separating equestrian trails from our hiking/mountain biking trails to reduce conflict and to protect trail surfaces.
- We need to build more trails, create more connectivity within the community. The connectivity is what people are really looking for. They don't want to drive to a trailhead. They want to leave their house and walk or ride to a nearby trail which can take them all over the community.
- We need to improve trail connectivity!
- We would like to add more as we have the land just not the funds. We have a high demand for the use.
- Working with governmental agencies.

What other non-motorized trail opportunities within Urban Growth Boundaries are important to you and your organization?

- 40 mile trail for connection, Lewis and Clark to Troutdale Bridge
- ADA accessibility
- ADA accessible trails
- Additional hard surface bicycle trails, single-track mountain bike trails, multiple skill level freeriding trails, continue connectivity with hiking and shared-use trails across the Ridgeline Trail system.
- Additional walking/biking paths to allow citizens nearby access for healthy lifestyles.
- Beginner trail for bikes (wide & mellow), and connections between trailheads in town that lead to trails surrounding the community (outside UBG).
- Bike and sidewalk connections, road improvements.
- Bike park facilities (e.g., pumptracks, skill features)
- Bike Parks (dirt jumps, pump tracks, skill building areas). Alternative transportation corridors to recreation opportunities.
- Completing the Deschutes River Trail
- Completing the Minto Island bridge and trail connections from Riverfront Park and Minto Island. Then better connectivity along River Road to Minto Park, and from North Downtown to Downtown, parks/Union St RR bridge, etc.
- Connecting parks and sports facility.
- Connecting the city of Sutherlin as articulated in their Parks and Open Space Plan.
- Connecting to existing trails (increasing the trail web). Cooperative planning and implementation for trail maintenance and new trails between land managers including sharing of resources and recreational trail management plans Working with private and public land owners to acquire trail easements across their lands to link to existing trail networks. Common rules of the road for trail networks that span multiple land ownerships and management organizations.

- Connection to other communities trail system. Regional trail connections.
- Connections between a trail segment and another trail segment or a destination.
- Connections between PDX and Portland pedestrian and bicycle networks
- Connections to City trail system.
- Connections to trails outside UGBs.
- Connectivity and filling in of gaps, linkage to USFS and BLM trails, joint use of irrigation canal corridors.
- Connectivity between resources.
- Connectivity between trails in various jurisdictions.
- Connectivity to specific nodes in town.
- Connectivity within the UGB.
- Connectors between trails; access from neighboring communities.
- Creating an 'emerald necklace' of trails around our community, with main trails that can also serve as off street bicycle commuter routes.
- Creating an off street, non-motorized transportation trail system that accesses public services, education, businesses, and all residential areas.
- Crossing at railroad tracks are a huge obstacle for creating a network of connected trails.
- Currently the City does not have any trails. We would like to have safe trails that lead to our K-8 school.
- Educational components
- Enhanced disabled access.
- Eugene to Pacific Crest Trail would connect UGB to our parks in Southern Willamette.
- Funding mechanisms for small cities with limited budget. We can't make 50% match requirements on our own, even 20% is a challenge and limits what we can accomplish.
- Geocaching
- Greenbelt
- Horse carting
- Improved bike lanes
- Increased opportunities for close to home non-motorized and motorized trails are needed for Oregon's urban populations.
- Interconnectedness. Linking different parks, neighborhoods, commercial areas, etc. Used for transportation as well as recreation.
- Larsen Creek Greenway
- Linkages between existing trails, along the rivers, and along Mt. David (prominent butte).
- Links to trails outside of UGB's
- Making safe and aesthetically pleasing connections with neighborhoods, other park trail systems and connecting regional trails planned and existing.
- Managing events. Working on re-writing our recreational permits.
- METRO west side trail plan.
- More multi-use trails from community areas up into our federal land areas.
- More shared use soft surface trails for bikes generating loops.
- Mountain bicycle-specific trails such as bike parks.
- Mountain bike skills area, pump track, jumps etc.
- Mountain bike trails, inter-connected systems, boardwalks in wet areas
- Multi use trail standards.
- Multi-use trails
- Neighborhood connections/ off street trails

