Impacts of a Cascadia Subduction Zone Earthquake on the CEI Hub

EMBARGOED DRAFT REPORT

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Prepared for:

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SALUS RESILIENCE

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1 Introduction

> **Embargoed Report Note:** This report and the accompanying Appendix A and Appendix B represent the work products from two of the four tasks involved in the project that ECONorthwest and Salus Resilience are completing for Multnomah County and the City of Portland. The subsequent tasks will involve estimating monetary damages resulting from failures at the CEI Hub following a Cascadia Subduction Zone earthquake event, including clean-up costs as well as damage and liability assessments under the Oil Pollution Act based upon Natural Resource Damage Assessment processes. The assumptions about the extent and magnitude of the failure and potential impacted resources in this report will be used to estimate the monetary impacts and damages in the later stages of this project.

1.1 Background on CEI Hub

The Critical Energy Infrastructure Hub (CEI Hub) is a six-mile area in Northwest Portland along the Willamette River (Figure 1). The CEI Hub facilities are critical to Oregon's fossil fuel infrastructure - over 90 percent of the state's liquid fuel supply is transported through CEI Hub facilities, including gasoline and diesel. Roughly 70 percent of the fuel arrives by pipe and another 30 percent arrives by tanker barge. [1] The CEI Hub supplies all of the jet fuel to Portland International Airport. In addition to the fuel storage facilities, the CEI Hub also contains liquid fuel and natural gas pipelines and transfer stations, a liquefied natural gas storage tank, storage of other non-fuel materials, a high-voltage electrical substation, and transmission lines.

[1] Oregon Seismic Safety Policy Advisory Committee. (2013). *The Oregon Resilience Plan: Reducing Risk and Improving Recover for the Next Cascadia Earthquake and Tsunami, Chapter 6: Energy*.

Figure 1. CEI Hub Location

Source: Created by ECONorthwest

A magnitude 8 or 9 Cascadia Subduction Zone (CSZ) earthquake would impact the CEI Hub with ground shaking, liquefaction (soil softening and movement), lateral spread (horizontal soil movement), and landslides.[2] The significant ground disturbance and resulting impacts to the tanks could result in releases of the materials stored at the CEI Hub into land, water, and air. A fire is also possible at the site due to the combination of flammable fuels and earthquake disturbances. Releases from fuel tanks at the CEI Hub would pose a major hazard to people, marine life, and property, as well as contaminate the environment and require significant clean-up. The purpose of this analysis is to model the likely scenarios of releases and describe the potential resulting physical impacts.

1.2 Study Purpose

The purpose of this study is to identify the magnitude and extent of potential fossil fuel releases at the CEI Hub from a CSZ earthquake and to evaluate the resulting damages. Specifically, this research performs the following:

- Summarizes available information about conditions at the CEI Hub.
- Describes the likely effects of a major earthquake on CEI Hub facilities.

[2] Yumei Wang, Steven F. Bartlett, and Scott B. Miles. (2012). *Earthquake Risk Study for Oregon's Critical Energy Infrastructure Hub: Final Report to Oregon Department of Energy and Oregon Public Utility Commission.* Oregon Department of Geology and Mineral Industries. August.

- Develops qualitative descriptions and quantitative estimates of the earthquake's effects at the CEI Hub, including potential releases of fossil fuels.
- Estimates the economic impacts of fossil fuel releases and infrastructure failures.
- Identifies and describes what costs might be covered by existing insurance or federal programs and what costs are not clearly the responsibility of either owner-operators or another party.

This evaluation is limited to only the effects of a CSZ earthquake at the CEI Hub. A CSZ earthquake would also affect other nearby infrastructure for fuels and materials. The industrial areas of Portland, Oregon and Vancouver, Washington along the Willamette River and Columbia River store, use, and transport other fossil fuels and chemicals, including toxic inhalation hazard materials that also have the potential to be released due to earthquake damages and would complicate response efforts and strain response resources.[3]

[3] As defined in the Federal Register (69 FR 50987): "Toxic inhalation hazard materials (TIH materials) are gases or liquids that are known or presumed on the basis of tests to be so toxic to humans as to pose a hazard to health in the event of a release during transportation".

2 Prior Studies Related to the CEI Hub

Several prior studies have evaluated the impacts of a CSZ earthquake on the CEI Hub, documented hazardous materials releases, and described impacts to the surrounding environment and economy. However, these studies have not performed the analysis needed to identify the magnitude, location, and extent of releases and the specific costs on the surrounding environment. This report builds upon these prior studies to supply that needed information. As background information on the history of research of the risks at the CEI Hub, a summary of relevant prior literature is detailed below.

2.1.1 Dusicka and Norton – Liquid Storage Tanks at the Critical Energy Infrastructure (CEI) Hub Seismic Assessment of Tank Inventory (2019)

The Dusicka and Norton study from 2019 is directly related to the work being performed for this report.[4] In this publication, the authors evaluate the seismic integrity of the tanks at the CEI Hub and provide a conceptual estimate of $300 million as the cost for seismic mitigation for the large capacity tanks. As part of this work the researchers also estimated the quantity and characteristics of the tanks and the supporting soil.

Through a public records request and information from the City of Portland, the authors identified nine companies with a total of total of 514 known tanks, of which 146 were identified as out of service. The majority of the tanks were built before 1960. Based on secondary information, this report concludes that there is a risk of both liquefaction and landslides at the CEI Hub from a CSZ earthquake. Structural mitigation (i.e., retrofitting the tanks so that they are more seismically resilient) could occur through tank anchoring or soil mitigation.

2.1.2 DOGAMI – Earthquake Risk Study for Oregon's CEI Hub (2012)

Prepared for the Oregon Department of Geology and Mineral Industries (DOGAMI), this 2012 study evaluated the geomorphic earthquake risks at the CEI Hub.[5] The seismic hazards of a CSZ earthquake on the CEI Hub include ground shaking, liquefaction, lateral spread, landslides, co-seismic settlement, and bearing capacity failures. Secondary hazards resulting from the initial seismic impacts include fire and hazardous materials releases. In addition to the tanks at the CEI Hub, this study also evaluated the pipeline that runs under the Willamette River. The pipeline was built in the 1960s and could be damaged or broken by the seismic hazards from the earthquake, particularly liquefaction and lateral spread.

[4] Dusicka, P. and Norton, G. (2019). *Liquid Storage Tanks at the Critical Energy Infrastructure (CEI) Hub Seismic Assessment of Tank Inventory.* Mapleaf LLC and Portland State University. Prepared for Portland's Bureau of Emergency Management. May.

[5] Wang, Y., Bartlett, S.F., Miles, S.B. (2012). *Earthquake Risk Study for Oregon's CEI Hub. Prepared for Oregon Department of Geology and Mineral Industries (DOGAMI).*

The findings from this report indicate that western Oregon will likely face an electrical blackout, extended natural gas service outages, liquid fuel shortages, and damage and losses in the tens of billions of dollars in a future major Cascadia earthquake. The report recommends immediate proactive seismic mitigation actions.

2.1.3 Other Relevant Studies

OSSPAC - CEI Hub Mitigation Strategies: Increasing Fuel Resilience to Survive Cascadia (2019)

A study completed by the Oregon Seismic Policy Advisory Safety Commission (OSSPAC) at the request of the Oregon Governor and the State Resilience Officer focused on fuel resilience following the CSZ event.[6] Through meetings and testimony with experts, agencies, and interested stakeholders, OSSPAC presented findings and recommendations on the regulatory authority for: seismic upgrades, statutory authority to develop long-term mitigation efforts, public-private partnerships and incentives to harden current infrastructure, and encouraging seismic awareness in the private sector. The major finding from this work is as follows:

> "The Critical Energy Infrastructure Hub is a major threat to safety, environment, and recovery after a Cascadia Subduction Zone earthquake on par with the 2011 Fukushima nuclear meltdown in Japan. Owners of privately-owned liquid fuel tanks at the Hub need to be compelled to seismically strengthen their infrastructure. No state agency is a perfect fit to be designated as the regulatory authority over these facilities."

Oregon Solutions – Critical Energy Infrastructure Hub Assessment Findings (2019)

A 2019 study by Oregon Solutions identified potential avenues for collaborative action that might increase resiliency of the CEI Hub.[7] Oregon Solutions was established at the state level through the passage of the 2001 Sustainability Act and provides collaborative governance assistance through partnerships. The report is the product of interviews conducted by Oregon Solutions with parties and stakeholders representing key interests related to the CEI Hub between July 2018 and January 2019.

[6] Oregon Seismic Safety Policy Advisory Commission of the State of Oregon (OSSPAC). (2019). *CEI Hub Mitigation Strategies: Increasing Fuel Resilience to Survive Cascadia*. December 31. OSSPAC Publication 19-01.

[7] Oregon Solutions. (2019). *Critical Energy Infrastructure Hub Assessment Findings.* Prepared for the Portland City Club's Earthquake Resiliency Advocacy Committee (CCERAC) and the city of Portland's Bureau of Emergency Management (PBEM).

Other Reports

In addition to these reports that are specific to the CEI Hub, other relevant information sources include the Oregon Resilience Plan, particularly *Chapter 5: Transportation*, as well as the studies associated with the Portland Harbor Superfund site.[8, 9]

[8] More information and a copy of the Oregon Resilience Plan is available at: https://www.oregon.gov/gov/policy/orr/pages/index.aspx

[9] More information about the Portland Harbor Superfund is available at: https://cumulis.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.Cleanup&id=1002155#bkground

3 CEI Hub Fuel Releases

3.1 Methodology

Estimating the potential failures and releases associated at the CEI Hub due to a CSZ earthquake requires combining data about the location, contents, and integrity of critical infrastructure with information about the stability and risks of the soils that they are located on. Tank data is based upon information from the Office of Oregon State Fire Marshal (OSFM) and the City of Portland (COP), the latter of which was developed from the Portland State University (2019) study of the CEI Hub.[10, 11] The geological risks and susceptibility of the location to earthquake impacts is based upon a geologic analysis, detailed in Appendix A.

As tanks deform and fail during an earthquake, a portion of the materials contained inside them will be released. The specific volume that is released will depend on the ground displacement, nature of the failure, capacity of the tank, and the amount of material in the tank at that time. Most tanks in the CEI Hub have floating lids, meaning that in the event of an earthquake materials could slosh outside of the tank's containment. Connection failures and other incidental damages could also result in releases even if the tank itself does not fail. Throughout the CEI Hub there is a high likelihood of liquefaction and lateral spread from a CSZ earthquake that would disturb tanks and their contents.

Because soils are unstable throughout the CEI Hub, the likelihood of tank failure varies based upon the age of the tank to reflect engineering design considerations for if and how much of the contents could be released. Engineering design standards have changed over time. American Society of Civil Engineers design standards and state and city building codes prior to 1993 do not meet current seismic design standards. Liquefaction of soft soils was incorporated into City of Portland requirements for seismic design after 2004. Accordingly, these dates are used as thresholds for estimating the likelihood of tank failure and percent of contents that could be released, as follows:

- **Prior to 1993:** Tanks will likely fail during the CSZ event and release 50 to 100 percent of contained materials.
- **Between 1993 and 2004:** Tanks are assumed to be designed for shaking but are susceptible to failure due to liquefaction settlement and lateral spread.[12] Up to 10 percent

[10] A full description of the methodologies used for the information in this section are detailed in Appendix A, which contains an evaluation of the geotechnical risks at the CEI Hub, and Appendix B, which contains an evaluation of tank contents, likelihood of failure, and location of releases.

[11] Dusicka, P. and Norton, G. (2019). *Liquid Storage Tanks at the Critical Energy Infrastructure (CEI) Hub Seismic Assessment of Tank Inventory.* Mapleaf LLC and Portland State University. Prepared for Portland's Bureau of Emergency Management. May.

[12] Liquefaction is the phenomenon after an earthquake when soils lose holding strength, causing them to behave like a liquid rather than a solid and contents above or below the soil to be displaced. Lateral spread refers to the lateral movement of soils which can result in ground tears, open surface cracks, and fissures.

of contained materials could be released due to connection failures and other incidental damages.
- **After 2004:** Tanks have been designed to withstand appropriate shaking and deformation and thus are not likely to fail during the CSZ event. However, up to 10 percent of contained materials could be released.

Released materials will flow out onto the ground and properties of the various operators. While on-site containment structures are designed to capture a potential release, it is possible that the CSZ earthquake could damage these masonry containment walls. In many cases, these containment structures are insufficient to contain the potential cumulative volume of releases from multiple tank failures. As a result, depending on tank location, damage zone, distance from the water, and topography, substantial portions may flow into the Willamette River. Damage zones vary throughout the CEI Hub properties, with different volumes staying on land or entering the water, as described in Table 1. Appendix B provides additional information about releases by area type.

Table 1. Damage Zones by Area

	Damage Zone (distance from water in feet)		
Location	In Water	Potentially in Water	On Land
Area 1 - Kinder Morgan N	0-500	500-750	750+
Area 2 - Linnton N	0-500	500-750	750+
Area 2 - Linnton S	0-500	500-750	750+
Area 3 - NW Natural	0-250	250-500	500+
Area 4 - Willbridge	0-250	250-500	500+
Area 5 - Equilon	N/A	N/A	All

Source: Created by Salus Resilience, see *Appendix B*.

3.2 Fuel and Hazardous Material Types

There are over 150 different types of materials stored at the CEI Hub, each with a unique chemical composition. Most of the fuels stored at the CEI Hub are petroleum-based but react in the environment in different ways. The American Petroleum Institute (API) gravity is a measure of how heavy or light a petroleum liquid is compared to water. If a product has an API gravity of less than 10, it sinks in water. If the product has an API gravity greater than 10, it floats in water. Based on API ranking, the materials at CEI Hub can be assigned to the following categories.

- **Heavy Oil (API: Between 10 and 22.3)**: Heavy oils are dense and have a high resistance to flow. They generally float in water and do not disperse readily.
  - **Asphalt (API: 11):** Also known at bitumen, asphalt is a highly viscous petroleum product primarily used in road construction.
  - **Bunker (API: 12 to 14)**: Bunker crude oil is heavy oil typically used as a vessel fuel.
- **Medium Oil (API: Between 22.3 and 31.1)**: Medium oils include motor oils, which are derived from both petroleum and non-petroleum chemicals. Most motor oils are derived

from crude oil, with additives to improve certain properties. Motor oils are generally used for lubricating internal combustion engines.

- **Biodiesel (API: 25.7 to 33.0):** Biodiesel is a fuel made from natural, renewable sources, such as new and used vegetable oils and animal fats, for use in a diesel engine.
- **Light Oils (API: Greater than 31.1)**
    - **Diesel (API: 35)**: Diesel oil is produced from crude oil. It is used as a fuel for diesel vehicles and burning.
    - **Jet fuel (API: 45):** Jet fuel is an aviation fuel. The most commonly used fuels for commercial aviation are Jet A and Jet A-1. Jet fuel is a mixture of a large number of different hydrocarbons.
    - **Ethanol (API: 48)**: Ethanol is an alcohol product produced from corn, wheat, sugar cane, and biomass and is primarily used as an additive in gasoline to increase its octane level or as a stand-alone fuel.
    - **Gasoline (API: 60)**: Gasoline or petrol is a petroleum-derived liquid flammable mixture consisting mostly of hydrocarbons and enhanced with isooctane or aromatics hydrocarbons toluene and benzene to increase octane ratings.[13] It is used as fuel for gasoline vehicles and burning.
- **Liquified Natural Gas (API: N/A):** Natural gas is lighter than air and will dissipate into the air if released.
- **Additives (API: N/A)**: Nearly all commercial motor oils contain additives. Additives are used for viscosity and lubricity, contaminant control, for the control of chemical breakdown, and for seal conditioning of oil.
- **Slop Oil (API: Varies):** Slop Oil is defined as oil that is emulsified with water and solids. It is not usable as a fuel and contains similar contamination properties as the original oil source it contains.
- **Other:** Other products that do not fall into one of the prior categories includes unknown/unavailable contents, cutter, hydraulic fluids, storm water, and water.
- **Empty:** Tanks without any materials are categorized as "Empty".
- **Out of Service:** Tanks listed as out of service, rather than empty or with materials.
- **Extra Heavy Oil (API: Less than 10):** There is no evidence of extra heavy oils at the CEI Hub.

