Potential Fishing Impacts and Natural Resource Damages from Worst-Case Discharges of Oil on the Columbia River

Report in the Matter of Application No. 2013-01
Vancouver Energy Distribution Terminal
EFSEC Case Number 15-001

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List of Acronyms and Abbreviations

Abt	Abt Associates
ADIOS2	Automated Data Inquiry for Oil Spills 2
API	American Petroleum Institute
BTEX	benzene, toluene, ethylbenzene, and xylenes
DEIS	Draft Environmental Impact Statement
DEM	digital elevation model
dilbit	diluted bitumen
DSAY	discounted service acre-year
DWH	*Deepwater Horizon*
EFSEC	Energy Facility Site Evaluation Council
ELS	early-life-stage
GIS	geographic information system
HEA	habitat equivalency analysis
LCR	lower Columbia River
MHHW	mean higher high water
MLLW	mean lower low water
NOAA	National Oceanic and Atmospheric Administration
NRDA	natural resource damage assessment
NWI	National Wetlands Inventory
ODFW	Oregon Department of Fish and Wildlife
OPA	Oil Pollution Act
PAH	polycyclic aromatic hydrocarbon
RDA	Resource Damage Assessment
REA	resource equivalency analysis
RM	river mile
SIMAP	Spill Impact Model Application Package
Tesoro	Tesoro Savage Petroleum Terminal LLC
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UV	ultraviolet

Vancouver Terminal	Vancouver Energy Distribution Terminal Facility
WCD	worst-case discharge
WDFW	Washington Department of Fish and Wildlife

S. Executive Summary

The Tesoro Savage Petroleum Terminal LLC has submitted an Application for Site Certification to the Washington State Energy Facility Site Evaluation Council (EFSEC) to construct and operate the Vancouver Energy Distribution Terminal Facility at the Port of Vancouver in Vancouver, Washington. Abt Associates and Bear Peak Economics were tasked with estimating potential economic impacts to fisheries and potential natural resource damages from an effective worst-case oil spill based on a tanker grounding in the Columbia River near Vancouver, Washington. In addition, we examined potential natural resource damages from a train derailment near the Bonneville Dam.

The scope of this task was restricted to assessing the impacts in the Columbia River from these two scenarios; we did not evaluate potential impacts in the Pacific Ocean or along the Pacific Coast. We also did not separately assess how the public or Indian Tribes would value the potential losses to natural resources if either of these spills were to occur, although these values may be at least partly accounted for in the methods we used. Thus, we expect that we are underestimating the potential impacts to fisheries and the potential natural resource damages from these spill scenarios.

The “effective worst-case discharge” for a tanker grounding in the lower Columbia River is a spill of 189,845 bbls (about 8 million gallons) of Bakken crude oil (EFSEC, 2015). Based on data from a 1984 oil spill in the river as well as models presented in the Draft Environmental Impact Statement (DEIS; EFSEC, 2015), we concluded that oil spilled near Vancouver would reach Longview (approximately 40 miles downstream) in 1 day, then travel slowly through the estuary, reaching the mouth after an additional 4 days. In the reach from Vancouver to Longview (Reach 2), we estimated that most of the oil would be on the surface, based on the physical properties of Bakken crude and the oil transport models presented in the DEIS. However, even a small percentage of 8 million gallons mixing into the water column could create concentrations of polycyclic aromatic hydrocarbons (PAHs) potentially toxic to exposed fish. In the lower reach from Longview to the mouth (Reach 1), tides cause diurnal current reversals, and the model from the DEIS predicts that a higher percentage of surface oil will disperse into the water column.

The worst-case discharge for a train derailment is a spill of 20,000 bbls (840,000 gallons) of Bakken crude oil (EFSEC, 2015). The worst-case scenario would be for the oil spill to occur immediately upstream of the Bonneville Dam, with most of the oil going through the spillway. In this highly turbulent environment, much of the oil would be mixed into the water column, potentially exposing white sturgeon to highly elevated PAH concentrations in their protected spawning grounds immediately downstream of the Bonneville Dam (Reach 4), in addition to exposing adult salmon migrating upstream to spawn and juvenile salmon (smolts) migrating downstream to the Pacific Ocean. The oil would move downstream, exposing river habitat both upstream of Vancouver (Reaches 4 and 3) and downstream of Vancouver (Reaches 2 and 1) to the oil.

Economic Impacts to Fisheries

We evaluated the potential economic impacts related to commercial and recreational fisheries for the tanker grounding scenario only. A tanker grounding that discharges 8 million gallons of Bakken crude oil into the river environment would have a substantial impact on commercial and recreational fishing. While past spills at other sites throughout the country have not always resulted in fishing closures, some spills have resulted in closures lasting from several months to almost a full year. Given the large amount of oil discharged under this scenario and the confined river environment of the potential spill, we estimate that a 6-month closure of all fishing on the lower Columbia River is a likely outcome.

Impacts to recreational fishing are likely to continue even after a closure is lifted. In past spills, recreation impacts have usually lasted for a period of several months to a year or more. For the spill under consideration, we have assumed that impacts to recreational fishing last a full year. The first 6 months involve a 100% loss of trips during the closure, and the remaining 6 months involve losses that decline linearly to zero at the end of a year.

For the specific values estimated below, we assumed the spill would occur in May and would affect the highly valued summer and fall fishing seasons. We calculated three different types of fishing losses:

- ***Lost revenue from commercial landings***: $4.7 million. This is a measure of the economic losses to commercial fishermen. Lost revenue may differ from total losses because commercial fishermen may recoup some costs while the fishery is closed, or may continue to incur losses after the fishery is reopened due to public perceptions about fish harvested from the river.
- ***Decline in expenditures by recreational anglers****:* $14.4 million. This is a measure of the potential disruption to local economic activity, with the most direct impacts on local businesses, such as bait shops and marinas. If anglers make up for lost trips on the Columbia River by taking additional trips to other sites nearby, some of these expenditures may not be diverted from the local area.
- ***Decline in the value of recreational fishing***: $17.8 million. This is the monetary quantification of lost enjoyment by recreational anglers whose preferred fishing opportunities are degraded or eliminated by the spill.

Because each of these losses is measuring something conceptually different, these values may not be strictly additive.

Natural Resource Damages

To estimate potential natural resource damages from these oil spill scenarios in the lower Columbia River, we used a habitat equivalency analysis (HEA). This is a commonly used technique where damages are based on the cost to restore habitat and natural resource services equivalent to those that were harmed by the oil. We estimated the service loss from oil exposure based on available data and knowledge from other spills, noting that in the event of an actual spill, federal and state natural resource Trustees would use data collected during the spill to estimate lost habitat services. In addition, we again note that we have not accounted for impacts in the Pacific Ocean and along the coast, and we have not separately assessed potential losses in the value of natural resources to the public or to Tribes, and thus these estimates are not comprehensive.

Our HEA generally followed methods developed for natural resource damage assessments in Puget Sound (Commencement Bay/Hylebos Waterway, Elliot Bay/Duwamish River). The assumed restoration is estuarine marsh habitat. If oil caused harm (injury) to natural resources in other habitats, those service losses were converted to an amount of marsh habitat that provides equivalent services. In this analysis, we estimated service loss to estuarine and freshwater marsh habitats both in the river channel and in the floodplain adjacent to the river channel; these wetland habitats were assumed to provide the same services as a restored estuarine marsh. We also estimated service loss to riverine, subtidal, and other habitats in the river channel; these habitats were assumed to provide 10% of the services of an estuarine marsh.

In a HEA model, future service losses from the lingering effects of the spill and future service gains from habitat restoration are discounted to a base year using a 3% discount rate to reflect consumer time preference. The discounted losses and gains in each year are summed, creating an estimate of total natural resource injuries in units of discounted service acre-years (DSAYs), and an estimate of total restoration benefits in DSAYs per acre. Dividing the total injuries (DSAYs) by the benefits of restoration (DSAYs per acre) provides an estimate of the number of acres of marsh habitat restoration required to make the public whole.

For these scenarios, we assumed that the spill occurs in the spring of 2016 (present year, for discounting purposes), and that most of the service losses occur in 2016 and 2017. Complete recovery to pre-spill conditions occurs slowly thereafter until 2025. We assumed that the marsh restoration required to offset these impacts would be completed in 2021, it would take 15 years for the marsh to become fully established and provide 100% of marsh habitat services (Commencement Bay Natural Resource Trustees, 2002), and those restored services would be provided for 100 years. This provides 20.5 DSAYs of restoration “credit” per acre restored.

We found a wide range of costs for restoring estuarine marsh habitat; some projects restored hundreds of acres of habitat by breaching a dike and flooding former fields, at a cost of a few thousand dollars per acre. Other projects, including those in Commencement Bay, required land purchase, waste removal, and a complicated engineering design to restore the habitat; these projects cost over $1 million per acre. We used the recent Fir Island restoration in the Skagit Valley (WDFW, 2014) as the basis for cost estimates. This project restored 130 acres of marsh habitat supporting Chinook salmon and snow geese at a cost of $110,000 per acre.

Tanker Grounding

An 8-million-gallon oil spill in the Columbia River near Vancouver would expose fish, birds, pinnipeds, and other biota (and their supporting habitats) to oil, with the largest impacts most likely to result if the spill occurs in the spring (mid-April to mid-May). Potential natural resource impacts from this oil spill include:

- ***Birds***: There are four wildlife refuges between Vancouver and the mouth of the river, with many thousands of birds potentially exposed to oil. In 2007, approximately 140 bald eagles were known to reside and breed along the river. Data from the literature suggest that most birds exposed to oil are impaired and may die from symptoms ranging from hemolytic anemia to hypothermia to heart failure. Oiled eggs rarely produce offspring, and oiled feathers impact flight behavior, which could lead to increased predation and decreased hunting and migration success.

- ***Pinnipeds***: Hundreds of Steller sea lions, California sea lions, and harbor seals are in the estuary in the spring; sea lions can be found throughout the lower Columbia River, including at the base of the Bonneville Dam. Data from other spills suggest adverse health effects on marine mammals exposed to oil.
- ***Adult salmon***: We calculated the potential exposure of salmon to oil from this scenario based on fish count data from the Bonneville Dam. Data from the literature suggest that adult salmon swimming upstream take up to 3 weeks to reach the dam; about 2 weeks' worth of adult salmon would intersect the oil slick as it moved downstream from Vancouver. We estimated 45,000 to 70,000 adult salmon would be exposed to the oil in Reach 1, and an additional 20,000 to 60,000 adult salmon would be exposed in Reach 2. Recent literature suggests that PAH exposure reduces the physical fitness of fish, which could affect the ability of adult salmon to reach their spawning grounds.
- ***Juvenile salmon***: Salmon smolts migrate downstream in the spring. The literature suggests that smolts migrate with the current until they reach the estuary, where they linger for several days before swimming out to sea. We assume that one daily cohort of smolts would follow the oil downstream, and several additional daily cohorts would then intersect the oil in the estuary. In total, we estimate 1.4 million to 1.6 million smolts would be exposed to the oil in the river over the approximately 5 days that the oil is primarily in the river before discharging into the Pacific Ocean. Although few studies have exposed juvenile fish oil, the literature suggests that the concentrations of PAHs expected in the Columbia River from this spill scenario would exceed thresholds for multiple toxic endpoints in early life-stage fish.

To determine the appropriate compensation for the impacts of oil exposure, we calculated the total area of the river channel from Vancouver to the mouth (Reaches 1 and 2, extending nearly 100 river miles). Using bathymetric and National Wetlands Inventory (NWI) data in a geographic information system (GIS), we calculated 16,152 acres of wetland habitat and 91,579 acres of riverine/subtidal habitat would be oiled in the river channel. We estimated a 90% loss of habitat services in Reach 2 and a 75% loss in Reach 1 in 2016, recovering to a 10% service loss by the end of 2017, and reaching pre-spill conditions by 2025. This results in 21,276 DSAYs of natural resource injury (HEA "debit").

With a total calculated debit of 21,276 DSAYs, and using a credit of 20.5 DSAYs per acre of restored wetland calculated above, the total the total quantity of restoration required to offset the injuries in Reach 1 and Reach 2 of the river channel is 1,040 acres. At a cost of $110,000 per acre, the total damages for injuries to the river channel habitats would be about $114.4 million (Table S.1).

Table S.1. Estimated cost to restore marsh habitat sufficient to offset injuries to river channel habitats in the lower Columbia River downstream of Vancouver

Debit (DSAYs)	Credit (DSAYs/acre)	Restoration required (acres)	Unit cost ($/acre)	Total
21,276	20.5	1,040	$110,000	$114.4 million

To capture likely natural resource injuries to birds that are exposed to oil in the river but are found in adjacent floodplain habitats, we estimated habitat service loss in wetlands in the 100-year floodplain but outside of the area designated as river channel. These wetlands could be directly exposed to oil if the river stage is high, they could have stranded oil on the margins, and the birds residing in the wetlands could be exposed to oil on the river channel.

Using NWI data in a GIS, we calculated 29,867 acres of floodplain wetlands in Reaches 1 and 2 downstream of Vancouver. We estimated a 25% loss in Reaches 1 and 2 in 2016, recovering to a 5% service loss by the end of 2017, and reaching pre-spill conditions by 2025. For the 29,867 acres of floodplain wetland habitat, the total HEA debit is 10,580 DSAYs.

With a total calculated debit of 10,580 DSAYs and a credit of 20.5 DSAYs per acre, the total quantity of restoration required to offset the injuries to refuge habitat and biota is 517 acres. At a cost of $110,000 per acre, the total damages would be about $56.9 million (Table S.2).

Table S.2. Estimated cost to restore marsh habitat sufficient to offset injuries to floodplain wetland habitat in the lower Columbia River downstream of Vancouver

Debit (DSAYs)	Credit (DSAYs/acre)	Restoration required (acres)	Unit cost ($/acre)	Total
10,580	20.5	517	$110,000	$56.9 million

Train Derailment

Although the worst-case train derailment scenario is a spill of roughly 10% of the oil spilled in a worst-case tanker grounding, it will expose a greater area of the lower Columbia River to oil. Assuming most of the oil goes through the Bonneville Dam spillway, it will be mixed into the water column and expose fish in the 4.8-mile reach below the dam (Reach 4) to highly elevated PAH concentrations. This oil will then continue downstream, exposing biota in Reach 3 (which extends downstream to Vancouver) and, to a lesser degree, biota in Reaches 2 and 1 downstream of Vancouver. In total, this is approximately 140 river miles of potential oil exposure.

Natural resource damages are not scalable based on the quantity of oil spilled; therefore, we would not expect damages from this spill scenario to be 10% of the damages from the previous scenario. Although the quantity of oil is less and the oil exposure will decrease with distance from the dam, the amount of exposed habitat in the lower Columbia River is greater than in the tanker scenario. In addition, as noted previously, we would expect a large quantity of oil in the tanker scenario to be discharged into the ocean and deposited on the coastline. We have not quantified damages in those habitats.

Similar to the previous scenario, an 840,000-gallon oil spill in the Columbia River just upstream of the Bonneville Dam would expose fish, birds, pinnipeds, and other biota (and their supporting habitats) to oil, with the largest impacts most likely to result if the spill occurs in the spring (mid-April to mid-May). Potential natural resources exposed to the oil include:

- ***Birds***: There are seven wildlife refuges (and one small game management area) between the Bonneville Dam and the mouth of the river. As described previously, these refuges are home to thousands of birds that would potentially be exposed to the oil, and the oil directly or indirectly would cause mortality for many of these exposed birds.
- ***Pinnipeds***: Sea lions congregating at the base of the Bonneville Dam would be exposed to highly elevated oil concentrations. Other pinnipeds would be exposed to lower concentrations of oil in the estuary (Reach 1).

- ***Adult salmon***: For this scenario, we only calculated the number of salmon exposed at the base of the dam (Reach 4). The number of adult salmon per day counted at the Bonneville Dam in mid-May from 2011 to 2015 ranged from 2,000 to 9,000, with an average of 4,000. The daily cohort present at the base of the dam when the spill occurs would be exposed to highly elevated PAH concentrations. As mentioned previously, it takes adult salmon approximately 3 weeks to travel from the mouth of the river to the dam; each of those daily cohorts would be exposed to the oil as well, at lesser concentrations with distance downstream.

- ***Juvenile salmon***: The number of salmon smolts per day counted at the Bonneville Dam in mid-May between 2011 and 2015 ranged from 27,000 to 220,000, with an average of 112,000. This daily cohort would be exposed to highly elevated PAH concentrations near the dam, and their exposure would likely continue for several days as they traveled downstream with the oil plume. Additional daily cohorts of smolts would be exposed in the estuary before swimming out to sea.

Using the same methods described for the tanker grounding scenario, we calculated the total area of the river channel from the Bonneville Dam to the mouth (Reaches 1 through 4, extending nearly 140 river miles). Using bathymetric and NWI data in a GIS, we calculated that 16,687 acres of wetland habitat (primarily in the estuary, Reach 1) and 110,316 acres of riverine/subtidal habitat would be oiled in the river channel. Because 866 acres of riverine habitat in Reach 4 is protected white sturgeon spawning habitat, we assumed this reach provides the equivalent of 100% of estuarine marsh habitat services, rather than the 10% estimate that we used for all other riverine habitat.

We estimated a 90% loss of habitat services in Reach 4, a 50% loss in Reach 3, and a 15% loss in Reaches 2 and 1 in 2016. Reaches 4 and 3 would recover to a 10% service loss by the end of 2017 and to pre-spill conditions by 2025. Reaches 2 and 1 would recover to a 5% service loss by the end of 2017 and to pre-spill conditions by 2025. This results in 10,135 DSAYs of natural resource injury (HEA debit).

With a total calculated debit of 10,135 DSAYs and a credit of 20.5 DSAYs per acre, the total quantity of marsh restoration required to offset the injuries to river channel habitats is 495 acres. At a cost of $110,000 per acre, the total damages would be about $54.5 million (Table S.3).

Table S.3. Estimated cost to restore marsh habitat sufficient to offset injuries to river channel habitats in the lower Columbia River downstream of the Bonneville Dam

Debit (DSAYs)	Credit (DSAYs/acre)	Restoration required (acres)	Unit cost ($/acre)	Total
10,135	20.5	495	$110,000	$54.5 million

To capture likely natural resource injuries to birds that are exposed to oil in the river but are found in adjacent floodplain habitats, we again estimated habitat service loss in wetlands in the 100-year floodplain but outside of the area designated as river channel. Using NWI data in a GIS, we calculated 32,055 acres of floodplain wetlands downstream of the Bonneville Dam.

We estimated a 75% loss of habitat services in Reach 4, a 25% loss in Reach 3, and a 10% loss in Reaches 2 and 1 in 2016. Reach 4 would recover to a 25% service loss by the end of 2017 and to pre-spill conditions by 2025. Reach 3 would recover to a 10% service loss by the end of 2017 and to pre-spill conditions by 2025. Reaches 2 and 1 would recover to a 2% service loss by the end of 2017 and to pre-spill conditions by 2025. This results in 5,643 DSAYs of natural resource injury (HEA debit).

With a total calculated debit of 5,643 DSAYs and a credit of 20.5 DSAYs per acre, the total quantity of marsh restoration required to offset the injuries to floodplain wetland habitat and biota is 276 acres. At a cost of $110,000 per acre, the total damages would be about $30.4 million (Table S.4).

Table S.4. Estimated cost to restore marsh habitat sufficient to offset injuries to floodplain wetland habitat in the lower Columbia River downstream of the Bonneville Dam

Debit (DSAYs)	Credit (DSAYs/acre)	Restoration required (acres)	Unit cost ($/acre)	Total
5,643	20.5	276	$110,000	$30.4 million

Conclusions

We examined potential impacts to commercial and recreational fisheries from a tanker grounding near Vancouver, and we estimated potential natural resource damages from both the tanker grounding scenario near Vancouver and a train derailment scenario near the Bonneville Dam. The scope of this work was restricted to impacts in the Columbia River. Though oil in the Columbia River (particularly from a tanker grounding near Vancouver) would be discharged to the Pacific Ocean and would impact natural resources along many miles of coastline, we have not quantified those impacts.

To estimate natural resource damages, we used a HEA model that calculates damages based on the cost to restore habitat equivalent to what the oil injured. If a major spill were to occur in the Columbia River, Trustees would incorporate laboratory and field data to calculate the habitat losses. Trustees might also choose to estimate damages based on values that humans place on natural resources, including Tribal cultural values. A damages estimate incorporating these values could be substantially higher than the restoration-based calculations in this analysis.

The estimated fisheries impacts from a tanker grounding near Vancouver include a 6-month fisheries closure, plus lingering effects on recreational fishing for an additional 6 months, range from $4.7 million to $17.8 million (Table S.5). As noted previously, these losses are not strictly additive.

Table S.5. Summary of estimated losses to fisheries from a worst-case vessel grounding near Vancouver

Type of loss	Value
Lost revenue from commercial landings	$4.7 million
Decline in expenditures by recreational anglers	$14.4 million
Decline in value of recreational fishing	$17.8 million

The estimated damages to Columbia River habitats from a worst-case 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 (Table S.6).

Table S.6. Summary of estimated restoration-based damages to Columbia River habitats from a worst-case vessel grounding near Vancouver

Habitat	Damages
Wetland and non-wetland (riverine, subtidal) habitats in the lower Columbia River channel downstream of Vancouver	$114.4 million
Wetland habitat in the 100-year floodplain adjacent to the lower Columbia River channel downstream of Vancouver	$56.9 million
Total	$171.3 million

The estimated damages to Columbia River habitats from a worst-case train derailment near the Bonneville Dam 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 (Table S.7).

Table S.7. Summary of estimated restoration-based damages to Columbia River habitats from worst-case train derailment near the Bonneville Dam

Habitat	Damages
Wetland and non-wetland (riverine, subtidal) habitats in the lower Columbia River channel downstream of the Bonneville Dam	$54.5 million
Wetland habitat in the 100-year floodplain adjacent to the lower Columbia River channel downstream of the Bonneville Dam	$30.4 million
Total	$84.9 million

These estimates are considerably less than major oil spill settlements such as *Exxon Valdez* or *Deepwater Horizon*. Although damages are not scalable based on the volume of oil discharged, such calculations can provide useful context. Summarizing data from multiple incidents, the range of damages from other oil spill incidents scaled by the volume of oil spilled in the Columbia River scenarios is $232 million to $1.16 billion for the tanker grounding, and $24.4 million to $122 million for the train derailment. The restoration-based damages estimate of $171.3 million calculated for the vessel grounding is below this range; the damages estimate of $84.9 million calculated for the train derailment is within this range. These estimates do not include damages from oil discharged to the ocean, which, if considered, would result in substantially higher estimated damages.

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1. Introduction

The Tesoro Savage Petroleum Terminal LLC (Tesoro) has submitted an Application for Site Certification to the Washington State Energy Facility Site Evaluation Council (EFSEC) to construct and operate the Vancouver Energy Distribution Terminal Facility (Vancouver Terminal) at the Port of Vancouver in Vancouver, Washington (Figure 1.1).

The Washington Attorney General's Office retained Abt Associates (Abt) to evaluate potential fisheries impacts and natural resource damages if a worst-case oil spill were to occur in the Columbia River. This report evaluates selected categories of potential environmental and economic impacts for a hypothetical oil spill resulting from an incident related to Vancouver Terminal operations, including the potential economic impacts of a closure of the lower Columbia River (LCR) to commercial and recreational fishing, as well as a restoration-based approach to quantifying potential damages to natural resources in the LCR.