- New multi-use (walking, bicycling, jogging, etc.) trail connections to expand the existing trail system.
- New trail opportunities may be important as the Tribe wants to connect its developed facilities in Coos Bay and Florence communities.
- Paddle / water trails.
- Paved paths connecting outlying communities in the Sisters area.
- Rails to trails or the use of the rail right-of-way to provide trails would be very welcome to our City.
- Safe trail/pathway along highway right-of-way alternative to people walking along 1 mile of Highway 42.
- See other above & develop a walking and biking trail connecting Stanfield and Echo
- Separate trails for horseback riding
- Taking advantage of trail opportunities within the community that encourage locals to walk to services and frequented destinations with the city.
- There is a proposal for a trail around Klamath Lake that sounds very good.
- Trail connection to nearby regional trails.
- Trail down to water front on river side of island park
- Trail linkages between parks and incorporated into the city's bicycle pedestrian trail plan.
- Trail races and bike races.
- Trails connecting to Main Street areas and retail core areas.
- Trails that connect to facilities outside of the Urban Growth Boundary. We need more trails that provide pedestrian and bicycle use in the City.
- Water trails.
- Water trails/paddling and non-motorized watercraft.
- We need to take care of what we have before adding to the inventory.
- We would like to implement a walking trail around our city park.

What other non-motorized trail opportunities in dispersed settings outside of UGBs are important to you and your organization?

- Additional hiking trail to access fishing opportunities and other natural resources valuable to Tribal members.
- Any new trail opportunities that connect communities in unincorporated areas of the 5 counties in which the tribes have identified in their designated service area.
- Bike park facilities within State Parks.
- Connection with Mildred Kanipe County Park in Oakland.
- Connections to the UGB
- Connections to trails inside the UGB.
- Connectivity
- Connectivity (e.g., Oregon Coast Trail) between destinations.
- Connectivity to the UGB, a seamless trail system.
- Connectivity with surrounding cities for bike and walking trails would be nice.
- Cultural, heritage and natural area trails.
- Designing trails to accommodate disabled access -- where practical.

- Development of gravity assisted mountain bike trails. Development of more trails within the regional trail system in an effort to create loops and add to trail system diversity (difficulty and use type) Longer distance trail systems that can accommodate backpacking.
- Equestrian use outside of UGB, but close in to town would relieve some pressure on Elijah Bristow State Park.
- Greater connectivity between regional trail systems (e.g. city to city).
- Hike and bike campsites and/or development of environmental campsites that require hiking in to the site.
- Hiking/backpacking wilderness trails
- Horseback riders would also like new trail opportunities, especially more trails near current horse camps. When planning new trailheads, we respectfully request adequate parking for horse trailers.
- Improved trail connections to the coast.
- Lift-accessed bike parks
- Link to County Park.
- Linking trails to create a trail system.
- Links from Row River Trail to other natural resource areas/destinations (including National Forest, USACE property, etc.)
- Longer distance multi-use trails that connect people with desired destinations as well as scenic areas giving people the chance to ride bikes / walk outside of the UGB, connecting those trails with areas within the UGB so that people can leave from home and enjoy a longer trail.
- Loop opportunities
- Making connections between recreation areas and small communities for motorized use such as ATV and UAV side by sides.
- Making facilities more ADA friendly is our top priority.
- Making more of our out and back trails into loops. Connecting trail systems.
- Many of our current hiking and shared-use trails are outside the UGB and we are continuing to plan for additional trails since much of our parkland is outside the UGB.
- More shared use soft surface trails for bikes generating loops.
- Most of what I said above but also need to identify longer trail connections re: rails to trails, Corvallis to the Sea opportunities and methods to realize these opportunities.
- Multi Model Paved Trails for ADA, bike, hike, strollers.
- Not interested in new trails, we have enough.
- ODOT apparently has an easement that parallels Highway 101 from Ona Beach to Newport (and possibly beyond those two areas). An asphalted, multi-use trail with a parallel "soft shoulder" would get bikers, hikers and equestrians off the highway; and provide an alternative, non-motorized commute option for workers and students.
- Paddle / water trails.