Flammability

Different fuel types have different risks of ignition. Whether materials burn following a release determines the range of air-quality and in-water environmental impacts. The assigned flammability of the materials is based upon Occupational Safety and Health Administration (OSHA) categories, as follows:[14]

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[13] ALS Life Sciences. (No Date). *Library of Petroleum Products and Other Organic Compounds*. Retrieved from https://www.alsglobal.es/media-general/pdf/library-of-petroleum-products-and-other-organic-compounds.pdf

[14] OSHA's Directorate of Training and Education. (No Date). *Flammable Liquids: 29 CFR 1910.106*. Retrieved from https://www.osha.gov/sites/default/files/training-library_TrngandMatlsLib_FlammableLiquids.pdf

- **Category 1:** Liquids with flashpoints below 73.4°F (23°C) and boiling point at or below 95°F (35°C). Examples: gasoline, some medium oils, and natural gas.
- **Category 2:** Liquids with flashpoints below 73.4°F (23°C) and boiling points at or above 95°F (35°C). Examples: Unleaded gasoline, ethanol, and bunker.
- **Category 3:** Liquids with flashpoints at or above 73.4°F (23°C) and at or below 140°F (60°C). Examples: Diesel, biodiesel, and jet fuel.
- **Category 4:** Includes liquids having flashpoints above 140°F (60°C) and at or below 199.4°F (93°C). When a Category 4 flammable liquid is heated for use to within 30°F (16.7°C) of its flashpoint, it must be handled as a Category 3 liquid with a flashpoint at or above 100°F (37.8°C). Examples: Marine diesel.

Hazardous Materials

Materials are deemed hazardous based on a combination of flammability, environmental harm, and risk from direct exposure to humans. Materials have their own Material Safety Data Sheets (MSDSs) that define the risk of harm. The categories used for this analysis are based on the MSDSs, as follows:

- **Category H – Hazardous**
  - All flammable materials are considered hazardous except for biodiesel.
  - Examples include gasoline, diesel, ethanol, jet fuel, and others.
- **Category NH – Non-Hazardous**
  - Examples include contact water and stormwater.
- **Not Available**
  - Information was not available for these materials.
  - Examples include motor oil, transmission fluid, additives, and others.

3.3 Quantities of Materials at CEI Hub

There are **630 tanks** of varying sizes throughout the CEI Hub holding a combined active storage tank capacity of at least **350.6 million gallons**.[15, 16] There is varying information available about the 630 tanks, as follows:

- **558 tanks** have available location data from either OSFM data, COP data, or City of Portland permitting information.[17] Of these tanks:
  - o 143 are listed as "Out of Service" and thus not evaluated in the analysis.
  - o 18 are listed as "Empty".

[15] For comparison to prior research estimates, Dusicka and Norton (2019) estimated that there are at least 362 tanks with a total capacity of 362.9 million gallons (8.64 million barrels) across all tanks (including out of service tanks).

[16] The 350.6 million gallons value does not account for out of service tanks or the 102 tanks that have unknown capacity. Accordingly, the true value of total capacity is likely higher than this value. However, tanks are rarely filled to full capacity, so this total capacity value does not reflect the amount of total materials on site.

[17] City of Portland, *Portland Maps*, available at: portlandmaps.com

    - 4 tanks have unknown contents. These tanks are located at Chevron (1 tank), and Shore Terminals (3 tanks). These tanks are evaluated in the analysis as “Unknown” material types.
    - 393 tanks are in service and have known contents information. Of these tanks:
        - 365 tanks have tank capacity information, measured in gallons.
        - 28 tanks are missing capacity information. These tanks are located at BP (2 tanks), Shore Terminals (1 tank) and Zenith Energy (25 tanks).
- **72 tanks** were identified via aerial photographs but are not identified in the OSFM or COP datasets; these tanks are all in Area 4 (Zenith Energy) and are all relatively small tanks. These tanks are missing specific location details, tank age, tank contents, and tank capacity information. Because of the missing information these tanks were excluded from the analysis. Due to the location of the property, it is likely that any releases from these tanks would be onto the ground.

The are 415 active tanks, defined as tanks that are not out of service and excluding the 72 tanks in Area 4 of unknown status that were identified in aerial photos alone. Empty tanks are included in the active tank definition, as they could be filled. The majority of the active tank total capacity at the CEI Hub, approximately 65 percent or 215 million gallons, are light oils (e.g., gasoline and diesel) (Table 2).

Table 2. Total Maximum Capacity of Materials at CEI Hub in Active Tanks

Material Type	Maximum Tank Capacity (gallons)	Percent of Total Maximum Capacity	Number of Tanks	Percent of Tanks
Light Oil	215,337,397	65%	130	31%
Medium Oil	43,829,634	13%	144	35%
Heavy Oil	34,928,796	10%	29	7%
Other	24,587,064	7%	50	12%
Natural Gas	7,100,000	2%	1	0%
Biodiesel	4,082,877	1%	10	2%
Slop Oil	1,826,017	1%	16	4%
Additive	702,924	0%	13	3%
Empty	344,469	0%	18	4%
Unknown	0	0%	4	1%
Total	**332,739,178**	**100%**	**415**	**100%**

Source: Salus Resilience, Appendix B
Note: Out of service tanks and the tanks of unknown status in Area 4 are not included in the total.

Although total maximum tank capacity represents the maximum amount of materials that could be located at the CEI Hub, tanks are not usually filled to full capacity. Average fill levels are available for 314 tanks from the COP data. On average for the tanks with information, tanks are filled to 67 percent capacity. Tank capacity is variable, since active tanks have their contents filled and distributed regularly. The utilization of the tanks varies by day, tank, owner, material, shipments, and other factors. An assumption in this analysis is that all active tanks are filled to

67 percent capacity. Using the 67 percent fill assumption, the total contents in active tanks at is 233.5 million gallons, on average (Table 3).

Table 3. Estimated Filled Capacity of Materials at CEI Hub in Active Tanks

Material Type	Average Expected Fill (gallons)
Light Oil	144,738,841
Medium Oil	39,585,777
Heavy Oil	23,402,293
Other	16,473,333
Natural Gas	4,757,000
Biodiesel	2,808,788
Slop Oil	1,223,431
Additive	470,959
Empty	0
Unknown	0
Total	**233,460,422**

Source: Salus Resilience, Appendix B

Note: Out of service tanks and the tanks of unknown status in Area 4 are not included in the total.

3.4 Tank Age

Of the 415 active tanks, 91 percent were built prior to 1993 or are missing information on year built, in which case they are assumed to have been built prior to 1993 (Table 4).[18] Tank age drives the assumptions for which tanks will fail, as described in Section 3.1.

Table 4. Number of Active Tanks and Year Built by Material Type

Material Type or Status	Built before 1993 or Unknown	Built between 1993-2004	Built after 2004	Total
Medium Oil	142	2		144
Light Oil	110	14	6	130
Other	47		3	50
Heavy Oil	25	4		29
Empty	16	2		18
Slop Oil	15	1		16
Additive	11		2	13
Biodiesel	10			10
Unknown	4			4
Natural Gas			1	1
Total	**380**	**23**	**12**	**415**

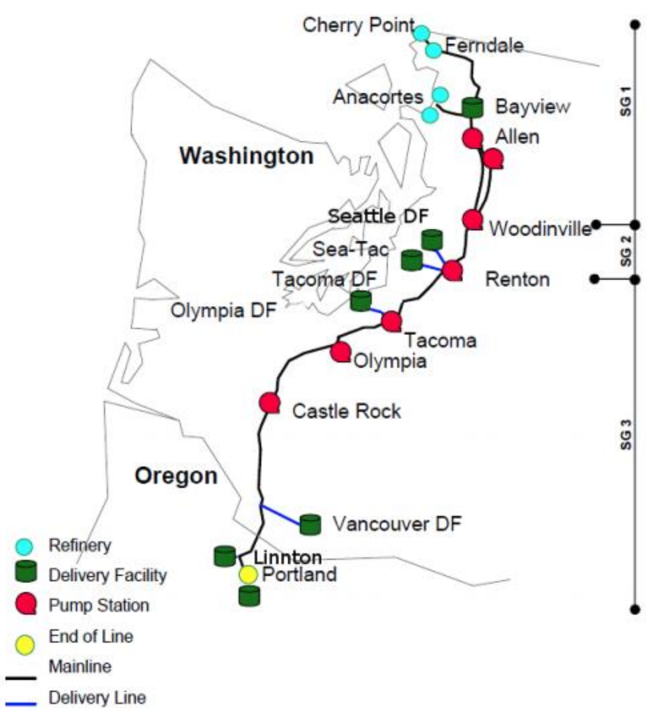
Source: Salus Resilience, Appendix B

[18] There were 72 tanks without a known year built and assumed to have been built prior to 1993.

3.5 Pipelines

The CEI Hub is supplied by the Olympic Pipeline which connects as far north as Bellingham, Washington and transports gasoline, diesel, and jet fuel in pipes between 12 to 20 inches in diameter (Figure 2).[19] There are also other pipelines connecting to the CEI Hub for fuels, including the Kinder Morgan pipeline that links petroleum terminals in the Portland region, including to the Portland International Airport. Like tanks, pipelines are also subject to potential failure due to seismic risks. For the Olympic Pipeline, breaks could occur north of the CEI Hub. Pipeline contents and the resulting risk of release vary by day. Since the material is ultimately stored in tanks at the CEI Hub, the effect of pipeline releases is partially accounted for in the tank capacity. Underground pipelines may be more protected than the above-ground tanks. Given these uncertainties, this analysis does consider the effects of a pipeline rupture at the CEI Hub, but focuses solely on tank capacity.

Figure 2. Olympic Pipeline Map



Source: BP, Olympic Overview website, available at: https://www.bp.com/content/dam/bp/country-sites/en_us/united-states/home/documents/products-and-services/pipelines/olympic-overview.pdf

[19] For more information see BP Olympia Pipeline website: https://www.bp.com/en_us/united-states/home/products-and-services/pipelines/our-pipelines.html#accordion_olympic

3.6 Ground Releases

Of the 415 total active tanks, 308 are in active use and have the potential to release contents onto to the ground.[20] Based on location and tank age, 285 tanks have the potential to release 50 to 100 percent of their tank contents onto the ground and 23 tanks have the potential to release up to 10 percent of their contents onto the ground. In total, a range of 53.9 million gallons to 111.2 million gallons would be released to ground surfaces (Table 5).

Table 5. Materials with Potential to Release to the Ground Surface

Substance Type	Number of Tanks	Volume Released Min (gal)	Volume Released Max (gal)
Medium Oil	144	19,506,218	39,069,770
Light Oil	73	30,811,094	63,657,094
Other	36	2,195,027	5,241,511
Empty	18	0	0
Heavy Oil	17	323,948	647,895
Slop Oil	8	462,794	925,588
Additive	7	146,803	293,605
Biodiesel	3	436,369	872,738
Natural Gas	1	0	475,700
Unknown	1	0	0
Total	**308**	**53,882,252**	**111,183,900**

Source: Created by Salus Resilience, Appendix B

3.7 Water Releases

Based on location and tank age, 107 active tanks have the potential to release materials that could flow into the Willamette River.[21] Of those, 96 of these tanks have the potential to release between 50 to 100 percent of their contents to the Willamette River and 11 tanks have the potential to release up to 10 percent of their contents into the water. In total, a range of 40.8 million to 82.5 million gallons could potentially reach the water (Table 6).

[20] A detailed table is provided in Appendix B.

[21] A detailed table is provided in Appendix B.

Table 6. Materials with Potential to Release to the Water Surface

Substance Type	Number of Tanks	Volume Released Min (gal)	Volume Released Max (gal)
Light Oil	57	26,474,505	53,930,869
Other	14	1,782,545	3,565,452
Heavy Oil	12	11,290,612	22,598,542
Slop Oil	8	148,763	297,557
Biodiesel	7	968,025	1,936,050
Additive	6	87,303	174,881
Unknown	3	0	0
Total	**107**	**40,751,753**	**82,503,352**

Source: Created by Salus Resilience, Appendix B

3.8 Total Potential Releases

In total, 397 tanks could release stored materials as a result of the CSZ earthquake.[22] Based on tank age and location, approximately 365 tanks could release 50 to 100 percent of their materials and 32 tanks could release up to 10 percent of stored materials. Together, the total potential releases from the materials stored in tanks at the CEI Hub range from 94.6 million to 193.7 million gallons (Table 7). Approximately 57 percent of the total potential releases would be released onto ground and 43 percent have the potential to flow into the Willamette River.

Table 7. Summary of Total Potential Releases by Location

Spill Location	Number of Tanks with 50–100 percent failure	Number of Tanks with up to 10 percent failure	Volume Released Min (gal)	Volume Released Max (gal)
Ground	269	21	53,882,252	111,183,900
Water (Including potentially in water)	96	11	40,751,753	82,503,352
Total	**365**	**32**	**94,634,005**	**193,687,251**

Source: Created by Salus Resilience, Appendix B

3.9 Burning Materials and Fire Potential

A fire at the CEI Hub involving the fuels stored on-site is a likely scenario following a CSZ earthquake. Many fuel storage tanks have a metal floating lid which in an earthquake could scrape against the metal perimeter, creating a spark and potentially a fire. Fires within tanks could result in large explosions, further threatening people, property, and environmental resources. There are also power lines throughout the CEI Hub which could fall due to the earthquake and serve as a potential ignition source.

Of the 393 active tanks that are not empty and have known contents at the CEI Hub, 200 tanks (approximately 51 percent), have materials that have are known to be flammable (Table 8). Based on the total estimate of releases, approximately 93 percent of releases will be of flammable materials (i.e., in Category 1 through 4). The total capacity of tanks with flammable materials is 298.7 million gallons. Therefore, the contents of these tanks all have the potential to

[22] This value excludes empty tanks from the active tanks that could release materials.

burn, either on land or in the water. Because burning requires both a fuel and an ignition source, the specific amount of materials that would burn are a function of location and event-specific factors.

Table 8. Tanks and Capacity by Flammability Category

Flammability Category	Number of Tanks	Volume Released Min (gal)	Volume Released Max (gal)
Category 1 (Most Flammable)	106	37,987,895	78,549,612
Category 2	28	22,455,581	45,248,842
Category 3	66	27,474,245	55,541,111
Category 4	0	0	0
Not Flammable	14	864,764	1,729,889
Unknown	183	5,851,521	12,617,797
Empty	18	0	0
Total	**415**	**94,634,005**	**193,687,251**

Source: Created by Salus Resilience, Appendix B

4 Substance Information

4.1 Substance Toxicities

The fuels stored at the CEI Hub are toxic, meaning that they can harm living things. Accordingly, release of these materials will be harmful to organisms that they come in to contact with through the ground, water, and/or air. The level of harm depends on the substance, the level of exposure, and the pathway of exposure. Harm to living organisms can be caused by direct physical contact – such as oil smothering plant and animals – or biochemical, which refers to the poisonous nature of the chemicals.[23] The chemical characteristics of petroleum substances also interact with the physical and biochemical features of the habitat where a spill occurs – meaning that the total effect is a combination of both the substance that is released as well as the environment that it is released into.

The biochemical response varies based on the specific chemical composition of the compound. Because fuels, additives, oils, and the other substances stored at the CEI Hub have different chemical compositions depending on the specific blend, they can vary in toxicity even within certain categories of substances.[24]

Two of the primary toxic biochemical substances associated with petroleum products are **volatile organic compounds (VOCs)** and **polycyclic aromatic hydrocarbons (PAHs)**. VOCs disperse into the air and can be toxic when inhaled. Because VOCs evaporate into the air, they are generally a concern only right after oil is spilled – oil floating on water surfaces quickly volatize and lose their VOCs. At the site of a fresh oil spill, these VOCs can threaten nearby residents, responders working on the spill, and air-breathing marine mammals.[25] In contrast, PAHs can persist in the environment for many years, in some cases continuing to harm organisms long after the oil first spills. Studies in Alaska and Washington suggest that PAHs are particularly harmful to fish eggs and embryos.[26]

[23] NOAA, Office of Response and Restoration, *The Toxicity of Oil: What's the Big Deal?*. Available at: https://response.restoration.noaa.gov/about/media/toxicity-oil-whats-big-deal.html

[24] NOAA, Office of Response and Restoration, *How Toxic is Oil*?. Available at: https://response.restoration.noaa.gov/oil-and-chemical-spills/significant-incidents/exxon-valdez-oil-spill/how-toxic-oil.html

[25] NOAA, Office of Response and Restoration, *The Toxicity of Oil: What's the Big Deal?*. Available at: https://response.restoration.noaa.gov/about/media/toxicity-oil-whats-big-deal.html

[26] NOAA, Office of Response and Restoration, *How Toxic is Oil*?. Available at: https://response.restoration.noaa.gov/oil-and-chemical-spills/significant-incidents/exxon-valdez-oil-spill/how-toxic-oil.html

4.1.1 Toxicity by Substance

Oil is grouped into five basic groups in the Code of Federal Regulations (Table 9).[27] The two most common substances at the CEI Hub, gasoline and diesel, are in Group 1 and Group 2, respectively. Diesel is one of the most acutely toxic oil types and can cause high mortality rates in fish and invertebrates when released into water resources.[28]

Table 9. Five Basic Groups of Oil

Group 1: Non-Persistent Light Oils (Gasoline, Condensate)	Highly volatile (should evaporate within 1-2 days). Do not leave a residue behind after evaporation. High concentrations of toxic (soluble) compounds. Localized, severe impacts to water column and intertidal resources. Cleanup can be dangerous due to high flammability and toxic air hazard.
Group 2: Persistent Light Oils (Diesel, No. 2 Fuel Oil, Light Crudes)	Moderately volatile; will leave residue (up to one-third of spill amount) after a few days. Moderate concentrations of toxic (soluble) compounds. Will "oil" intertidal resources with long-term contamination potential. Cleanup can be very effective.
Group 3: Medium Oils (Most Crude Oils, IFO 180)	About one-third will evaporate within 24 hours. Oil contamination of intertidal areas can be severe and long-term. Oil impacts to waterfowl and fur-bearing mammals can be severe. Cleanup most effective if conducted quickly.
Group 4: Heavy Oils (Heavy Crude Oils, No. 6 Fuel Oil, Bunker C)	Little or no evaporation or dissolution. Heavy contamination of intertidal areas likely. Severe impacts to waterfowl and fur-bearing mammals (coating and ingestion). Long-term contamination of sediments possible. Weathers very slowly. Shoreline cleanup difficult under all conditions.
Group 5: Sinking Oils (Slurry Oils, Residual Oils)	Will sink in water. If spilled on shoreline, oil will behave similarly to a Group 4 oil. If spilled on water, oil usually sinks quickly enough that no shoreline contamination occurs. No evaporation or dissolution when submerged. Severe impacts to animals living in bottom sediments, such as mussels. Long-term contamination of sediments possible. Can be removed from the bottom of a water body by dredging.