1.1 Scope of the Report

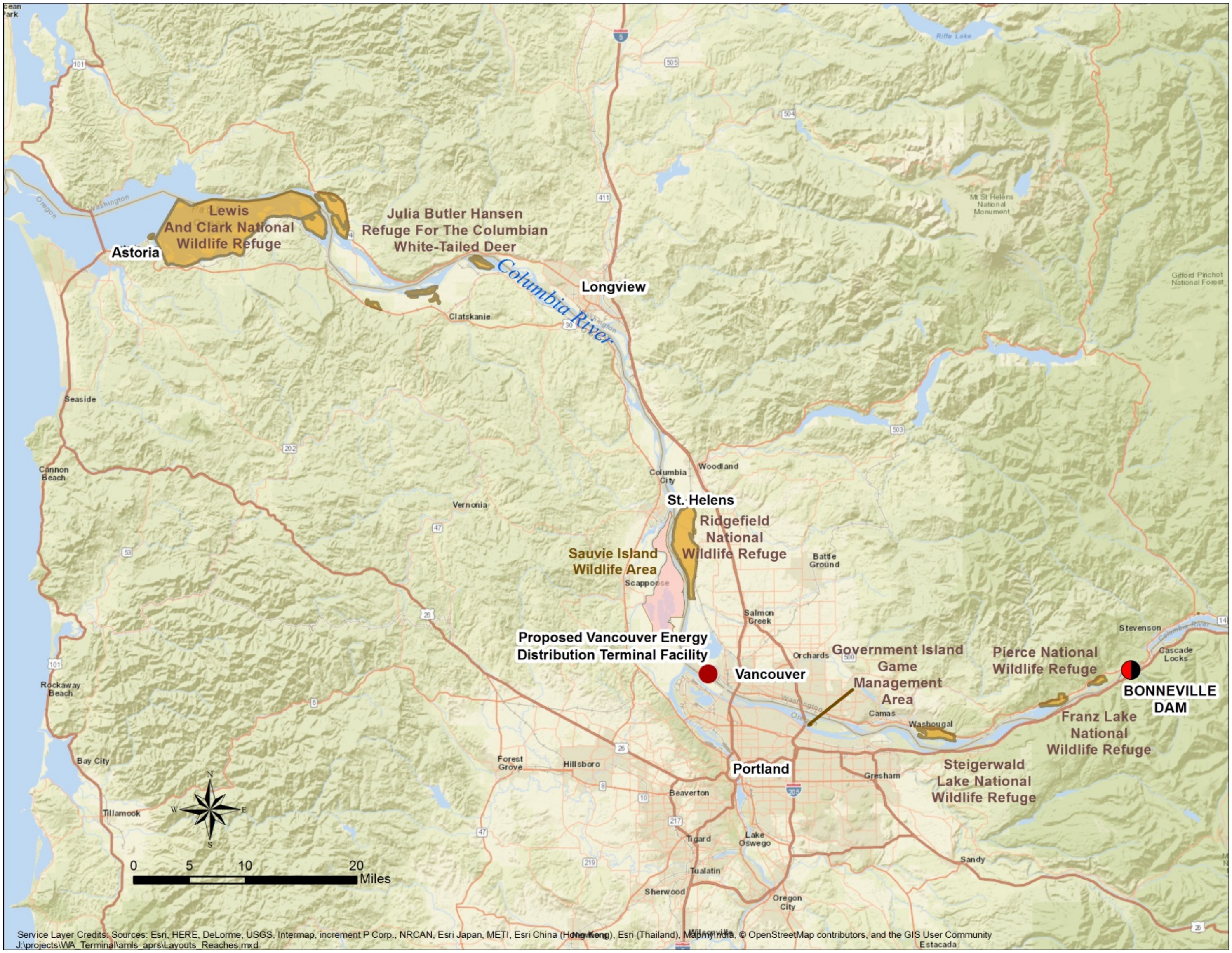
The object of this report is to provide approximate estimates of potential fisheries impacts and natural resource damages that could be associated with hypothetical oil spill scenarios, based on a rapid review of readily available data. It is not intended to be a comprehensive examination of these topics. Some of the limitations of the scope of the analysis presented herein include the following:

- ***Geographic scope***. This analysis includes impacts solely to the LCR. A major oil spill in the LCR could lead to a substantial amount of oil exposure in the Pacific Ocean, and could potentially result in the deposition of oil along many miles of coastline. Depending on winds and tides, the oil could also move up the Willamette River into Portland Harbor. Consequently, our analysis likely underestimates the geographic extent of impacts to natural resources, perhaps by a substantial degree, and we may also be underestimating the impacts on commercial and recreational fisheries.

- ***Trustee scope***. This analysis of natural resource damages does not include cultural impacts to Tribes. Tribes are Trustees of natural resources. Any oil-related diminution of the cultural value that Tribes place on natural resources is compensable as damages. A large oil spill in the LCR would likely impact Tribal cultural values; we have not incorporated those losses in this analysis.

- ***Methodological scope***. For these hypothetical spill scenarios, we use a common method of calculating damages based on the cost to restore natural resources similar to those harmed during the spill. We can make a reasonable approximation of the impacts of the spill and the amount of restoration that might be required based on existing data. However, Trustees have multiple options for assessing damages, including natural resource valuation methods that incorporate the value that the public places on natural resources. Trustees may elect to design a survey that asks the public what they are willing to pay to prevent a recurrence of this size of oil spill in the LCR, or how much restoration they think is appropriate to offset the impacts from the oil spill. Such a survey of public opinion could lead to an estimate of damages considerably higher than the estimates provided herein.

Figure 1.1. Location of proposed the Vancouver Terminal and surrounding Columbia River environment.



- ***Volumetric scope***. We evaluated only the impacts of the effective worst-case scenarios discussed in the Draft Environmental Impact Statement (DEIS) for the Vancouver Terminal (EFSEC, 2015). For a tanker grounding near Vancouver, this is a spill of over 189,845 bbls, and for a train derailment near the Bonneville Dam, 20,000 bbls. These worst-case spill scenarios are unlikely. However, the estimates of fisheries closures and natural resource damages that we provide in this report are applicable to spills that are not nearly as large. Such estimates are not linearly scalable; the fisheries impacts and natural resource damages presented in this report may be nearly the same even if only 10% of the volume of oil from the worst-case scenario spilled into the LCR.
- ***Oil source scope***. We evaluated only the potential impacts of a Bakken crude oil spill on the LCR. The proposed Vancouver Terminal would also handle diluted bitumen (dilbit), which would likely behave quite differently if discharged to the river. Dilbit is a heavier oil and would have a higher potential to sink to the river bottom. This could have profound effects on the types and timing of natural resource damages as well as the timing of fishery closures.

In addition to the limitations on the scope of our evaluations, there are limitations on the available data that we can use to predict the impacts of a hypothetical spill. Although a large body of literature exists that describes oil fate and transport and the toxicity of oil on biota, existing models and literature do not enable comprehensive prediction of oil exposure and resulting adverse effects on natural resources without actual data. Thus, none of the damages estimates in this report should be considered definitive; if a large spill were to occur in the LCR, the Trustees would likely collect both field and laboratory data to assess oil exposure and the adverse impacts of the exposure on natural resources.

Existing literature that allows us to make this initial estimate of potential impacts of a large oil spill in the LCR includes literature on the natural resources of the LCR; on potential oil fate and transport processes; and on the effects of oil on biota such as fish, birds, and invertebrates. Resource officials have long been concerned about oil spills in the LCR; the latest *Lower Columbia River Geographic Response Plan* (ODEQ et al., 2015) includes detailed summaries of natural resources and habitats likely to be exposed to oil if a major spill were to occur. In this report, we provide summary information (e.g., wildlife refuges shown on Figure 1.1) but generally refer the reader to existing literature without reproducing the information in detail.

1.2 Report Organization

The remainder of this report is organized as follows. Chapter 2 describes two worst-case discharge (WCD) scenarios: a tanker grounding in the LCR near Vancouver (Section 2.1) and a train derailment downstream of The Dalles Dam and upstream of the Bonneville Dam (Section 2.2). These scenarios are based on information that EFSEC published in the DEIS for the Vancouver Terminal (EFSEC, 2015).

The remaining chapters discuss the potential impacts from these oil spill scenarios. Specifically, Chapter 3 discusses the potential economic impacts of commercial and recreational fishery closures; and Chapter 4 discusses potential natural resource damages in the LCR after the WCD from a tanker grounding. Chapter 5 discusses potential natural resource damages after the WCD from a train derailment upstream of the Bonneville Dam (Figure 1.1).

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2. Worst-Case Discharge Scenarios

As background context for the oil spill scenarios, we first summarize the *MobilOil* tanker spill that occurred in the Columbia River in 1984, and then presents two separate potential future scenarios: a WCD from a tanker grounding near Vancouver in the LCR, and a WCD from a train derailment. These two scenarios are based on WCD analyses presented in Chapter 4 (EFSEC, 2015) and Appendices E (Etkin et al., 2015) and (Etkin and Moore, 2015) of the Tesoro Vancouver Terminal DEIS. The *MobilOil* spill was substantially smaller than the WCD spills from the DEIS, but it provides some information on the fate and transport of oil in the Columbia River.

2.1 *MobilOil* Spill of 1984

The tanker *MobilOil* grounded in the Columbia River near St. Helens, Oregon [river mile (RM) 88], shortly after midnight on March 19, 1984. Damage to the tanks resulted in a spill of approximately 3,925 bbl (165,000 gals) of heavy residual oil, number six fuel oil, and an industrial fuel oil (Kennedy and Baca, 1984). This spill occurred near St. Helens, approximately 15 mi downstream of the proposed Vancouver Terminal in Vancouver; the total discharge was about 2% of the effective WCD for a tanker grounding (see next section).

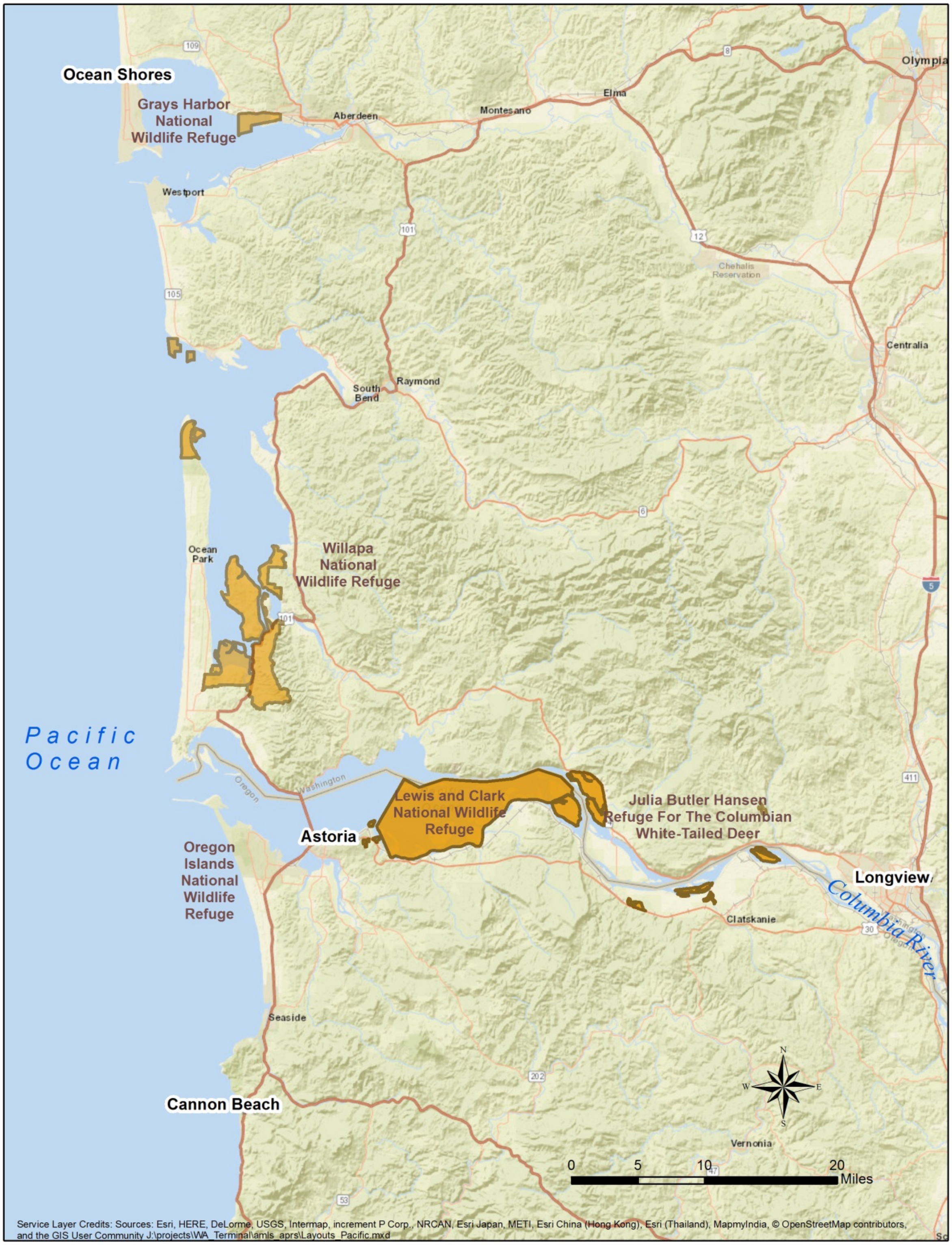
At the time of the tanker grounding, the calculated discharge in the Columbia River at the Bonneville Dam was 239,300 cfs. Over the next several days, the discharged oil ranged from about 215,000 to 273,000 cfs (USACE, 2016).

According to Kennedy and Baca (1984), the U.S. Army Corps of Engineers (USACE) estimated that the Columbia River discharge downstream of the Willamette River confluence (more than 40 miles downstream of Bonneville Dam) was approximately 320,000 cfs at the time of the spill. The average downstream current was 2 kts, or 2.3 mph, ranging from about 2.5 kts (2.9 mph) at the low, outgoing tide to 1.5 kts (1.7 mph) at the high, incoming tide (Kennedy and Baca, 1984). By the morning of March 19, 1984, the leading edge of the oil slick was over 20 mi downstream, near Longview, Washington, at RM 65. The following morning (March 20), the oil slick had progressed to RM 35. This is downstream of where the river current reverses diurnally with slow tides (Kennedy and Baca, 1984), and thus the net progression downstream was substantial.

The oil reached the mouth of the river and entered the Pacific Ocean within 2 to 3 days after being discharged from the damaged tanker. By March 25, 1984, the oil had spread about 50 mi northward up the Washington Coast to Ocean Shores. Lesser amounts of oil spread southward along the Oregon Coast, with oil reported as far south as Cannon Beach, about 25 mi south of the river mouth (Figure 2.1; Speich and Thompson, 1987).

The oil discharged from the ship settled to the river bottom in an eddy, before eventually entering the main flow of the river as oil droplets in the water column, or as a slow-moving oil plume along the river bottom. Oil was stranded on the river banks, pushed higher up the banks at high tide, and stranded as the tide dropped. Some of the stranded oil was washed back into the river; however, stranded oil in marshes and sloughs may have remained for a considerable amount of time, as oil does not readily rewash into the river from these habitats, and the spill occurred during a spring tide cycle when the high tide was particularly elevated (Kennedy and Baca, 1984).

Figure 2.1. Oil from the *MobilOil* in 1984 discharged from the Columbia River to the Pacific Ocean and washed ashore from Cannon Beach, Oregon, to Ocean Shores, Washington.



Although they did not discuss their methods, Kennedy and Baca (1984, p. 36) estimated that surface oil reached the mouth of the river in “a few days,” oil in the water column reached the mouth of the river in about 1 week, oil near the river bottom may have remained for several weeks, and stranded oil may have remained even longer. This information helps to inform estimates of oil fate and transport for future oil spills (see next section); Chapter 4 contains summaries of the reported adverse environmental effects of this spill.

2.2 WCD from a Tanker Grounding in the LCR near Vancouver

The WCD in the Columbia River is based on a hypothetical grounding of a large tanker in the vicinity of Vancouver. Although the proposed Vancouver Terminal will handle both Bakken crude and dilbit, we focused solely on the potential impacts of Bakken crude. Exposure and injury of natural resources during an oil spill depend on the type of oil discharged and its physical and chemical properties; the toxicity of the oil; processes influencing fate and transport of oil in the environment; and the potential impacts of the oil on terrestrial, freshwater, and estuarine/marine environments (EFSEC, 2015). In this chapter, we consider these factors for the WCD scenario.

2.2.1 Physical Properties of Bakken Crude

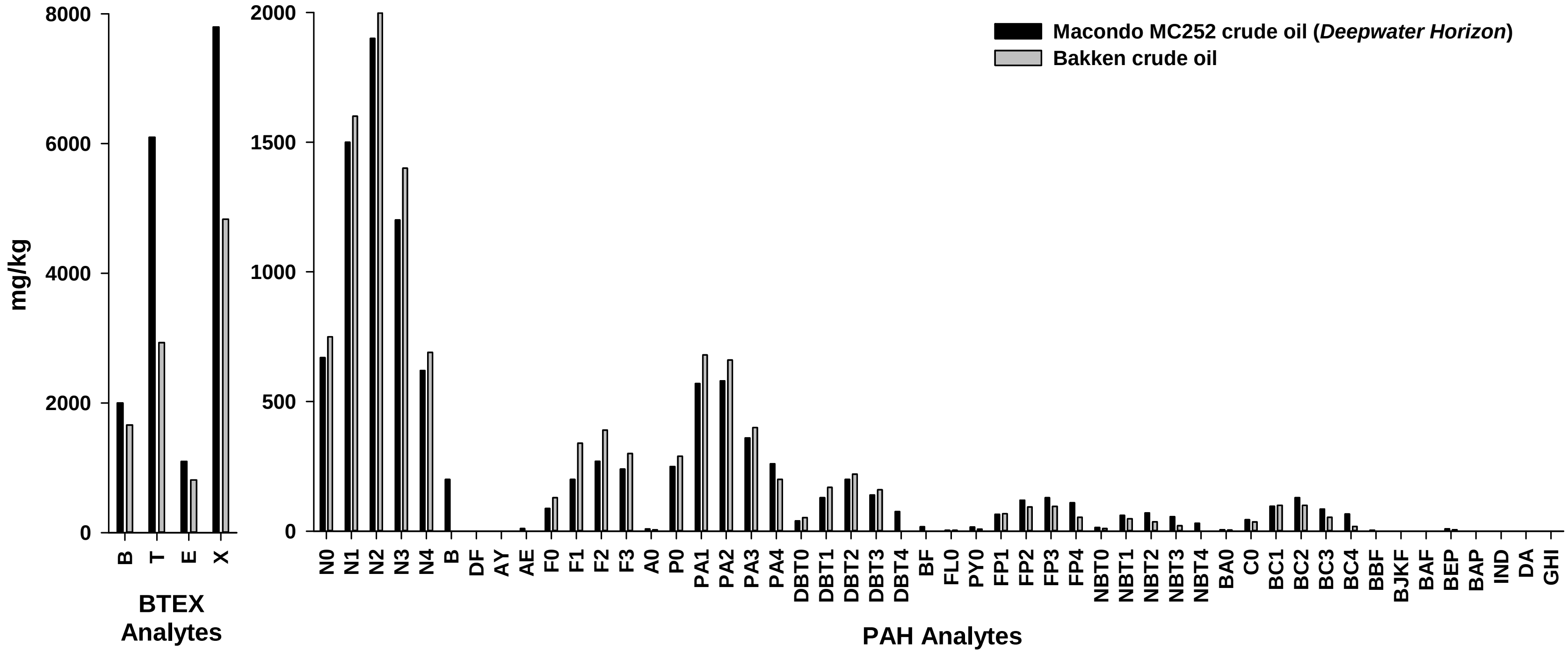
Bakken crude oil is considered a light crude with physical characteristics similar to other light crude oils, with relatively low viscosity, low sulfur content, low density, and an American Petroleum Institute (API) gravity between 40 and 43 (EFSEC, 2015). As noted in the DEIS, Bakken crude has a reputation for being highly volatile, in part from the Lac Megantic disaster in 2013. However, Bakken crude is similar to other light crudes as described in Auers et al. (2014), including the crude oil that was released during the *Deepwater Horizon* (DWH) oil spill. For example, the profiles of volatile components [e.g., benzene, toluene, ethylbenzene, and xylenes (BTEX)] and polycyclic aromatic hydrocarbons (PAHs) in Bakken and DWH crude oil are very similar (Figure 2.2). Thus, the extensive recent literature on the mobility and toxicity of the MC252 crude is relevant and applicable to the evaluation of potential impacts resulting from a Bakken crude oil spill.

2.2.2 Weathering of Bakken Crude

As described in the DEIS, “When oil is released into the environment, it is altered by various chemical and biological processes that are collectively referred to as ‘weathering,’ including spreading/dispersion, evaporation, dissolution, emulsification, photo-oxidation, adsorption/sedimentation, and biodegradation” (EFSEC, 2015, p. 4-36). Thus, the spatial and temporal impact of a WCD event will be influenced by dispersal and weathering of the crude after the spill.

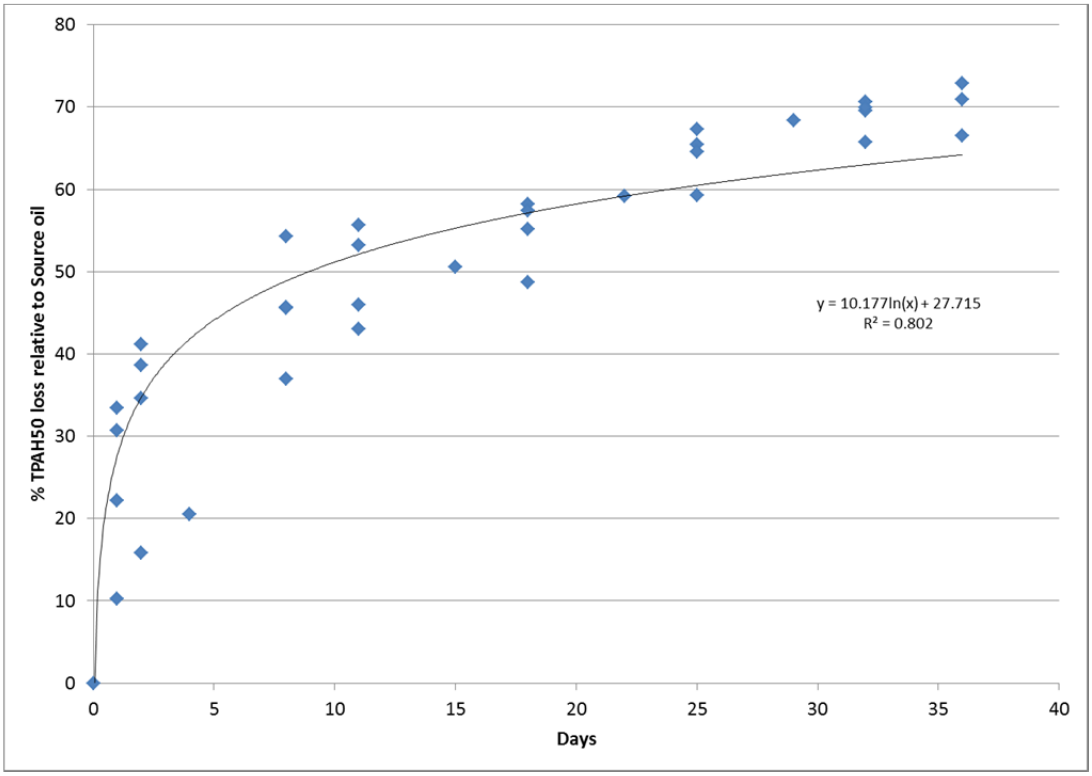
Chemically, within 5 days, the Bakken crude will have lost its volatile components, BTEX will be gone, and most naphthalenes (i.e., lighter PAHs) will be lost as well. Heavier PAHs will remain, and the oil can become increasingly tarry, more difficult to capture, and may eventually become heavier than water and sink. Abt scientists and collaborators conducted numerous studies on weathering of DWH oil, which is similar to Bakken crude. Based on these studies, we can estimate oil weathering in terms of loss of PAHs for up to 36 days (Figure 2.3; Johnson et al., 2016). We calculated that samples of fresh Bakken crude have a fraction PAH of 1.12%,

Figure 2.2. Comparison of concentrations of volatile compounds such as BTEX and PAHs in Bakken crude oil and DWH crude oil collected from the riser of the Macondo well during the DWH oil spill.



Sources: Etkin and Moore, 2015, Tables 45–46 (Bakken); Forth et al., 2015 (DWH).

Figure 2.3. Total PAH depletion in fresh DWH oil weathered in outdoor chambers that simulated natural weathering conditions. The depletion rate presented here was used to estimate total PAH depletion in Bakken crude oil over 5 days.



Source: Johnson et al., 2016.

using data presented in Appendix J, Table 46, of the DEIS (Etkin and Moore, 2015). Using weathering data from DWH oil, we estimated that the PAH fraction of spilled Bakken crude will decrease to 0.6% over 5 days.

DWH oil skimmed off the ocean surface many days after being discharged was naturally weathered and was similar to samples we weathered under our controlled outdoor weathering process for 22–36 days (Forth et al., 2015; Johnson et al., 2016). Thus, during the DWH oil spill, substantial quantities of oil remained in the system after days or even weeks of weathering; this highly weathered oil was still toxic to aquatic organisms (Morris et al., 2015). A discharge of Bakken crude into the Columbia River might likewise remain in the environment and be toxic to aquatic organisms for days or weeks after a spill.

2.2.3 Effective WCD

To the extent possible, the WCD scenarios we evaluated are based on those presented in Chapter 4 and Appendix J of the DEIS. The DEIS includes multiple, low-probability WCD scenarios, based primarily on groundings or collisions of various tankers. EFSEC defined the "effective" WCD as "the most credible or realistic volume for a WCD based on the amount of oil that would effectively be released in the event of a tanker impact accident (collision or grounding) based on maximum possible outflow as determin[ed] by modeling" (EFSEC, 2015, p. 4-26). The WCD varies based on tanker type and other assumptions. In our analysis, we used the scenario presented in the DEIS involving a grounding of an Aframax tanker carrying Bakken crude, with an effective WCD of 189,845 bbls (EFSEC, 2015) or about 8 million gallons. For comparison, the oil released from the *Exxon Valdez* was 257,000 bbls (11 million gallons) (NOAA, 2001). As discussed in subsequent chapters, we assumed that the spill occurs in the spring (between mid-April and mid-May), corresponding with peak salmon populations in the LCR.

2.2.4 Oil Fate and Transport

Although a tanker spill could occur downstream of the proposed Vancouver Terminal or along the coast, for our analysis we assumed that the WCD would occur in the Columbia River near Vancouver.

The fate and transport of oil discharged to the Columbia River will depend on the chemical and physical properties of the oil spilled, the nature of release, and the environmental conditions present at the time of the discharge, including river and tidal currents, winds, and temperature. Because we are evaluating a hypothetical spill, we must develop a reasonable set of conditions. To estimate the fate and transport of the oil discharged under this effective WCD scenario, we reviewed information from the 1984 *MobilOil* spill, the modeling studies cited in the DEIS (EFSEC, 2015), and other available information.

Unquantified impacts: Spatial domain of analysis

A WCD in the Columbia River could result in crude oil reaching the mouth of the river and discharging into the Pacific Ocean, particularly if the tanker accident occurred downstream of Vancouver. It is also likely that a spill of this magnitude could result in oil moving up the Willamette River and into Portland Harbor. We have not attempted to quantify fisheries impacts or natural resource damages to the Pacific Coast or the Willamette River in this analysis.