- Providing additional mountain bike specific trail opportunities throughout the state are needed.
- Providing unique bicycle experiences (flow trail) and beginner trail for bikes (wide & mellow).
- Re-route of the Oregon Coast Trail between Seven Devils and Whiskey Run. Eliminate trail portions that go over private property due to conflicts with land owners and difficult management of the recreational easements for those portions. The trail should stay on the beach and go over Fivemile Point. An alternative would be to have access around Fivemile Point at low tide only.
- Reconnecting/reconstructing logging road trail between Canby and Molalla.
- Roxy Anne Peak/Prescott Park Trail System
- Single track mountain bike trails.
- The boomer generation is going to create a demand for passive recreational opportunities in the upcoming years.
- Trail connectivity.
- Trails that connect from the UGB to other UGB's and to natural features or major rural trail systems.
- Trails that highlight historic/cultural resources and help tell a story, particularly about ancient trails and early settlement historic roads. Also river trail opportunities on the Deschutes downstream of Tumalo State Park and at Willow Creek and Crooked River outside Prineville.
- Use of retired logging roads/rail road beds for rainy season use for hikers and equestrians.
- Utilizing utility easement and rail rights-of-ways.
- Viewing platforms
- Water access and fishing
- Water Trails
- Water Trails - at Lake Billy Chinook there is an increasing demand for kayak and canoe opportunities. The bulk of our visitors, particularly from out of town is Memorial Day - Labor Day; however the shoulder seasons are when locals are looking for something to do and our location provides a variety of choices for varying skill levels.
- Water Trails- facilities and connections.
- We would like to see a walking trail between our City and an Oregon State Park which is about 1/2 mile away.

What other non-motorized trail resource needs are important to you and your organization?

- $$$ funds for trail maintenance and upkeep
- Access to organizations with equipment and tools to assist in building trails. More access to organizations with capable trail building crews Assistance for layout, engineering and design of new trail systems.
- ADA accessibility

- Balancing the needs of various user groups and natural resource protection. Also, recreation permit standards for groups who want to do organized runs or events in natural areas.
- Benches, shelter, picnic table at trail heads.
- Bike parks.
- Boat launches, camping
- Trail counter systems for use data collection.
- Dollars to develop restrooms and showers as well as hard surface trails within parks.
- Easy access to trails. Placing trail access in the UGB and providing the trail linkage to systems outside the UGB.
- Easy trails for novice hikers, mountain bikers, horseback riders - trail system diversity. Difficult trails for mountain bikers and horseback riders - trail system diversity Single use gravity assisted downhill mountain bike trails.
- For the BLM the biggest need is managed access to bring the very high number of access points, entry roads and entry trails down to a smaller, manageable number.
- Funding all aspects of trails.
- Funding for land acquisition / easements and for trail development to meet community needs and wishes. Making the connections so that people can enjoy non-motorized recreation close to home.
- Getting enough funding to keep up with routine maintenance, and finding/recruiting competent people to do the work.
- Improved crossings at trail/street intersections
- It is important to maintain the improvements in place.
- Land acquisition support.
- Land managers to help with trail maintenance issues.
- Leveraging resources among various jurisdictions. Marketing.
- Maintenance and educational opportunities. Educating our users on the importance of staying on trails and the effect they have on our spaces when rouge trails are built and habitat areas are disturbed.
- Maintenance of older trail systems.
- More emphasis on bird watching opportunities along established and planned trails.
- More hiking trails for Tribal member to access natural resources important to the Tribe such as fish, berries, and other plants.
- More multi-use, natural surface trails and trail connectivity.
- Nature and scenic viewing.
- Pack it Home, for Garbage need to work, if you put out garbage cans they will always be full.... "Pack it Home."
- Paddle / water trails
- Picnic sites and hike-in camp sites.
- Safety of existing trails, erosion and over usage is a constant maintenance problem.
- Streamline trail proposal process. Assessments need to be completed in a timely manner.
- That future hard surface trails utilize the better trail surfacing products other than asphalt concrete (AC) to maximize the sustainability of all surfaces in moist climates.
- These priorities in this survey reflect my desire to prioritize the trail-related management concerns. A question should be added after this to include what the realities are in our ability to follow through with staff resources.

- Very basic and primitive wilderness area-like pit toilets (literally a toilet seat on a support over a pit in the ground with three visual protection sides about 4 feet high, no roof) in such areas along the Oregon Coast Trail. This could potentially help prevent people urinating and defecating just anywhere along the trail, thereby protecting and minimizing impacts on cultural and natural resources. It would seem that concentrating such human waste would be a better alternative to going anywhere, therefore better serve the goals of the Department of Environmental Quality, too.
- Water trails and more water trail access points (i.e., canoe launches).
- We do not have enough annual snow to plan for activities around that activity. We also currently do not have a lot of voiced interest on horseback trails.
- We would like to see and ADA Fishing pier at Lake of the Woods that is connected to our parking area in at least one of our day use areas. We are planning to improve ADA access to the lake shore area and this is a logical need for us.