Source: NOAA, Office of Response and Restoration, *Oil Types*, Available at: https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/oil-types.html

Jet fuel is not included in the five basic groupings, but is also stored at the CEI Hub. Jet fuel is composed of light hydrocarbons with low viscosities. When spilled on open water, most of the

[27] Title 33, Chapter I, Subchapter O, Part 155, Subpart D. §155.1020.

[28] NOAA, Office of Response and Restoration, *Small Diesel Spills*. Available at: https://response.restoration.noaa.gov/sites/default/files/Small-Diesel-Spills.pdf

jet fuel will evaporate or naturally disperse within a day or less, leading predominantly to air quality impacts rather than aquatic impacts.[29] However, jet fuel can attach to fine-grained suspended sediments in the water, which then settle out and get deposited on the bottom of a waterbody. Although jet fuels are relatively less acutely toxic than diesel, high levels of mortality in animals and plants are expected where larger amounts of this type of petrochemical soak into wetland soils.

Biodiesel and non-petroleum oils, which are also stored at the CEI Hub in lower quantities, generally have low fire risk and a lower risk of biochemical toxicity, but pose a high risk of smothering to wildlife. The physical effects of coating animals and plants with oil include hypothermia, dehydration, diarrhea, starvation, or suffocation from the clogging of nostrils, throat, or gills, as well as from the reduction in water oxygen content.[30]

Ethanol, another substance present at the CEI Hub, is also toxic to animals through primarily physical effects. However, instead of smothering, the main risk from ethanol is lower dissolved oxygen levels which can kill fish and other aquatic species.[31]

4.2 Fate and Transport of Contaminants

Fate and transport refer to the outcomes of released materials – how far they go and where they end up. Because of their different chemical compositions, oils vary in terms of how they react with the environment. Depending on their density, oils that are heavier than water will sink while oils that are lighter than water will float on the surface (absent heavy disturbances). Light oils like gasoline have a density of 0.85 gram per cubic centimeter (g/cc) – most types of oils have densities between about 0.90 and 0.98 g/cc.[32] The density of river water is usually about 1.0 g/cc.

Heavy oils can have a density as high as 1.01 g/cc, meaning they would sink in a river. Clean up can be very difficult and disruptive to the environment for this type of spill. Methods for cleaning up heavy oil spills can include vacuuming, dredging, scraping, and other invasive methods. Because these methods directly affect the environment, they can result in relatively greater injury to habitats, species, and other natural resources.

Medium and light oils are lighter than water and, due to their volatility, will disperse into the air through evaporation. Within a few days following a spill, light crude oils can lose up to 75 percent of their initial volume and medium crudes up to 40 percent through evaporation, but

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[29] NOAA, Office of Response and Restoration, *Kerosene and Jet Fuel Spills*. Available at: https://response.restoration.noaa.gov/sites/default/files/Kerosene-Jet-Fuel.pdf

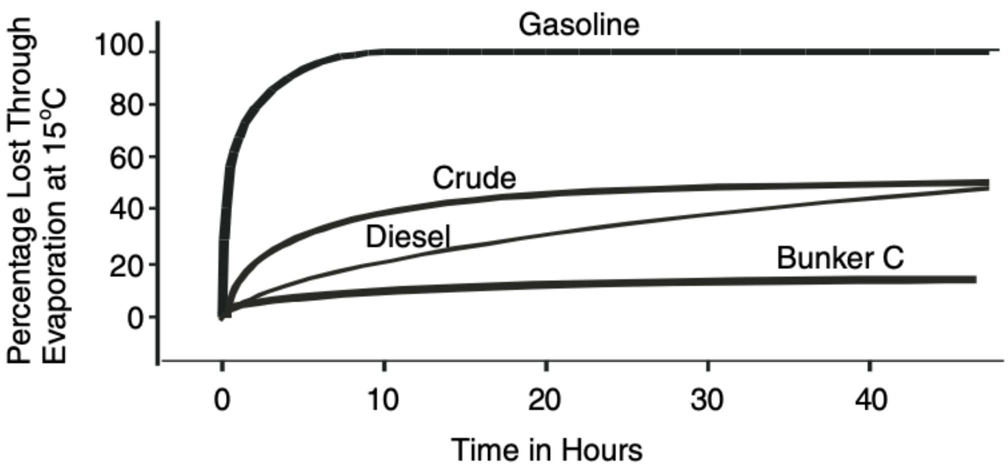
[30] NOAA, Office of Response and Restoration, *Non-Petroleum Oil Spills*. Available at: https://response.restoration.noaa.gov/sites/default/files/Non-Petroleum-Oil.pdf

[31] NOAA, Office of Response and Restoration, *Denatured Ethanol Spills*. Available at: https://response.restoration.noaa.gov/sites/default/files/Denatured-Ethanol.pdf

[32] NOAA, Office of Response and Restoration, *Oil Spills in Rivers*. Available at: https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/oil-spills-rivers.html

heavy oils will lose only 10 percent of their volume in the first few days following a spill (Figure 3).[33]

Figure 3. Evaporation Rates of Different Types of Oils



Source: National Research Council. (2003). *Oil in the Sea III: Inputs, Fates, and Effects*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10388.

After a spill occurs, how the physical and chemical characteristics of oil interact with the physical and biochemical features of the habitat is known as "weathering". Weathering is influenced by the characteristics of the substance, including:

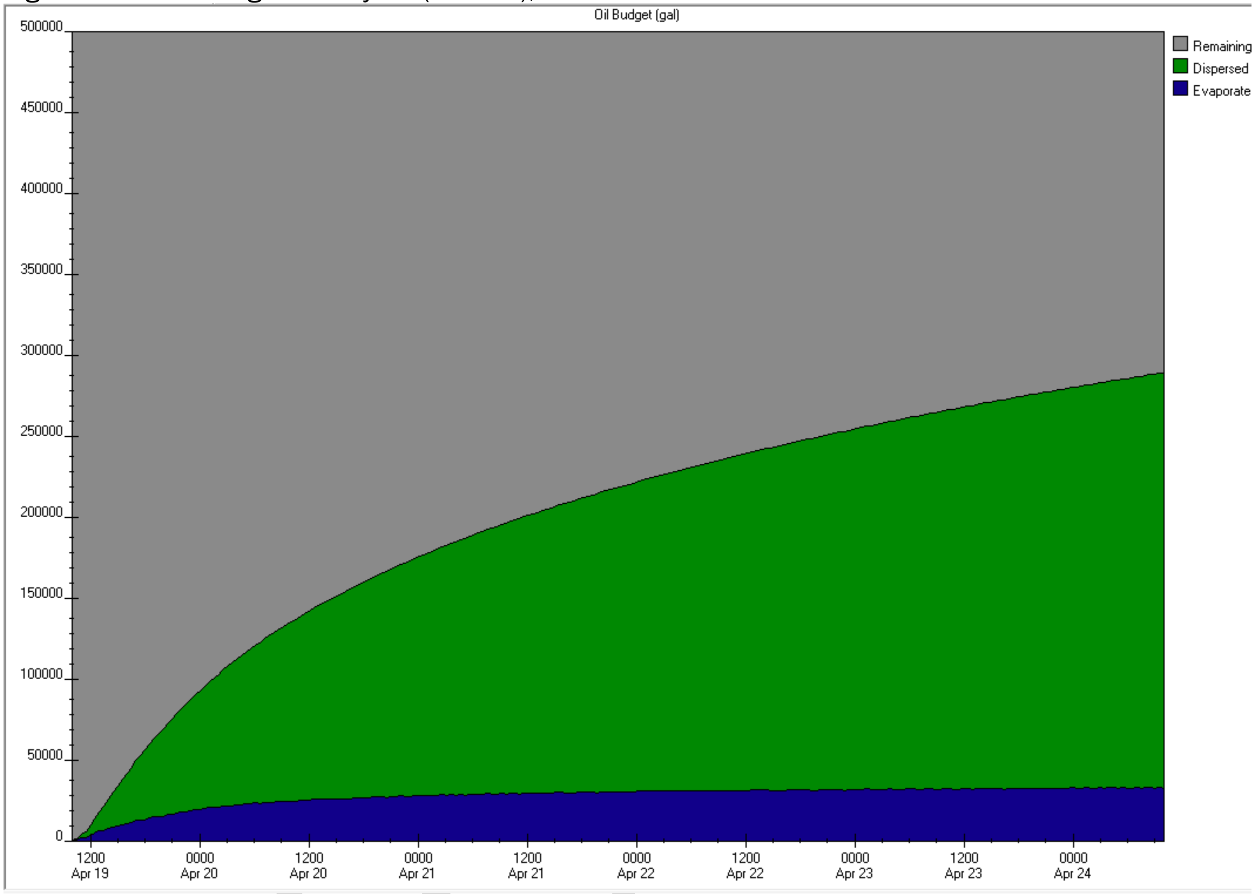
- How rapidly the substance evaporates;
- How easily the substance is broken down by microbes in the environment; and
- How rapidly sunlight degrades the substance.

Weathering can be modeled using NOAA's Automated Data Inquiry for Oil Spills (ADOIS) that uses location- and material-specific parameters to model the results of oil releases into water environments.[34] For a heavy oil, like bunker, a large percentage of the oil will remain even weeks later (Figure 4). In contrast, a light oil, like gasoline, will fully disperse or evaporate within 1 or 2 days (Figure 5).

[33] National Research Council. (2003). *Oil in the Sea III: Inputs, Fates, and Effects*. Washington, DC: The National Academies Press.

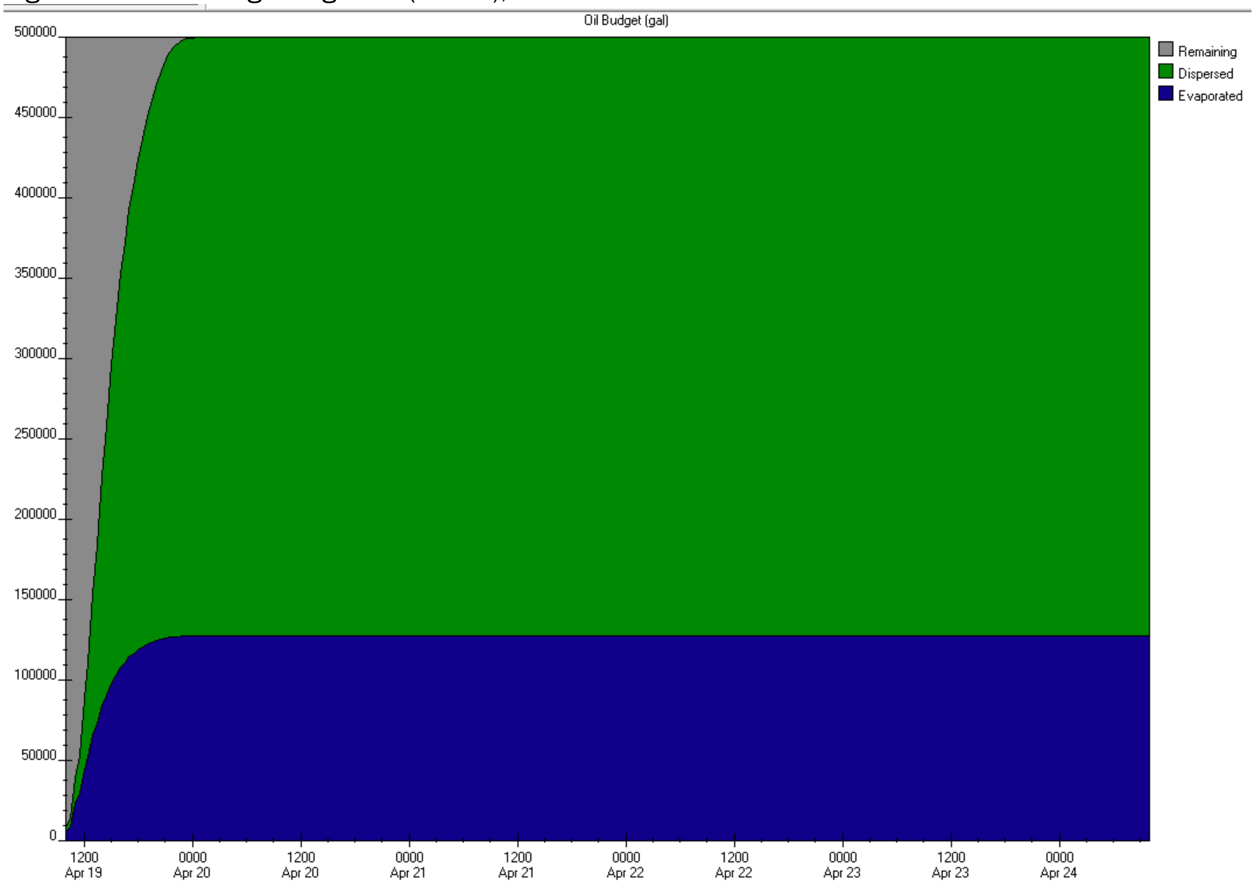
[34] More information about the ADIOS model can be found at: https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/response-tools/adios.html

Figure 4. Weathering of Heavy Oil (Bunker), NOAA ADIOS Model Results



Source: NOAA ADIOS® (Automated Data Inquiry for Oil Spills) Model

Figure 5. Weathering of Light Oil (Diesel), NOAA ADIOS Model Results



Source: NOAA ADIOS® (Automated Data Inquiry for Oil Spills) Model

Materials that are dispersed through the water column are not easily recoverable via clean-up. Dispersed and remaining materials will continue to interact with the environment in which they reside through oxidation, biodegradation, and emulsification, defined as follows:[35]

- **Oxidation** is when water and oxygen combine with oil to produce water-soluble compounds. This process affects oil slicks mostly around their edges. Thick slicks may only partially oxidize, forming *tar balls*. These dense, sticky, black spheres may linger in the environment, and can collect in the sediments of slow-moving streams or lakes or wash up on shorelines long after a spill.

- **Biodegradation** occurs when micro-organisms such as bacteria feed on oil. A wide range of micro-organisms is required for a significant reduction of the oil. As a clean-up method to support biodegradation, nutrients such as nitrogen and phosphorus are

[35] Environmental Protection Agency. (No Date). *The Fate of Spilled Oil*. Retrieved from https://archive.epa.gov/emergencies/content/learning/web/html/oilfate.html#:~:text=Evaporation%20occurs%20when%20the%20lighter,sink%20to%20the%20ocean%20floor.

sometimes added to the water to encourage the micro-organisms to grow and reproduce. Biodegradation tends to work best in warm water environments.

- **Emulsification** is a process that forms *emulsions*, a mixture of small droplets of oil and water. Emulsions are formed by wave action, and greatly hamper weathering and cleanup processes. Two types of emulsions exist: water-in-oil and oil-in-water. Water-in-oil emulsions formed when strong currents or wave action causes water to become trapped inside viscous oil. These emulsions may linger in the environment for months or even years. Emulsions cause oil to sink and disappear from the surface, which give the false impression that it is gone and the threat to the environment has ended.