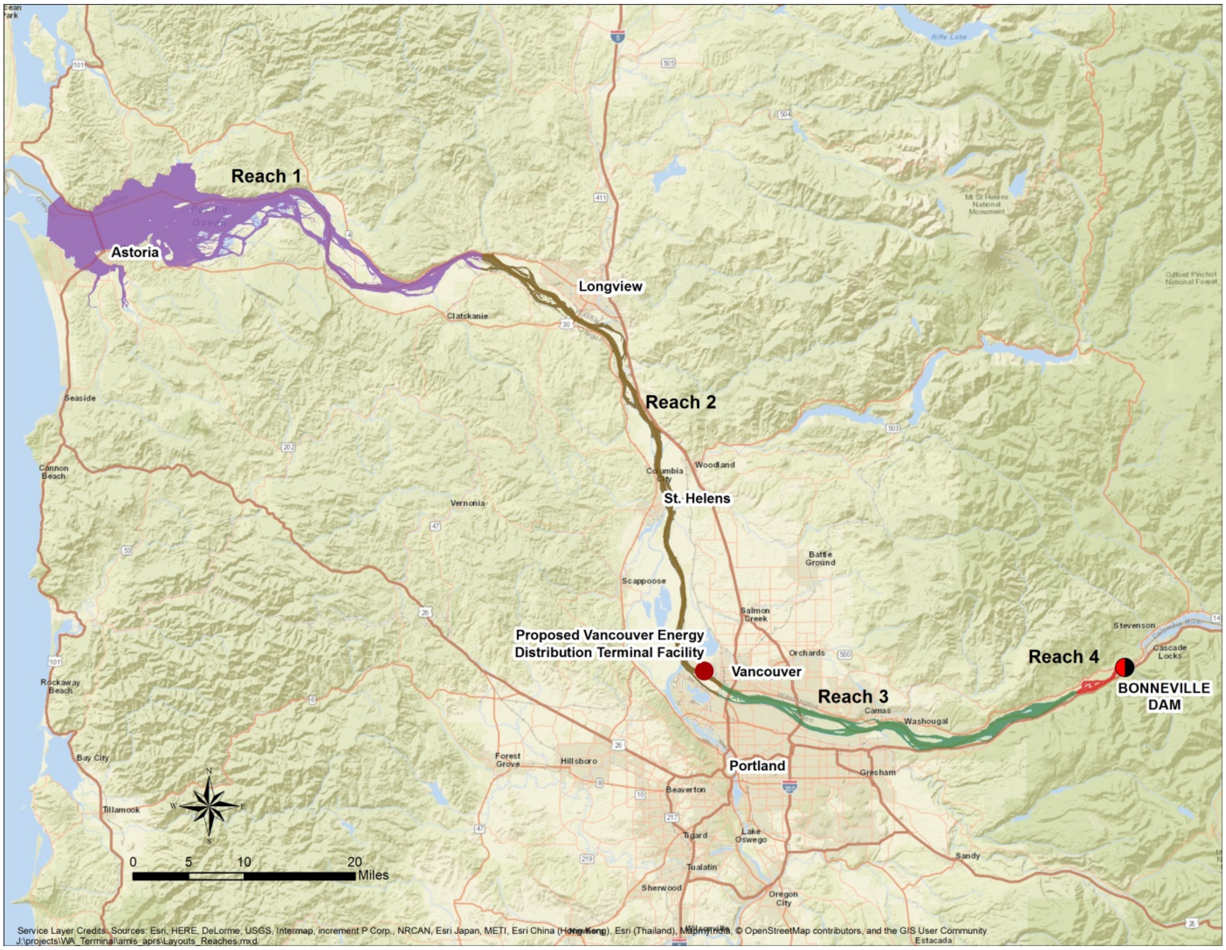
For our analysis, we divided the LCR into four reaches (Figure 2.4) based on river hydrodynamics and habitat. Reach 1 extends from the mouth of the Columbia River to just downstream of Longview. This portion of the river has diurnal reversals in flow direction based on tides. Reach 2 extends from Longview to Vancouver, the location of the proposed Vancouver Terminal. Reach 3 extends from Vancouver to a point about 5.5 mi downstream of the Bonneville Dam. Reach 4 extends to the dam and comprises protected sturgeon spawning habitat.

River Currents

Transport of oil spilled in the Columbia River will depend on the river and tidal currents at the time of the spill, as well as on other factors, including winds. As discussed previously, oil discharged during the *MobilOil* spill flowed downstream at 1.7 to 2.9 mph, reaching the mouth of the river in 2 to 3 days. The river flow dominated the movement of oil from this spill, with the wind acting as a secondary influence on the movement of floating oil (Kennedy and Baca, 1984).

A recent evaluation of the average surface water velocity for the LCR indicated slower velocities than those reported during the *MobilOil* spill. The oil spill response plan (NAC, 2015, ODEQ et al., 2015) states that velocities at Vancouver are 1 to 1.5 kts (1.2 to 1.7 mph) downstream. Surface water velocity in the LCR at low summer/fall flow depends on the tide, and averages 0.5 kts (0.6 mph) upstream on an incoming high tide, and 1.0 kts (1.2 mph) downstream on an outgoing low tide (NAC, 2015).

Figure 2.4. LCR reaches defined for this analysis.



In addition, for Reach 1 we estimated the average current speed from station-specific Tidal Current Predictions data computed by the National Oceanic and Atmospheric Administration's (NOAA's) Center for Operational Oceanographic Products and Services (NOAA, 2016a). Station predictions are available in approximately 3.5-hour time steps for 2014–2016. We computed averages at select stations (Figure 2.4, Table 2.1) for mid-May, 2014–2016, and found the data to be highly variable between stations. Average net downstream currents ranged from less than 0.1 mph to up to 0.5 mph. Flow velocities predicted for these tidally influenced current stations are at considerable depth rather than at the surface of the river, and may not represent the currents at the surface that would influence floating oil. In particular, the NOAA-predicted currents likely underestimate downstream surface velocities within the lower 18 mi of the river, where density differences between fresh river water and saline seawater result in a two-layered flow system. In this region, currents at depth may move in the opposite direction at the surface, because freshwater surface currents move downstream and saline water moves upstream (NAC, 2015; ODEQ et al., 2015).

Table 2.1. Tidal current stations average net velocity downstream (toward the ocean) within Reach 1

Station identification	Station name	Approximate depth (ft)	Average May current (mph)
1171	Chinook Pt	14	0.1
1191	Woody Island Channel (off Seal Island)	12	0.2
1216	Hunting Island	20	0.2
1231	Cathlamet Channel	19	0.5

For our WCD tanker oil spill scenario, we estimated average surface water velocities and travel times below Vancouver for two reaches (Figure 2.4), extending about 100 mi downstream from the proposed Vancouver Terminal to the river mouth (Figure 2.5). We assumed that the average current in the first reach is 0.5 mph or 12 mi/day, for a transit time within Reach 1 of approximately 4 days. For Reach 2, we assumed a velocity on the high end of the range reported by NAC (2015) of 1.7 mi/hr. The distance from Vancouver to Longview is approximately 40 RM, so at this velocity the water transit time in this reach is approximately 1 day. This estimate is consistent with the modeling cited in the DEIS, which indicated that oil would be transported this distance in 24 hrs (French McCay et al., 2006; Etkin and Moore, 2015). It is also consistent with Kennedy and Baca (1984, p. 36), who estimated that the residence time of oil in the Columbia River from the *MobilOil* spill ranged from “a few days” for surface oil to about 1 week for oil in the water column, several weeks for oil near the river bottom, and longer still for stranded oil.

Water Volume

We estimated the volume of water within the four reaches we defined within the LCR. We used the channel area of each reach to estimate the water surface area. We obtained channel boundaries from the U.S. Geological Survey (USGS) National Hydrographic Dataset (USGS, 2012), based on the “perennial, Stream/River” feature code within the attribute table of the geographic information system (GIS) data. We obtained bathymetric data in the form of a 30-m digital elevation model (DEM; NOAA, 1998) from the mouth of the Columbia River to the Bonneville Dam.[1] Table 2.2 presents the estimated volume, surface area (derived from the bathymetric data footprint), and approximate start and end mile for the four reaches below the Bonneville Dam.

1. The DEM was generated from 306,711 soundings dating from 1935 to 1958 with depths relative to the local tidal datum which, according to the metadata from NOAA, is typically the mean lower low water (MLLW) datum. We derived volumetric estimates by reach within a GIS by calculating the volume below a reference plane that we defined using either the average great diurnal tide range [mean higher high water (MHHW) minus MLLW from the tide gauge information (NOAA, 2016b) within the reach (Reaches 1 and 2), or the highest value within the bathymetric layer (Reaches 3 and 4). In the latter case, this was expressed as positive values (i.e., values above the MLLW datum).

Figure 2.5. Location of Bonneville Dam, tidal current stations and tide stations, and river miles on the LCR.

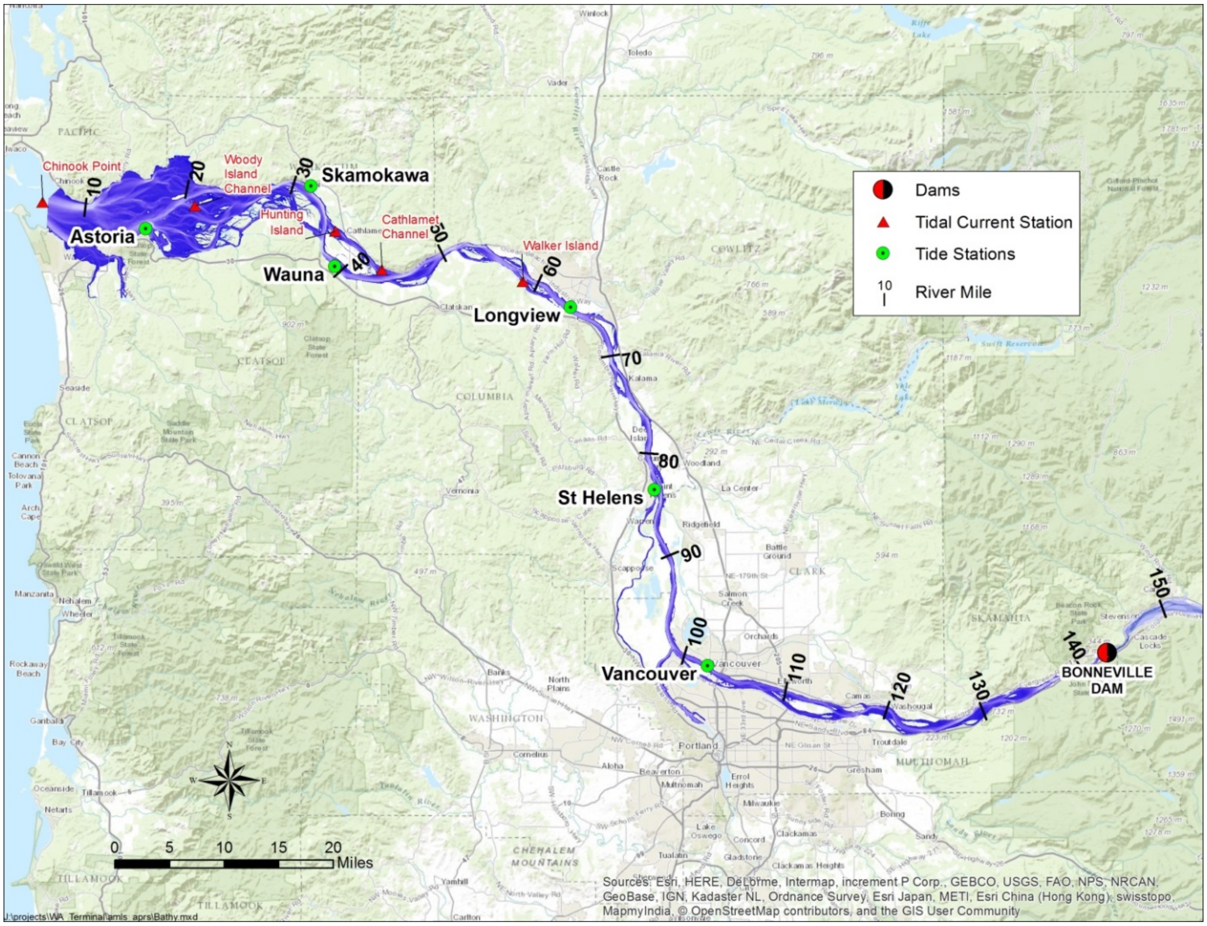


Table 2.2. Approximate volume, surface area, and river mile of reaches

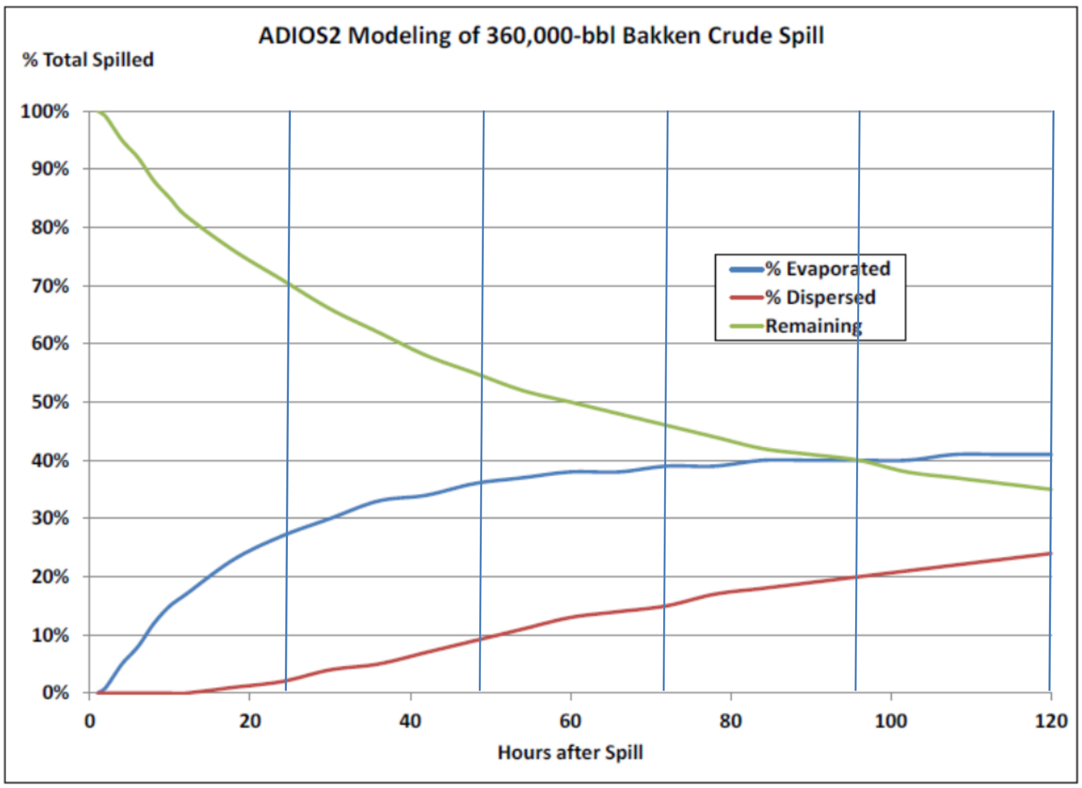
Reach	Volume (ft^3)	Surface area (ft^2)	Average depth (ft)	Start of reach (RM)	End of reach (RM)
1	7.99E+10	3.66E+09	13.5	7	53
2	2.10E+10	8.29E+08	20.0	53	103
3	1.32E+10	7.60E+08	10.7	103	138
4	5.65E+08	3.30E+07	12.4	138	143

Automated Data Inquiry for Oil Spills 2

The Vessel Spill Risk Analysis (Etkin and Moore, 2015) provides results using the Automated Data Inquiry for Oil Spills 2 (ADIOS2) model, to simulate the fate of a large Bakken crude spill into an estuary. ADIOS2 is a NOAA model developed to predict the weathering processes and characteristics of oil slicks (Lehr et al., 2002). ADIOS2 uses information on the physical properties of the oil and environmental conditions, such as wind speed, to predict the fate of oil spilled onto water. It simulates the processes of oil spreading, evaporation, emulsification, and dispersion into the water column for up to 5 days following a spill (Lehr et al., 2002). As presented in the DEIS, the model was based on 360,000 bbls of Bakken crude spilling into 50°F estuarine waters with 8 mph winds, and the properties of the crude were based on "Lac Megantic samples with API of 41.8, density 0.827 g/cc at 50°F, viscosity 3.6 cSt at 50°F" (Etkin and Moore, 2015, p. 46).

The model predicts that after 1 day, approximately 4% of the oil will have dispersed into the water column, 29% of the oil will have evaporated, and about 67% of the oil will remain floating on the water surface. After 5 days, approximately 24% of the oil will have dispersed into the water column, 41% will have evaporated, and 35% of the spilled oil will still be on the surface (Figure 2.6). The ADIOS2 model does not simulate other effects of the fate of spilled oil, such as stranding of oil on the shoreline, biodegradation, or photo-oxidation.

Figure 2.6. ADIOS2 modeling of 360,000 bbl Bakken crude spill in estuary. Vertical lines added to indicate 1, 2, 3, 4, and 5 days post-spill.

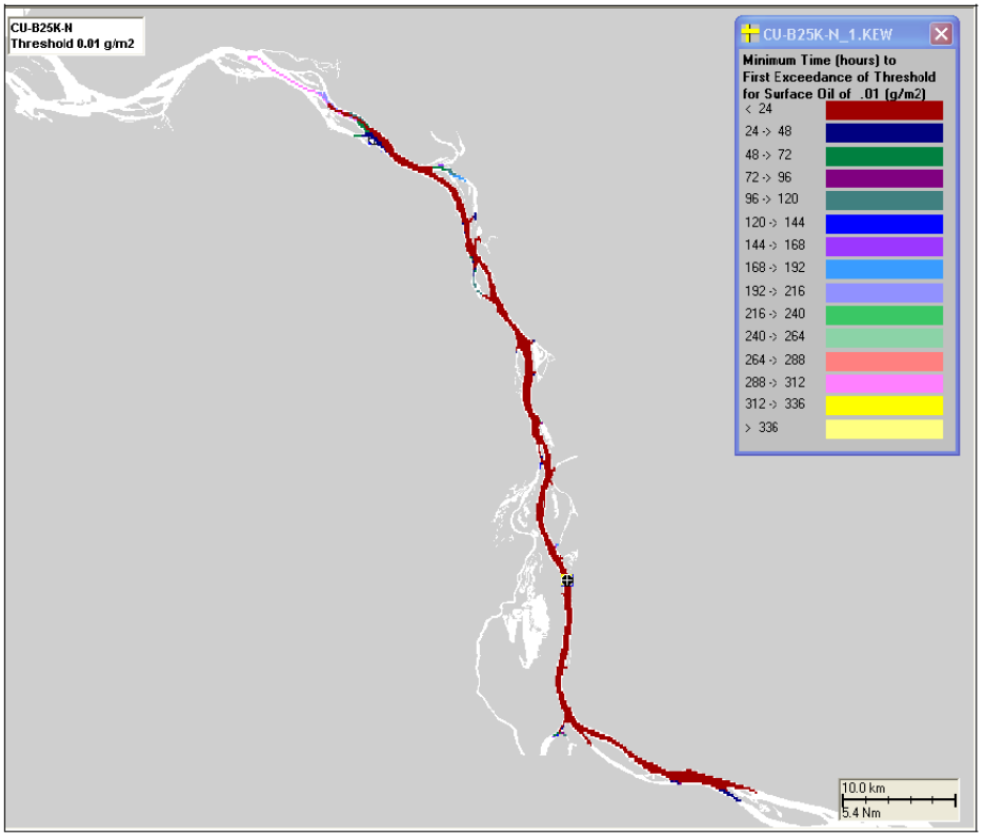


Source: Etkin and Moore, 2015, Figure 14.

Spill Impact Model Application Package

French McCay et al. (2006) used the Spill Impact Model Application Package (SIMAP) to model a spill of 25,000 bbls of Bunker C fuel oil in a location between Longview and Vancouver, WA. This model scenario differs from the WCD scenario we evaluated in this report in many ways. For instance, Bunker C is a heavier and more viscous oil than Bakken crude, and 25,000 bbls is less than 15% of the effective WCD spill. French McCay et al. (2006) estimated that this considerably smaller spill would result in oil slicks traveling downstream to Longview, WA, within 24 hours (Figure 2.7).

Figure 2.7. SIMAP model results showing the time after spill (hrs) when surface floating total hydrocarbons could first exceed 0.01 g/cm^2.



Source: French McCay et al., 2006, as cited in Etkin and Moore, 2015, Figure 11.

The fate and transport of the oil will depend on environmental conditions at the time of the spill, as well as the nature of the release of the oil. To bracket the release scenarios, we developed two WCD scenarios: one scenario assumes a rapid release from the tanker and all the oil is discharged within 2 hrs, and the other scenario assumes that the oil is discharged continuously for 24 hrs. The shorter timeframe results in more concentrated oil and less spreading over the river, while the longer timeframe results in a larger footprint of oil, but less oil within the contaminated surface area. As mentioned previously, we assumed this spill would occur in the spring (approximately mid-April to mid-May).

2-Hour Release of Oil

For our short timeframe discharge scenario, we assumed that the WCD of 189,845 barrels of Bakken crude is released over 2 hrs near the proposed Vancouver Terminal. Integrating the data from our data evaluation and the modeling efforts cited in the DEIS, we estimated the following:

Vancouver to Longview – Reach 2

- Within 1 day, the oil is estimated to travel from Vancouver to Longview, consistent with both the estimated transit time based on river velocity and the aforementioned modeling data. Some oil could also migrate upstream as the result of winds, but we did not consider upstream migration in this scenario.

- Some of the oil could strand on the banks and floodplain habitat. Some of the stranded oil could be re-released during inundation with water during tidal fluctuations, but in other areas it could remain for days or weeks, or even longer. Sedimentation of oil could also result in contaminated sediments in more quiescent areas of the river. The ADIOS2 model results (Etkin and Moore, 2015) do not provide an estimate of the amount of oil lost from the water column by stranding and sedimentation.
- Biota could be exposed to stranded oil and oil in sediments.

Unquantified impacts: Upstream movement of oil

French McCay et al. (2006) predicted the oil would go both upstream and downstream. Other data suggest that while the river is tidally influenced as far upstream as the Bonneville Dam, it generally does not reverse flow upstream of Longview. It is possible that oil from a WCD would flow upstream as well as downstream, but we have not included the upstream reach in this analysis.

- Based on the ADIOS2 modeling, approximately 4% of the oil could disperse into the water column over the 1-day transit time. Using the estimated volume of water in Reach 2 (Table 2.2), and assuming this dispersed oil is evenly mixed laterally, vertically, and longitudinally within the Columbia River, we estimated the oil concentration in the water would be approximately 20,000 µg/L (Table 2.3). In an actual spill, the oil would not mix completely, and concentrations would be more patchy and variable.
- Assuming a percentage PAH percentage in the oil of 1.12% (Etkin and Moore, 2015, Table 46), the concentration of total PAHs[2] would be approximately 230 µg/L.
- Biota in the water column could be exposed to both the floating oil and oil dispersed into the water column.

Longview to Mouth of Columbia River – Reach 1

- Over the next few days, the oil could continue to flow downstream with the currents, as well as spread and disperse due to winds and waves.
- We estimated the transit time for the oil in Reach 1 to range from 3 days based on the 1984 *MobilOil* spill to 5 days based on the net velocity in this reach. For calculation purposes, we assumed the oil would be present on the water for 4 days before exiting the mouth of the Columbia River. We did not account for impacts to the ocean habitat or coastal areas in this analysis.
- Some of the oil could strand on river banks and floodplain habitat. Some of the stranded oil could be released again during inundation with water during tidal fluctuations, but in other areas it could remain for days to weeks, or even longer. Sedimentation of oil could also result in contaminated sediments in more quiescent areas of the river. The ADIOS2 model results (Etkin and Moore, 2015) do not provide an estimate of the amount of oil lost from the water column by stranding and sedimentation.
- Biota could be exposed to stranded oil and oil in sediments.

2. Total PAHs in this report refer to the sum of 50 commonly measured parent and alkylated PAHs; see Forth et al. (2015) for more information.

Table 2.3. Estimated oil and PAH concentrations in the LCR for an effective WCD near Vancouver

Days since oil spill	Reach with floating and dispersed oil	Oil dispersed into water column (ADIOS2)	Estimated oil dispersed into the water column (gals)	Estimated percentage of total PAH in oil	2-hr release estimated oil in the water column (µg/L)	2-hr release estimated total PAH in water column (µg/L)	24-hour release estimated oil in the water column (µg/L)	24-hour release estimated total PAH in water column (µg/L)
1	2	4%	318,900	1.12%	20,000	230	2,000	20
2	1	9%	717,500	0.73%	48,000	350	4,000	30
3	1	15%	1,195,900	0.68%	80,000	540	7,000	50
4	1	20%	1,594,500	0.65%	110,000	690	9,000	60
5	1	24%	1,913,400	0.63%	130,000	800	11,000	70

- Based on the ADIOS2 modeling results, oil would continue to disperse into the water column, with approximately 24% of the oil being dispersed into the water column within 5 days (Etkin and Moore, 2015).
- The ADIOS2 modeling predicts that at the end of 5 days, 35% of the oil would remain floating on the water.
- The floating oil would weather, resulting in a lower fraction of PAHs in the oil over time.
- We assumed that oil would cover one-quarter of Reach 1 each day as it migrates through the reach over 4 days.
- As above, we assumed that the available oil would be fully mixed within the water column.
- Using the estimated volume of water in Reach 1 (Table 2.2), and the amount of dispersed oil, we estimated oil concentrations could range from 48,000 to 130,000 µg/L in the water column beneath the floating oil slicks (Table 2.3).
- Assuming that total PAH is 1.12% of fresh oil and decreases to 0.63% after 5 days, the total PAH concentrations in the water column in Reach 1 could range from 350 to 800 µg/L (Table 2.3).
- Biota in the water column could be exposed to both the floating oil and oil dispersed into the water column.