APPENDIX B: QUESTIONNAIRE

Dear Non-motorized trail provider,

The Oregon Parks and Recreation Department (OPRD) requests your assistance in completing a brief online survey for your jurisdiction/organization. Survey results will identify non-motorized trail facility and service need and management issues in Oregon as part of the Statewide Trails Planning effort.

This survey is intended for land management agencies and non-profit organizations providing non-motorized trail opportunities on public lands in the state of Oregon. Survey results, along with information gathered in general user surveys and regional public meetings will be used to develop evaluation criteria for distribution of Recreational Trails Program (RTP) funding administered by OPRD.

The survey is very brief, and should take no more than 5 minutes of your time. If you have any questions about this survey, please contact Terry Bergerson, OPRD planner:

Email: terry.bergerson@oregon.gov
Phone: 503-986-0747

Thank you for participating in this important survey.

Oregon Parks and Recreation Department

OREGON STATE PARKS

Nature
HISTORY
Discovery

1. Name of your organization:

____

2. Contact person (or person completing this survey):

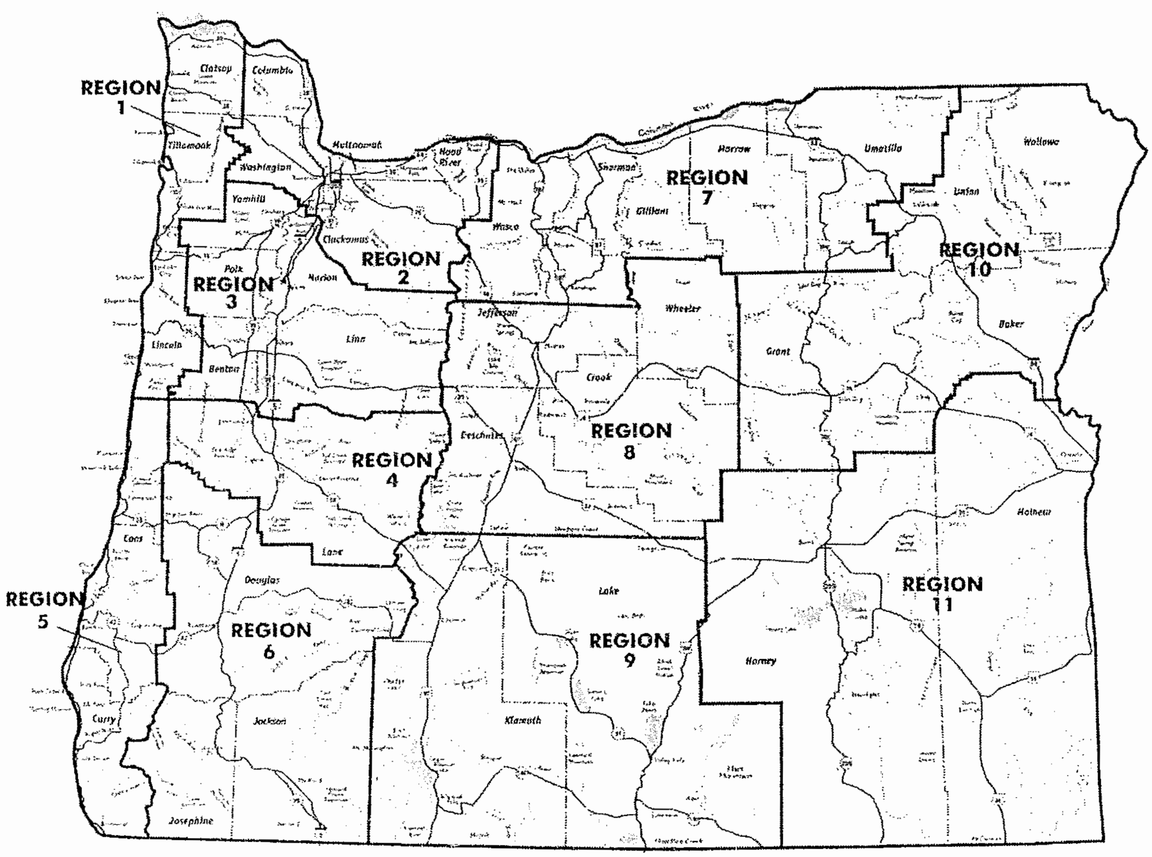
____

3. Organization Type (Please check one only)

- ☐ City Park & Recreation Dept.
- ☐ Special Parks & Recreation District
- ☐ County Parks Dept.
- ☐ Port District
- ☐ Tribal Government
- ☐ State Agency
- ☐ Federal Agency
- ☐ Utility
- ☐ Non-profit Organization
- ☐ Other