4.3 Oil Spill Clean-Up

Clean-up actions following oil spills in water resources fall generally into three categories depending on the weathering characteristics of the released substance(s):

- **Containment without removal**: Generally performed for volatile substances like light fuels that will naturally quickly evaporate or disperse and often is done using booms. Because the oil remains on the surface, this is an effective method.
- **Containment with removal**: Generally used with heavier fuels, such as through accelerated biodegradation, use of skimmers, use of sorbents (materials to soak up liquids), use of dispersants, and in situ burning.[36]
- **Intensive removal**: Intensive removal includes dredging and scraping vegetation and soils, as well as direct removal of oil residues from animals.

Clean-up on shorelines or other land depends on the habitat characteristics. Clean-up responses are time-sensitive to prevent the runoff of substance into water resources. Containment methods can be used to minimize this risk. Natural processes of evaporation, oxidation, and biodegradation also occur for spills on land. Physical clean-up methods can include wiping with sorbent materials, pressure washing, raking, and bulldozing, as well as burning – with proper disposal after materials have been removed from the site.[37]

[36] EPA Office of Emergency and Remedial Response. (1999). *Understanding Oil Spills and Oil Spill Responses*.

[37] EPA Office of Emergency and Remedial Response. (1999). *Understanding Oil Spills and Oil Spill Responses*.

5 Case Studies of Other Fossil Fuel Infrastructure Failures

Other fossil fuel releases provide examples of the effects of releases in different environments and for different substances. This section describes other fossil fuel infrastructure failures, their effects, and their associated damages. These case studies are not meant to be comprehensive of all instances of fossil fuel failures and oil spills. Rather, it provides examples that can be used to understand the potential effects of fuel releases at the CEI Hub. Failures at the CEI Hub due to a CSZ earthquake have the potential to result in the largest oil spill in U.S. history. Estimates of releases are the same magnitude as what was released in the Deepwater Horizon spill – the largest oil spill in U.S. waters to date.

5.1 Case Study Details

The case studies are organized into four categories:

- Case studies of fuel releases in Oregon;
- Case studies of fuel releases in river shipping channels and water resources;
- Case studies of other fuel releases at tank farms, near sensitive habitat, or due to earthquakes.

5.1.1 Fuel Releases in Oregon

There have been spills of other fossil fuels in Oregon, particularly related to road and rail incidences. A failure at the CEI Hub would be more than ten times larger than the previous largest oil spill that occurred in 1984. An oil spill on the scale of the potential releases at the CEI Hub is unprecedented. In terms of the environmental effects of the spill, the guidance from the Clean Water Act and the Oregon Department of Environmental Quality highlights how even minimal oil releases require a response to minimize damages. Any amount of oil spilled into water and spills over 42 gallons on land must be reported to emergency services in Oregon.[38]

Lindsey Lake Tanker Spill near Hood River, OR (2019)

On February 11, 2019, a tanker truck carrying winter-grade diesel fuel overturned on Interstate 84 near Hood River, Oregon. An estimated 4,400 gallons of winter blend diesel were spilled onto the roadway, approximately half of which flowed into the partially frozen Lindsey Lake

[38] Oregon Department of Environmental Quality, *How To Report A Spill*. Available at: https://www.oregon.gov/deq/Hazards-and-Cleanup/env-cleanup/Pages/How-To-Report-A-Spill.aspx#:~:text=The%20National%20Response%20Center%3A%201%2D800%2D424%2D8802&text=Where%20is%20the%20spill%3F,What%20spilled%3F

nearby.[39] Lindsey Lake is hydraulically connected to the Columbia River as well as a known salmon spawning lake habitat, making the spill a threat to the greater regional ecosystem. As part of containment, responders placed a boom on the lake to protect spawning locations and sensitive vegetation.[40] In addition, impacted snow was collected and monitoring wells were installed to further determine environmental damage. Oregon Department of Environmental Quality (DEQ) issued the operating party Space Age Fuel a civil penalty of $66,000 for environmental damages.[41] As of October 22, 2019, the cleanup cost to date was $3.4 million.[42]

Columbia River Oil Train Derailment near Mosier, OR (2016)

On June 3, 2016 an oil train derailed near Mosier, Oregon, resulting in the discharge of 47,000 gallons of Bakken crude oil approximately 600 feet from the Columbia River.[43] Four train cars caught fire and the fire was extinguished the next day. The incident resulted in the closure of I-84 (10 hours) and the rail line, as well as a nearby park. People were evacuated from their homes ,and damage to the city's wastewater system prevented residents from using water for three days.

The day after the incident, an oil sheen on the Columbia River prompted the use of booms for containment. Within a few days, the sheen dissipated with no further cleanup beyond the containment booms. There were no observed effects on wildlife from the incident.[44] Air quality monitoring began the day of the incident. In the immediate area of the derailment, there were detected levels of Benzene, Hexane, O_2, $PM_{2.5}$, and VOC.[45] More broadly, PM_{10}, O_2, $PM_{2.5}$, and VOCs were detected as far as 3 miles away.[46]

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[39] U.S. Environmental Protection Agency. (No Date). *Lindsey Lake Tanker Truck Spill*. Available at: https://response.epa.gov/site/site_profile.aspx?site_id=14106

[40] Oregon Department of Environmental Quality. (2019). *Presentation to the Environmental Quality Commission*. November 15. Available at: https://www.oregon.gov/deq/EQCdocs/11152019_EmergencyResponse_Slides.pdf

[41] Oregon Department of Environmental Quality. (2020). *Notice of Civil Penalty Assessment and Order Case No. LQ/SP-ER-2019-296*. April 24. Available at: https://www.oregon.gov/deq/nr/0420SpaceAgeFuel.pdf

[42] Oregon Department of Environmental Quality. (2019). *Presentation to the Environmental Quality Commission*. November 15. Available at: https://www.oregon.gov/deq/EQCdocs/11152019_EmergencyResponse_Slides.pdf

[43] U.S. Environmental Protection Agency, Region 10. (2016). *Mosier Oil Train Derailment*. Available at: https://response.epa.gov/site/site_profile.aspx?site_id=11637

[44] U.S. National Response Team. (2016). *Mosier Oil Train Derailment*. Available at: https://nrt.org/site/download.ashx?counter=4472

[45] Center for Toxicology and Environmental Health. (2016). *Mosier Unit Train Derailment Mosier, OR Preliminary Summary of Air Monitoring Results June 5, 2016*. Available at: https://www.deq.state.or.us/Webdocs/Forms/Output/FPController.ashx?SourceIdType=11&SourceId=6115&Screen=Load

[46] Center for Toxicology and Environmental Health. (2016). *Mosier Unit Train Derailment Mosier, OR Preliminary Summary of Air Monitoring Results June 5, 2016*.

Tanker SS MobilOil, Columbia River, OR (1984)

On March 19, 1984, the oil tanker SS MobilOil grounded on the Columbia River near St. Helens. The National Transportation Safety Board determined the cause to be a steering gear failure which forced the ship to run aground on a rocky reef.[47] The reef ripped open four holding tanks and released an estimated 170,000 gallons of heavy residual oil, number six fuel oil, and industrial fuel oil into the river.[48] Oil was spread along the Washington and Oregon coastal shoreline as far south as Cannon Beach and as far north as the entrance to the Strait of Juan de Fuca.

The containment and cleanup effort involved 60 people who used booms to block moorings and marinas. The total cleanup cost was estimated at $3 million, and the cost to repair the tanker was estimated at $5 million.[49] After the spill, there were many dead waterbirds in the area.

5.1.2 Fuel Releases into Shipping Channels and Water Resources

The CEI Hub is along the Willamette River, a shipping channel for accessing the Port of Portland and other port facilities. Previous incidents of oil spills in river shipping channels demonstrate not only the environmental effects of discharge into water and riparian habitats but also the economic impact that results from the closure of shipping lanes.

Refugio Incident near Gaviota, CA (2015)

The Refugio Incident near Gaviota, California was a pipeline oil spill located north of Refugio State Beach in Santa Barbara County, California. On May 19, 2015, Line 901, a 10.6-mile pipeline owned by Plains All American Pipeline, ruptured and spilled over 123,000 gallons of crude oil.[50] Over 53,000 gallons of the spilled oil ended up in the Pacific Ocean, where it caused death and disruption to wildlife and vegetation, as well as other environmental damages.[51] The oil reached

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[47] Speich, S.M., and Thompson, S.P. (1987). *Impacts on Waterbirds from the 1984 Columbia River and Whidbey Island, Washington, Oil Spills.* Available at: https://sora.unm.edu/sites/default/files/journals/wb/v18n02/p0109-p0116.pdf

[48] U.S. Department of Energy Office of Scientific and Technical Information (1984). *Marine accident report - grounding of United States Tankship SS MOBILOIL, in the Columbia River near Saint Helens, Oregon, March 19, 1984.* Available at: https://www.osti.gov/biblio/5742109-marine-accident-report-grounding-united-states-tankship-ss-mobiloil-columbia-river-near-saint-helens-oregon-march

[49] U.S. Department of Energy Office of Scientific and Technical Information. (1984). *Marine accident report - grounding of United States Tankship SS MOBILOIL, in the Columbia River near Saint Helens, Oregon, March 19, 1984.*

[50] Anderson, M. (2020). *Refugio Beach Oil Spill Draft Damage Assessment and Restoration Plan/ Environmental Assessment Presentation.* May 13. Available at https://pub-data.diver.orr.noaa.gov/admin-record/6104/DARPPublicMeetingMAndersonIntroOverviewSlides_5-13-20_forwebposting.pdf

[51] NOAA. (2015). *Refugio Beach Oil Spill*. Available at https://darrp.noaa.gov/oil-spills/refugio-beach-oil-spill; National Oceanic and Atmospheric Administration (NOAA). (2020). *Draft Restoration Plan to Support Recovery of Natural Resources Following Refugio Beach Oil Spill.* April 22. Available at: https://pub-data.diver.orr.noaa.gov/admin-record/6104/20200422_FINAL%20DARP%20Press%20Release.mediaready.pdf

other beaches as far south as Los Angeles County.[52] In March of 2020, nearly five years after the incident, a $22.3 million settlement was authorized through the Damage Assessment and Restoration Plan and Environmental Assessment.

The spill impacted recreation, commercial fisheries, and closed beaches. Recreation closures occurred at Refugio State Beach (1 month)[53] and El Capitán State Beach (2 months).[54] The Draft Restoration Plan estimates over 140,000 lost recreational user-days valued at $3.9 million.

Air quality monitoring began the day after the spill for approximately one month for VOCs, benzene, hexane, toluene, atmospheric flammability as a percent of the lower explosive limit, and hydrogen sulfide (H2S).[55] The air monitoring did not detect crude oil-associated compounds that exceeded U.S. Environmental Protection Agency standards for VOCs. As such, the assessment determined no human health risks from these airborne compounds. Of note is that there was no fire or ignition of VOCs from the event.

TX City Y Spill in Houston Channel, TX (2014)

On March 22, 2014, the bulk carrier M/V Summer Wind collided with the oil tank-barge Kirby 27706 in Galveston Bay near Texas City, Texas. As a result, the barge spilled approximately 168,000 gallons of intermediate fuel oil into lower Galveston Bay, the majority of which then flowed into the Gulf of Mexico.[56] Most of the discharged oil was on shorelines between Galveston and Matagorda Islands.[57] Damages and impacts for this incident are still being evaluated, but the release caused the closure of the heavily trafficked Port of Houston for 3 days.[58] As of 2015, PAHs from the oil spill continue to pose environmental risks in the marine environment.[59] In 2016, Kirby Island Marine L.P. agreed to pay $4.9 million in Clean Water Act civil penalties due to the incident.[60]

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[52] NOAA. (2020). *Draft Restoration Plan to Support Recovery of Natural Resources Following Refugio Beach Oil Spill.* April 22.

[53] Rocha, Veronica (2015). "El Capitan beach to reopen a month after Santa Barbara County oil spill". *Los Angeles Times*. June 19.

[54] Moore, J.C. (2015). "Refugio State Beach to reopen today after oil-spill closure". *Ventura County Star*. July 17.

[55] Center for Toxicology and Environmental Health, LLC. (2015*). Community Air Monitoring and Sampling Summary: Refugio Incident.* June 15.

[56] NOAA, Office of Response and Restoration. (2014). *Texas City Y Oil Spill*. Available at: https://darrp.noaa.gov/oil-spills/texas-city-y

[57] Yin, F., Hayworth, J. S., & Clement, T. P. (2015). A tale of two recent spills—comparison of 2014 Galveston Bay and 2010 Deepwater Horizon oil spill residues. *PloS one*, 10(2), e0118098.

[58] NOAA, Office of Response and Restoration. (2014). *Update on the Texas City "Y" Response in Galveston Bay*. Available at: https://response.restoration.noaa.gov/about/media/update-texas-city-y-response-galveston-bay.html

[59] Yin, F., Hayworth, J. S., & Clement, T. P. (2015). A tale of two recent spills—comparison of 2014 Galveston Bay and 2010 Deepwater Horizon oil spill residues. *PloS one*, 10(2), e0118098.

[60] U.S. Department of Justice. (2016). *Kirby Inland Marine to Pay $4.9 Million in Civil Penalties and Provide Fleet-Wide Improvements to Resolve U.S. Claims for Houston Ship Channel Oil Spill.* September 27. Available at:

Deepwater Horizon in the Gulf of Mexico (2010)

The Deepwater Horizon oil spill is the largest spill in the history of the United States. On April 20, 2010, an explosion occurred on the Deepwater Horizon drilling platform in the Gulf of Mexico, leading to the largest offshore oil spill in U.S. history. The explosion caused the rig to sink and leaked 134 million to 206 million gallons of oil into the Gulf over three months.[61] The initial explosion killed eleven men. The Deepwater Horizon oil spill killed thousands of marine mammals and sea turtles, and also contaminated their habitats.[62] Containment measures included floating booms, skimmer boats, and sorbents. Chemical dispersants were also used to facilitate oil degradation. During the spill response there was a temporary flight restriction over the area as well as on-the-ground access restrictions.

A major public health impact was air pollution. A study following the incident found four primary sources of pollutants: (a) Hydrocarbons (HCs) evaporating from the oil; (b) smoke from deliberate burning of the oil slick; (c) combustion products from the flaring of recovered natural gas; and (d) ship emissions from the recovery and cleanup operations.[63] Studies have noted that the air pollution impacts could have been much worse for a spill of similar size closer to populated areas, closer to the surface, or in a region with larger NOx sources.

The financial claims were largely settled when a Federal District judge approved the largest environmental damage settlement in United States history – $20.8 billion – on April 4, 2016.[64] In 2016, BP calculated their total cost for the oil spill, including both damages, fines, and economic loss, as $61.6 billion.[65]

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https://www.justice.gov/opa/pr/kirby-inland-marine-pay-49-million-civil-penalties-and-provide-fleet-wide-improvements

[61] United States of America v. BP Exploration & Production, Inc., et al. (2015). *Findings of fact and conclusions of law: Phase Two trial. In re: Oil spill by the oil rig "Deepwater Horizon" in the Gulf of Mexico, on April 20, 2010, No. MDL 2179, 2015 WL 225421.* (Doc. 14021). U.S. District Court for the Eastern District of Louisiana. Retrieved from https://www.gpo.gov/fdsys/pkg/USCOURTS-laed-2_10-md-02179/pdf/USCOURTS-laed-2_10- md-02179-63.pdf

[62] NOAA. (2017). *Deepwater Horizon Oil Spill Longterm Effects on Marine Mammals, Sea Turtles*. Available at: https://oceanservice.noaa.gov/news/apr17/dwh-protected-species.html#:~:text=The%20scientists%20concluded%20that%20the,turtles%2C%20and%20contaminated%20their%20habitats.

[63] Middlebrook, A. M., Murphy, D. M., Ahmadov, R., Atlas, E. L., Bahreini, R., Blake, D. R., & Ravishankara, A. R. (2012). Air quality implications of the Deepwater Horizon oil spill. *Proceedings of the National Academy of Sciences*, *109*(50), 20280-20285.

[64] NOAA. (2017). *Explosion triggered economic, environmental devastation, and a legal battle*. April 20. Available at https://www.noaa.gov/explainers/deepwater-horizon-oil-spill-settlements-where-money-went

[65] BP. (2016). *2Q 2016 Results: Conference Call on July 24, 2016*. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/investors/bp-second-quarter-2016-results-presentation-slides-and-script.pdf

Eagle Otome in Port Arthur, TX (2010)

On January 23, 2010, a barge and its towing vessel collided with the tanker Eagle Otome on the Sabine Neches Canal in Port Arthur, Texas. The Eagle Otome was punctured and an estimated 462,000 gallons of Olmeca crude sour oil was spilled into the canal.[66] The spill caused a shipping lane closure of 16 miles and impacted local residents, 136 of whom were temporarily evacuated from the site. Clean up responses at the crash site were delayed for approximately 12 hours due to high levels of hydrogen sulfide. Air monitoring beyond the immediate area did not indicate the presence of hydrogen sulfide, but there was a strong petroleum odor. The spill resulted in $1.5 million in damages to the Eagle Otome, $35,000 to the towing vessel, and $381,000 to the barge vessel.