24-Hour Oil Spill

If the oil is released over 24 hrs, the WCD of 8 million gallons of oil would be spread out over a much larger geographic area. We estimated that oil concentrations in the water could be as high as 2,000 µg/L in Reach 2, with total PAH concentrations of 20 µg/L (Table 2.3). As above, the ADIOS2 model results indicate that dispersion into the water column will increase over time, while weathering of the oil will reduce the fraction of PAH in the oil. Using the same assumptions described above, but with oil spread over a much larger spatial footprint, we estimated oil concentrations in the water in Reach 1 to range from 4,000 to 11,000 µg/L, with total PAH concentrations ranging from 30 to 70 µg/L.

Although these estimates of the fate and transport of a Bakken crude WCD into the Columbia River are uncertain, the scenarios described above provide a reasonable estimate of oil transport given available data.

2.3 WCD from Train Derailment into Columbia River Upstream of Bonneville Dam

In addition to estimating damages and economic impacts of fishery closures in the LCR, we also assessed potential damages from a train derailment upstream of the Bonneville Dam. The BNSF railroad carrying Bakken crude from North Dakota and Montana run on the bank of the river through that reach (Etkin et al., 2015).

The Rail Spill Risk Analysis in Appendix E of the DEIS (Etkin et al., 2015) provides an effective WCD of 20,000 bbls for a train wreck, based on the derailment of 28 full tank cars, each carrying 714 bbls of crude. The DEIS states, “This represents approximately the 99th percentile with respect to derailed cars assuming all of the cars release oil. This is the volume that is the most credible or realistic WCD with respect to the likelihood of the largest number of cars involved in a derailment and the likelihood of the cars releasing all of their contents" (Etkin et al., 2015, footnote 11, p. 14).

Crude oil trains can have as many as 120 rail cars, with a theoretical maximum discharge of 85,860 bbls (Etkin et al., 2015). However, the Rail Risk Spill Analysis states that this scenario is "extremely unlikely based on the very low probability of all of the cars derailing and the very low probability that all of the cars would release oil" (Etkin et al., 2015, p. 24). We used the effective WCD of 20,000 bbls cited in Table 4-14 of the DEIS (EFSEC, 2015), rather than the theoretical WCD of 85,860 bbls.

2.3.1 Fate and Transport

We evaluated a worst-case scenario of a train derailment near the Bonneville Dam, where spilled oil went over the spillway at the dam and entered the protected white sturgeon (*Acipenser transmontanus*) spawning area 4.5 miles downstream of the dam. For this scenario, we evaluated only natural resource damages, although it is likely a fishery closure would also be enforced as assumed in the tanker spill scenario described above. We have no existing models of oil fate and transport in this area, and developing our own model is beyond the scope of this analysis. We made some simple assumptions that likely underestimate potential natural resource exposure to a WCD scenario of Bakken crude oil spilled into this reach.

To evaluate potential natural resource damages from a WCD train derailment, we assumed that the oil spill occurred just upstream of the Bonneville Lock and Dam. All of the oil was discharged from the rail cars within 2 hours. Oil spread on the surface of the Bonneville Pool and was transported downstream toward the dam.

The Bonneville Dam has two powerhouses generating electricity, and a spillway to allow water to bypass the turbines (Figure 2.8; USACE, Undated). In the spring and summer, water is discharged over the spillway. In this WCD spill scenario, we assumed that the discharged oil passed over the spillway, turbulently mixing with Columbia River water.

The concentrations of oil in the river downstream of the Bonneville Dam would depend on the assumed volume of the oil discharged, the discharge in the Columbia River at the time of the spill, and the assumed time for the spilled oil to pass over the spillway. River discharge at The Dalles Dam, upstream of the Bonneville Dam, averages 270,000 cfs during the spring months, and decreases to an average of 140,000 cfs by August.[3] At the Bonneville Dam, water during the spring and summer is discharged over the Bonneville Dam spillway as well as through the turbines at the two powerhouses. USACE (2008) reported an average discharge over the spillway of 100,000 cfs in the spring and 85,000 cfs during the day in the summer. The percentage of the flow directed over the spillway and through the powerhouses varies with operational conditions. As an example, a fish-tagging study by Adams and Rondorf (2007) from April 29 to June 6, 2005, reported a mean river discharge at the Bonneville Dam of 216,400 cfs, with 47.3% of flow discharged at the second powerhouse, 40.3% at the spillway, and 12.4% at the first powerhouse.

3. USGS Station 14105700, average monthly mean discharge from 1985 to 2015.

Figure 2.8. Bonneville Lock and Dam on the Columbia River. The photograph was taken looking upstream to the east. The spillway is in the center, the two powerhouses are on the left and right of the spillway, and the lock is on the far right.

Source: USACE, 2003.

Given the highly turbulent environment beneath the spillway, we assumed that the spilled oil mixed completely with water discharged over the spillway. Downstream of the dam, oil-contaminated water would be further mixed with water flowing through the powerhouses. Even with dilution, the result of mixing a WCD of oil with the water in the Columbia River results in substantial oil concentrations downstream of the Bonneville Dam. Using average mean May discharge (2005–2015) from the Bonneville Dam of 284,000 cfs (USACE, 2016), a density of the Bakken crude of 0.827 g/cm^3 (Etkin and Moore, 2015, p. 46), and assuming that all 20,000 bbls of discharged oil passed over the spillway within 2 hrs, we estimated the concentration of oil fully mixed downstream in the Columbia River would be 45,000 µg/L. Assuming PAHs are 1.12% of the oil (see previous section), we calculated a total PAH concentration of 500 µg/L.

Unquantified impacts: Effects of a spill on dam operations

A WCD either upstream or downstream of the Bonneville Dam could disrupt dam operations. If a major spill occurred downstream of the dam, one potential response action would be to spill enough water to create a downstream flood that would flush surface oil out to the sea. If a major spill occurred in the impoundment upstream of the dam, a possible response action would be to greatly reduce downstream flows (and power generation) to try to capture the oil before it went over the spillway, through the turbines or over the fish ladders. These potential impacts are not quantified in this analysis.

It is possible that some of the oil may not pass over the spillway, perhaps getting trapped behind the dams and removed from the river before it can be mixed. Even if only 40% of the oil passed over the spillway in 2 hours, after full mixing, oil concentrations in the river would be approximately 18,000 µg/L and total PAH would be about 200 µg/L. These concentrations are sufficient to cause adverse effects on exposed biota (see Chapter 4).

This scenario would result in a pulse of highly contaminated water moving down the LCR. The spatial and temporal dimensions of the pulse would depend on the quantity of oil and the time for the discharged oil to spill over the spillway. Some of the oil droplets would rise to the surface of the river and form an oil slick, and other droplets would remain entrained in the water column. The oil would disperse as it migrated downstream and be diluted by tributary inflows, but the oil would continue to affect natural resources as it migrated approximately 140 miles downriver.

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3. Impacts to Commercial and Recreational Fishing

This chapter evaluates the potential economic impacts to commercial and recreational fishing from the hypothetical WCD in the LCR. This stretch of the river, from the Bonneville Dam to the Pacific Ocean, supports substantial commercial and recreational fishing throughout most of the year for species such as salmon, shad, and smelt. It does not include areas specifically devoted to Treaty fishing by Indian Tribes.

3.1 Commercial Fishing

Chinook salmon (*Oncorhynchus tshawytscha*) is the most prevalent species for commercial fishing in the LCR, with landings averaging 1.7 million pounds over the last 5 years, from 2011 to 2015. Landings of coho salmon (*Oncorhynchus kisutch*) averaged 653,000 pounds over the same period. Other commercial species include sockeye salmon (*Oncorhynchus nerka*), shad (*Alosa sapidissima*), smelt (*Thaleichthys pacificus*), and white sturgeon. Total landings of all species averaged 2.4 million pounds over the last 5 years. Data on commercial landings and prices in the Columbia River were provided by the Oregon Department of Fish and Wildlife (ODFW).[1]

Commercial fishing occurs over several seasons, defined in part by the spawning migrations of the primary species. The winter season includes January and February, with fishing for small amounts of Chinook salmon and white sturgeon. The spring season extends from March 1 to June 15, when Chinook salmon and shad are the primary species. The summer season extends from June 16 to July 31, and includes the harvest of Chinook salmon and sockeye salmon. The fall season extends from August 1 to October 31, when Chinook salmon and coho salmon are the primary species. Smelt are present in the river throughout the year, though the commercial harvest is sometimes limited to certain months.

The value of commercial landings can be estimated using ex-vessel prices, which represent the amount that commercial fishermen receive for their catch. Prices vary by species and season, ranging from about $6.00 per pound for spring Chinook salmon to less than $0.50 per pound for shad. Ex-vessel prices do not account for the value to consumers of fish harvested in the Columbia River, which can be difficult to estimate given that alternative sources of fish are available. Ex-vessel prices also may not accurately reflect losses to commercial fisherman when fishing is disrupted. A complete estimate of losses to commercial fisherman could be lower because of factors such as reductions in cost and effort when the commercial harvest is restricted, or could be higher because of oil damage to boats and fishing equipment or because of impacts to the public's perception of seafood harvested in the Columbia River even after closures are lifted.

1. Data were provided by personal communication from Douglas Case of the ODFW on April 16, 2016, and from the ODFW website at: http://www.dfw.state.or.us/fish/oscrp/crm/comm_fishery_updates_15.asp.

3.1.1 Baseline Activity

Table 3.1 shows commercial landings and value by month for the 2011 to 2015 period. Value is calculated as landings in pounds multiplied by ex-vessel prices per pound. The average of landings and value over this five-year period represents an estimate of expected baseline activity in the event of a future spill. "Baseline" refers to the level of activity that would have occurred in the absence the spill and represents the amount of activity that could be impacted by the spill.

Based on the averages for 2011–2015, baseline landings are 2.4 million pounds per year and the baseline value is $5.1 million per year. The most significant baseline activity occurs in the fall season, with the monthly ex-vessel value exceeding $1 million for both August and September. Total baseline landings for the fall season are 2.2 million pounds.

3.1.2 Period of Impact

Many previous oil spills in the United States have led to closures of commercial fisheries. In some cases the closures lasted only a week or two. Often these short-term closures have been precautionary, imposed wherever oil is potentially present and lifted when testing does not find contamination in fish. For example, following the Chalk Point oil spill on a tributary to Chesapeake Bay in 2001, commercial fishing was closed for 2½ weeks while fish were tested for contamination. In other cases, contamination was detected and closures remained in effect until testing confirmed that fish were safe to eat. This was the case following the DWH oil spill in the Gulf of Mexico in 2010, when many areas were subject to fishing closures lasting between 3 months and 11 months, depending on proximity to the source of the spill.

Table 3.2 summarizes commercial fishing closures for selected past spills in the United States where reliable information on closures could be found. A more extensive list of oil spills since 1990, along with source documentation for information about closures, is provided in Appendix A.

As evident in Table 3.2, the amount of oil released can affect the period of a fishing closure, with larger spills often resulting in longer closures than smaller spills. The type of oil released can also be a factor, and the type of oil released in each spill is reported in the more extensive table in Appendix A. However, this factor was not deemed critical to this analysis because Bakken crude oil includes both light and heavy components. The area impacted can also affect the period of closure, because spills on the open ocean may dissipate more rapidly than spills in a confined bay or river. The type of fishing affected is also important. For example, shellfishing closures often last longer than closures for other types of fishing because shellfish are stationary on the sea or river bottom and can be heavily exposed to oil.

The most common oil spills have involved quantities of oil of less than 150,000 gallons and have resulted in relatively short fishing closures. For example, the Chalk Point spill, the Cosco Busan spill, and the Refugio spill were modest in size and led to fishing closures lasting from 2½ to 6 weeks. The North Cape spill on the coast of Rhode Island in 1996 involved a release of 828,000 gallons and led to a 3-month fishing closure. The Bouchard 120 spill in Buzzards Bay, Massachusetts, led to closures lasting 6 months or more despite the modest size of the spill (less than 100,000 gallons). However, the closure did not apply to finfish in the open water but to shellfish beds on the sea floor that are often slow to recover. The DWH oil spill occurred in the open ocean, involved an extremely large release, and led to closures for all fishing lasting up to 11 months in some areas.

Table 3.1. Commercial landings in pounds and value of landings, 2011–2015[a]

	2011		2012		2013		2014		2015		Average, 2011–2015	
Month	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value	Pounds	Value
January	965	$2,718	1,098	$3,003	126	$407	–	–	–	–	730	$2,043
February	3,088	$15,415	962	$5,032	889	$3,886	16,750	$24,566	17,026	$23,464	7,743	$14,473
March	19,906	$118,794	2,786	$16,383	8,421	$56,541	8,268	$50,793	22,709	$145,937	12,418	$77,689
April	49,849	$299,743	103,081	$687,890	42,263	$314,747	30,107	$203,455	35,167	$228,581	52,094	$346,883
May	119,133	$685,593	48,080	$282,091	66,228	$382,080	46,083	$248,476	112,981	$735,148	78,501	$466,677
June	143,738	$386,960	81,502	$359,295	60,727	$288,526	46,110	$182,941	94,466	$461,194	85,309	$335,783
July	19,748	$61,022	14,432	$56,995	34,636	$140,882	46,340	$167,968	37,196	$128,869	30,470	$111,147
August	716,354	$1,397,382	638,944	$1,145,926	997,541	$2,365,051	599,342	$1,022,362	639,507	$1,368,035	718,337	$1,459,751
September	1,101,695	$1,890,787	412,952	$732,737	895,315	$1,760,385	2,576,664	$3,383,431	970,474	$1,730,747	1,191,420	$1,899,617
October	124,900	$228,780	82,209	$168,012	178,059	$338,963	701,404	$907,313	130,691	$248,290	243,453	$378,272
November	–	–	–	–	1,038	$2,005	–	–	–	–	1,038	$2,005
December	–	–	–	–	–	–	–	–	–	–	–	–
Total	2,299,377	$5,087,193	1,386,045	$3,457,364	2,285,243	$5,653,473	4,071,067	$6,191,304	2,060,217	$5,070,263	2,421,512	$5,094,341

a. Monthly data were available for landings by numbers of fish, but landings in pounds and value of landings were available only by fishing season. Development of monthly estimates of landings and value may have resulted in some approximations. Harvest of pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) were small and were excluded from the estimates.

Table 3.2. Commercial fishing impacts in past U.S. oil spills

Name of spill	Year	Location	Quantity of oil (gallons)	Impact area	Impact period	Severity of impacts	Type of impacts
Bouchard 120	2003	MA	22,000–98,000	Coastline, variable extent (maximum = 65 mi)	6 months or more	Closure	Shellfishing
Chalk Point	2000	MD	140,000	20 RMs	2.5 weeks	Closure/ advisory	Shellfishing closure; fishing advisory
Cosco Busan	2007	CA	54,000	San Francisco Bay, plus 45 mi of coastline	3 weeks	Closure	All fishing
DWH	2010	Gulf of Mexico	134,000,000	Ocean, variable extent (maximum = 84,000 mi^2)	3–11 months	Closure	All fishing
North Cape	1996	RI	828,000	250 mi^2 of ocean	3 months	Closure	All fishing
Refugio	2015	CA	142,000	22 mi of coastline	6 weeks	Closure	All fishing
Selendang Ayu	2004	AK	321,000	166 mi^2 of ocean/bay	10 months	Closure	All fishing

The quantity of oil potentially released in the Columbia River, given the scenario under evaluation, is greater than the quantity released in many past spills. Though Bakken crude is a light oil with many components dissipating in a few weeks, the heavier components could remain in the river for many months. Also, the river environment may prevent oil from dissipating as quickly as spills in the open ocean. For the purposes of evaluating the impacts of an oil spill of 8 million gallons on the LCR, we assumed that the entire lower reach of the Columbia River, from the Bonneville Dam to the Pacific Ocean, would be closed to fishing for 6 months.

3.1.3 Economic Losses for Commercial Fishing

Following an oil spill in mid-spring (we use May 1 as the specific date), a 6-month closure would eliminate commercial fishing from May through the following October. Using the baseline estimates from the last two columns of Table 3.1, and summing across the appropriate months, would result in a loss of 2.3 million pounds of commercial landings, and a loss of $4.7 million in commercial fishing value.

3.2 Recreation Fishing

About 375,000 recreational fishing trips are taken annually to the LCR. A trip in this context is defined as any part of a day spent fishing. Species targeted by recreational anglers include Chinook salmon, coho salmon, steelhead trout (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarki*), white sturgeon, shad, and walleye (*Sander vitreus*). Recreational fishing occurs by boat and from shore, with about 70% of recreational fishing trips by boat (Watts, 2009). The period from March to October is the most popular time of year for recreational fishing on the LCR. Data on the number of recreational fishing trips to the Columbia River were provided by the ODFW.[2]

2. Data were provided by personal communication from Kevleen Melcher of ODFW, April 14, 2016.

3.2.1 Baseline Activity

Table 3.3 shows the number of recreational fishing trips by month for the most recent 5 years of available data. The average of these 5 years represents an estimate of baseline activity that could be impacted by a future spill.

Table 3.3. Recreational fishing trips, expenditures, and value

	Recreational fishing trips							
						Average, 2011–2015		
Month	2011	2012	2013	2014	2015	Trips	Expenditures[a]	Value[b]
January	1,405	722	1,119	–	–	649	$30,499	$37,654
February	7,231	11,066	6,520	3,452	5,170	6,688	$314,193	$387,892
March	61,502	41,123	42,222	25,435	41,044	42,265	$1,985,619	$2,451,382
April	51,111	58,541	30,882	60,457	50,545	50,307	$2,363,432	$2,917,818
May	26,701	24,853	28,106	40,426	42,427	32,503	$1,526,972	$1,885,151
June	73,238	70,095	78,494	58,370	43,875	64,814	$3,044,981	$3,759,235
July	64,266	60,139	26,080	31,015	33,012	42,902	$2,015,555	$2,488,339
August	70,829	56,326	67,996	53,877	43,642	58,534	$2,749,927	$3,394,972
September	69,127	65,386	63,889	74,072	70,086	68,512	$3,218,694	$3,973,696
October	25,883	8,212	9,982	16,439	18,274	15,758	$740,311	$913,964
November	3,399	–	–	–	–	680	$31,937	$39,428
December	1,890	–	–	–	–	378	$17,758	$21,924
Total	456,582	396,463	355,290	363,543	348,075	383,991	$18,039,878	$22,271,455

Notes: Totals may not sum due to rounding. Estimates of the total number of trips may be low due to incomplete sampling in winter months.

a. Average expenditures are the average number of trips mutliplied by $46.98 in expenditures per trip.

b. Average value is the average number of trips mutliplied by $58.00 in value per trip.

Table 3.3 also shows two types of value associated with recreational fishing trips. The first value is angler expenditures. Expenditures do not represent a loss to anglers, who recoup expenditures in the event that they cancel trips after an oil spill. However, the loss of spending by anglers can represent a disruption to local economic activity, particularly for businesses close to the affected areas and those businesses that provide services specifically for anglers, such as bait shops and marinas. The second value is the enjoyment value of fishing trips, or “consumer surplus.” This represents the amount anglers would be willing to pay, above what they actually pay, for the ability to take recreation trips to the Columbia River.

Expenditures were calculated by multiplying the number of fishing trips by $46.98 in estimated per-trip expenditures. This amount was calculated as the total angler trip-related expenditures in Washington and Oregon divided by the total angler trips in Washington and Oregon (USFWS and Census Bureau, 2014). Expenditures for anglers fishing on the Columbia River could differ from expenditures by anglers using sites throughout Washington and Oregon, but data specific to the Columbia River could not be obtained for this analysis.

The value of a fishing trip was taken from a report prepared for the Washington Department of Fish and Wildlife (WDFW) on the economic value of commercial and recreational fisheries in Washington State (TCW Economics, 2008). That report provided value estimates for several types of fishing, with a value of $58.00 per day for salmon fishing in Washington State. Salmon are the most popular species for recreation anglers on the Columbia River (Watts, 2009). For context, other related values include an estimate of $44.36 per trip for the value of Pacific Coast fishing (Loomis, 2005), calculated using a synthesis of values from 15 studies. A recent study of steelhead trout fishing on the Snake River in Idaho, a tributary of the Columbia River, found values ranging from $47.64 to $71.84 per trip (McKean et al., 2010).

3.2.2 Period of Impact

Following an oil spill, fishing closures may be imposed for several weeks or many months. However, the loss of recreational fishing depends as much on the behavioral response of anglers as any government-imposed closures. In some cases, such as the Athos oil spill on the Delaware River in Philadelphia, there was no fishing closure but angers avoided the spill area for many months (Athos/Delaware River Lost Use Technical Working Group, 2007). In other cases, such as the Chalk Point oil spill in Maryland, a closure was imposed and then lifted, but the level of recreational fishing activity did not return to normal until several months later (Byrd et al., 2001).

Table 3.4 summarizes the extent of impacts to recreational fishing for selected past oil spills in the United States. Additional information on the recreation impacts of past spills is included in Appendix A. The time period of impacts varies from a low end of 1 or 2 months to a high end of a year or more. The limited number of examples where impacts lasted a year or more includes two cases of an oil spill in a river (the Athos spill[3] and the Kalamazoo River spill); in these cases, the ability of oil to dissipate over a wider area was limited. In the Bouchard 120 spill, impacts lasted 2 years, but the impacts involved shellfishing for which prolonged impacts are more common than for other types of fishing. Investigators often find that impacts to boat-based fishing decline more quickly than shoreline fishing. This can be observed in Table 3.4 by comparing the boating assessments for the Bouchard 120 spill and the DWH spill to other activities assessed for those spills.

Overall, Table 3.4 illustrates that the severity of impacts from past spills typically varies from a 100% decline in trips during a fishing closure, to declines of approximately 10–60% when closures are not in place.

In evaluating a potential spill on the Columbia River, the potential release of 8 million gallons in the contained environment of a river suggests that significant impacts to recreational fishing would occur. While the lighter components of Bakken crude oil could dissipate quickly, significant amounts of heavier oil could remain for many months. In the previous section, we concluded that a fishing closure of the entire LCR could be in place for 6 months. In addition to affecting commercial fishing, a closure would also eliminate recreational fishing for that period. After the closure, evidence from past spills indicates that some recreational anglers would continue to avoid the spill area for some time. We assume that impacts to recreational fishing activity would decline linearly over the next 6 months, from 100% during the last month of the closure, to zero 1 year after the spill.

3. Impacts in the Athos spill were calculated over a period of 7 months, as shown in Table 3.4. However, the assessment of impacts did not begin until 5 months after the spill event because the spill occurred at the start of the winter season when little fishing occurred. The total elapsed time before impacts subsided was therefore a full year.

Table 3.4. Recreational fishing impacts in past U.S. oil spills

Name of spill	Year	Location	Quantity of oil (gallons)	Impact area	Impact period	Severity of impacts	Type of impacts
American Trader	1990	CA	416,598	14 mi of coastline	7.5 weeks	85% decline in trips for first 5 weeks; 30% decline for next 2.5 weeks	Beach use, including some fishing
Athos	2004	DE	263,000	60 RMs	7 months	11% decline in trips	Fishing
Bouchard 120 (shoreline)	2003	MA	22,000–98,000	65 mi of coastline	2 months	9% decline in trips	Shoreline use, including some fishing
Bouchard 120 (shellfishing)	2003	MA	22,000–98,000	65 mi of coastline	2 years	59% decline in trips in first year; 11% decline in second year	Shellfishing
Bouchard 120 (boating)	2003	MA	22,000–98,000	65 mi of coastline	1 month	3% to 6% decline in trips	Boating, including fishing
Chalk Point	2000	MD	140,000	17 RMs	6 months	10% decline in trips	Shoreline use, including some fishing
Cosco Busan	2007	CA	54,000	San Francisco Bay, plus 45 mi of coastline	3 months	57% decline	Fishing, including boat and shore
DWH (shoreline)	2010	Gulf of Mexico	134,000,000	575 mi	11 months	Not available	Shore fishing
DWH (boating)	2010	Gulf of Mexico	134,000,000	575 mi	4 months	Not available	Boating, including fishing
Kalamazoo River (shoreline)	2010	MI	> 840,000	39 RMs	27 months	60% decline (initially 100% due to closure, declined over time)	Shoreline use, including fishing
Kalamazoo River (boating)	2010	MI	> 840,000	39 RMs	27 months	69% decline (initially 100% due to closure, declined over time)	Boating, including fishing

3.2.3 Economic Losses for Recreational Fishing

For this analysis, we assume that a large oil spill on the Columbia River would lead to a closure of the entire lower river to fishing for a period of 6 months. The closure would cause a 100% loss of recreational fishing from May, when the spill occurs, through October. Impacts over the next 6 months are assumed to decline following a linear trend. Specifically, in the seventh month (November) there is an 86% loss of trips; in the eighth month there is a 71% loss of trips; and the losses are 57%, 43%, 29%, and 14% for the remaining 4 months, respectively. Applying these percentage losses to the baseline amounts for the appropriate months in Table 3.3, the result is a total decline in recreational fishing on the Columbia River of 306,376 trips. This corresponds to a decline in trip-related expenditures of $14.4 million, and a decline in fishing value of $17.8 million.