4. Using the map below, please identify the trails planning region in the area that you service (write in)

Region # ____



4. In which county is your primary service area located in (please check one only)

	Baker		Crook		Harney		Lake		Morrow		Union
	Benton		Curry		Hood River		Lane		Multnomah		Wallowa
	Clackamas		Deschutes		Jackson		Lincoln		Polk		Wasco
	Clatsop		Douglas		Jefferson		Linn		Sherman		Washington
	Columbia		Gilliam		Josephine		Malheur		Tillamook		Wheeler
	Coos		Grant		Klamath		Marion		Umatilla		Yamhill

Q5. Based on your trail management in Oregon in the past 12 months, how important do you feel each of the following is on trails in your trails planning region?

Issue	Not important				Very important
Controlling overcrowding on trails	1	2	3	4	5
Single use-trails to avoid user conflicts	1	2	3	4	5
Ability to experience the natural environment	1	2	3	4	5
Trails connecting towns / public places	1	2	3	4	5
Trail maintenance	1	2	3	4	5
Availability of drinking water	1	2	3	4	5
Availability of benches	1	2	3	4	5
Restroom facilities at trailheads	1	2	3	4	5
Trash cans at trailheads	1	2	3	4	5
Pet litter bags and dispensers at trailheads	1	2	3	4	5
Information about getting to the trail	1	2	3	4	5
Parking space at trailheads	1	2	3	4	5
Security of parking areas	1	2	3	4	5
Sense of safety at trailheads	1	2	3	4	5
Trail maps at trailheads	1	2	3	4	5
Trail information on the Internet	1	2	3	4	5
Enforcement of trail rules	1	2	3	4	5
Trail surface quality	1	2	3	4	5
Nature / wildlife information at trailheads / trails	1	2	3	4	5
Trail signs (directional and distance markers, and level of difficulty)	1	2	3	4	5

Q6. What other issues are important to you and your organization?

____

____

____

____

____

____

Q7. Which activities would you prioritize with respect to creation of new trail opportunities in your planning region in the next 10 years? These would be additional opportunities that do not detract from current opportunities. This includes trails for recreation, commuting, and other purposes.

Please circle one number to reflect your priority – separately for additional trail opportunities within Urban Growth Boundaries (UGBs) and in dispersed settings outside of UGBs.

Example: If you feel that more walking trails is a high priority within Urban Growth Boundaries, but only a slight priority in dispersed settings, you would circle 4 in the first column and 2 in the second column.

Activity on trails in Region	**Priority for additional trails in Planning Region** 1 = not a priority, 2 = slight priority, 3 = moderate priority, 4 = high priority							
	Within UGBs				**Dispersed Settings**			
Walking (includes hiking)	1	2	3	4	1	2	3	4
Running / jogging	1	2	3	4	1	2	3	4
Walking + running specifically with a dog on-leash	1	2	3	4	1	2	3	4
Walking + running specifically with a dog off-leash	1	2	3	4	1	2	3	4
Backpacking (involves overnight along / near trail)	1	2	3	4	1	2	3	4
Biking on singletrack trails (narrow natural / soft surface)	1	2	3	4	1	2	3	4
Biking on hard surface trails (wider dirt, gravel, or paved routes with little or no automobile use)	1	2	3	4	1	2	3	4
Horseback riding	1	2	3	4	1	2	3	4
In-line skating (roller blading), roller skating, or roller skiing	1	2	3	4	1	2	3	4
Skateboarding	1	2	3	4	1	2	3	4
Cross-country skiing on groomed trails	1	2	3	4	1	2	3	4
Cross-country skiing on ungroomed trails	1	2	3	4	1	2	3	4
Snowshoeing	1	2	3	4	1	2	3	4
Other (please describe)	1	2	3	4	1	2	3	4

Q8. What other new trail opportunities are important to you and your organization?

____

____

____

____

____

____

Q9. Now please share your priorities for trails in your planning region over the next 10 years, keeping in mind limited funding and land. For each action, circle one number to indicate how high a priority that action is for you and your organization.