Enbridge Line 6B in the Kalamazoo River, MI (2010)

On July 25, 2010, a rupture in the Enbridge line 6B pipeline caused oil to leak into the wetlands adjacent to the Kalamazoo River in Michigan. The leak consisted of two batches of heavy bituminous crude oil diluted with lighter petroleum products.[67] It was several hours before the leak was discovered in which time several residents had called the local health department complaining from a heavy oil smell in the air. The spill flowed downstream 38 miles.

Containment and recovery were ongoing for the next four years. Responders installed oil absorbent and a boom at two parks near battle Creek and used vacuum trucks to recover oil from the source area. The Kalamazoo River was closed to the public for 1.5 years, then periodically opened and closed for dredging of submerged oil for the next three years. The presence of benzene and other constituents in the oil posed a respiratory threat to public health and safety. The Michigan Department of Community Health issued a Fish Consumption Advisory and a Swimming Advisory, both of which were in place until June 28, 2012.

DM932 Tanker and Barge Collision near New Orleans, LA (2008)

On July 23, 2008, tanker Tintomara collided with fuel barge DM932 on the Mississippi River near downtown New Orleans. The Tintomara suffered minor damage, but the DM932 barge split into two sections, releasing 270,000 gallons of spilled #6 fuel oil into the Mississippi River. [68] Response to the spill required 2,300 personnel, 130,000 feet of containment boom, 200 boats, and 35 skimmers.[69]

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[66] National Transportation Safety Board. (2010). *Collision of Tankship Eagle Otome with Cargo Vessel Gull Arrow and Subsequent Collision with the Dixie Vengeance Tow Sabine-Neches Canal, Port Arthur, Texas*. January 23. Available at: https://maritimesafetyinnovationlab.org/wp-content/uploads/2015/02/ntsb-eagle-otome-collision-2010.pdf

[67] https://www.fws.gov/midwest/es/ec/nrda/MichiganEnbridge/pdf/FinalDARP_EA_EnbridgeOct2015.pdf

[68] NOAA, Damage Assessment, Remediation, and Restoration Program. (2008). *Fuel Barge DM 932*. Available at: https://darrp.noaa.gov/oil-spills/fuel-barge-dm932

[69] Simmons, R. (2009). *Tank Barge DM 932 Spill: Response from the Perspective of the "Environmental Unit"*. Available at: https://archive.epa.gov/emergencies/content/fss/web/pdf/simmons.pdf

Oil from the barge spread over 100 miles of the lower Mississippi River. More than 130,000 gallons of an oil and water mix were recovered.[70] The river was temporarily closed to vessel traffic for 8 hours to lift the barge out of the water. The incident impacted terrestrial and riparian habitats in the over 100-mile span. In addition, the sediments at the bottom of the river were contaminated.

M/V Westchester in Plaquemines Parish, Louisiana (2000)

On November 28, 2000, the M/V Westchester tanker lost steerage and grounded in Plaquemines Parish, Louisiana. The initial loss of steerage was due to a crankcase explosion onboard.[71] The grounding punched a hole in the cargo tank and an estimated 550,000 gallons of crude oil spilled into the Mississippi River.

Containment measures included placing booms at key bayous and cuts and deploying skimmers to collect oil from the water surface. The case is notable for its efficient recovery of lost oil which was aided by the riprap on the west bank which trapped the oil. Vessel traffic on the Mississippi River was halted the next day for 21 river miles. The river was reopened to in-bound traffic one day later on November 30, 2000 and was opened to both up-river and down-river traffic on December 1, 2000.[72] Several thousand acres of terrestrial, riparian, and oceanic habitat were impacted by the spill. The spill exposed flora and fauna in these areas to black oil, emulsified oil, and sheen. Approximately 19,000 kilograms of finfish and shellfish biomass were lost through direct kill and lost production. In addition, recreation fishing and waterfowl hunting were affected by closures and limited access to boat launch points.

5.1.3 Other Fuel Releases

Failure and fuel releases at the CEI Hub would not only flow into the Willamette River, but also affect the ground resources. The case studies in this section include others at fuel tank farms as well as fuel releases caused by earthquakes. In addition to the effect on terrestrial resources, these incidents also demonstrate the potential for fire and air quality hazards that could result from fossil fuel tank failures.

Savoonga AVEC Tank Farm in Savoonga, AK (2021)

On February 27, 2021, a bulk oil storage tank located at Savoonga Power Plant, operated by Alaska Village Electric Coop, spilled while fuel was being transported between tanks. The power plant is located on St. Lawrence Island, 450 feet from the Bering Sea. The tank leaked an

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[70] NOAA. (2000). *Tanker and Barge Collision in New Orleans, LA Update August 4, 1000 EDT*. Available at: https://incidentnews.noaa.gov/incident/7861/521838/8929

[71] Michel, J., Henry Jr, C. B., & Thumm, S. (2002). Shoreline assessment and environmental impacts from the M/T Westchester oil spill in the Mississippi River. *Spill Science & Technology Bulletin*, 7(3-4), 155-161.

[72] NOAA. (2001). *Final Damage Assessment/Restoration Plan and Environmental Assessment: M/V Westchester Crude Oil Discharge*. Available at: https://www.gc.noaa.gov/gc-rp/west-fnl.pdf

estimated 20,000 gallons of #2 Diesel into secondary containment.[73] A valve left open on a bulk fuel tank caused the leak. The valve was closed and investigators determined there was no environmental impact – oil did not flow into the Bearing Sea or into the nearby wetland tundra.[74] Containment of the spill involved excavating contaminated snow and pumping diesel fuel pooled under the snow. In addition, nine cubic feet of impacted frozen soil was chipped out with a jackhammer. There were no public closures associated with the spill due to its remote location.

Contra Costa NuStar in Crockett, CA (2019)

On October 15, 2019, an explosion occurred at the NuStar energy fuel storage facility in Crockett, California. The facility stored ethanol, gasoline, diesel, and aviation fuels. The fire damaged two tanks containing 250,000 gallons of ethanol.[75] The explosion started a seven-hour-long fire which had serious health and safety effects on the region. All personnel were evacuated from the site and emergency response services were onsite within minutes. The fire consumed thousands of gallons of fuel and investigators found high levels of smoke particulates, but not unusually high amounts of toxic substances.[76] A small grass area also caught on fire. The fires were put out later that same day.

There was a shelter in place ordered approximately one hour after the explosion for nearby residents of Crockett and Rodeo for approximately 7 hours. Contra Costa County also issued a public health order for people in the neighboring communities of Crockett, Rodeo, and Hercules to stay indoors due to poor air quality.[77] Residents were advised to leave air conditioning and fans off and place damp towels in door and window openings. In addition, the twelve-home community of Tormey (located near the NuStar facility entrance) was evacuated and four schools in the area were closed for two days. Both directions of Interstate 80 near the facility were shut down for six hours to help manage the fire. The fire was eventually contained with foam.

Great East Japan (Tohoku) Earthquake and Tsunami (2011)

The devastating Great East Japan Earthquake and Tsunami, also known as the Tohoku Event, occurred on March 11, 2011 when a magnitude 9.0 earthquake occurred about 80 miles off the

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[73] Alaska Department of Environmental Conservation. (2021). *Savoonga AVEC Tank Farm Diesel Oil Release*.

[74] McChesney, R. (2018). No *environmental impact from 22,000-gallon heating oil spill in Savoonga*. Alaska Public Media. March 18. Available at: https://www.alaskapublic.org/2018/03/15/no-environmental-impact-from-22000-gallon-heating-oil-spill-in-savoonga/

[75] Associated Press. (2019). *Earthquake probed as possible cause of California fuel fire*. October 16. Available at: https://apnews.com/article/4b2b77c5ecec4b01b8ef6c70beeb7ca6

[76] Sciacca, A. (2019). "Supes consider tightening rules over fuel storage facilities in wake of NuStar explosion". *East Bay Times*. Available at: https://www.eastbaytimes.com/2019/10/22/concerns-about-nustar-explosion-in-crockett-prompt-contra-costa-officials-to-review-safety-ordinance/

[77] Contra Costa Health. (2019). *Data Incident Report: October 15, 2019*. Available at: https://cchealth.org/hazmat/data-incident-report/60548099.pdf

northeast coast of Japan. Over 20,000 people died and over 500,000 were forced to evacuate. The Fukushima nuclear plant disaster is the most well-known hazardous materials release resulting from the event. However, there were also many instances of toxic substance releases, explosions, and fires resulting from failures at other industrial facilities. At some facilities, the cause of the damage was the earthquake, while at others it was the tsunami.[78] Excluding the costs of the Fukushima nuclear power plant failures, the total economic damages of the event exceed $210 billion.

The Great East Japan earthquake also demonstrates the complexities of responding to oil spill events during an environmental disaster. In Ichihara City, liquefied petroleum gas tanks exploded due to ground motion and resulted in fires that spread to asphalt tanks and buildings throughout the facility that took ten days to extinguish.[79] In the Sendai area, a fire at a petrochemical complex, ignited by a spark caused by tank friction, burned a gasoline tank, asphalt tanks, molten sulfur tanks, and oil handling facilities. Many other oil tanks and petrochemical facilities were damaged by the tsunami and often were washed out to sea.

5.2 Case Studies Summary

The case studies in this section vary in terms of the amount of the spill, the contents spilled, and where it was spilled at. Accordingly, the extent and costs of damages and secondary effects like fires also vary as well. Of the case studies discussed in this section, the potential releases at the CEI Hub following a CSZ event will be similar to the large events, Deepwater Horizon and the Great East Japan earthquake, in terms of level of releases and resulting damages to the environment, health, and safety. Table 10 summarizes common elements for each case study.

[78] Krausmann, E., & Cruz, A. M. (2013). Impact of the 11 March 2011, Great East Japan earthquake and tsunami on the chemical industry. *Natural hazards*, 67(2), 811-828.

[79] Zama, S., Nishi, H., Hatayama, K., Yamada, M., Yoshihara, H., & Ogawa, Y. (2012). On damage of oil storage tanks due to the 2011 off the Pacific Coast of Tohoku Earthquake (Mw9. 0), Japan. In *Proceedings of the 15th world conference on earthquake engineering (WCEE)* (Vol. 2428, pp. 1-10).

Table 10. Case Study Summary

Case Study	Year	Spill Amount	Type of Oil	Spill Location	Fire Status
Fuel Releases in Oregon					
Oregon Lindsey Lake Tanker Spill	2019	4,400 gallons	Diesel fuel (Light Oil)	Ground and freshwater	None
Columbia River Oil Train Derailment	2016	47,000 gallons	Bakken crude oil (Light Oil)	Ground and freshwater	Fire on ground
Tanker SS MobilOil Spill	1984	170,000 gallons	Number 6 Crude Oil and Industrial Fuel Oil (Light and Medium Oils)	Freshwater and saltwater	None
Fuel Releases into Shipping Channels and Water Resources					
Refugio Incident	2015	123,000 gallons	Crude oil	Freshwater and saltwater	None
TX City Y Spill	2014	168,000 gallons	Intermediate fuel oil (Medium Oil)	Ground, freshwater, and saltwater	None
Deepwater Horizon	2010	134-206 million gallons	Macondo crude oil (Light Oil)	Saltwater	Fire on the drilling platform
Eagle Otome	2010	462,000 gallons	Olmeca crude oil (Light Oil)	Freshwater and saltwater	None
Enbridge Line 6B	2010	Over 1 million gallons	Diluted bitumen (Heavy Oil)	Freshwater	None
DM 932 Tanker	2008	270,000 gallons	Number 6 fuel oil (Heavy Oil)	Freshwater	None
M/V Westchester	2000	550,000	Sweet Nigerian crude oil (Light Oil)	Freshwater	None
Other Fuel Releases					
Savoonga AVEC Tank Farm	2021	20,000 gallons	#2 Diesel (Light Oil)	Ground	None
Contra Costa NuStar	2019	250,000 gallons	Ethanol (Light Oil)	Ground	Fire on the ground
Great East Japan (Tohoku) Earthquake and Tsunami	2011	Large (exact amount unknown)	Multiple fuel types (e.g., diesel, asphalt, crude) (Light, Medium, and Heavy Oils)	Ground, freshwater, and saltwater	Multiple fires at petrochemical and fuel storage facilities

Source: Created by ECONorthwest

5.3 Other Evaluations of Fossil Fuel Impacts Near CEI Hub

5.3.1 Tesoro Savage Petroleum Terminal at the Port of Vancouver

The Vancouver Energy Distribution Terminal Facility was proposed to be located on the Columbia River, approximately 10 miles north of the CEI Hub and would be owned and operated by the Tesoro Savage Petroleum Terminal LLC. The proposed crude oil terminal facility would have a capacity of 360,000 barrels of crude oil per day that it would receive by train, store onsite, and then load onto marine vessels to be transported to west coast refineries.

Given the proximity and the similar resources that would be transported at the Tesoro Savage Petroleum Terminal compared to what is stored at the CEI Hub, the research conducted as part of this proposal is also relevant to the potential impacts of releases at the CEI Hub due to a CSZ earthquake.

A 2016 report[80] evaluated impacts to fishing and natural resources from the "worst-case scenarios" from the Draft Environment Impact Statement for the proposed Vancouver Energy Distribution Terminal Facility.[81] The two scenarios are a tanker grounding near Vancouver that would spill over 189,845 barrels (bbls) (about 8 million gallons), and for a train derailment near the Bonneville Dam that would spill 20,000 bbls.

The authors assumed that the spill occurred during spring (between mid-April and mid-May), corresponding with peak salmon populations in the Lower Columbia River. Based on the timing assumptions as well as estimates detailed in the report about fate and transport modelling, the estimated damages to Columbia River habitats from the vessel grounding in Vancouver is $171.3 million, including $114.4 million for injured habitats in the river channel and $56.9 million for injuries to floodplain wetlands adjacent to the river. The estimated damages to Columbia River habitats from the upriver train derailment scenario is $84.9 million, including $54.5 million for injured habitats in the river channel and $30.4 million for injuries to floodplain wetlands adjacent to the river.[82]

[80] Abt Associates Inc. and Bear Peak Economics. (2016). Potential Fishing Impacts and Natural Resource Damages from Worst-Case Discharges of Oil on the Columbia River. Submitted to: Matthew Kernutt, Assistant Attorney General Washington Attorney General's Office. May 12.

[81] The Draft Environment Impact Statement is available at: https://www.efsec.wa.gov/efsec-document/Tesoro%20Savage/SEPA/docGroup/Draft%20Environmental%20Impact%20Statement

[82] All dollar values from Abt Associates Inc. and Bear Peak Economics are 2016 values.

6 Direct Impacts of a CSZ Earthquake on the CEI Hub

The direct impacts of a CSZ earthquake on the CEI Hub and the resulting effects on the surrounding people, property, and environment will likely be exacerbated by the surrounding destruction of the event. Roads, bridges, and many other infrastructure types will be damaged in the earthquake, which will likely impair access to the site to take actions like fire suppression, rescues, containment, monitoring, and other immediately needed steps to minimize the damage from releases. Absent any failures of the CEI Hub and associated fuel releases, there would still be threats to people, property, and the environments from the earthquake. For example, commercial and recreational river activity would likely be impacted from an earthquake due to accessibility and hazards for a period of time, even without any releases from the CEI Hub. The intent of this analysis is to include only effects that are attributable to containment failures at the CEI Hub, and not impacts from the earthquake in general.

The impacts that could be attributable to releases at the CEI Hub that are evaluated in this analysis include:

- Loss of life and injuries directly related to releases at the CEI Hub site or adjacent parcels;
- Effects on navigation and river-related commercial activity;
- Short-term and long-term effects on the environment;
- Short-term and long-term effects from air quality impacts;
- Impacts to cultural resources.

6.1 Earthquake Considerations

Impacts from CEI Hub releases will vary both on the magnitude of the earthquake, the extent of releases, if a fire occurs, and the ability to respond quickly to contain releases. Spill response will be a primary determining factor in how quickly the releases are contained and how far they spread, particularly for releases into the water. Spill responses usually occur as soon as a spill is reported to the spill response team.[83] However, response actions to fuel releases resulting from the CSZ earthquake will likely be substantially delayed due to damaged infrastructure and resource shortages.

The Cascadia Playbook from Oregon Office of Emergency Management suggests that Regional Hazardous Materials Emergency Response Teams (RHMERT) will be contacted within 6 hours

[83] The Lower Columbia Spill Response Plan, as well as all the response plans associated with Region 10 Regional Response Team (RRT) and the Northwest Area Committee (NWAC) is available at: https://www.rrt10nwac.com/GRP/

after an event where oil and hazardous materials need to be controlled and contained.[84] Initiating containment of oil and hazardous materials spills or releases in impacted areas is estimated to begin 24 hours after the event. While these timelines represent best practices, there are potential impediments to a rapid response particularly around access, personnel and resource availability, and other hazards present at the site, each of which are discussed below.