3.3 Conclusions

A tanker accident on the LCR has the potential to release 8 million gallons of Bakken crude oil into the river environment (Etkin and Moore, 2015). An oil spill of this size would have a significant impact on commercial and recreational fishing. While past spills have not always resulted in fishing closures, some spills have resulted in closures lasting from several months to almost a full year. Given the large amount of the release under consideration and the confined river environment of the potential spill, a fishing closure of 6 months was determined to be a likely result.

Both commercial and recreational fishing would be affected by a fishing closure, but impacts to recreational fishing are likely to continue even after a closure is lifted. In past spills, recreation impacts have usually lasted for period of several months to a year or more. For the spill under consideration, we have assumed that impacts to recreational fishing last a full year. The first 6 months involve a 100% loss of trips during the closure, and the remaining 6 months involve losses that decline linearly to zero at the end of a year.

Although the impacts to fishing could affect areas of the Pacific Ocean as well as the Columbia River, we have evaluated impacts only down to the mouth of the river. Although upstream currents from ocean tides may not carry oil all the way to the Bonneville Dam, we have included the entire lower river up to the dam in our impact area. Given that the large majority of the lower river is downstream of the potential release, and given that fish spawning runs pass through oiled areas of the river, it is reasonable to include the entire lower river in the evaluation of spill impacts.

We calculated three different types of fishing losses: the loss in revenue from commercial landings, the decline in expenditures by recreational anglers, and the decline in the value of recreational fishing. Each of these values measures something conceptually different, and these values may not be strictly additive. For example, methods to calculate the value of fishing do not include angler expenditures, because anglers recoup their expenditures when they cannot fish. It would therefore be inappropriate to sum expenditures and angler values. Likewise, the loss in revenue from commercial landings is not a direct measure of economic loss, since commercial fishermen may recoup some costs, and may engage in other economic activities such as aiding in cleanup of the spill.

The loss in revenue from commercial landings is $4.7 million. This is a measure of the economic losses to commercial fishermen, although lost revenue does not directly represent total losses due to factors that are difficult to quantify, as noted above. The decline in expenditures by recreational anglers is $14.4 million. This should be viewed as a measure of the potential disruption to local economic activity, with the most direct impacts on local businesses, such as bait shops and marinas. If anglers make up for lost trips on the Columbia River by taking additional trips to other sites nearby, some of these expenditures may not be diverted from the local area.

The decline in the value of recreational fishing is $17.8 million. This is a monetary quantification of the loss of enjoyment by anglers whose preferred fishing opportunities are degraded or eliminated by the spill.

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A. Summary of Impacts to Recreational and Commercial Fishing from Past Oil Spills

Table A.1. Impacts to recreational and commercial fishing from past oil spills

Spill incident	Year	Location	Quantity of oil	Type of oil	Type of environment	Recreational impacts				Commercial impacts				Sources
						Impact area	Impact period	Severity of impact	Type of impacts	Impact area	Impact period	Severity of impact	Type of impacts	
American Trader	1990	CA	416,598 gallons	Alaska North Slope crude	Ocean beaches	14 miles of coastline	7.5 weeks	85% decline for first 5 weeks; 30% decline for next 2.5 weeks	Beach use, including some fishing					Chapman and Hanneman (2001)
Athos	2004	DE	263,000 gallons	Heavy crude oil	River	60 RMs	7 months	11% decline in trips	Fishing, including boat and shore					Athos/Delaware River Lost Use Technical Working Group (2007); NOAA et al. (2009)
Berman	1994	PR	1.5 million gallons	#6 fuel oil	Ocean beaches	169 miles of coastline	2 months	30% decline in trips	Beach use, including some fishing					NOAA et al. (2002c); Tetra Tech (2006)
Bouchard 120 (shoreline)	2003	MA	22,000 to 98,000 gallons	#6 fuel oil	Bay/ocean beaches	65 miles of coastline	2 months	9% during first 2 months; 0.7% over next 3 months	Shoreline use, including some fishing					Bouchard B-120 Oil Spill Lost Use Technical Working Group (2009)
Bouchard 120 (shellfishing)	2003	MA	22,000 to 98,000 gallons	#6 fuel oil	Near-shore bay/ocean	65 miles of coastline	2 years	59% decline in first year; 11% decline in second year	Shellfishing	65 miles of coastline	6 months or more	Closure of some shellfishing areas	Shellfishing closure	Bouchard B-120 Oil Spill Lost Use Technical Working Group (2009)
Bouchard 120 (boating)	2003	MA	22,000 to 98,000 gallons	#6 fuel oil	Bay/ocean	65 miles of coastline	1 month	3% to 6% decline	Boating, including fishing					Bouchard B-120 Oil Spill Lost Use Technical Working Group (2009)
Chalk Point	2000	MD	140,000 gallons	#6 and #2 fuel oil	River, estuary	17 RMs	6 months	10% decline in trips	Shoreline use, including some fishing	20 RMs	2.5 weeks	Closure/advisory	Shellfish closure, fishing advisory	MDE (2000); U.S. EPA et al. (2000); Byrd et al. (2001); NOAA et al. (2002a)
Citgo Refinery/ Calcasieu River	2006	LA	2 million gallons	Waste oil	River and lake	67 square miles (Lake Calcasieu)	> 10 days	10-day closure, impacts could be longer	Fishing, boating					Associated Press (2006); Peck (2006)
Cosco Busan	2007	CA	54,000 gallons	Intermediate fuel oil	Ocean shoreline, near-shore ocean, estuary	San Francisco Bay, plus 45 miles of coastline	3 months	57% decline	Fishing, including boat and shore	San Francisco Bay, plus 45 miles of coastline	3 weeks	Closure	All fishing; $6 million in damages paid to 120 commercial fisherman	Leggett and Curry (2010); Bay City News (2011); CDFG et al. (2012)
Deepwater Horizon (fishing)	2010	Gulf of Mexico	134 million gallons	Louisiana sweet crude oil	Ocean shoreline	575 miles	11 months		Shore fishing					English and McConnell (2015)
Deepwater Horizon (boating)	2010	Gulf of Mexico	134 million gallons	Louisiana sweet crude oil	Ocean	575 miles	4 months		Boating, including fishing	Ocean, variable extent	3 to 11 months	Closure	Fishing closure	NOAA (2010a, 2010b, 2010c, 2010d, 2011); DWH NRDA Trustees (2015); English and McConnell (2015)

Table A.1. Impacts to recreational and commercial fishing from past oil spills

Spill incident	Year	Location	Quantity of oil	Type of oil	Type of environment	Recreational impacts: Impact area	Recreational impacts: Impact period	Recreational impacts: Severity of impact	Recreational impacts: Type of impacts	Commercial impacts: Impact area	Commercial impacts: Impact period	Commercial impacts: Severity of impact	Commercial impacts: Type of impacts	Sources
Deepwater Horizon (shoreline)	2010	Gulf of Mexico	134 million gallons	Louisiana sweet crude oil	Ocean beaches	575 miles	19 months		Shoreline use, including fishing					English and McConnell (2015)
Ever Reach	2002	SC	12,500 gallons	#6 fuel oil	Near-shore ocean	Charleston Harbor	5 weeks	32% decline in trips	Shrimping					English (2004); SCDNR et al. (2012)
Julie N	1996	ME	170,000 gallons	#2 fuel oil	Bay/ocean	5 miles of coastline	1 month	100% decline (assumed)	Boat-based fishing					Clark et al. (1998)
Kalamazoo River (shoreline)	2010	MI	> 840,000 gallons	Crude tar-sands oil	River	39 RMs	27 months	60% decline (initially 100% due to closure, declined over time)	Shoreline use, including fishing					Mitchell (2015); USFWS et al. (2015)
Kalamazoo River (boating)	2010	MI	> 840,000 gallons	Crude tar-sands oil	River	39 RMs	27 months	69% decline (initially 100% due to closure, declined over time)	Boating, including fishing					Mitchell (2015); USFWS et al. (2015)
North Cape	1996	RI	828,000 gallons	#2 fuel oil	Bay/ocean	250 square miles of ocean	Several months	Closure	Charter fishing, recreational fishing	250 square miles of ocean	3 months	Closure	Fishing	Burroughs and Dyer (1996); NOAA et al. (2002b); RI DEM et al. (Undated)
Pearl Harbor	1996	HI	41,000 gallons	#6 fuel oil	Bay/ocean	Fishing closure for an unspecified period of time.				Fishing closure for an unspecified period of time.				Pearl Harbor Natural Resource Trustees (1999)
Refugio	2015	CA	142,000 gallons	medium to heavy crude oil	Near-shore ocean					138 square miles, 22 miles of coastline	6 weeks	Closure	All fishing; the primary focus of the fishery is sea urchin and crabs	Kacik (2015); NOAA (2015); Refugio Response Joint Information Center (2015)
Selendang Ayu	2004	AK	321,000 gallons	Viscous fuel oil (IFO 380 intermediate fuel oil)	Near-shore ocean	166 square miles of ocean/bay	10 months	Closure	All fishing	60 square miles of ocean/bay	10 months	Closure	All fishing	Alaska Department of Fish and Game (2005); Impact Assessment (2011); NOAA et al. (2015)

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4. Natural Resource Damages in Lower Columbia River

Natural resources in the Columbia River are held in trust for the public. The Trustees of natural resources in the LCR include the United States (Department of the Interior and NOAA), designated officials in agencies from the State of Washington and the State of Oregon, and numerous Tribes. The Oil Pollution Act (OPA) provides statutory authority for these Trustees to pursue damages (compensation) when oil pollution impacts natural resources.

As mentioned in Chapter 1, a comprehensive natural resource damage assessment (NRDA) for a major oil spill in the Columbia River could take years. In this chapter, we attempt to provide an approximate range of potential damages to specific natural resources, based on literature from other spills and on illustrative restoration-based "equivalency" analyses (see following section).

Trustees are entitled to compensation for direct losses to natural resources as well as lost use of natural resources. Recreational fishing losses are part of natural resource damages. The methods described in this chapter to estimate natural resource damages are likely to account in part but not entirely for recreational fishing losses. Therefore, the damages estimated in this section should not be added to the recreational fishing losses described in the previous chapter, but recreational fishing losses are not entirely subsumed in these estimates either.

The diminution of the cultural values that Tribes place on natural resources in the LCR would likely be an integral part of an NRDA for these oil spill scenarios. An evaluation of Tribal losses was not in the scope of the work presented here. As noted in the sidebar, Tribal losses from a catastrophic oil spill in the LCR could be considerable.

Unquantified impacts: Tribal losses

OPA provides Tribes with the authority to pursue damages for impacts to natural resources of particular significance to the Tribe. A large oil spill in the LCR could have considerable impacts on Tribal natural resources. This report does not include a calculation of these Tribal losses, and therefore may greatly underestimate natural resource damages from oil in the Columbia River.

4.1 NRDA Methods

NOAA has promulgated NRDA guidance under OPA [15 CFR Part 990]. The guidance provides methods for evaluating natural resource damages from an oil spill. Although not mandatory, the guidance presents three phases of oil spill assessment: a preassessment phase, where the Trustees determine that a full assessment is worthwhile; a restoration planning phase, in which the Trustees evaluate the impacts of the spill on natural resources and lost human uses and calculate the type and amount of restoration required to offset the impacts; and a restoration implementation phase.

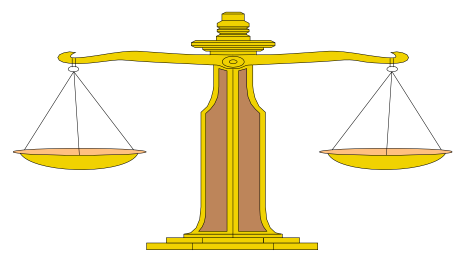
Observable or measurable adverse changes to natural resources are defined as natural resource injuries [15 CFR § 990.30]. As part of the injury assessment process, Trustees quantify injuries over time and space. Trustees then develop restoration plans that describe the type and scale of restoration needed to compensate for the injuries to natural resources. A comprehensive examination of potential injuries from a worst-case oil spill and potential restoration projects to offset those injuries is well beyond the scope of this exercise. Rather, we present a commonly-used model to calculate an approximate amount and cost of habitat restoration that would offset potential injury scenarios.

One common approach to calculating natural resource damages is equivalency analysis, in which the Trustees calculate the amount and cost of restoration that will restore the equivalent to what was injured as a result of the oil spill. Models used to make these calculations include the resource equivalency analysis (REA) and the habitat equivalency analysis (HEA), which is a variation of a REA with restoration based on units of habitat. Equivalency methods have been published in peer-reviewed literature, have been codified in NOAA's regulations for NRDA, have been accepted by U.S. Courts,[1] and are routinely performed at natural resource damage sites throughout the United States and overseas. Technical approaches for conducting equivalency analyses have been presented in published articles (e.g., Strange et al., 2002, 2004; Allen et al., 2005; Cacela et al., 2005; NOAA, 2006a).

Equivalency analyses are used to quantify impacts resulting from injuries to natural resources (i.e., the debit) as well as the expected benefits from restoration (i.e., the credit; Figure 4.1). Determining equivalency (scaling) between the debit and credit is conceptually simple:

- Sum the quantity of natural resource injuries over space and time
- Determine the amount and timing of natural resource benefits or services expected per unit of restoration
- Divide the total losses by the benefit per restored unit to calculate the quantity of required restoration.

Figure 4.1. HEA and REA are used to determine the type and amount of restoration needed to balance losses from natural resource injuries.



In this report, we perform equivalency analyses for different components of injury, including a HEA focused on aquatic habitat that could be injured in the LCR, and a HEA focused on floodplain habitat for birds that could be killed by the hypothetical spill. As mentioned previously, this report is not intended to replicate a detailed NRDA as spelled out in 15 CFR Part 990, but rather serves as illustration of the magnitude of potential natural resource damages that could occur.

To quantify potential natural resource injuries, we have estimated exposure of fish and birds to the oil, and then discussed the adverse effects that the oil exposure would have. This approach integrates data from other oil spills, including in particular the 1984 *MobilOil* spill that occurred in the LCR; and the DWH spill in the Gulf of Mexico, which led to a tremendous body of new literature on the effects of oil on fish and birds. Much of the DWH research is summarized in the Programmatic Damage Assessment and Restoration Plan that the DWH NRDA Trustees published recently (DWH NRDA Trustees, 2016). The Abt co-authors of this report managed the toxicity testing program for fish and birds on behalf of the Trustees.

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1. United States v. Melvin A. Fisher et al., Case No. 92-10027-CIVIL-DAVIS (S.D Fla, 1992); United States v. Great Lakes Dredge and Dock Co., 259 F. 3d 1300, (11th Cir. 2001); In re: ASARCO LLC Chapter 11 Bankruptcy, Case No. 05-21207 (U.S. Bankruptcy Court, Southern District of Texas, Corpus Christi Division).

4.2 Natural Resource Exposure

To assess the magnitude of natural resource injuries from the oil spill, we first estimate the exposure of natural resources to oil. For this analysis, we include data from the 1984 *MobilOil* spill, and we summarize recent data on water bird and salmon presence in the LCR reaches. We compare the fate and exposure data from Chapter 2 with these estimates of salmon and water birds presence to estimate the exposure of these natural resources to oil from an effective WCD. This is obviously not a comprehensive estimate of natural resource exposure, but quantifying injuries and damages to these biota provides an initial estimate of the magnitude of damages that may occur from the WCD spill.

Unquantified impacts: Injuries caused by response actions

Trustees may seek natural resource damages for injuries that occur as a result of oil spill response actions. These may include dispersant application, skimming, burning, destruction of vegetation to access the river, destruction of bank habitat removing stranded oil, etc. This analysis does not include any estimates of damages for such activities.

4.2.1 Fish

The LCR system serves as a staging and rearing habitat and major migration portal for millions of anadromous fish each year. Major salmonid species include Chinook salmon, coho salmon, sockeye salmon), and steelhead trout. Additionally, the LCR serves as one of a few remaining intact habitats supporting white sturgeon populations in the United States. In 2010, Jones et al. (2011) estimated white sturgeon populations in the LCR to be as high as one million fish including juvenile, sub-adult, and adult life stages. However, the 2016 sturgeon fishing regulations for the LCR suggest that the population is highly stressed, as sturgeon angling is catch-and-release only and closed entirely from May 1 to August 31 from RM 82 to the Bonneville Dam (ODFW, 2016).

In the LCR Geographic Response Plan, ODEQ et al. (2015) list many of the fisheries resources in the LCR that would likely be exposed to oil during a major spill, including millions of juvenile and adult salmonids; other anadromous fish including green sturgeon (*Acipenser medirostris*), shad, and smelt; juvenile bottom-dwelling larval fish including several species of sole and flounder; numerous freshwater fish species in the more upstream reaches; and important shellfish such as Dungeness crab (*Metacarcinus magister*) in the estuary.

Unquantified impacts: Potentially injured natural resources

This estimate of natural resource damages is based on oil exposure to birds and salmonid fishes during the spill. Many other natural resources would also be exposed to oil, including other anadromous and resident fish species, marine mammals (particularly pinnipeds), benthic organisms, vegetation, etc. Estimates of damages here are based on costs to restore bird habitat and salmonids. While these restoration projects will restore more than just salmonids and birds, they are not going to restore all natural resources that are exposed to an oil spill of this magnitude.

Fish Exposure to Oil in the 1984 *MobilOil* Spill

The 1984 *MobilOil* spill, summarized in Chapter 2, released about 3,925 bbl of heavy fuel oil into the Columbia River at St. Helens, Oregon. This was about 2% of the effective WCD spill for this reach of the river. The natural resource exposure data from this spill are quite limited. There was no estimate of the number of fish that might have been exposed to oil. After the spill, a gill net pulled up 55 white sturgeon, of which 13 (24%) had visible signs of oil in their mouths. A commercial petrale sole (*Eopsetta jordani*) cannery discarded some fish with visible oil in their mouths, and some anglers turned in surf perch (family Embiotocidae) with evidence of oil exposure. Kennedy and Baca (1984) mention that pens in Rainier, Oregon, about 10 miles downstream from the spill site, were stocked with coho salmon on the day of the spill, but the fate and transport data (Chapter 2) suggest that most of the surface oil had passed Rainier by the time the pens could be stocked. The fish were apparently healthy 9 days after the spill, but it is not clear if they were exposed to the oil.

Estimating Exposure from Current Fish Counts

To provide an illustrative evaluation of potential natural resource injuries to fish in the LCR, we focus on potential injury to salmonids. Adult salmon and steelhead trout return to the LCR and begin migrating up river to natal spawning grounds beginning in late spring through early fall. Peak migration periods vary for different species and strains (Figure 4.2A).

Young salmon or smolts also migrate downstream to the mouth of the LCR during their first 1–2 years of life as they transition physiologically and behaviorally in preparation for their oceanic life stage. These runs occur roughly from March through October, with the majority of smolts migrating in late spring and early summer (Figure 4.2B). These migrations are taxing and stressful for both adult fish swimming upstream while undergoing major physiological changes in preparation for spawning, as well as for smolts that are also undergoing major physiological alterations that allow them to quickly transition from a freshwater to a marine environment.

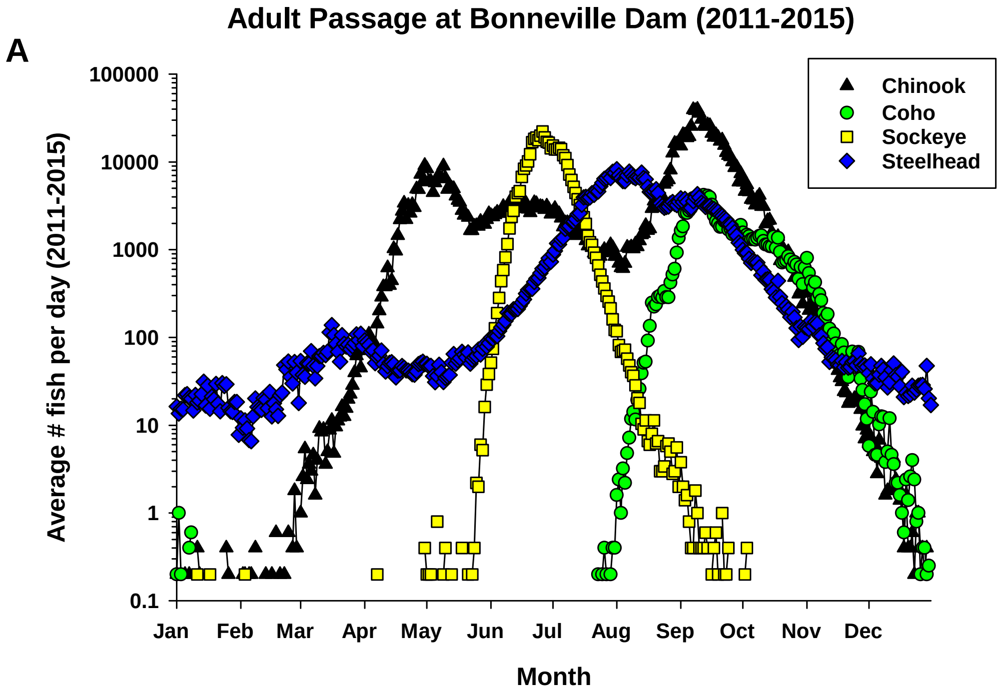
We estimated adult and smolt salmon populations in different reaches in the LCR based on 5-year average adult and smolt passage data at the Bonneville Dam (Columbia Basin Research, 2016a, 2016b; Figure 4.2). Our estimate of the total number of adult salmon swimming upstream that would intersect the plume of oil coming downstream is based on data suggesting that it takes an adult salmon about 3 weeks to travel from the mouth of the river to the Bonneville Dam (Rub et al., 2012). To estimate the total number of smolts exposed to oil, we assumed that a daily cohort of smolts counted at the Bonneville Dam would be in Vancouver 1 day later (McMichael et al., 2013) and travel downstream with the oil plume. Once that daily cohort reaches the estuary near the mouth of the river, they typically remain for several days before migrating out to sea (McMichael et al., 2013). This could cause several more daily cohorts of smolts to intersect the oil near the mouth of the river in Reach 1.

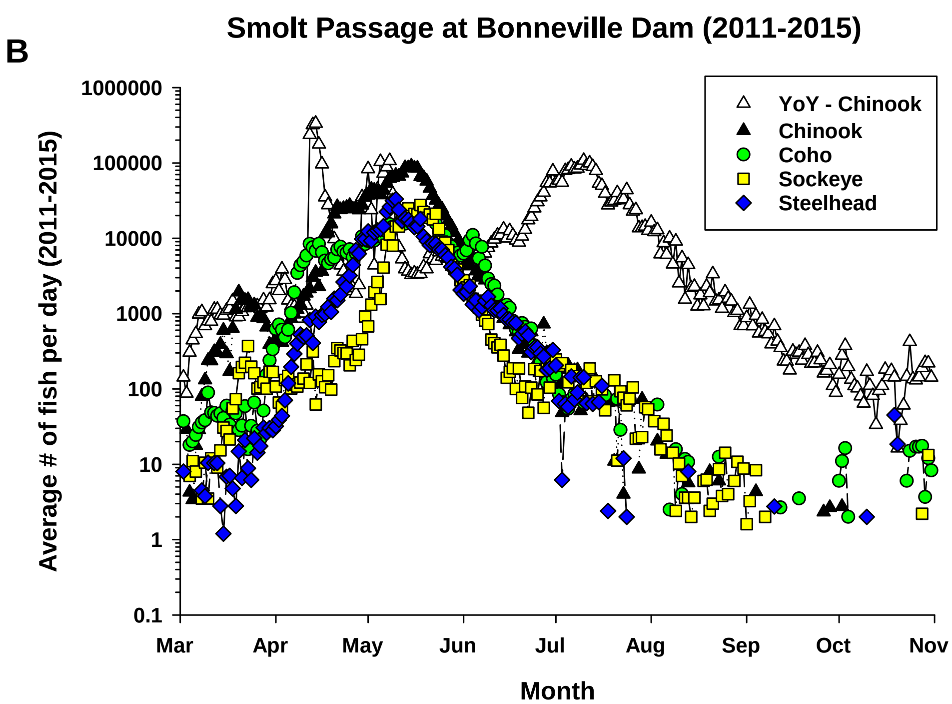
Based on the data from the Bonneville Dam, we estimate that if a tanker spill occurred near the proposed Vancouver Terminal between mid-April and mid-May, between 45,000 and 70,000 adult salmon could be exposed in Reach 1 (approximately Longview, Washington to the mouth of the river; see Figure 2.4), and as many as 20,000–60,000 adult salmon could be exposed in Reach 2 (approximately Longview to Vancouver, Washington). Juvenile salmon (smolts) would be moving downstream with the oil and the river flow. We estimate that approximately 1,400,000–1,600,000 smolts would be exposed to the oil in the river; because both the oil and the smolts are moving downstream, we have assumed that the same fish would be exposed in Reach 2 and Reach 1.