Action	**Low priority need**				**High priority need**
Routine removal of litter / trash	1	2	3	4	5
Routine upkeep of the trails themselves	1	2	3	4	5
Repair major trail damage	1	2	3	4	5
Connecting trails into larger trail systems	1	2	3	4	5
Protection of natural features, including wildlife habitat	1	2	3	4	5
More restrooms	1	2	3	4	5
More parking	1	2	3	4	5
More signs at trailhead	1	2	3	4	5
More signs along trails	1	2	3	4	5
More trail maps / trail information	1	2	3	4	5
More information about required parking permits	1	2	3	4	5
More soft surface walking trails	1	2	3	4	5
More hard surface walking trails	1	2	3	4	5
More trails for persons with disabilities	1	2	3	4	5
More natural-surface trails for mountain bikers	1	2	3	4	5
More hard-surface trails for bikers generally	1	2	3	4	5
More trails for runners / general exercise	1	2	3	4	5
More trails for in-line skaters (roller bladers), roller skaters, or roller skiers	1	2	3	4	5
More trails for horseback riders	1	2	3	4	5
More trails for off-leash dog recreationists	1	2	3	4	5
More trails for cross-country skiers	1	2	3	4	5
More trails for snowshoers	1	2	3	4	5

Q8. What other resource needs are important to you and your organization?

____

____

____

____

APPENDIX C: UNCOLLAPSED PERCENTAGES

1. Name of your organization:
NA

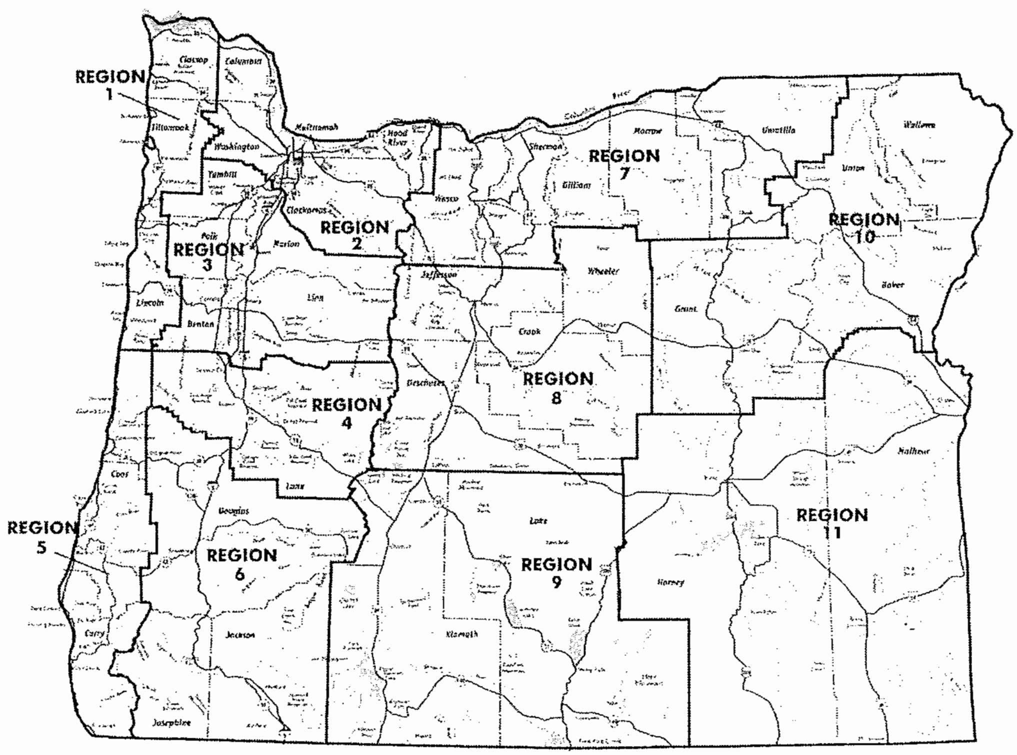
2. Contact person (or person completing this survey):
NA

3. Organization Type (Please check one only)

41% City Park & Recreation Dept.
6% Special Parks & Recreation District
6% County Parks Dept.
3% Port District
1% Tribal Government
14% State Agency
7% Federal Agency
0% Utility
17% Non-profit Organization
5% Other