Prior Characterizations of Responding to CEI Hub Failures After a CSZ Event from OSSPAC (2019)[85]
"Other large-scale catastrophes would be unfolding throughout the City and region. Emergency response personnel would struggle to address the disaster occurring at the CEI Hub because roads, bridges, utilities, and communication systems would be damaged or destroyed. And recovery vehicles would be unable to access and use the very fuel that spills from the CEI Hub's tanks."

6.1.1 Access Considerations

Access to the CEI Hub via road or river may be difficult or dangerous due to damage to roads and infrastructure. Following the CSZ earthquake, reopening Tier 1 and Tier 2 state highways in the Willamette Valley will take approximately 1 to 3 days.[86] Access via waterway will also be complicated due to the CSZ earthquake. Structures such as bridges and piers may collapse into the waterway, posing hazards for both access and containment. Access to boat launches may similarly be restricted, causing delays.

6.1.2 Personnel and Resource Availability

The CEI Hub will not be the only area with hazardous releases due to a CSZ earthquake. Release of hazardous materials could also occur from train derailments or damage to vessels. Within the Lower Columbia River, there are additional fuel storage facilities at the NuStar and Tesoro terminals in the Port of Vancouver. There are also other fuel storage facilities in surrounding areas which could have spills due to the CSZ earthquake. Accordingly, resources may be thinly spread throughout these response sites and spills either at the CEI Hub or other locations may extend further than they would have if resources were not constrained by the coinciding incidents.

6.1.3 Release of Toxic Inhalation Hazard Materials

As defined by the Hazardous Materials Regulations, toxic inhalation hazard materials (TIH materials) are gases or liquids that are known or presumed on the basis of tests to be so toxic to humans as to pose a hazard to health in the event of a release.[87] Chlorine gas and anhydrous ammonia are the most common TIH chemicals. Other TIH chemicals include sulfur dioxide,

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[84] Oregon Office of Emergency Management. (2018). *Cascadia Playbook Version 3.0.* Retrieved from https://www.oregon.gov/oem/emresources/Plans_Assessments/Pages/Other-Plans.aspx

[85] Oregon Seismic Safety Policy Advisory Commission of the State of Oregon (OSSPAC). (2019). *CEI Hub Mitigation Strategies: Increasing Fuel Resilience to Survive Cascadia*. December 31. OSSPAC Publication 19-01.

[86] Oregon Seismic Safety Policy Advisory Commission (OSSPAC). (2013). *The Oregon Resilience Plan: Chapter 5. Transportation*. February.

[87] 49 CFR parts 171-180.

ethylene oxide, hydrogen fluoride, and others. Although not stored at the CEI Hub itself, TIH materials are present within the area near the CEI Hub. Evaluating the effect of these chemical releases is beyond the scope of this study, however, the release of those materials due to a CSZ earthquake could complicate spill response efforts at the CEI Hub. In particular, release of TIH materials could limit access to respond to the spill if the presence of TIH substances renders the area too dangerous for emergency personnel.

6.2 Direct Impacts to People and Property

6.2.1 People Near the CEI Hub

There are ten companies on 31 properties located at the CEI Hub that vary in size from 0.1 to 31.27 acres for a total of 219.85 acres.[88] On average there, are 0.8 full-year equivalent workers per acre,[89] for a total of approximately 200 people on-site throughout the CEI Hub properties. More generally, the zip codes where the CEI Hub is located (97231 and 97210) have a total combined population of 16,508 and total employment of 31,517.[90] In addition to the physical presence of these people, there are also people driving through for personal or business reasons and river-related transport that could put people at risk from CEI Hub failures from a CSZ earthquake. Impacts would not only be in these zip codes, but this area represents the immediate nearby population.

The potential for CEI Hub failures to impact people and cause injury or loss of life will depend in part on when the event happens – if it happens on a weekday or weekend, during the day or at night, and what season – since that will influence how many people are working in and around the site. During weekends and at night, there will be fewer people in the area based on use patterns. Similarly, during the winter there may be fewer people on the water compared to a sunny day at the height of the fishing season.

In the event that there are also fires at the CEI Hub or at nearby industrial sites, which are likely to occur, people and property will be further threatened by direct fire risk as well as air quality health impacts. Evacuations will be extremely challenging during this time due to ground damage, potential impacts to the telecommunication network, and strained emergency response resources. Fire response resources may not be able to immediately address the blazes at these locations, which could result in the fire spreading throughout the area. Of note, burning is sometimes a clean-up mechanism used for oil spills, so fuel ignition could decrease the amount of oil that contaminates the environment via land or water. Air quality impacts are discussed further in Section 6.5 of this report.

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[88] See Appendix B for a fill list of properties and their characteristics.

[89] Quarterly Census of Economics and Wages (QCEW) contains confidential information and was available for this study through a data use agreement with the Oregon Employment Department. All results are aggregated and reported in a way that maintains confidentiality standards.

[90] IMPLAN 2019 Study Area Data for Combined Zip Codes 97231 and 97210.

A March 12, 2019 fire at NW Metals Inc. in Portland demonstrates the emergency response and potential health effects from fires at industrial sites. During this event the City of Portland and Multnomah County issued an evacuation order for residents between Northeast 60th and 76th avenues and Northeast Columbia Boulevard and Alberta Street, using buses to evacuate residents without personal transportation. Particulate matter was the primary concern from this event, which poses a health risk, particularly to young children, seniors, and people with compromised respiratory systems.[91] Toxic chemicals in the air were also a concern, including asbestos, aldehydes, acid gases, sulfur dioxide, nitrogen oxides, polycyclic aromatic hydrocarbons, benzene, toluene, styrene, metals, and dioxins.

6.2.2 Impacts to Properties

CEI Hub property owners will experience the largest property damage resulting from tank failures. Some of the tank failures and lateral spread ground movement has the potential to impact adjacent property owners as private property is displaced throughout the area. Fires can also spread across properties – the extent of the damage will vary by the spread of the fire. CEI Hub fuel releases that reach the Willamette River or flow downstream will primarily impact the state-owned waterways, since the State of Oregon owns the bed and the banks of navigable rivers up to the high-water mark.[92]

6.3 Navigation and Commercial Activity Impacts

The navigation channel of the Willamette River is a critical shipping area for marine vessels that provides access to the CEI Hub as well as other nearby facilities, including Terminal 2, Terminal 4, the Swan Island Industrial Park, and other private businesses. To understand the extent of navigation and commercial activity, vessel counts were derived from vessel Automatic Identification System (AIS) data provided by the Bureau of Ocean Energy Management (BOEM) and NOAA as of 2017.[93] This data source contains total counts for large vessels, but excludes small vessels not required to have automatic identification systems. Daily counts were calculated for the entire year for the Willamette from the 405 bridge to the confluence of the Willamette River with the Columbia River. Each vessel was counted once per day for each day of the year using a unique identifier. Vessel types in the AIS data are standard categories used by the U.S. Coast Guard, NOAA, and the BOEM.[94]

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[91] Multnomah County. (2018). *Evacuations expand Monday night in Northeast Portland due to unhealthy smoke from fire.* March 12. Available at: https://multco.us/multnomah-county/news/evacuations-expand-monday-night-northeast-portland-due-unhealthy-smoke-fire

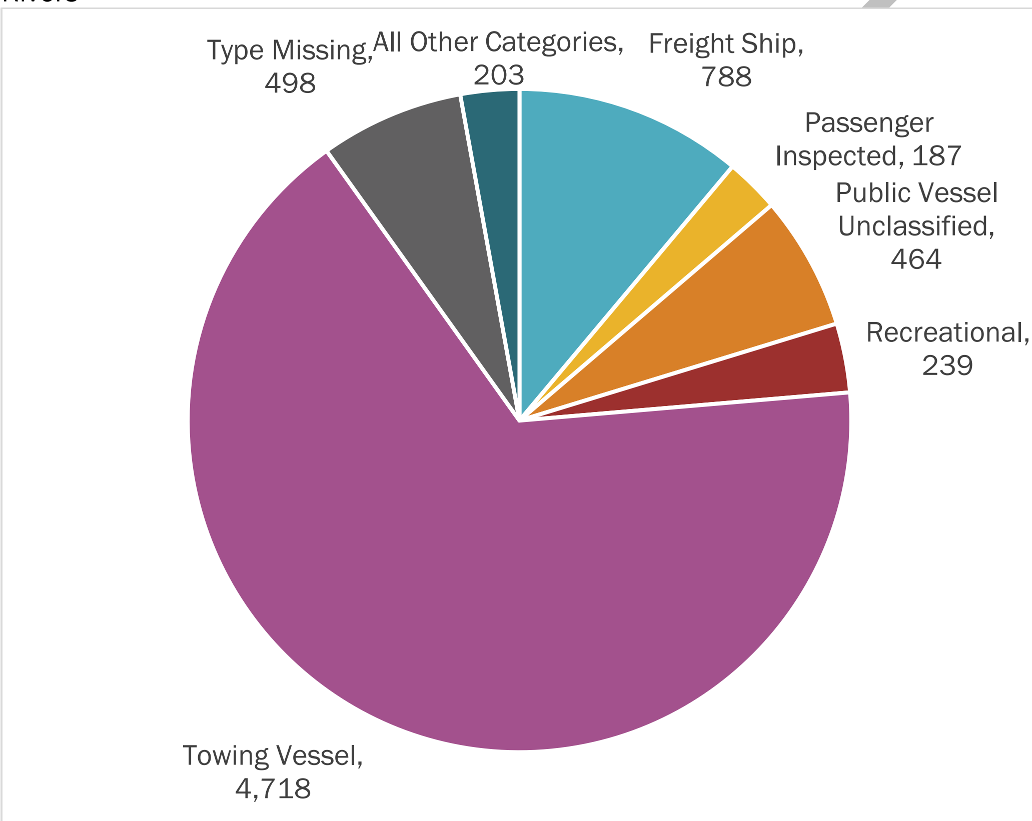
[92] Oregon Department of State Lands. (No Date). *Public Use of Oregon's Rivers and Lakes.* Available at: https://www.oregon.gov/dsl/ww/documents/nav_brochure.pdf

[93] Automatic Identification System (AIS) data obtained from: https://marinecadastre.gov/data/

[94] More information on the classification of vessel types is available at: https://coast.noaa.gov/data/marinecadastre/ais/VesselTypeCodes2018.pdf

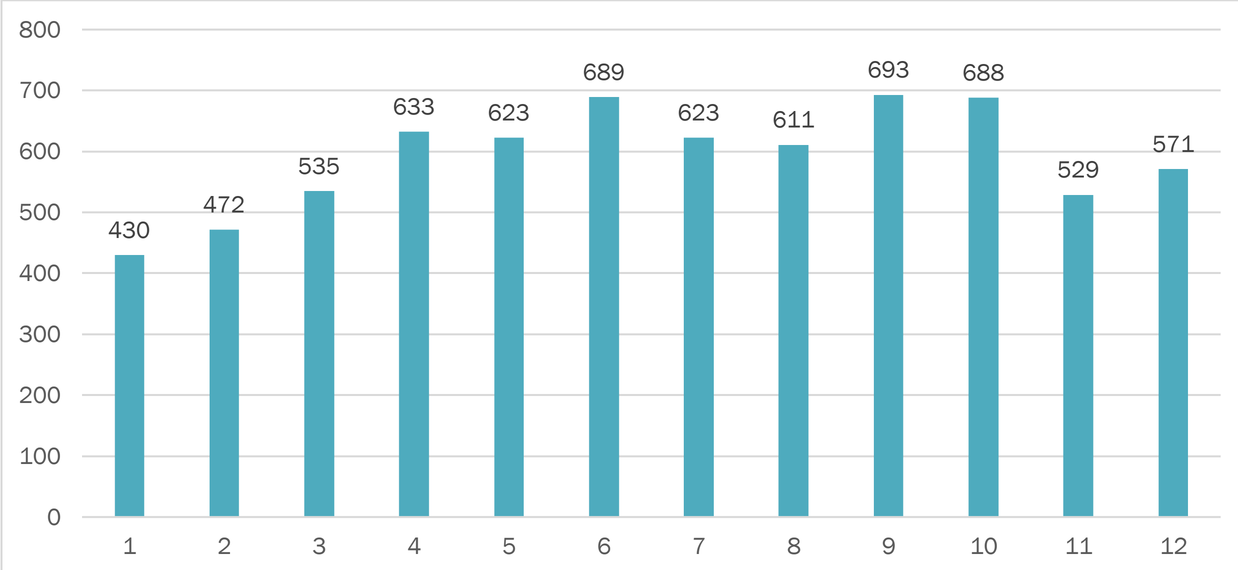
Based on the AIS data, there were 7,097 total vessels that passed by the CEI Hub on the Willamette River in 2017 (annual total). Of the total vessels, approximately 67 percent were towing vessels and the remainder where other vessel types including public, commercial, and recreational vessels (Figure 6). Vessel counts vary slightly by day of week, ranging from a low of 17 average vessels per day on Sunday to a high of 21 vessels per day on Tuesdays and Fridays. Similarly, there is some variation by month, with a low of 430 vessels in January and a high of 693 vessels in September – for an average of 591 vessels per month (Figure 7).

Figure 6. Annual Vessel Counts by Type, 2017, I-405 to Confluence of Willamette and Columbia Rivers



Source: Automatic Identification System (AIS) data provided by the Bureau of Ocean Energy Management (BOEM). (2017). Retrieved from https://marinecadastre.gov/data/

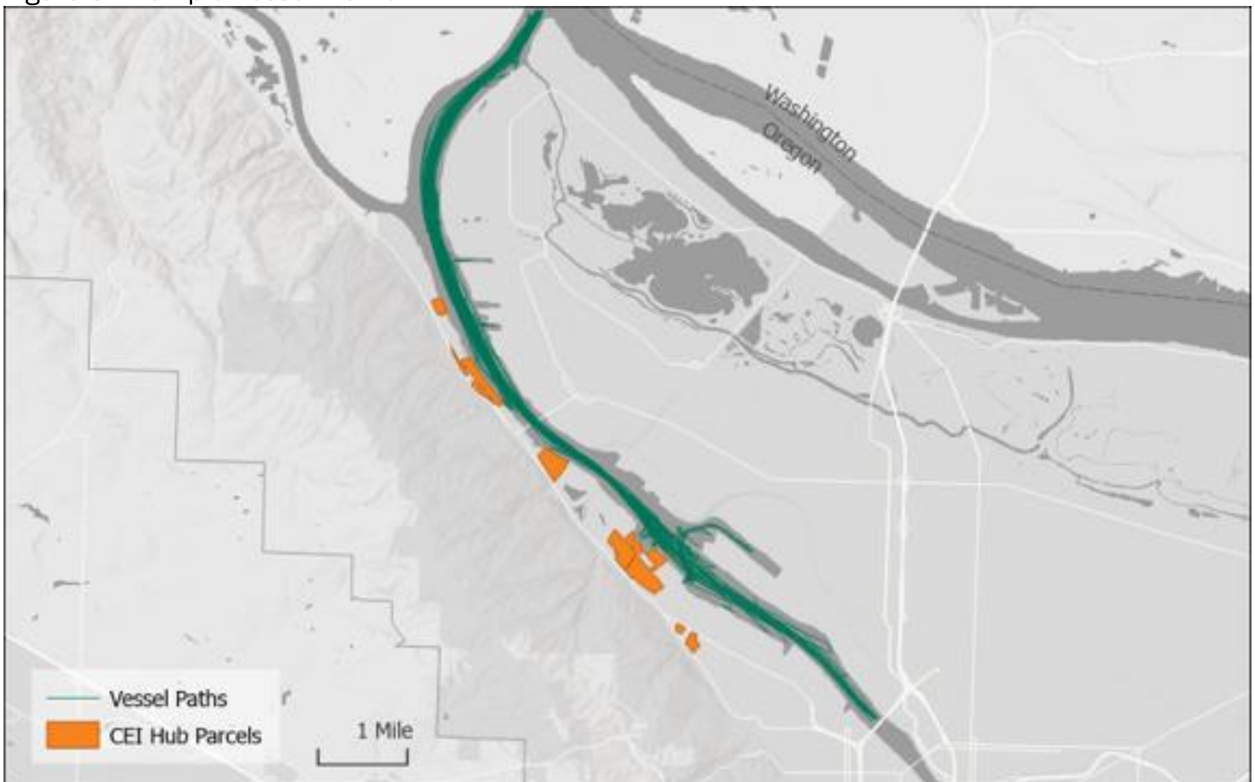
Figure 7. Total Vessel Traffic by Month, 2017, I-405 to Confluence of Willamette and Columbia Rivers



Source: Source: Automatic Identification System (AIS) data provided by the Bureau of Ocean Energy Management (BOEM). (2017). Retrieved from https://marinecadastre.gov/data/

Figure 8 depicts towing vessel traffic paths (in green) for a combination of high volume, average volume, and low volume sample days from 2017. As demonstrated in the map, the river area immediately adjacent to the CEI Hub and downstream between the CEI Hub and the confluence with the Columbia River are the most heavily used vessel traffic areas of the Willamette River.