Unquantified impacts: Geographic scope of salmon smolt evaluation

Our estimates of exposed salmon smolts are based on data from automated fish counters at the Bonneville Dam. The dam is about 40 miles upstream of the presumed location of the spill. We are not accounting for additional smolts entering the river from tributaries in that 40-mile stretch.

Figure 4.2. Average daily counts over 5 years (2011–2015) of adult salmon and steelhead moving upstream (A) and smolts moving downstream (B) at the Bonneville Dam.





Source: Columbia Basin Research, 2016a, 2016b.

4.2.2 Birds

The LCR downstream of Vancouver includes four wildlife refuge areas with hundreds of bird species present at all times of year. The bird species most likely to be exposed to oil will be those that most heavily rely on water access to obtain food, including piscivores, dabbling and diving birds, shorebirds, and waders.

High-profile obligate piscivores like bald eagles (*Haliaeetus leucocephalus*), great blue herons (*Ardea herodias*), osprey (*Pandion haliaetus*), and belted kingfishers (*Megaceryle alcyon*) would likely be injured as a result of exposure to contaminated water caused by a spring/summer spill. These species, and many others, breed during this period, so adults and young could be impacted. Exposure of eggs and nestlings to oil occurs through transfer from contaminated food, nesting materials, and parental feathers. Impacts to adult bird health may in turn lead to nest abandonment and further loss.

Shorebirds and waders that rely on shorelines and marshy edges for foraging likely would also be affected by a spring/summer spill through lost food resources, habitat loss for both foraging and predator avoidance, and be exposed to toxic PAHs. Insectivorous birds, particularly those that rely on insects emerging from aquatic environments or that feed on invertebrates near shorelines, would likely be exposed to oil in shoreline habitats.

A major oil spill in the LCR would potentially expose a tremendous number of birds to oil. The LCR Geographic Response Plan (ODEQ et al., 2015) provides a summary of the bird species and habitats potentially exposed, including many threatened and endangered species. ODEQ et al. (2015) include the following when summarizing birds in the LCR:

- The Columbia River estuary is a shorebird site of world significance, supporting over 100,000 birds during peak migration periods. Tens of thousands of birds nest, feed, and/or roost throughout the lower 10 miles of the river during the spring and summer months. Some key species identified include Caspian terns (*Hydroprogne caspia*), double-crested cormorants (*Phalacrocorax auritus*), brown pelicans (*Pelecanus occidentalis*), and several species of gulls. In addition, seabirds such as marbled murrelets (*Brachyramphus marmoratus*) feed in the mouth of the estuary throughout the year.
- Bald eagles and great blue herons are nesting residents found throughout the region. Peregrine falcons (*Falco peregrinus*) are commonly found as winter and spring visitors to the lower estuary.
- Both resident and migratory songbirds heavily utilize riparian habitats year-round and are susceptible to oiling if riparian vegetation and shorelines become contaminated.

According to Collis et al. (1998), “Rice Island, a dredge material disposal island in the Columbia River estuary, supported the largest known caspian tern colony in North America (about 8,000 breeding pairs in 1998), and the only known breeding colony of this species in coastal Oregon and Washington. The colony of double-crested cormorants on East Sand Island in the estuary is the largest of its kind on the Pacific Coast of North America.” Both of these species nest in the estuary in the spring, typically laying eggs in late April or early May and incubating until early June. If the effective WCD spill occurred during these months, many of these birds would be exposed to oil while feeding in the river, and they would likely expose eggs to oil when incubating with oily feathers.

From 1978 to 2009, the number of nesting pairs of bald eagles along the LCR increased dramatically. In 1978, only 6 breeding pairs were found in Oregon, and 1 pair in Washington, in the Columbia River estuary. By 2007, 83 nesting pairs were in Oregon and 57 were in Washington (Isaacs and Anthony, 2011).

Bird Exposure to Oil in the 1984 *MobilOil* Spill

In response to the *MobilOil* spill, a bird rehabilitation facility was established at the Julia Butler Hansen Refuge for the Columbian White-tailed Deer (see Figure 1.1). Nearly 700 oiled birds, primarily western grebes (*Aechmophorus occidentalis*), common murres (*Uria aalge*), and scoters (*Melanitta* spp.) were brought to the facility. This includes birds oiled in the Columbia River and birds oiled along the Pacific Coast (Kennedy and Baca, 1984; Speich and Thompson, 1987). Kennedy and Baca (1984) include a list of 11 ducks, geese, and other waterfowl that they identified as target bird species most likely to have been exposed to the oil. No bald eagles were observed to have been exposed to oil (Kennedy and Baca, 1984), but very few bald eagles (9 nesting pairs on each side of the estuary) were present at that time (Isaacs and Anthony, 2011).

Estimating Bird Exposure

Unlike anadromous fish that are counted automatically at the Bonneville Dam, there are no automated bird counts for the LCR. The Audubon Society conducts Christmas bird counts annually, which provide brief snapshots of birds in specific small areas along the river. The data we examined were not at a sufficient scale over time and space to allow us to estimate the total number of birds (of any species, size, or guild). Thus, as discussed below, we used alternate methods for quantifying potential injuries to birds.

4.2.3 Pinnipeds

Harbor seals (*Phoca vitulina*), Steller sea lions (*Eumetopias jubatus*), and California sea lions (*Zalophus californianus*) can be found in the LCR and could be exposed to oil from a WCD spill. Seals and sea lions tend to congregate near the mouth of the river but are known to travel up the river all the way to the Bonneville Dam to feed on salmon and sturgeon (NOAA, 2006b; Wiles, 2015). The number of sea lions observed feeding near the bottom of the Bonneville Dam since 2002 has ranged from 85 to 111; more than 1,000 sea lions can be found in the LCR between the Bonneville Dam and the mouth (Norman, 2006).

NOAA (2014) estimates that the population of harbor seals in the LCR is approximately 5,700. Seals have their pups along the coast between mid-April and July (Seekins, 2009). Thus, it is possible the both adults and pups could be exposed to oil from the WCD spill.

The population of Steller sea lions in the LCR can range from 100 to 2,000 individuals (Wiles, 2015). During a typical day in May, there can be up to 3,000 harbor seals, 1,000 Steller sea lions, and 800 California sea lions on haul-outs in the Columbia River estuary (NOAA, 2006b).

4.3 Natural Resource Injuries

This section presents evidence from other spills and studies, including limited data from the 1984 *MobilOil* spill, that show that natural resources are injured in large oil spills. As discussed previously, we focus on fish and birds, because these resources are more readily quantifiable.

4.3.1 Early-Life-Stage Fish

Developing early-life-stage (ELS) fish (i.e., embryos and larvae) are more sensitive to toxic components in crude oil than older life stages of fish. In particular, PAHs are highly toxic to ELS fish in concentrations in the low parts per billion range. For example, many ELS fish exposed to mixtures of DWH oil from the Macondo well in the Gulf of Mexico ("DWH oil") experienced mortality or severe cardiac impairment at concentrations ranging from 0.5 to 40 µg/L of total PAH and that subsequent exposure to ultraviolet (UV) light increased the toxicity of this oil by a factor of 10 to 100 (DWH NRDA Trustees, 2016, Chapter 4). Although PAHs are often used as the predominant quantitative metric to explain oil toxicity, it is important to remember that PAHs only comprise about 1% of the total mass of fresh crude oil, which contains thousands of additional compounds that may also elicit additional toxicity.

As described in Chapter 2, Bakken crude is also a light crude oil with a similar PAH profile to DWH oil. Therefore, it is reasonable to assume that the toxicity of Bakken crude will be similar to the toxicity of DWH oil.

4.3.2 Adult Anadromous Fish

Although ELS fish are typically more sensitive to oil than older life stages, juvenile and adult fish may also be adversely affected by oil exposure. The DWH NRDA Trustees (2016) developed a comprehensive toxicity testing program that included testing the effects of oil exposure on several juvenile and adult fish species. These tests focused on the effects of short-term oil exposure (1–7 days) on swim performance and immune function. These endpoints are relevant for migrating salmon that migrate from the mouth of the LCR to their natal spawning grounds, which could be hundreds of miles upstream. These fish need to be able to perform at a high level while undergoing major physiological and endocrinological changes in preparation for spawning, all of which can cause major stress to the fish.

Similarly, emigrating smolts may be more susceptible to immune challenges due to the stress of their migration and physiological changes taking place in preparation for the oceanic portion of their life history. Additional stress will compromise normal immune responses and make fish more susceptible to disease. Therefore, oil exposure can exacerbate natural stressors and increase mortality by decreasing swim performance and immune function in adult fish.

As part of the DWH NRDA, researchers determined that adult mahi-mahi (*Coryphaena hippurus*), a high-performing pelagic species, experienced significantly reduced swim performance at concentrations as low as 8 µg/L of total PAH (DWH NRDA Trustees, 2016; Stieglitz et al., 2016) after only 24 hours of exposure. The immune function of several juvenile fish species was compromised after PAH exposure, resulting in many adverse physiological effects including mortality. Effect levels and durations for these tests (Ortell et al., 2015) include:

- Red snapper (*Lutjanus campechanus*; 16.5 µg/L of total PAH, 7 days)
- Atlantic croaker (*Micropogonias undulates*; 541 µg/L of total PAH, 4 days)
- Red drum (*Sciaenops ocellatus*; 245 µg/L of total PAH, 4 days).

Similar immunological effects have been observed with Pacific herring (*Clupea pallasi*) exposed to Alaska North Slope crude oil for 16–18 days, where Carls et al. (1998) observed immunosuppression and histopathologic abnormalities in adult fish exposed to oil-water mixtures with total PAH concentrations of about 25–60 µg/L.

In addition to sublethal effects on juvenile and adult fish, mortality has also been documented at relatively low oil exposure concentrations. For example, Birtwell et al. (1999) conducted yearly acute toxicity tests on juvenile pink salmon for 3 straight years and reported 96-hour LC50 (concentration lethal to 50% of the organisms in a test) values of 1.0 to 2.8 mg/L of total petroleum hydrocarbons. The estimated PAH values for these tests (assuming 1% of the total petroleum hydrocarbon content is PAH) would be 10 to 28 µg/L of total PAH.

Although controlled laboratory tests generate meaningful data that may help predict or explain adverse effects to fish in the wild, there are also observations of adverse effects to fish that occur after actual oil spills that we can use to assess possible injury. It may be difficult to quantify injuries to aquatic resources during and after these incidents because many dead fish will never be observed and counted and it is impossible to track survivors and monitor effects on their survival and reproductive success following exposure to oil. Therefore, actual observations of adverse effects in the field are underestimates of the full magnitude of injured resources.

Nonetheless, other oil spills in large rivers/estuaries have caused observable injuries to aquatic resources. For example, in August 2000, a pipeline rupture on the Pine River in British Columbia released approximately 6,200 barrels of light crude oil about 110 km (68 mi) upstream of the town of Chetwynd (BC Government, 2016). Reports indicate that 8% of the total oil spilled was not recovered from the water or soil, leaving about 500 barrels in the aquatic environment. Following the Pine River spill, surface sheen was reported 150 km (93 mi) downstream, major fish kills were observed downstream from the spill (BC Ministry of Environment, 2000), and the benthic invertebrate community was adversely impacted for up to 3 years following the spill (de Pennart et al., 2004). Although every incident will have unique characteristics, this example does suggest that a large oil spill in the LRC could adversely affect the aquatic community and cause major fish kills.

4.3.3 Birds

A tremendous amount of research has demonstrated that oil is toxic to birds. Studies have shown that oil on eggs affects reproductive success; ingested oil causes toxic responses such as anemia; and external oil damages feathers, causes hypothermia, and adversely affects flight. The DWH NRDA damage assessment report (DWH NRDA Trustees, 2016) and the supporting technical reports (e.g., Ziccardi and Drayer, 2015) include a review of much of the literature, and they summarize new findings that were discovered as part of the avian toxicity research during the NRDA process. Some of the highlights are included below; a more detailed review of oil toxicity to birds is beyond the scope of this document.

Toxicity

Dozens of studies have shown that ingested oil is toxic to birds. The most prominent adverse effect of ingested oil is hemolytic anemia; studies as far back as the 1960s have shown this as a common response. Leighton (1993) provides a summary of the older studies. The DWH avian toxicity studies showed a direct link between oil ingestion and anemia endpoints (reduced packed cell volume, increased immature blood cells) in double-crested cormorants (DWH NRDA Trustees, 2016). Anemic animals lack sufficient functional red blood cells required for oxygen transport in the blood; eventually it is fatal, but anemic birds in the wild are subject to predation and less likely to be able to find sufficient food, which could result in mortality indirectly related to the oil.

Numerous studies have demonstrated that oil ingestion causes direct effects on the adrenal cortex that leads to cellular damage and an inability of the bird to respond to stress (e.g., Gorsline et al., 1982; see Leighton, 1993 for a review). Oil ingestion has also been shown to cause adverse effects to the immune system, including inflammation and infections (e.g., Newman et al., 2000). Finally, the DWH testing revealed that double-crested cormorants that ingested oil had reduced cardiac function and blood clotting dysfunction (DWH NRDA Trustees, 2016).

Reduced Reproductive Success

Studies decades ago demonstrated that minute amounts of oil on eggs can be sufficient to disrupt the developing embryo within. When avian eggs are exposed to even microliter volumes of oil during the first week of embryonic development, mortality and deformity rates are high (Albers, 1977, and many others; see Leighton, 1993 for review). The exposure can occur via oil transfer from contaminated nesting materials or from parental feathers. Additionally the reproductive success of adult females can be delayed and reduced following experimental oil ingestion (Cavanaugh and Holmes, 1982, 1987). Oiled birds are more likely to abandon nests and showed reduced parental care such as the 10-fold increase in nest abandonment observed in south polar skuas (*Stercorarius maccormicki*; Epply and Rubega, 1990).

Thermoregulation

Feathers provide birds with excellent insulation and waterproofing. Oil causes feathers to become matted, reducing both insulation and buoyancy. In cold waters, loss of buoyancy will compound thermoregulation issues from lack of insulation, which can rapidly causes hypothermia and death (O'Hara and Morandin, 2010).

Birds exposed to oil for only a few hours showed increases in heat production and thermal conductance even at room temperature (Erasmus et al., 1981; Dorr et al., 2015). The consequences of increased energetic demands to maintain body temperature, combined with behavioral changes such as increased time spent preening and changes in foraging patterns, have the potential to cause weight loss, interfere with reproduction, affect the immune response and prevent optimal body condition for migration.

Flight

Recent studies as part of the DWH avian toxicity work (see Ziccardi and Drayer, 2015) demonstrated that sublethal oil on feathers interferes with takeoff angles, reduces takeoff speed, and reduces flight endurance in western sandpipers (*Calidris mauri*). Homing pigeons (*Columba* *livia domestica*) with light to moderate oil on their feathers were significantly impaired, flying indirect routes at slower speeds with multiple elevation changes as they tried to fly home. It took an average of 58% longer to return, and the oiled feathers became frayed and brittle (DWH NRDA Trustees, 2016).

Thus, while the oil did not cause immediate obvious toxic effects or death, even the light amount of oiling greatly reduced the fitness of birds that depend on peak fitness in flight for survival. Birds with reduced fitness as a result of oil exposure are more vulnerable to predation, less likely to catch food if they are predators themselves, and less likely to reach their breeding grounds and reproduce if they are oiled while migrating. Delays of only 1 week can have negative consequences on their reproductive success such that a bird with even trace oiling could experience a 3–23% reduction in survival and a 19% decrease in reproductive output (DWH NRDA Trustees, 2016).

In summary, the large body of avian toxicity research investigating the effects of oil on birds strongly suggests that a bird exposed to oil will be stressed at a minimum, and many will die as a result of exposure. Nesting birds that roost with oil on their feathers are unlikely to successfully hatch and fledge their young. Birds that require peak metabolic performance (predators, migrators) may die from indirect oil effects if they do not die directly from oil exposure. Thus, most birds exposed to oil will be injured, and many will die directly or indirectly from the oil exposure.

4.4 Injury Quantification

A worst-case oil spill like the 8-million gallon scenario in the DEIS would have substantial ecological impacts in the LCR. Some of these impacts would be quantifiable, but many would not. The illustrative damage calculations presented in this analysis are qualitatively based on estimated adverse effects to fish and birds. As discussed previously, restoring habitat that will be increase the populations of the target species will also restore other natural resources that were injured but have not been explicitly quantified in this analysis, but would likely not comprehensively restore all injured natural resources.

4.4.1 Fish

The literature summarizing the 1984 *MobilOil* spill provides no direct evidence of injuries to salmonids. A 96-hour in situ bioassay conducted in Elochoman Slough (approximately RM 35) using Chinook salmon fingerlings found no significant mortality. The tests were designed to ensure that the state fish hatchery could release their fish without killing them; the timing of the test was not reported, nor was the actual exposure to oil, if any. Coho salmon fry stocked into a pen in Rainier, Oregon, on the day of the spill were alive and apparently not stressed 9 days later, but again, there was no quantification of oil exposure for these fish. It is unlikely that the fish in these tests were exposed to PAH concentrations representative of ambient conditions mid-river at the height of the spill.

As discussed in Chapter 2, the effective WCD scenario for the LCR is a spill from a tanker grounding, from which about 8 million gallons of Bakken crude spills into the LCR near Vancouver. A discharge of that magnitude occurring the spring (mid-April to mid-May) would likely expose fish to elevated PAH concentrations for the entire length of the river downstream of Vancouver (Reaches 2 and 1). If the oil spilled into the river over a 24-hour period, the estimated concentrations of total PAH could range from roughly 20 to 70 µg/L; if the grounded tanker broke apart and all the oil spilled into the river in a 2-hour period, the estimated concentrations of total PAH could range from approximately 230 to 800 µg/L (see Chapter 2). Summarized by reach, the anticipated concentrations in Reach 1 would be 30 to 800 µg/L (Figure 4.3a), and the anticipated concentrations in Reach 2 would be 20 to 230 µg/L (Figure 4.3b). These concentrations are well above concentrations known to cause toxicity in ELS and older life stage fish.

Although the data clearly suggest that the PAH concentrations in the water column would be sufficient to cause injury to fish, the magnitude of injury is uncertain. It is likely that some but not all exposed salmon smolt would be killed. For this analysis, we have included a range of mortality, from 25% to 75%. At 25% mortality, we estimate that about 5,000 adult salmon could be killed as a result of oil exposure in Reach 2 (approximately Vancouver to Longview), and 10,000 adult salmon could be killed as a result of oil exposure in Reach 1 (approximately Longview to the mouth). We also estimate that 350,000 smolts would perish as a result of oil exposure in the LCR.

At 75% mortality, we estimate that up to 50,000 adult salmon would perish in Reach 1 and up to 45,000 adult salmon would perish in Reach 2 (Table 4.1). In addition, at 75% mortality, an estimated 1,200,000 smolts would perish in the LCR as a result of oil exposure. The total range of estimated salmonid mortality (Reach 1 plus Reach 2) is from 15,000 adults and 350,000 smolts at 25% mortality up to 95,000 adults and 1.2 million smolts at 75% mortality (Table 4.1).

Table 4.1. Estimated range of salmonid mortality from the WCD oil spill in the LCR

Location	Mortality	Adults	Smolts	Mortality	Adults	Smolts
Reach 2 (Vancouver-Longview)	25%	5,000		75%	45,000	
Reach 1 (Longview mouth)	25%	10,000	350,000	75%	50,000	1,200,000
Total		15,000	350,000		95,000	1,200,000

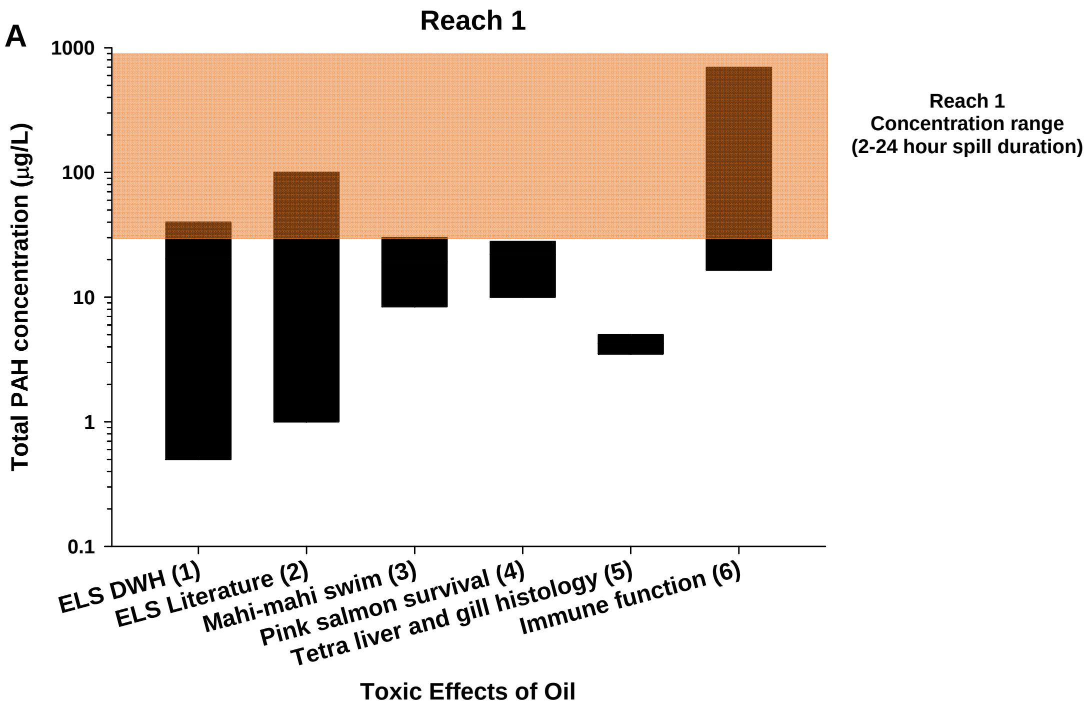
4.4.2 Birds

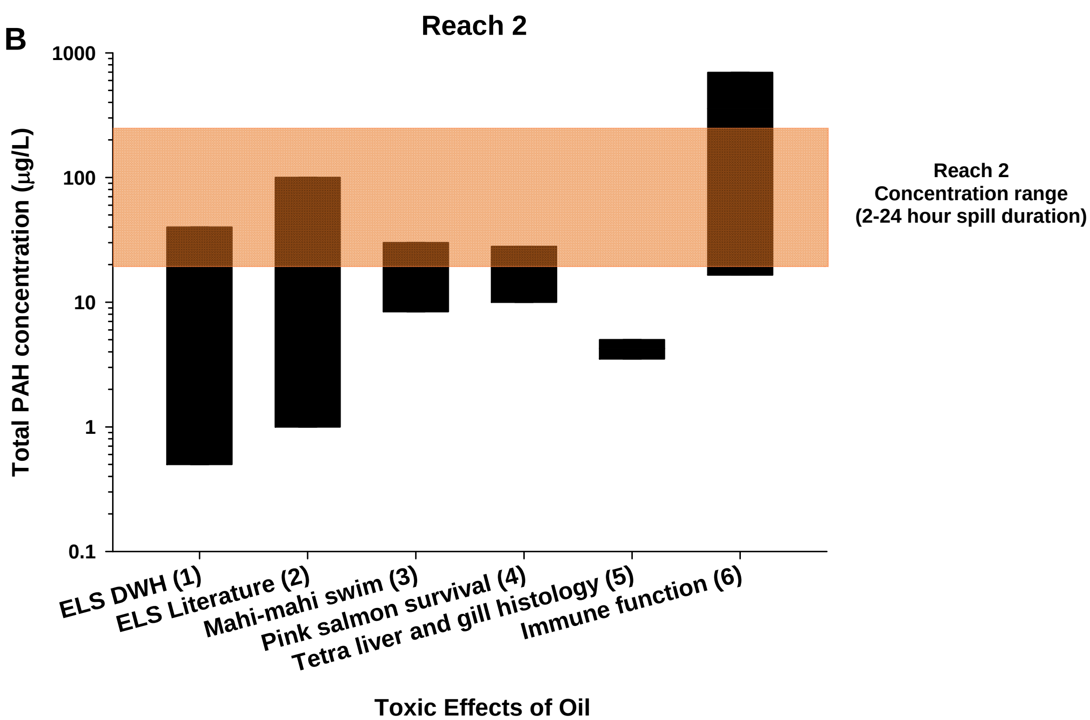
We do not have an analogous model for estimating total numbers of potential dead birds resulting from oil exposure. While the avian toxicity data presented previously clearly demonstrates that most birds exposed to oil are likely to be injured and oiled eggs rarely develop into healthy birds, estimating a specific number of birds of different species that could be injured exceeds the scope of this analysis.

Quantifying Bird Mortality in the 1984 *MobilOil* Spill

Of the ~ 700 oiled birds recovered from the *MobilOil* spill, 475 were cleaned and released, and the remainder perished. Unfortunately, the released birds were not banded or tracked, and thus there are no data on how long those birds survived.

Figure 4.3. Ranges of published adverse effects levels of total PAH to ELS and older life stage fish (black bars) compared to the concentration ranges estimated for Reach 1 (A) and Reach 2 (B) given spill scenarios described in Chapter 2.





Sources: Carls et al., 1998; Birtwell et al., 1999; Akaishi et al., 2004; Lee et al., 2015a, 2015b; Ortell et al., 2015; DWH NRDA Trustees, 2016.