4. Using the map below, please identify the trails planning region in the area that you service (write in)

Region # See report



4. In which county is your primary service area located in (please check one only)

2%	Baker	<1%	Crook	0%	Harney	0%	Lake	2%	Morrow	2%	Union
3%	Benton	2%	Curry	4%	Hood River	15%	Lane	4%	Multnomah	1%	Wallowa
5%	Clackamas	7%	Deschutes	3%	Jackson	4%	Lincoln	2%	Polk	<1%	Wasco
1%	Clatsop	4%	Douglas	<1%	Jefferson	3%	Linn	0%	Sherman	4%	Washington
2%	Columbia	<1%	Gilliam	1%	Josephine	0%	Malheur	4%	Tillamook	<1%	Wheeler
3%	Coos	2%	Grant	3%	Klamath	5%	Marion	1%	Umatilla	2%	Yamhill

Q5. Based on your trail management in Oregon in the past 12 months, how important do you feel each of the following is on trails in your trails planning region?

Issue	Not important				Very important
Controlling overcrowding on trails	20%	32%	26%	16%	7%
Single use-trails to avoid user conflicts	20	29	31	15	5
Ability to experience the natural environment	1	1	12	34	52
Trails connecting towns / public places	3	9	15	21	52
Trail maintenance	0	2	10	34	54
Availability of drinking water	16	30	32	15	7
Availability of benches	19	25	34	16	6
Restroom facilities at trailheads	6	16	38	21	19
Trash cans at trailheads	10	16	24	27	23
Pet litter bags and dispensers at trailheads	13	15	32	20	20
Information about getting to the trail	2	10	22	41	25
Parking space at trailheads	4	6	26	41	24
Security of parking areas	6	15	33	29	17
Sense of safety at trailheads	3	12	27	31	29
Trail maps at trailheads	6	11	24	37	23
Trail information on the Internet	4	5	18	38	35
Enforcement of trail rules	4	11	38	31	16
Trail surface quality	2	5	21	38	35
Nature / wildlife information at trailheads / trails	5	19	39	25	11
Trail signs (directional and distance markers, and level of difficulty)	1	6	22	38	32

Q6. What other issues are important to you and your organization?

See report

Q7. Which activities would you prioritize with respect to creation of new trail opportunities in your planning region in the next 10 years? These would be additional opportunities that do not detract from current opportunities. This includes trails for recreation, commuting, and other purposes.

Please circle one number to reflect your priority – separately for additional trail opportunities within Urban Growth Boundaries (UGBs) and in dispersed settings outside of UGBs.

Example: If you feel that more walking trails is a high priority within Urban Growth Boundaries, but only a slight priority in dispersed settings, you would circle 4 in the first column and 2 in the second column.

Activity on trails in Region	Priority for additional trails in Planning Region 1 = not a priority, 2 = slight priority, 3 = moderate priority, 4 = high priority							
	Within UGBs				Dispersed Settings			
Walking (includes hiking)	4	3	21	72	7	8	21	63
Running / jogging	6	9	39	46	12	18	34	36
Walking + running specifically with a dog on-leash	11	20	39	30	19	21	37	22
Walking + running specifically with a dog off-leash	41	29	20	11	33	24	29	14
Backpacking (involves overnight along / near trail)	58	21	16	5	28	19	30	23
Biking on singletrack trails (narrow natural / soft surface)	18	28	29	25	15	17	27	41
Biking on hard surface trails (wider dirt, gravel, or paved routes with little or no automobile use)	10	15	38	37	19	14	39	28
Horseback riding	50	27	13	11	27	25	29	19
In-line skating (roller blading), roller skating, or roller skiing	54	29	14	4	69	24	6	1
Skateboarding	44	33	18	5	65	27	7	1
Cross-country skiing on groomed trails	79	7	10	4	61	12	19	7
Cross-country skiing on ungroomed trails	77	9	10	3	59	16	17	9
Snowshoeing	77	11	9	3	59	16	18	8
Other (please describe)	63	5	11	21	68	5	5	21

Q8. What other new trail opportunities are important to you and your organization?

See report

Q9. Now please share your priorities for trails in your planning region over the next 10 years, keeping in mind limited funding and land. For each action, circle one number to indicate how high a priority that action is for you and your organization.