Figure 8. Example Vessel Traffic



Source: Created by ECONorthwest using vessel path data from Automatic Identification System (AIS) data provided by the Bureau of Ocean Energy Management (BOEM). (2017). Retrieved from https://marinecadastre.gov/data/

6.3.1 Impact of Navigation Closures

To the extent that navigation impedes commercial activity, it will be impacted by the closure of the shipping channel resulting from failure to contain the materials located at the CEI Hub. The length of time for closures of this shipping channel due to CEI Hub failure will likely extend for days, but debris from earthquake including potential bridge delays could lead to extended closures. Historically, shipping channel closures only last for several days to minimize the impact of closures on transportation and because clean-up actions occur as soon as possible.[95] Following a CSZ earthquake, there may be added delays due to access. For every day of closure there would be on average 19 vessels impacted.

6.4 Recreation Impacts

There are multiple recreation resources that could be impacted by releases at the CEI Hub. Water-based recreation would be impacted by discharges, likely resulting in closures to the area for multiple months. Terrestrial recreation would be impacted by air quality impacts as well as any fire that occurs at the site. Figure 9 is a map of recreation resources either on or within immediate proximity to the Willamette River from the City of Portland.

[95] For example, in the Texas City Y spill the shipping channel was open after 3 days.

Figure 9. Recreation Resources in Proximity to the CEI Hub

Source: City of Portland, Bureau of Planning and Sustainability. (2020). *Willamette River Greenway Inventory*. December 16.

In addition to the recreation resources in the immediate vicinity of the CEI Hub there are also popular recreation sites that could be impacted by released materials at the CEI Hub. Forest Park, a 5,200 urban forest owned by the Portland Parks and Recreation, is located Northwest of the CEI Hub in the upland area on the opposite side of Highway 30/NW Saint Helen's Road. Visitation at Forest Park is most likely to be impacted by air quality hazards, particularly during any fire that occurs. The Cascadia earthquake will also likely affect visitation at Forest Park due to the damage to roads and other infrastructure, as well as downed trees and other hazards within the park itself.

Downstream of the CEI Hub is Sauvie Island, an island located between the Willamette River and Columbia River that hosts a large wildlife refuge, agricultural farms, and private residences. During the summer, boat access and beaches are popular recreation sites. During the fall and early winter, Sauvie Island Wildlife Refuge is used for waterfowl hunting. Impacts from CEI Hub failure and releases would temporarily impact Sauvie Island recreation sites and activities from airborne releases caused by burning in the event of a fire. Water contamination could also impact Sauvie Island boating and swimming. The extent of water contamination would vary depending on containment actions in the spill response. Fishing and waterfowl hunting at Sauvie Island are likely to be impaired immediately and in the years following the spill due to lingering environmental toxins. The Cascadia earthquake will also likely affect visitation at Sauvie Island due to the damage to roads and other infrastructure, as well as downed trees and other hazards within the park itself.

6.4.1 Water-Based Recreation

The water-based recreation resources in and around the CEI Hub are primarily boat ramps with access to the Willamette River. Within the anticipated closure area from the confluence with the Columbia River and the I-405 bridge, there are two boat ramps that provide both motorized and non-motorized boat access, Swan Island boat ramp and Cathedral Park boat ramp, and two boat ramps that only allow non-motorized access, at McCarthy Park and Kelley Point Park. There is also the fishing dock at Cathedral Park, which is a short-term tie-up dock. Visitation counts are not maintained at any of these sites. However, estimates from Portland Parks and Recreation for Swan Island boat ramp suggest that there are 2,500 launches and retrievals each year from this site alone.[96]

River recreation along this stretch of the Willamette River is primarily for motorized fishing vessels. For this reason, use is especially pronounced in the fishing season for salmon and steelhead, beginning in May and extending through the summer months. Motorized personal watercraft also uses this stretch for boat tours along the Willamette River near the City Center. People also launch kayaks, paddleboards, sailboats, and other dingeys from these locations.

Immediate impacts to river recreation from failure of the CEI Hub would be the closure of these access points while clean-up occurs. Based on the timeline for the Refugio Incident in California which was likely smaller than what would occur at the CEI Hub, clean-up will likely last multiple months. Some of these closures as well as voluntary ends to use may occur regardless of the CEI Hub spill due to the damage from the CSZ earthquake. Depending on liquefaction at other sites, roads and access points likely would not be usable anyways for an extended period of time. Water quality of the Willamette River will likely also be impacted due to the sediment loading resulting from the earthquake, which would impact fishing conditions in particular.

6.4.2 Fish Consumption

Longer term, the residual contaminants from the CEI Hub failures could result in fishing advisories to limit consumption of aquatic species in this area. However, there are currently fishing advisories in place for resident fish in this stretch of the Lower Willamette.[97] Resident fish should not be eaten at all due to their high concentrations of polychlorinated biphenyls (PCBs) that pose a risk to human health. Resident fish include carp, brown bullhead, bass, walleye, and other fish that live their whole lives in the Lower Willamette. The advisory does not apply to migratory fish like salmon, steelhead, and shad.

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[96] Email communication from Maya Agarwal, Portland Parks & Recreation, on March 16, 2021.

[97] The April 11, 2018 Lower Willamette fish advisory is available from the Oregon Health Authority at: https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/RECREATION/FISHCONSUMPTION/Pages/Lower-Willamette-Fish-Advisory.aspx

6.4.3 Terrestrial Recreation

The terrestrial recreation sites located near the CEI Hub, between the confluence with the Willamette River and I-405 and with views of the river, include the following sites, as well as informal use along the banks of the river, particularly on the Northern side:

- Cathedral Park
- Forest Park
- Kelley Point Park
- Greenway Trail
- Willamette Cove Natural Area
- Harbor View Property
- McCarthy Park
- Swan Island Park
- St. Johns Bridge Viewpoint
- Railroad Bridge Viewpoint

Many of these are popular sites for people throughout the Portland metro area and beyond. Like water-based recreation, terrestrial recreation will be impacted by the earthquake due to access and potential hazards. There will likely be temporary air-quality impacts to these sites resulting from the smoke from the fire and hazardous aerosol chemical releases that—in absence of CSZ earthquake closures—could affect recreation at these sites, but there will likely already be recreation closures at these sites due to other CSZ earthquake impacts.

6.5 Air Quality and Health Impacts

With tank failure, the fuels, additives, gasses, and other materials stored at the CEI Hub could ignite, releasing a toxic plume into the air. Even if it did not ignite, volatilization of harmful components of the materials would also travel beyond the site. This air would spread throughout the area, posing health risks to people, pets, livestock, and wildlife. The health impacts of these releases would be most immediate and severe for the people working in and around the CEI Hub. There are populated areas located primarily north, south, and east of the CEI Hub, and depending on wind conditions there could be extreme risks to human health from this harmful plume.

Air quality in the Portland metro region is at times already hazardous, primarily the result of wildfire and wood burning stove smoke with stagnate air (ozone and particulate matter),[98] as well as releases from manufacturing facilities.[99] Any air quality impacts from a release at the CEI Hub would only compound any existing concerns. Burning petrochemicals produce several

[98] More information about smoke related DEQ air quality advisories is available at: https://www.oregon.gov/deq/aq/Pages/Air-Pollution-Advisories.aspx

[99] More information about industrial air quality concerns is available from Oregon Department of Environmental Quality at: https://www.oregon.gov/deq/aq/Pages/Air-Quality-Map.aspx

types of air pollutants including VOCs, NOx, sulfur dioxide (SO_2), and particulate matter ($PM_{2.5}$). All of these pollutants can have negative effects on human health and quality of life, from shortness of breath to respiratory infections and even cancer.[100] Local populations will be vulnerable to the adverse health effects of these pollutants, which may lead to increases in illnesses, reduced quality of life, and increased costs of treatment. These types of air quality impacts have been observed in other major oil spills.[101]

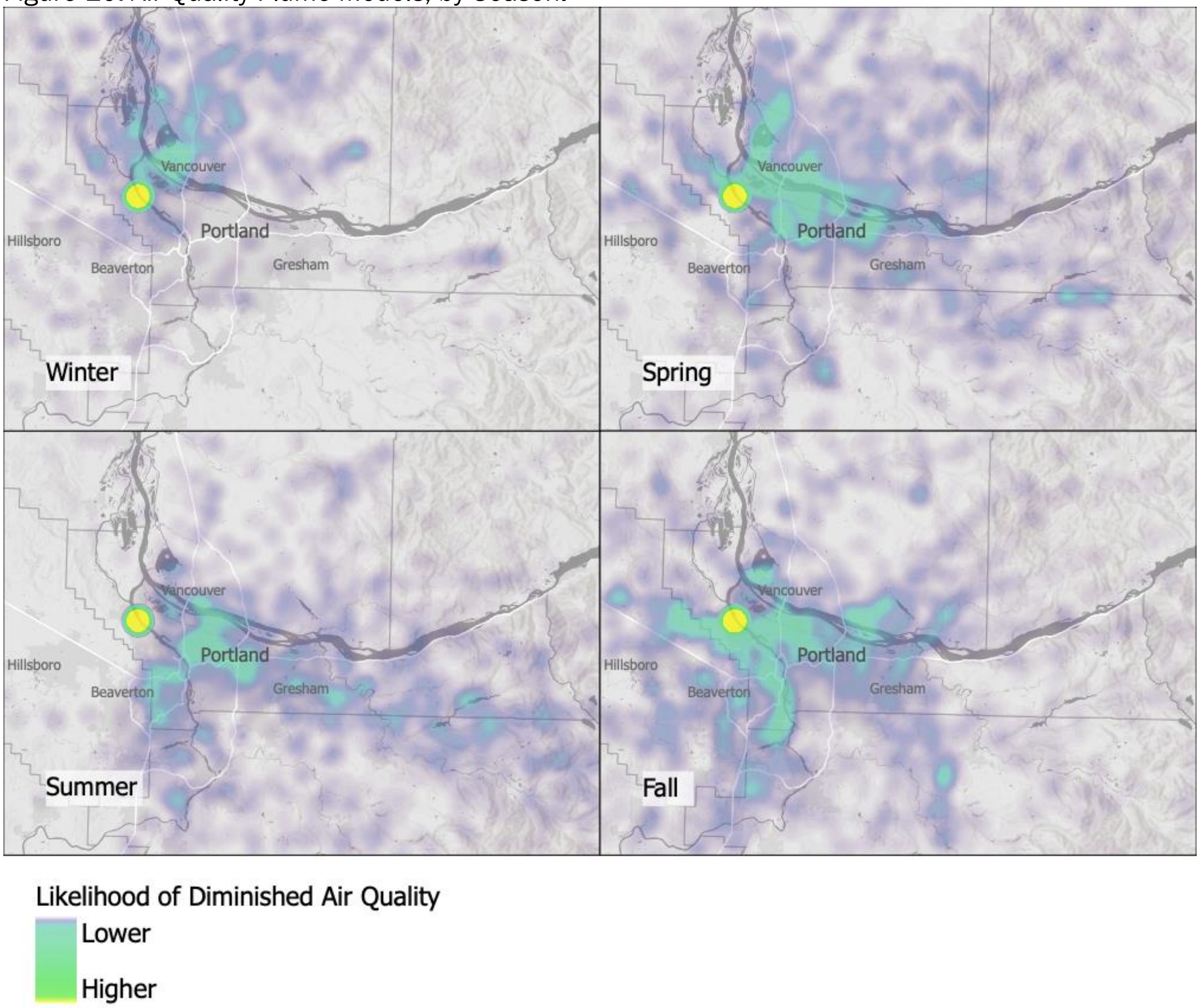
The ultimate direction of any air plume from releases at the CEI Hub are very weather specific and can vary from day to day. Nevertheless, there are seasonal trends that put certain portions of the Portland Metro region's population at higher risk. NOAA's Air Resources Laboratory's Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) is one of the most widely used models for atmospheric trajectory and dispersion calculations.[102] A series of scenarios modeling 24 hour releases during a systematic sample of 12 days per season in 2020 show that the Portland area experiences high weather variability in fall and spring, but more consistent trends in the winter and summer. Should the CSZ event occur in the summer, residents to the south and east of the CEI Hub are likely to experience the greatest air-quality decreases, while residents in the north are likely to experience greater harms in the winter (Figure 10).

[100] National Institute of Health. (2019). "Chemicals and Contaminants". *Tox Town: U.S National Library of Medicine*. Retrieved from: https://toxtown.nlm.nih.gov/chemicals-and-contaminants.

[101] Middlebrook, A. M., Murphy, D. M., Ahmadov, R., Atlas, E. L., Bahreini, R., Blake, D. R., & Ravishankara, A. R. (2012). Air quality implications of the Deepwater Horizon oil spill. *Proceedings of the National Academy of Sciences*, *109*(50), 20280-20285.

[102] Stein, A. F., Draxler, R. R., Rolph, G. D., Stunder, B. J., Cohen, M. D., & Ngan, F. (2015). NOAA's HYSPLIT atmospheric transport and dispersion modeling system. *Bulletin of the American Meteorological Society*, 96(12), 2059-2077.

Figure 10: Air Quality Plume Models, by Season.



Source: NOAA HYSPLIT analysis performed by ECONorthwest

6.6 Habitat Impacts

6.6.1 Effect of Substance Releases on Fish and Wildlife

Oil spills from CEI Hub failures have the potential to cause direct mortality and long-term harm to fish and wildlife in both the immediate area of the spill as well as in water resources as materials are transported downstream. Oil releases can affect wildlife not only through the initial direct exposure, but also through impacts to habitats and clean-up activities. Oil contamination can also degrade habitats and limit food supplies, which could cause secondary mortality or other harm to species and indirect mortality.[103] These factors of toxicity and habitat impairment, as well as the physiological stress from oil spills, can also affect the reproductive

[103] National Research Council. (2003). *Oil in the Sea III: Inputs, Fates, and Effects*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10388.

success of species.[104] Lastly, clean-up actions can also be disruptive, particularly more invasive actions like suctioning, dredging, and burning contaminated vegetation. Specific concerns from oil spills for different types of species include:[105]

- **Birds:** Birds are likely to be exposed to oil as they float on the water's surface. Oiled birds can lose the ability to fly, dive for food, or float on the water which could lead to drowning. Oil interferes with the water repellency of feathers and can cause hypothermia. Oil ingestion has been shown to cause suppression to the immune system, organ damage, skin irritation and ulceration, and behavioral changes. Damage to the immune system can lead to secondary infections that cause death, while behavioral changes may affect an animal's ability to find food or avoid predators.
- **Shellfish**: Oil can be toxic to shellfish including bottom dwelling (lobsters, crabs, etc.) and intertidal (clams, oysters, etc.) species. The bottom dwelling species may be particularly vulnerable when oil becomes highly concentrated along the shoreline.
- **Fish:** Fish can be impacted directly through uptake by the gills, ingestion of oil or oiled prey, effects on eggs and larval survival, or changes in the ecosystem that support the fish. Adult fish may experience reduced growth, enlarged livers, changes in heart and respiration rates, fin erosion, and reproductive impairment when exposed to oil. Oil has the potential to impact spawning success as eggs and larvae of many fish species are highly sensitive to oil toxins.

Because oil has the potential to persist in the environment long after a spill event, it can have long-term impacts on fish and wildlife populations. Accordingly, injuries can persist well beyond the direct clean-up from an incident.

6.6.2 Habitat Types in and Around CEI Hub

NOAA maintains environmental sensitivity maps that identify natural resources that are potentially at-risk if an oil spill occurs nearby. The NOAA environmental sensitivity maps for the Columbia River include mapping of the CEI Hub.[106] Resources immediately near the CEI Hub include birds, fish, and reptiles, such as:

- **Birds:** Bald eagle, osprey, and other waterfowl.
- **Fish:** Chinook salmon, coho salmon, sockeye salmon, steelhead, white sturgeon, and others.
- **Reptiles:** Western pond turtle and western painted turtle.

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[104] NOAA, Office of Response and Restoration, *How Toxic is Oil*?. Available at: https://response.restoration.noaa.gov/oil-and-chemical-spills/significant-incidents/exxon-valdez-oil-spill/how-toxic-oil.html

[105] U.S. Fish and Wildlife Department. (2010). *Effects of Oil on Wildlife and Habitat*.