It is important to note that dead birds recovered during an oil spill represent only a small portion of the total number of birds that died as a result of oil exposure. In fact, the likelihood that a dead bird in the estuary was recovered and brought to the facility is small. In many oil spill NRDAs such as the DWH spill (DWH NRDA Trustees, 2016), bird exposure estimates are adjusted to account for several factors, including:

- Carcass drift (i.e., the likelihood that a bird that dies on the water will drift to a bank or shoreline where a searcher can find it)
- Searcher efficiency (i.e., the likelihood that a person searching for bird carcasses will actually see it, based on carcass deposition studies)
- Carcass persistence (i.e., the length of time a stranded carcass can be found before it sinks or is scavenged).

Ford et al. (2001) and Ford and Zafonte (2009) conducted studies along the Oregon coast to quantify these factors. After the *New Carissa* oil spill in 1999, Ford et al. (2001) estimated that 2.75 large bird carcasses were not found for each one recovered on Oregon beaches, and 14.3 smaller bird carcasses were not found for each one recovered. They did not include a factor for birds exposed to oil but did not die until after flying away from the search area; this factor could increase the total estimated bird mortality by a substantial amount.

Similarly, for the *Nestucca* oil spill in 1988, resource agencies estimated that the total number of dead waterfowl was four to six times greater than the number of carcasses recovered (USFWS, 2004).

We could use these ratios to estimate the total number of dead waterfowl from the *MobilOil* spill, although it would primarily provide an estimate of dead oiled birds on beaches along the coast. It is likely that far more bird mortalities occurred in sloughs and wetlands in the estuary, and there are no available data because these carcasses would have been extremely difficult to find. It is also likely that some of the birds released from rehabilitation subsequently perished as a result of the oil exposure.

Thus, a very conservative estimate of the *MobilOil* bird mortality would be 223 recovered carcasses of large birds x 2.75 large birds not recovered for each one recovered = 613 large bird deaths.

At the higher multiplier range, 223 recovered carcasses x 6 birds not recovered for one recovered = 1,338 large bird deaths.

Although natural resource injuries are not scalable based solely on the quantity of oil discharged, scaling by volume can used as a range-finding exercise. The *MobilOil* was estimated to have discharged 3,925 bbls of oil, which is about 2.1% of effective WCD discharge of 189,845 bbl; if we scale the bird mortalities proportionally, the total waterfowl mortality would range from about 30,000 to 65,000 birds in coastal/beach habitat. Again, the *MobilOil* data likely includes few if any dead birds from estuarine habitat, where much of the bird injuries were likely to have occurred, but finding a carcass is extremely difficult.

Other Bird Mortality

As noted previously, Isaacs and Anthony (2011) reported 83 nesting pairs of bald eagles in Oregon and 57 in Washington as of 2007, for a total of 140 eagles (assuming each identified nesting site in fact had a pair of birds). Given the magnitude of the spill, it is highly likely that some bald eagles nesting along the Columbia River could get exposed to some oil and perish. Site-specific data would need to be collected during and after the spill to assess the impacts. It is likely that some bald eagles will die as a result of exposure to the oil.

Many thousands of songbirds living and nesting along the river would be exposed to oil and likely would die as well. For this analysis, we have not attempted to quantify songbird mortality, as we have little data on which to base an estimate.

4.4.3 Pinnipeds

Although we have estimates of the pinniped population in the LCR and number of seals and sea lions that NOAA (2006b) estimates will be present on a May day when a worst-case spill might occur, we do not have data to estimate the potential injuries to pinnipeds. Marine mammals are known to be sensitive to oil exposure; the overall health of common bottlenose dolphins (*Tursiops truncatus truncates*) exposed to DWH oil in Louisiana was substantially impaired (DWH NRDA Trustees, 2016). While it is likely that some pinnipeds would be injured in this WCD spill, we have not tried to quantify those injuries.

Unquantified impacts: Pinnipeds

Despite hundreds of pinnipeds potentially exposed to oil, we have not quantified injuries to these animals.

4.5 Damage Determination

As discussed previously, natural resource damages are frequently calculated based on the cost to restore equivalent resources or habitat. For this analysis, we present restoration-based damages for injuries to Columbia River habitat using a HEA model, where restoration is estuarine habitat restoration in Columbia River estuary. Generally, estuarine habitat is not equivalent to the oiled habitat in the middle of the river; therefore, we have used additional scaling factors to reflect the greater habitat services that estuarine habitat provides.

However, prior to presenting a restoration-based damages estimate, we first review other lines of data that can help provide an initial estimate of damages for a spill of this magnitude.

4.5.1 Washington State Oil Spill NRDA [WAC 173-183]

Washington State has a Resource Damage Assessment (RDA) Committee that determines appropriate methods for estimating damages from oil spills. The Committee uses a compensation schedule set out in WAC 173-183 to calculate appropriate damages for spills where restoration of injured resources is not technically feasible, damages are not quantifiable at a reasonable cost, or the responsible party proposes a restoration project that is insufficient to provide adequate compensation (Washington Department of Ecology, 2016).

WAC 173-183 contains a complicated multi-step method of calculating damages for spills in the Columbia River. Because the spill scenarios described here are unlikely to meet the criteria for using the compensation schedule, we did not undertake this endeavor.

WAC 173-183 also contains very simple methods of calculating damages: for spills less than 1,000 gallons, the range is $1 to $100 per gallon, and for spills of 1,000 gallons or more the range is $3 to $300 per gallon spilled. For an effective WCD spill of 8 million gallons, that scales to $24 million to $2.4 billion. This likely brackets natural resource damages for the WCD spill, but the two-orders-of-magnitude range is quite broad.

Washington Department of Ecology (2016) provides a spreadsheet of RDA oil spill incidents from 1991 through 2016. They report 50 spill incidents in the Columbia River or Columbia River Estuary for which damages have been calculated. The vast majority of the damages were calculated using the compensation schedule. None of these incidents is remotely of the magnitude discussed in these scenarios. In addition, as discussed previously, scaling compensable damages based solely on the volume of oil spilled is useful only to provide context for examining ranges of damage estimates. For the RDA incidents, a total of 20,385 gallons were discharged cumulatively from the 50 incidents, resulting in $594,000 in compensation to the State (in 2015 dollars).[2] This is an average of about $29 per gallon; an 8 million gallon spill at $29 per gallon is about $232 million in required compensation.

4.5.2 Damages from Other Spills

There are few historical oil spills that would be comparable to a catastrophe such as a spill of over 189,000 bbls of Bakken crude into the Columbia River. Again, damages from different spills in different locations are not scalable by volume spilled, but an examination of previous settlements can provide useful context. Here we examine natural resource damages from the *Exxon Valdez* in Alaska in 1989 and the DWH in the Gulf of Mexico in 2010, as well as the settlement from a smaller spill in Grays Harbor, Washington, in 1988.

The *Exxon Valdez* spilled approximately 257,000 bbls of oil into Prince William Sound in 1989. In 1991, Exxon reached a settlement with natural resource Trustees that included $900 million in natural resource damages (Rodgers et al., 2005). A $900 million settlement in 1991 dollars is approximately $1.56 billion in 2015 dollars. The unit cost in 2015 dollars is approximately $6,100 per bbl discharged (Table 4.2).

Table 4.2. Past damages settlements for two other major oil spills and one smaller spill near the Columbia River

Spill	Year settled	Spill volume (bbl)	Settlement ($)	$ (2015 dollars)	Cost/bbl
Exxon Valdez	1991	257,000	$900,000,000	$1,561,000,000	$6,100
Nestucca	1991	5,500	$7,480,000	$12,980,000	$2,400
DWH	2015	3,190,000	$8,800,000,000	$8,800,000,000	$2,800

The *Nestucca* spilled about 230,000 gallons (5,500 bbl) of No. 6 fuel oil into the Pacific Ocean near Grays Harbor, Washington, in 1988 (USFWS, 2004). In 1991, the United States and Canada reached settlements totaling $7.48 million for natural resource restoration (Helm et al., 2006). A $7.48 million settlement in 1991 dollars is approximately $13 million in 2015 dollars. The unit cost in 2015 dollars is approximately $2,400 per bbl discharged (Table 4.2).

2. See http://data.bls.gov/cgi-bin/surveymost?cu, U.S. All Items.

The DWH spill discharged approximately 3.19 million bbls of oil into the Gulf of Mexico. Recently, BP reached a settlement with natural resource Trustees that included $8.8 billion in natural resource damages (DWH NRDA Trustees, 2016). The unit cost for this spill is approximately $2,800 per bbl spilled (Table 4.2).

The effective WCD for the LCR is 189,845 bbls (EFSEC, 2015). Using the cost per bbl spilled for these other spills (Table 4.2) as context, natural resource damages could be in the range of $456 million ($2,400/bbl) to $1.16 billion ($6,100/bbl).

4.5.3 Value of Lost Adult Salmon Fishery

Natural resource damages can be based on the economic value of the injured resources. Placing a value on lost recreational fishing is a common method of estimating damages to adult fish. If the public is less willing to go fishing after an oil spill, either because of a fishery closure or because of the perception that the fish are tainted, Trustees are entitled to damages commensurate with the lost fishing, regardless of the demonstrable adverse effects on the fish.

Our estimate of the value of lost recreational fishing in the LCR (see Chapter 3) is $17.8 million. This estimate is based on the average number of trips per month from 2011 to 2015, assuming that the fishery is closed for 6 months starting in May, and that recreational fishing slowly recovers for another 6 months (see Section 3.3). This value is not subsumed in a restoration-based damages estimate, because it captures some value of lost fishing that restoration projects will not restore. By the same token, this value should not be added to a restoration-based estimate, because restoration projects will restore salmon, and that will help to offset the lost fishing in future years.

4.5.4 Restoration-Based Damages: Columbia River Habitat

A tremendous amount of effort has been focused on estuarine habitat restoration in the Columbia River estuary and other estuaries in the Pacific Northwest. It is well beyond the scope of this report to provide a thorough review of restoration projects that have been designed and conducted in this area.

As discussed previously, restoration-based damages are based on the cost to restore natural resources that are equivalent to those that were injured from the discharge of oil. In this report, we are only assessing potential natural resource injuries in the Columbia River and adjacent impacted habitat. To calculate damages using HEA to estimate the quantity of estuarine habitat restoration that must be conducted to offset injuries, we calculate the net improvement in habitat services over time as a result of the restoration, and we calculate the unit cost (per acre) to perform the restoration.

Estuarine habitat restoration projects in this area often target human-made obstructions such as dikes, ditches, and culverts that restrict water and fish from accessing habitat. One recent example in the LCR is Steamboat Slough, in the Julia Butler Hansen Refuge at about RM 35. In the environmental assessment for the restoration project, the Columbia River Estuary Study Task Force (CRESTF, 2013, p. 8) noted the following:

> Tidal, estuarine wetlands are one of the most impacted habitats in the Lower Columbia River system, and are a priority for restoration, particularly for their high functional value to threatened and endangered salmonids that use these areas

> as refugia, rearing and feeding before migrating to sea. Flood control measures, which include diking, filling, and ditching, have fragmented the estuary structure along the Columbia River and its tributaries. These actions limit and reduce the available habitat for juvenile salmonids throughout the greater Columbia River Basin.

In addition to simply opening habitat to juvenile salmonids, these restoration projects typically include construction or enhancement of wetland vegetation, regrading to provide complex multi-story habitat ranging from inundated wetland to occasionally inundated shrub/scrub to upland forest. While salmonids may be the target for restoration, many of these projects are restoring habitat for a wide range of biota, including waterfowl, songbirds, reptiles, amphibians, and invertebrates.

HEA Method

As discussed previously, the HEA method (NOAA, 2006a) requires estimating the total amount of natural resource injuries over time and space and the amount of natural resource improvement over time per unit (acre) of restoration. The quantity and cost of restoration required to offset the injury is then calculated.

The method requires calculating the total quantity of natural resource injury over space and time (debit). In a HEA, this debit calculation may also include an estimate of habitat service loss for each year of injury. This service loss factor is used to as a scaling factor, to balance services lost to injuries and services gained from restoration. Injuries in the future are discounted using a discount rate of 3% to account for the consumer time preference (i.e., habitat injured or restored today is worth more than the same amount of habitat injured or restored years in the future). The discounted service loss (in acres) of injured habitat in each year is summed to estimate a total debit, in units of discounted service acre-years (DSAYs).

The amount of restoration required to offset the debit is calculated similarly by estimating the service gain (in acres) of restored habitat each year multiplied by the discount rate and summed across all years to calculate the total amount of credit in DSAYs per unit of habitat restoration. The total debit (DSAYs) is divided by the total credit per unit of restoration (DSAYs per acre, in this case) to determine the total quantity of habitat restoration (acres) required to offset habitat injuries and make the public whole.

The specific HEA method that we use in this report is based on the methods described in the Commencement Bay NRDA (Commencement Bay Natural Resource Trustees, 2002, including appendices). For this settlement, the Trustees scaled all habitat injuries and restoration to a fully functioning estuarine marsh. Intertidal and subtidal habitats were assumed to provide 5% to 75% of estuarine marsh services for juvenile Chinook salmon and birds (Commencement Bay Natural Resource Trustees, 2002, Appendix C, Table 1). Service loss from exposure to contaminants was estimated based on sediment concentrations for multiple contaminant classes and toxicological dose-response curves for each class (see Cacela et al., 2005).

We use a similar scaling method to discount injured habitat that does not provide the equivalent services as estuarine marsh. However, for an oil spill that has yet to occur, we do not have sufficient data to use dose-response relationships as a service loss metric. Therefore, we estimate habitat service losses based on an overall integration of available data.

Debit

We calculated the total area of Columbia River habitat from Vancouver (RM 97) to the mouth of the river (RM 0) using bathymetric data from a commonly available U.S. hydrography data layer in GIS. The calculated area of Reach 2 is 20,556 acres, and calculated area of Reach 1 is 87,175 acres. Combined, the injured area is 107,731 acres.

We used the National Wetlands Inventory (NWI; USFWS, 2016) to delineate habitats within the river channel. We conducted separate HEA debit calculations for areas designated as wetland (including estuarine and marine wetland, freshwater emergent wetland, and freshwater forested/shrub wetland), and areas designated as other habitat (primarily riverine, with some areas of marine deepwater near the mouth). Reach 1 has 15,757 acres of wetland habitat, and Reach 2 has only 395 acres of wetland habitat. In the Commencement Bay NRDA (Commencement Bay Natural Resource Trustees, 2002), shallow subtidal habitats provided 40% of marsh habitat, and deep subtidal habitat provided 5% of marsh habitat. In the LCR, some of the riverine/estuarine habitat is deep and some is shallow. For the assessment of injury in the river channel, we assume that all habitats classified as wetland provide 100% of marsh services, and non-wetland habitats provide 10% of marsh services.

In Section 4.4, we discussed the toxicity of the oil in the river and the likelihood that substantial numbers of salmon would be injured by oil exposure. Despite the weathering and dispersion of oil as it moves downstream, the models in the DEIS suggest that more PAHs enter the water column in Reach 1, and the oil persists for longer in Reach 1 because of diurnal current reversals. We assumed a higher service loss in Reach 2 because of its proximity to the oil source; however, because Reach 1 is much bigger and has substantially more wetland habitat, most of the HEA debit in this analysis comes from oil exposure in Reach 1.

While most of the acute oil exposure will occur over a matter of days or weeks, it is likely that oil in sediments and stranded oil re-entering the river from the banks will keep some level of service loss occurring well into the future. To calculate damages in this scenario, we assumed that the spill occurs in May 2016 (in the present year, for purposes of discounting). Because debit and credit are calculated on a yearly basis, we estimated that overall habitat services provided in Reach 2 was 10% in 2016 (i.e., services were reduced by 90% as a result of the spill). We then estimated recovery to 90% of pre-spill services by the end of 2017, with a progressive increase to 100% of pre-spill services by 2025. In Reach 1, we estimated services to be 25% in 2016, increasing to 90% by the end of 2017 and 100% by 2025. For the Reach 1 and Reach 2 habitats combined, the total HEA debit is 21,276 DSAYs (Table 4.3).

Credit

The Commencement Bay Natural Resource Trustees (2002) estimated that restored estuarine marsh reaches 100% habitat services 15 years after the project is completed. The habitat services that were provided prior to restoration can range widely; for this analysis, we assumed that the typical estuarine habitat restoration project would increase habitat services by 90%, with services increasing linearly over a 15-year period as vegetation becomes established and complex habitat develops. Restoration projects typically do not start until many years after a spill occurs and the NRDA process has concluded; here, we assumed that restoration would be complete 5 years after the spill (2021). We further assumed that the project would continue to provide benefits for 100 years, through 2120. The HEA credit for this restoration is 20.5 DSAYs per acre (Table 4.4).

Table 4.3. HEA debit calculations for the LCR Reach 1 riverine/subtidal habitat (A) and Reach 2 riverine habitat (B), Reach 1 wetland habitat (C), and Reach 2 wetland habitat (D)

A. LCR Reach 1							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Non-wetland (primarily riverine and subtidal)							
	2016	25%	2017	90%	0.1	71,418	5,952
	2018	90%	2025	100%			
B. LCR Reach 2							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Non-wetland (primarily riverine)							
	2016	10%	2017	90%	0.1	20,161	1,832
	2018	90%	2025	100%			
C. LCR Reach 1							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Wetland							
	2016	25%	2017	90%	1.0	15,757	13,133
	2018	90%	2025	100%			
D. LCR Reach 2							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Wetland							
	2016	10%	2017	90%	1.0	395	359
	2018	90%	2025	100%			
						107,731	21,276

Table 4.4. Restoration credit per acre restored

Start year	%services	End year	% services	Scalar	Area (ac)	Credit (DSAYs)
2021	10%	2035	100%	1.0	1	20.5
2036	100%	2120	100%			

Quantity and Cost of Restoration Required

The unit cost of estuarine march habitat restoration varies widely. Some projects are quite simple; dozens of acres of new inundated habitat can be created by simply breaching a dike. Other projects are much more complicated and expensive, requiring fee purchase of habitat, removal and disposal of contaminated soils, and weeks of work with heavy machinery to create a new habitat.

We reviewed several sources to compile restoration cost information. NOAA (2016) has an online database of restoration projects (the Restoration Atlas) that contains summary project information, including type, cost, and year, for over 2,800 restoration projects. Several documents summarized the ecosystem-level benefits of estuarine restoration projects (e.g., Johnson et al., 2012; USACE and BPA, 2013), which further demonstrated the wide range of restoration costs and net habitat benefits. The unit cost of estuarine marsh restoration in these documents range from several hundred dollars to well over $1 million per acre.

For the Commencement Bay settlement (Commencement Bay Natural Resource Trustees, 2002), the unit cost of estuarine marsh restoration (in 2002 dollars) was approximately $1.2 million per acre. A 2012 evaluation of potential mitigation projects in the Port of Tacoma, Washington (Port of Tacoma, 2012, Table 6) included a summary of Port-owned properties where marsh habitat could be restored to mitigate other impacts. One project had a unit cost of $1 million per acre; the other six projects for which unit costs were listed were between $100,000 and $200,000 per acre.

We used the recent Fir Island restoration project in the Skagit River valley of northwestern Washington is as the basis for our estuarine marsh restoration cost estimate. According to the web site (WDFW, 2014):

> Estuary restoration has been identified as a priority in the Skagit Chinook Recovery Plan 2005. Based on the findings of the Fir Island Farm Snow Goose Reserve Restoration Feasibility Study (2011), WDFW's preferred 130 acre restoration site will significantly contribute to the recovery of Skagit Chinook salmon by restoring 126 acres of tidal marsh habitat, restoring 17.44 acres of new tidal channel habitat and producing an estimated 65,000–320,600 new Chinook smolts annually. Snow goose management and public access will be maintained at the project site and measures to maintain drainage, flood protection and protection from saltwater intrusion for adjacent farmland will be incorporated into the final project design. Climate change and sea level rise predictions will also be incorporated into the final project design.

Shannon & Wilson Inc. (2011) produced the feasibility study. The detailed estimate of project costs at the 90% design stage (Shannon & Wilson, 2014) was $14,235,565. Although the total area restored is hard to decipher from the WDFW quote above, we assumed 130 acres of restoration, which is a unit cost of approximately $110,000 per acre.

With a total calculated debit of 21,276 DSAYs and a credit of 20.5 DSAYs per acre, the total quantity of restoration required to offset the injuries to river channel habitats in Reach 1 and Reach 2 of the LCR is 1,040 acres. At an average cost of $110,000 per acre, the total damages would be about $114.4 million (Table 4.5).

Table 4.5. Estimated cost to restore habitat sufficient to offset river habitat injuries in the LCR

Debit (DSAYs)	Credit (DSAYs/acre)	Restoration required (acres)	Unit cost ($/acre)	Total
21,276	20.5	1,040	$110,000	$114.4 million

4.5.5 Restoration-Based Damages: Wildlife Refuges

In addition to the oil causing injury to the river habitat, it will also injure birds and riverbank and floodplain habitat. Some oil will become stranded in these habitats. To account for injuries to birds and riverbank/floodplain habitat, we conducted a separate HEA for wetlands located within the 100-year floodplain but outside of the designated channel of the Columbia River in Reaches 1 and 2. This includes designated NWI wetlands in the Sauvie Island Wildlife Area, the Ridgefield National Wildlife Refuge, the Julia Butler Hansen Refuge for the Columbian White-tailed Deer, and the Lewis and Clark National Wildlife Refuge (Figure 4.4). The total area of floodplain wetlands in Reaches 1 and 2 is 29,867 acres. The amount of oiling in these floodplain wetlands would depend on the river stage at the time of the spill; if the river was at flood stage, most of these wetland habitats would be oiled. If the river stage was low, the habitats could be oiled at the margins, but birds living within those habitats would likely be oiled when exposed to oil in the river.

Debit

To calculate debit for floodplain wetland habitat, we assumed that the spill occurred in May 2016. Habitat services in Reaches 1 and 2 were 75% of pre-spill conditions in 2016, recovering to 95% by the end of 2017 and 100% by 2025. For the 29,867 acres of floodplain wetland habitat, the total HEA debit is 10,580 DSAYs (Table 4.6).

Table 4.6. HEA debit calculations for Reach 1 floodplain wetland habitat (A) and Reach 2 floodplain wetland habitat (B)

A. LCR Reach 1							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Floodplain wetland							
	2016	75%	2017	95%	1.0	16,108	5,706
	2018	95%	2025	100%			
B. LCR Reach 2							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Floodplain wetland							
	2016	75%	2017	95%	1.0	13,759	4,874
	2018	95%	2025	100%			
						29,867	10,580

Credit

Because all injuries are scaled to marsh habitat and credit is based on marsh restoration, the credit for restored habitat is also 20.5 DSAYs per acre (Table 4.4), as described previously for the river channel HEA.

Quantity and Cost of Restoration Required

With a total calculated debit of 10,580 DSAYs and credit of 20.5 DSAYs per acre, the total quantity of restoration required to offset the injuries to floodplain wetland habitat and biota is 517 acres. At an average cost of $110,000 per acre, the total damages would be about $56.9 million (Table 4.7).

Figure 4.4. Wildlife refuges and managed areas along the LCR.

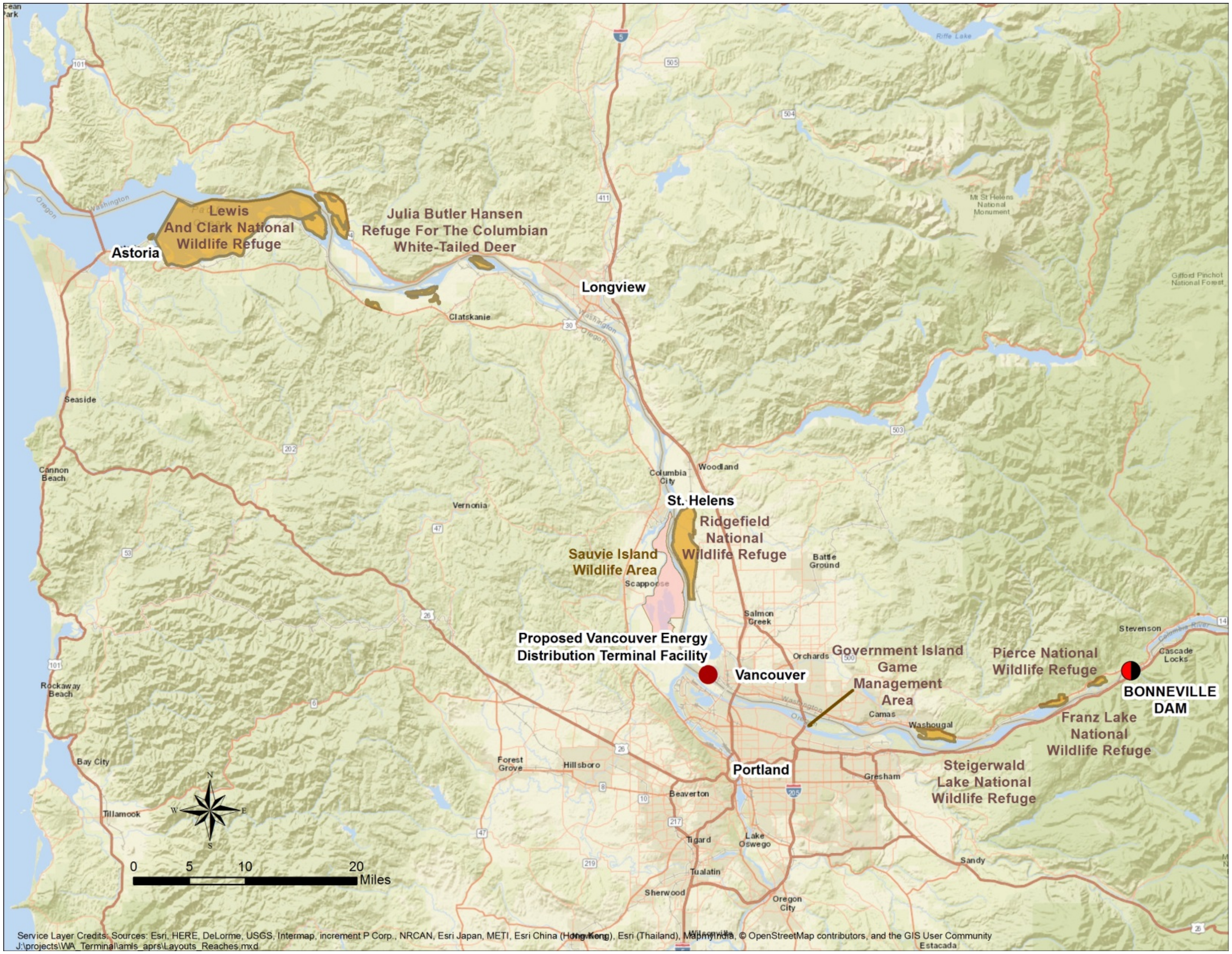


Table 4.7. Estimated cost to restore habitat sufficient to offset floodplain injuries in the LCR

Debit (DSAYs)	Credit (DSAYs/acre)	Restoration required (acres)	Unit cost ($/acre)	Total
10,580	20.5	517	$110,000	$56.9 million

4.5.6 Summary

Damages estimates presented in this section are summarized in Table 4.8. The estimates from scaling past damages calculations based on unit cost per volume of oil spilled do not account for specific natural resource injuries that may occur; instead, they are based on damages that occurred in similar habitats or on similar scales as the effective WCD spill.