Action	Low priority need				High priority need
Routine removal of litter / trash	4%	7%	25%	34%	30%
Routine upkeep of the trails themselves	2	2	5	33	58
Repair major trail damage	2	5	9	29	55
Connecting trails into larger trail systems	4	1	17	28	49
Protection of natural features, including wildlife habitat	2	2	15	33	48
More restrooms	15	26	35	16	8
More parking	17	21	38	17	7
More signs at trailhead	8	19	35	27	11
More signs along trails	9	18	36	24	14
More trail maps / trail information	7	15	34	29	16
More information about required parking permits	42	27	21	8	3
More soft surface walking trails	11	12	27	27	24
More hard surface walking trails	15	18	29	18	21
More trails for persons with disabilities	9	9	33	28	22
More natural-surface trails for mountain bikers	14	20	24	17	25
More hard-surface trails for bikers generally	15	16	27	22	21
More trails for runners / general exercise	8	18	23	26	26
More trails for in-line skaters (roller bladers), roller skaters, or roller skiers	51	31	13	3	2
More trails for horseback riders	38	20	20	12	10
More trails for off-leash dog recreationists	38	20	22	16	4
More trails for cross-country skiers	66	14	12	5	4
More trails for snowshoers	68	14	9	7	2

Q8. What other resource needs are important to you and your organization?

See report

WEST MULTNOMAH Soil & Water Conservation District (/)

Exhibit 32

WEST MULTNOMAH (https://wmswcd.org)
Soil & Water Conservation District

Find something...

LAND // WATER // WILDLIFE

PROGRAM

Water Quality Monitoring

We invite you to view the newly completed 2016 Water Quality Monitoring Report.

In addition, results of summer 2017 monitoring in McCarthy Creek have been mailed to landowners in the area.
This study aimed to identify elevated TSS concentrations and yields during storm events on both mainstem and tributary sampling locations, establish the relationship between Total Suspended Solids (TSS) and rainfall variables (rainfall depth, rainfall intensity, and rainfall

duration), and determine the most significant land cover variables as predictors of TSS based on delineated sub-watersheds in McCarthy Creek. Read a summary of the results here.

Since 2009 West Multnomah SWCD has been monitoring streams in the rural Tualatin Mountains ("West Hills"). The Water Quality Monitoring Program is intended to guide the strategic planning of WMSWCD while continuing to inform our restoration work and the story of how these watersheds are faring through time. The selection of the focus or "study area" has been driven by a lack of existing data (prior to 2009), finding salmon in McCarthy Creek, and the emphasis of these watersheds in the WMSWCD strategic plan.

Water quality data for perennial streams flowing out of the Tualatin Mountains is quite limited. Streams located within the City of Portland are often monitored by the Bureau of Environmental Services while streams on the south side of the Tualatin Mountains, which eventually flow into the Tualatin River, are monitored by Clean Water Services. However, the quality of streams in the rural areas of the Tualatin Mountains, which flow north into the Multnomah Channel, is poorly understood.

While none of the creeks in the study area have been identified through the Oregon Department of Environmental Quality's "303d" program, mainly due the relatively small size of the watersheds, questions have remained about the status of these creeks. Inadequate riparian areas and upland land uses (forestry and agriculture) are expected to impact water quality, however the magnitude is unknown.

The Water Quality Program focuses on the watersheds of Miller, McCarthy and Crabapple/Patterson Creeks. These are the largest watersheds within the study area and flow year-round. As a result they have the potential to be "salmon bearing" have been labeled as "priority watersheds" through the Conservation District's strategic planning process. We have seen salmon in Miller and McCarthy Creeks and McCarthy is listed by the Oregon Department of Fish and Wildlife as Essential Salmonid Habitat or ESH.

For more details on the water quality program, click here.

For more information on the watersheds in our District, please see the Watersheds page. Results from the Water Quality Program, along with our salmon sightings in 2012, make McCarthy Creek a focus watershed of the Healthy Streams Program, which provides free riparian habitat restoration.

Resources

PROGRAMS

Native White Oak Habitat

LIBRARY

Living cheek by gill in urban cities possible	DOCUMENTS
McCarthy Creek Monitoring flyer	DOCUMENTS
The Private Well Class	DOCUMENTS
Clean Water Loan Program for Septic Systems	DOCUMENTS
Living on the Water Appendix	DOCUMENTS
Student Field & GIS Internships	DOCUMENTS
Riparian Tree & Shrub Planting in the Willamette Valley	PUBLICATIONS
Living on the Water: A Guide for Floating Homeowners & Marina Managers	PUBLICATIONS
Stormwater Management	DOCUMENTS
Water Quality Program Overview	DOCUMENTS
Guide for Using Willamette Valley Native Plants Along Your Stream	PUBLICATIONS
2015 Report Card on Portland Watersheds	DOCUMENTS