[106] The CEI Hub is mapped as "ESI20" for the Columbia River, available at: https://response.restoration.noaa.gov/esi_download#Oregon

The lower Columbia River supports 74 populations of salmon, steelhead, and bull trout.[107] Many of these species are listed threatened or endangered under state and federal law. In 2020 there were 7.0 million adult and jack species counted at Bonneville dam and 70,000 counted at Willamette Falls.[108, 109]

Downstream of the CEI Hub, there are additional environmentally sensitive resources. The downstream area of the Willamette River, Columbia River, and their tributaries includes the Sauvie Island Wildlife Area, Ridgefield National Wildlife Refuge, Julia Butler Hansen Refuge for The Columbian White-Tailed Deer, and the Lewis and Clark National Wildlife Refuge.[110, 111] These refuge areas support wintering and migrating concentrations of waterfowl and shorebirds, provide juvenile salmonid rearing habitat, and contribute to the food supply for a wide swath of environmental resources. There are also multiple areas of Freshwater Forested/Shrub Wetland habitat located downstream of the CEI Hub that are hydrologically connected to the Willamette or Columbia Rivers.[112] Because they are downstream of the CEI Hub, all of these resources have the potential to be impacted depending on river conditions and spill response activities. Figure 11 displays the location of these sensitive habitat and wildlife areas.

[107] State of Salmon in Watersheds. (2020). *Lower Columbia River*. Available at: http://teststateofsalmon.wa.gov/regions/lower-columbia-river/salmon/

[108] Columbia Basin Fisheries Agencies and Tribes, *Fish Passage Center Website*. Available at: https://www.fpc.org/

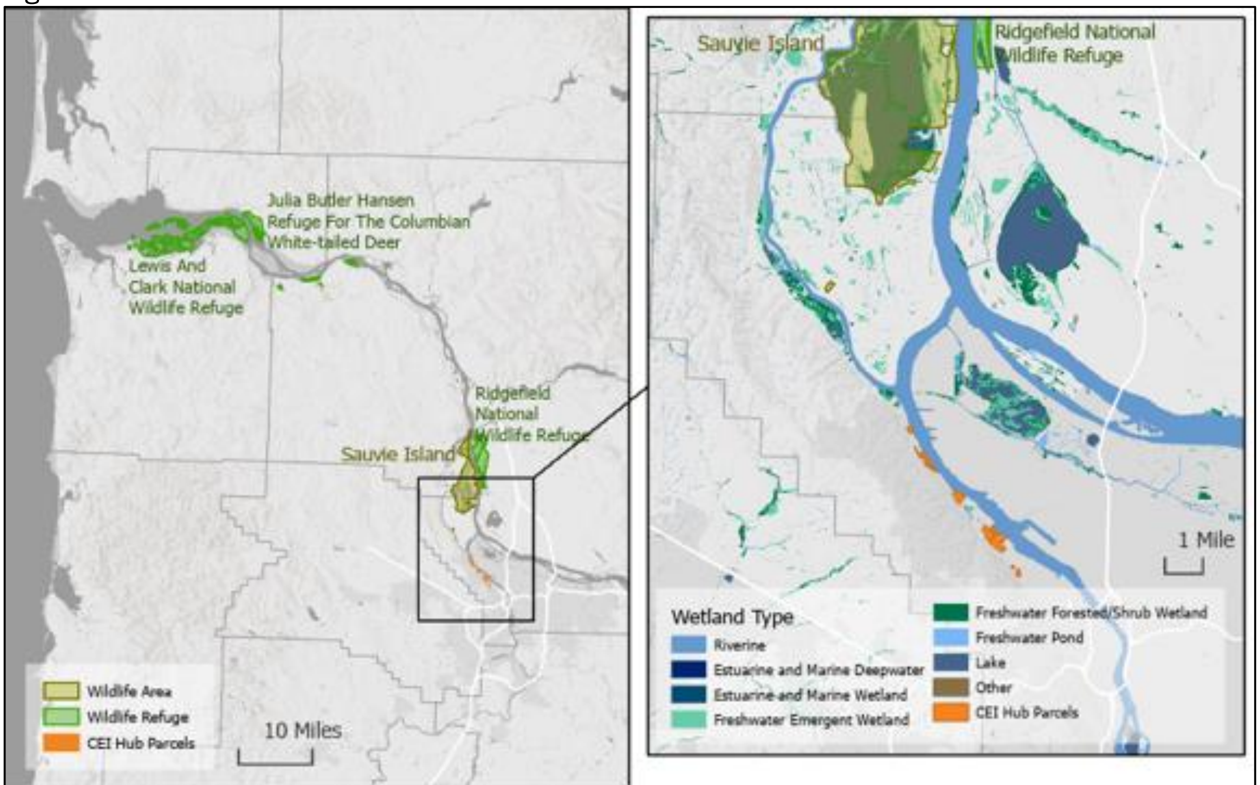
[109] Counts include Chinook salmon (Adult and Jack), Coho salmon (Adult and Jack), Steelhead, Sockeye salmon, Pink salmon, Chum salmon, Lamprey, and Shad.

[110] Abt Associates Inc. and Bear Peak Economics. (2016). *Potential Fishing Impacts and Natural Resource Damages from Worst-Case Discharges of Oil on the Columbia River.* Submitted to: Matthew Kernutt, Assistant Attorney General Washington Attorney General's Office. May 12.

[111] Region 10 Regional Response Team (RRT) and the Northwest Area Committee (NWAC). (2015). *Lower Columbia Spill Response Plan*. October. Available at: https://www.rrt10nwac.com/GRP/

[112] U.S. Fish and Wildlife Service, *National Wetland Inventory Mapper*. Available at: https://www.fws.gov/wetlands/data/mapper.html

Figure 11. Location of Sensitive Wildlife and Habitat Areas



Source: Created by ECONorthwest using information from U.S. Fish and Wildlife Service, National Wetland Inventory mapper

6.6.3 Extent of Releases from CEI Hub

The impact on habitats and species from tank failures at the CEI Hub is based primarily on the amount of material that flows into the water. Because the CEI Hub is an industrial area, releases only onto the ground are not likely to cause extensive habitat impacts. Fires and the chemical vapors that they produce could impact wildlife in the same way that they can impact humans.

As discussed in Section 3, between 40.8 million to 82.5 million gallons of oil and hazardous materials could potentially flow into the Willamette River due to a CSZ earthquake and subsequent tank failures. This level of spill would be between one-quarter to one-half of what was released over three months in the Deepwater Horizon oil spill. When the oil is released into the Willamette River, it will flow with the river current until it is contained or until it reaches the Pacific Ocean. Table 11 details the seasonal average river currents for the Willamette and Columbia Rivers at the closest upstream gages to the CEI Hub. As demonstrated in these values, the river current (i.e., velocity) can be more than to six times faster in the winter compared to the summer and is faster in the Columbia River than the Willamette River.

Table 11. Seasonal Average Water Velocity (feet per second)

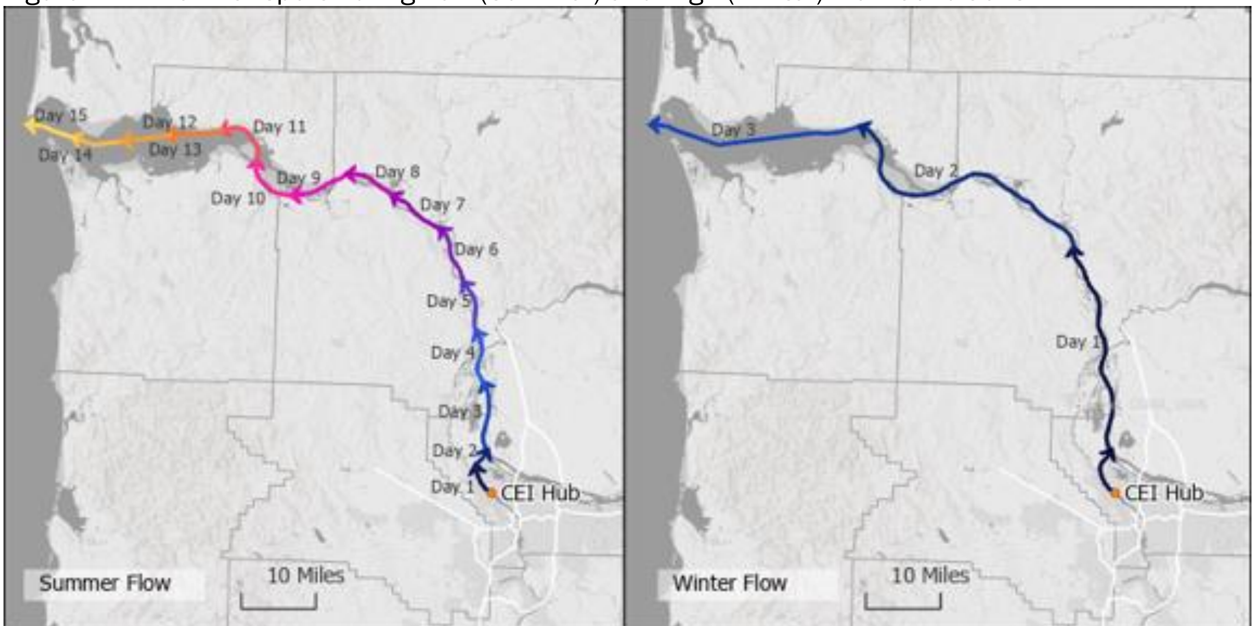
	Willamette River at Broadway Bridge, Portland, OR	Columbia River at Vancouver, Washington
Winter	1.58	2.45
Spring	0.48	1.20
Summer	0.24	0.47
Fall	0.56	1.09

Source: Calculated by ECONorthwest based on information from USGS, *National Water Information System: Web Interface*, available at: https://nwis.waterdata.usgs.gov/nwis

The river currents describe how fast remaining materials will flow downstream. As discussed in Section 4.2, because materials evaporate and disperse over time, there are fewer remaining materials each day. Heavier fuels will remain longer in the water without dispersing or evaporating. Modelling current and weathering information also informs the extent of contamination based on when containment and clean-up activities commence.

Based on the current in the summer it will take approximately 15.5 days for materials released from the CEI Hub into the Willamette River to reach the Pacific Ocean (Figure 12). In contrast, during the winter when currents are faster, it will take approximately 3 days for remaining materials released from the CEI Hub into the Willamette River to reach the Pacific Ocean. These timelines are without containment actions. With containment actions the flow of released materials would be stopped where the containment occurs. Of note, fuels and industrial containments are likely to also enter the Willamette River and Columbia River from other sites due to the CSZ earthquake, so containment actions will be needed at other locations as well. Containment before releases reach the ocean may not be possible due to the damages to infrastructure following the earthquake and other complications.

Figure 12. River Transport During Low (Summer) and High (Winter) Flow Conditions



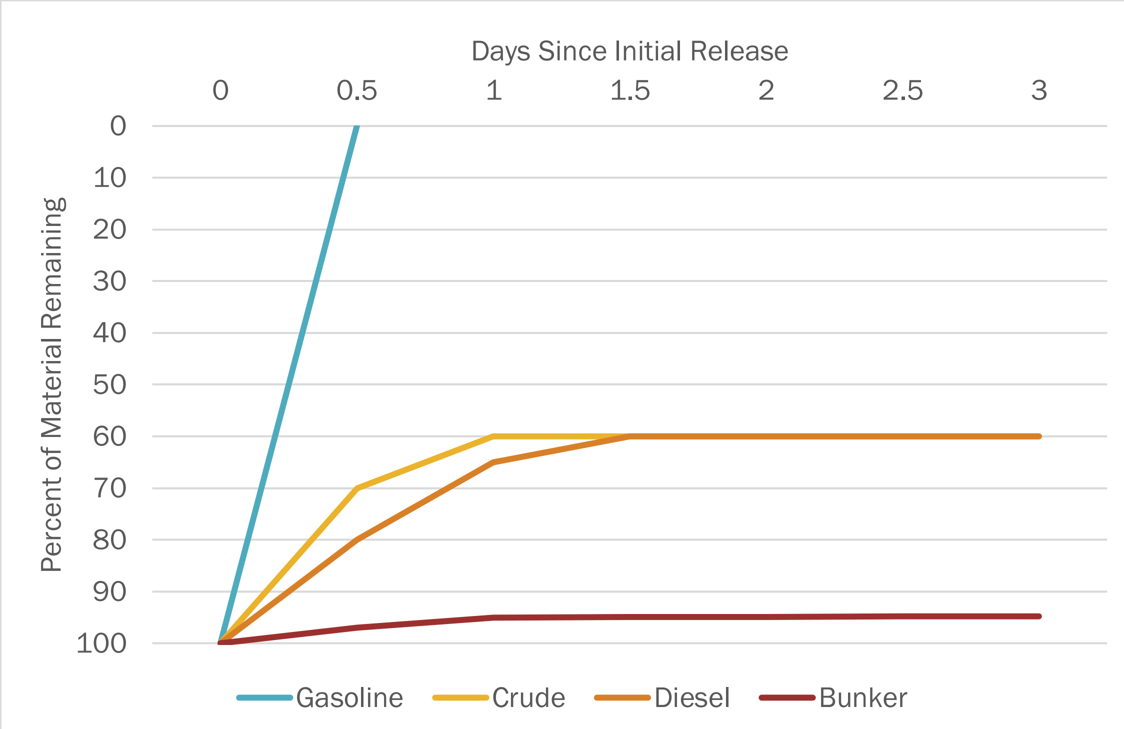
Source: Created by ECONorthwest using data from USGS

As discussed in section 4.2, not all the materials released from the CEI Hub will remain in the water for the length of time it would take to reach the Pacific Ocean. After 10 hours, almost of all the gasoline, ethanol, and aviation fuel will have evaporated into the air, particularly during hotter days when evaporation rates are higher and more sunlight and microbes can break down the chemicals.[113] Diesel and crude oil will evaporate in part, but up to 60 percent could be remaining when the materials reach the Pacific Ocean.[114] Because these light fuels float on top of the water they will largely flow with the river. Heavier oils like asphalt and bunker crude oil will sink in the water and largely remain in any environment that they come in contact with on riverbeds and shorelines. Despite sinking, heavier oils will continue to be transported by the water velocity, although at a slower rate than non-sinking lighter oils that remain on the water surface. Figure 13 models sample evaporation rates for gasoline, crude, diesel, and bunker fuels over time for the first three days.

113 National Research Council. (2003). *Oil in the Sea III: Inputs, Fates, and Effects*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10388.

114 National Research Council. (2003). *Oil in the Sea III: Inputs, Fates, and Effects*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10388.

Figure 13. Evaporation Rates



Source: Created by ECONorthwest using information from National Research Council (2003) and NOAA ADIOS model results.

Applying the evaporation rates described previously to the materials that could be potentially released at the CEI Hub results in the finding that after three days between 20.9 million and 42.3 million gallons of diesel, medium, and heavy oils could be remain in the water (excluding additives and unknown materials). Because most evaporation occurs early, in the low flow scenario in the summer these levels of materials are likely to remain about as high for the remaining days and be transported to the Pacific Ocean. This level of contamination is likely to result in significant mortality among aquatic species throughout the lower Willamette and Columbia Rivers. Mortality and impacts to sensitive species will be particularly pronounced if the spill occurs during the salmon spawning seasons in the late spring to early fall.

6.6.4 Effect of Ground Spills on Properties

The habitat impacts of spills onto the ground at the CEI Hub will not be as severe as the water resources because materials will not be transported on the ground and there are not sensitive habitats in the terrestrial area of the CEI Hub. However, releases on to the ground will contaminate the soil and require clean-up efforts and site remediation, such as soil removal. Oil sheens on the ground are possible for years afterwards even with remediation actions.

6.7 Impacts to Cultural Resources

Historically, the Willamette River has been used by local tribes for subsistence, transportation, commerce, and ceremonial purposes. The Cultural Resources Analysis Report for the Portland Harbor Superfund Site (2005) details some of the specific cultural resources near the CEI Hub:[115]

> "Some Tribes retain treaty rights to salmon and other fish including lamprey, not only as a source of food but also as part of their culture and spirituality. Wetlands in this region are also culturally important because wetlands support wapato, a harvested item that was traded between Chinookans in the Portland Basin and other Native peoples at the coast. The only known location that currently supports wapato is a small riverine wetland located in the Swan Island Lagoon. Native vegetation was also gathered for food and tools."

The Willamette River has been the site of tremendous investment through the Portland Harbor Superfund Clean Up,[116] and those efforts have been working to improve the environmental conditions to support cultural values related to habitats and the species they support. Particularly for tribes, restoring this ecosystem is of particular importance to correct historic loss of cultural value.

[115] Ellis, D.V., Allen, J.M., and Hajda, Y. (2005). *Cultural Resource Analysis Report for the Portland Harbor Superfund Site, Portland, Oregon*.

[116] More information about the Portland Harbor Superfund Site is available at: https://cumulis.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.Cleanup&id=1002155#bkground