Table 4.8. Summary of damages estimates for the effective WCD spill in the LCR

Method	Damages estimate
Possible range based on past major spills ($/bbl)[a]	$455 million to $1.16 billion
Extrapolation based on past (relatively minor) incidents in the Columbia River ($/gallon)[a]	$232 million
Value of lost recreational fishing (assuming 6-month closure plus additional 6 months recovery)	$17.8 million
Cost to restore injured river habitat + cost to restore injured floodplain wetland habitat (HEA)	$114.4 million + $56.9 million = $171.3 million

a. Settlements from other spills in other locations are generally not scalable, but they can be used to suggest a potential range of damages.

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5. Natural Resource Damages from an Upstream Train Derailment

The methods for calculating natural resource damages for the train derailment scenario are similar to those described in the previous chapter for calculating damages from a tanker grounding. The worst-case impacts from a 20,000-bbl spill are again going to be in the Columbia River. In this scenario, the oil is discharged farther upstream, and the total amount of oil discharged is about 10% of the effective WCD of a tanker grounding. Because this oil is going into the same river, we would expect the same types of adverse impacts in similar habitats.

There are some differences in this scenario, however, which are explained in the following sections. In particular, as described in Chapter 2, we have assumed that the worst-case scenario is for all the spilled oil to go over or through the Bonneville Dam, which will mix the oil into the water column and greatly increase the PAH concentrations in Reach 4 below the dam. Also, there are several more wildlife refuges in Reaches 3 and 4 with valuable habitat and biota that would exposed to the oil from this upstream spill. The adverse effects of the oil in the most downstream reach would be diminished, and the quantity of oil discharged to the ocean would be considerably less, as more oil would be weathered, evaporated, stranded, and deposited in sediments after traveling 140 miles downstream. Because we did not assess injuries and damages to oceanic and coastal habitat, this reduction in oil discharged to the ocean is not reflected in any of our damages calculations.

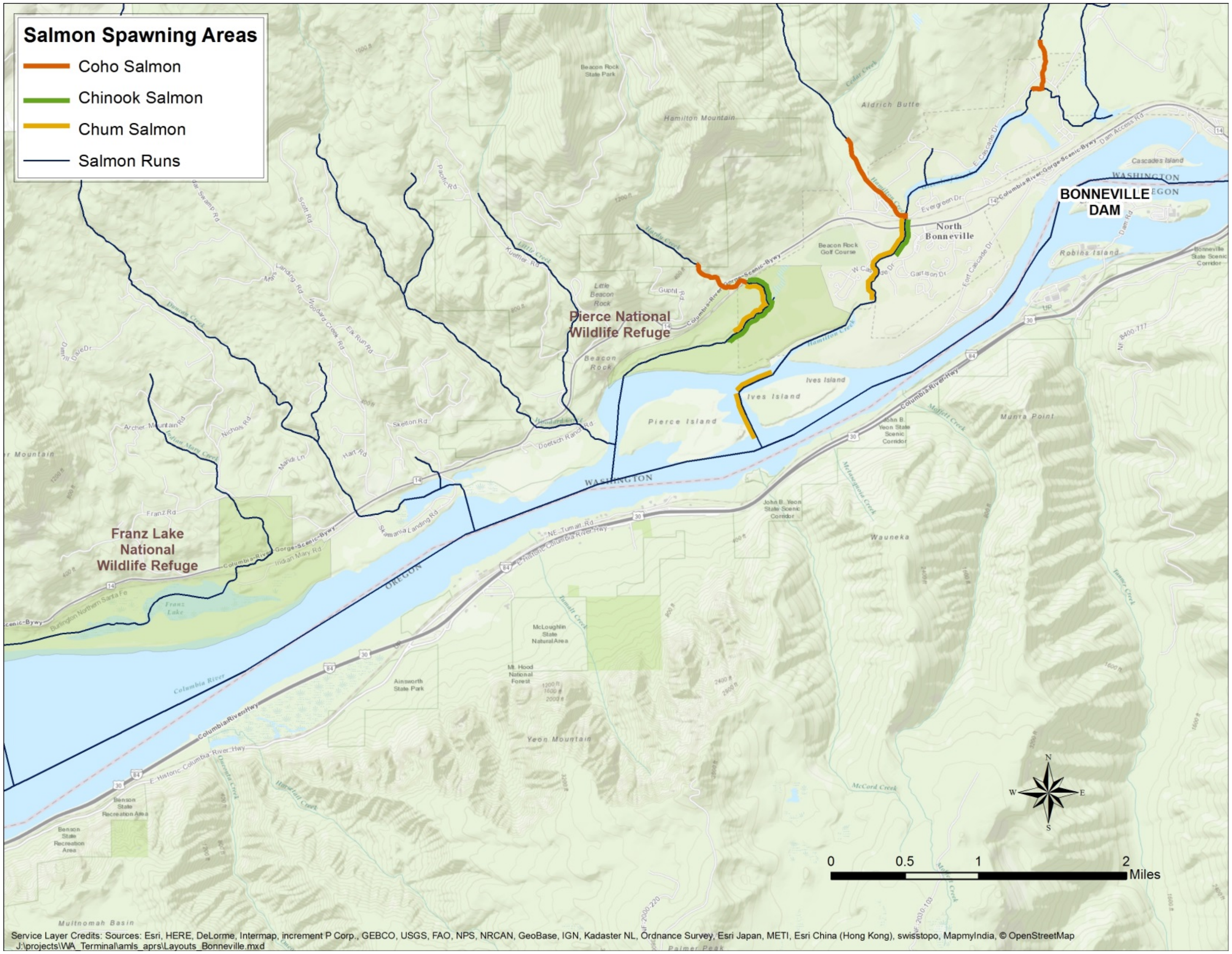
5.1 Natural Resource Exposure

Natural resources that would be exposed to the oil discharged from the derailed train are similar to the resources that would be exposed in the tanker spill scenario. The impoundment behind the Bonneville Dam (the Bonneville Pool) is primarily in a canyon, with little floodplain habitat. The habitat immediately below the dam is particularly high-value habitat, including salmon spawning habitat (Figure 5.1), protected spawning habitat for sturgeon, two wildlife refuges, and large areas of wetland habitat (Figure 5.2).

5.1.1 Fish

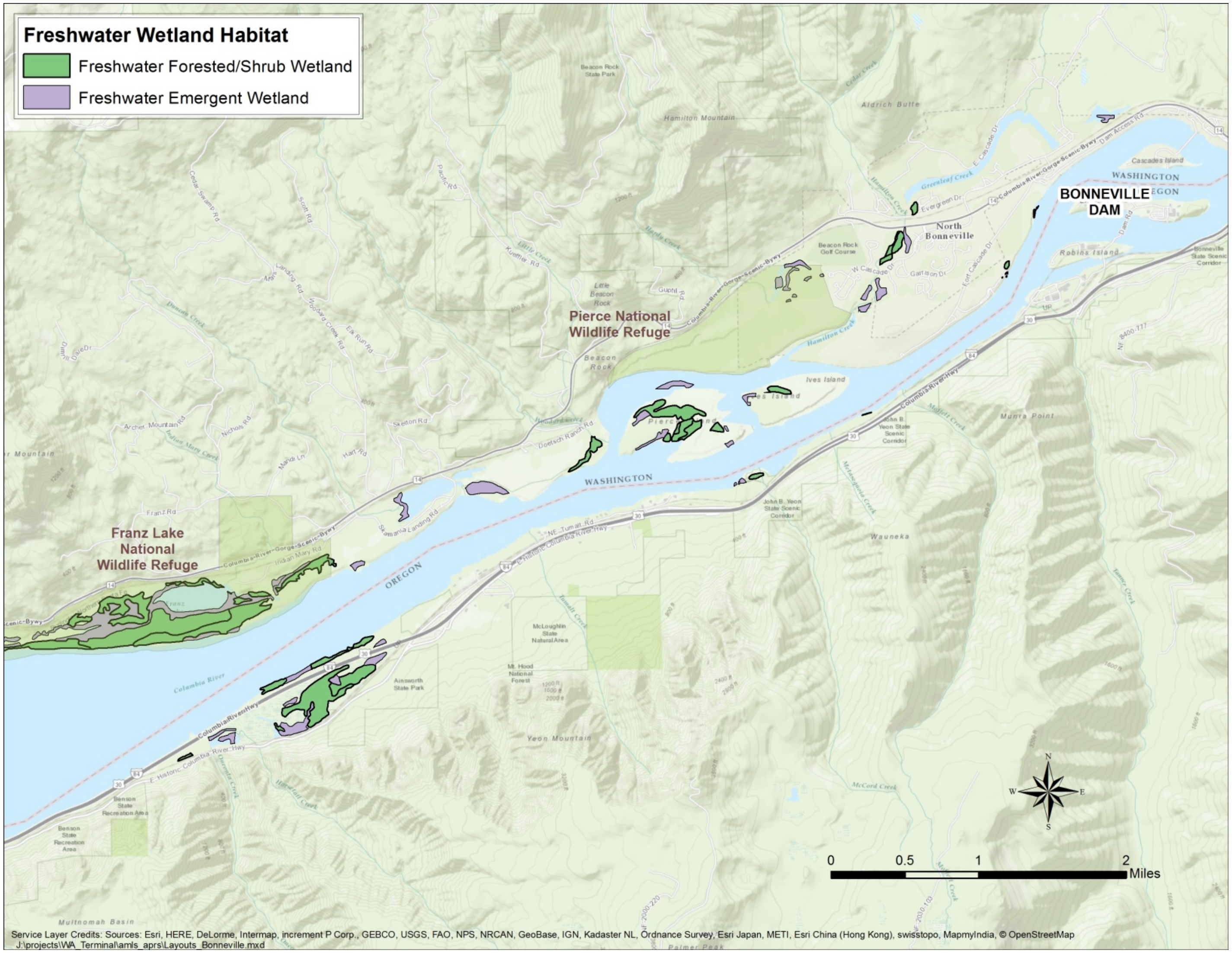
We estimated salmon exposure based on 5-year average adult and smolt passage data at the Bonneville Dam (Columbia Basin Research, 2016a, 2016b; see Figure 4.2). The average number of adult salmon per day counted at the Bonneville Dam in mid-May from 2011 to 2015 was about 4,000 (ranging from 2,000 to 9,000). The estimated travel time for a salmon to reach the dam from the mouth of the river is up to 3 weeks (Rub et al., 2012). Thus, as the oil plume travels downstream, it would intersect many daily cohorts of adult salmon traveling upstream. It is likely that the quantity of oil and the PAH concentrations would decrease with the distance downstream through Reaches 4 and 3. However, the oil transport modeling data in the DEIS (EFSEC, 2015; see Chapter 2) do not include Reaches 4 and 3. Therefore, for this train derailment WCD, we have not attempted to estimate adult salmon exposure to oil beyond the 1-day cohort that would be exposed in Reach 4 near the dam.

Figure 5.1. Tributaries off Reach 4 of the Columbia River are known salmon habitat, including several spawning areas.



Source: Statewide Washington Integrated Fish Distribution data repository.

Figure 5.2. Wetland habitat downstream of the Bonneville Dam.



Source: NWI.

The average number of smolts per day in mid-May is about 112,000 (ranging from 27,000 to 220,000). This daily cohort of smolts would move downstream with the oil for several days until reaching the estuary (McMichael et al., 2013; see Chapter 4). The total number of smolts exposed to the plume of oil would increase by an unknown number coming from tributaries downstream of the Bonneville Dam. We have not attempted to quantify these additional smolts, or any additional daily cohorts of smolts counted at the dam that might intersect oil in the estuary, where smolts remain for several days before swimming to sea (McMichael et al., 2013).

In addition to exposing salmon to oil, this spill scenario would expose white sturgeon to oil in a particularly important sturgeon spawning habitat. The upper 4.5 miles of Reach 4 directly below the Bonneville Dam is a protected spawning sanctuary for white sturgeon, which spawn from late April through early July (McCabe and Tracy, 1994). Sturgeon embryos (which are affixed to the bottom of the river) and larvae would also likely be exposed, as these life stages typically reside in the vicinity of where they were spawned until larvae begin downstream dispersion activities (Kynard and Parker, 2005).

5.1.2 Birds

Reaches 4 and 3 of the LCR downstream of the Bonneville Dam include three wildlife refuge areas and one (small) game management area (see Figure 1.1). As with the refuges in Reaches 2 and 1, these upstream refuges support thousands of bird species present at all times of the year. The bird species most likely to be exposed to oil will be those that most heavily rely on water access to obtain food, including piscivores and dabbling and diving birds.

High-profile obligate piscivores like bald eagles, harlequin ducks (*Histrionicus histrionicus*), great blue herons, osprey, and belted kingfishers will be greatly impacted by reductions in fish numbers and exposure to contaminated water caused by a spring oil spill. These species, and many others, breed during this period, so adults and young will be impacted. Exposure of eggs and nestlings to oil occurs through transfer from contaminated food, nesting materials, and parental feathers. Impacts to adult bird health may in turn lead to nest abandonment and further loss.

The national wildlife refuges maintain lists of birds that are typically present in each refuge. Nearly 100 bird species are listed as abundant or common in the Steigerwald National Wildlife Refuge in the spring (USFWS, 2010; see Figure 4.4). Many of these birds would be at risk of oil exposure if the effective WCD from a train derailment occurred in the spring immediately upstream of the Bonneville Dam.

5.1.3 Pinnipeds

Seals and sea lions tend to congregate near the mouth of the Columbia River but are known to travel up the river all the way to the Bonneville Dam to feed on salmon and sturgeon (NOAA, 2006; Wiles, 2015). Over 100 sea lions have been observed at one time feeding on fish at the bottom of the Bonneville Dam (Norman, 2006). These sea lions would be exposed to oil if the WCD spill occurred immediately upstream of the dam and the oil rapidly discharged downstream.

5.2 Natural Resource Injuries

Natural resource injuries from this train derailment WCD would be the same as those described for the tanker grounding in Chapter 4. The oil type (Bakken crude) is the same; see Chapter 4 for a discussion of the properties of this oil and the methods for estimating PAH concentration in the water column. Because in this scenario the oil goes over or through the dam in a highly turbulent environment, it will mix into the water column substantially more than oil spilled from a tanker grounding (see Chapter 2), and thus fish and other biota in the water column would be exposed to considerably higher concentrations of PAHs.

To summarize from previous chapters (see also DWH NRDA Trustees, 2016), PAHs are known to be toxic to fish. ELS fish exposed to PAHs experience cardiac disruption or death when exposed to elevated PAH concentrations, particularly in the presence of UV light. High-performance fish (such as migrating salmon) may experience a marked decrease in swim performance after PAH exposure, and juvenile fish (such as smolts) may suffer from compromised immune systems.

Oil has been shown to be toxic to birds through multiple pathways, including high embryo mortality when egg shells are oiled, induced hemolytic anemia when oil is ingested, and hypothermia and reduced flight performance when oil is on feathers (Ziccardi and Drayer, 2015; DWH NRDA Trustees, 2016).

5.3 Injury Quantification

5.3.1 Fish

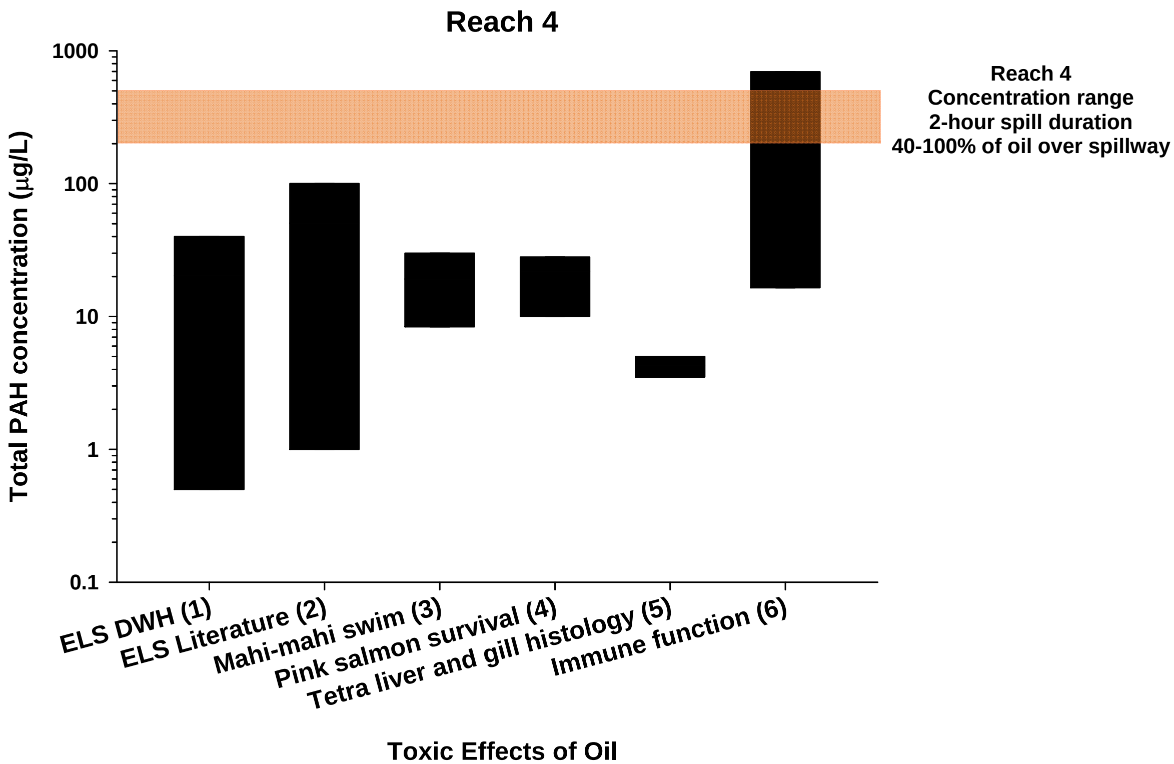
The concentration range of total PAH predicted in Reach 4 following a train derailment above the Bonneville Dam in May would be 200–500 µg/L of total PAH (see Chapter 2), which is well above ranges of published adverse effects levels (Figure 5.3). Assuming a range of mortality from 75% to 100%, we predict smolt mortality ranging from 20,250 (75% of the lowest daily smolt count of 27,000) to 220,000 (100% of the highest daily smolt count). Similarly, we predict adult mortality ranging from 1,500 (75% of the lowest daily adult count of 2,000) to 9,000 (100% of the highest daily adult count). Downstream of Reach 4, there would be additional adult salmon mortality, as the plume of oil moving downstream intersects other daily cohorts of adult salmon migrating upstream. As mentioned previously, we do not have sufficient data to quantify the injuries to these other adult cohorts.

In this scenario, the oil is mixed into the water column after going over the dam, which would likely expose larval sturgeon to highly elevated PAH concentrations in the protected spawning area downstream of the dam. We have not quantified the exposure or injuries to sturgeon.

5.3.2 Birds

We do not have an analogous model for estimating total numbers of potential dead birds resulting from oil exposure. While the avian toxicity data presented previously clearly demonstrate that most birds exposed to oil are likely to die, and oiled eggs rarely develop into healthy birds, it is particularly challenging to quantify the number of birds that would likely be exposed to oil in the LCR.

Figure 5.3. Ranges of published adverse effects levels of total PAH to ELS and older life stage fish (black bars) compared to the concentration ranges estimated for Reach 4, given spill scenarios described in Chapter 2.



Sources: Carls et al., 1998; Birtwell et al., 1999; Akaishi et al., 2004; Lee et al., 2015a, 2015b; Ortell et al., 2015; DWH NRDA Trustees, 2016.

The data from the 1984 *MobilOil* spill provided some information to help estimate bird mortality from a major spill near Vancouver. Those data are less relevant for this scenario, as most of those bird mortalities were found along the coast after the oil discharged into the ocean.

Isaacs and Anthony (2011) reported 83 nesting pairs of bald eagles in Oregon and 57 in Washington as of 2007, for a total of 140 eagles (assuming each identified nesting site in fact had a pair of birds). Given the magnitude of the spill, it is highly likely that some bald eagles nesting along the Columbia River would get exposed to some oil and perish. Site-specific data would need to be collected during and after the spill to assess the impacts.

Many thousands of songbirds living and nesting along the river would be exposed to oil and likely would die as well. For this analysis, we have not attempted to quantify songbird mortality, as we have little data on which to base an estimate.

5.3.3 Pinnipeds

Although more than 100 sea lions have been observed at the base of the Bonneville Dam in the past (NOAA, 2006), we do not have data to quantify the potential injuries to pinnipeds. Marine mammals are known to be sensitive to oil exposure; the overall health of common bottlenose dolphins exposed to DWH oil in Louisiana dropped substantially (DWH NRDA Trustees, 2016).

While it is likely that some pinnipeds would be injured in this WCD spill, we have not tried to quantify those injuries here.

5.4 Damage Determination

As discussed previously, natural resource damages are frequently calculated based on the cost to restore equivalent resources or habitat. As in Chapter 4, we present restoration-based damages for injuries to Columbia River habitat using an HEA model, where restoration is estuarine habitat restoration in the Columbia River estuary. This estuarine habitat is not equivalent to the oiled habitat in Reaches 4 and 3, which are well upstream of the estuary; therefore, we have used additional scaling factors to reflect the greater habitat services that estuarine habitat provides.

As in Chapter 4, prior to presenting a restoration-based damages estimate, we first review other lines of data that can help provide an initial estimate of damages for a spill of this magnitude.

5.4.1 Washington State Oil Spill NRDA [WAC 173-183]

As discussed previously, WAC 173-183 provides formulas for calculating damages from oil spills, when certain criteria are met. Those criteria would not be met for a major spill scenario such as the effective WCD from a train derailment, but we can use the past settlements context when examining compensation required. It is highly unlikely that the spill formula in WAC 173-183 would be used for a spill of this magnitude.

WAC 173-183 generally states that for spills less than 1,000 gallons, the range is $1 to $100 per gallon; and for spills of 1,000 gallons or more, the range is $3 to $300 per gallon spilled. For an effective WCD spill of 20,000 bbl (840,000 gallons), that scales to $2.5 million to $250 million.

As presented in Chapter 4, the Washington Department of Ecology (2016) provides a spreadsheet of RDA oil spill incidents since 1991. None of the incidents is even remotely as large as the scenario here. As summarized in the previous chapter, the average compensation for a spill in the Columbia River and the estuary was $29 per gallon; based on that unit cost, a spill of 840,000 gallons at $29 per gallon is about $24.4 million in required compensation.

5.4.2 Scaling Damages per Volume Spilled in Other Spills

In Chapter 4 (Section 4.5.2), we presented damages per bbl spilled from DWH, *Exxon Valdez*, and *Nestucca*, with the caveat that these damages settlements from different locations at different times are not scalable but can provide useful context. The settlements ranged from $2,400 to $6,100 per bbl (see Table 4.2). If we apply these to the train derailment WCD, the range of natural resource damages would be $48 million ($2,400/bbl) to $122 million ($6,100/bbl).

5.4.3 Value of Lost Adult Salmon Fishery

It is likely that a 20,000-bbl spill at the Bonneville Dam will discharge sufficient oil downstream of the dam to result in fisheries closures and/or reduced recreational fishing visits. However, quantifying lost recreational fishing for this train derailment scenario was not part of the scope of this report.

5.4.4 Restoration-Based Damages: Columbia River Habitat

For this scenario, we used the identical approach that we used for the tanker grounding spill in the previous chapter, where we estimated lost wetland and non-wetland habitat services in the river and scaled estuarine habitat restoration to calculate damages. We again assumed that non-wetland habitat provides 10% of estuarine marsh habitat services, with the exception of the riverine habitat in Reach 4, which contains protected sturgeon spawning habitat. Although the habitat type is different, we assumed that riverine habitat in this reach provides the equivalent of 100% of the services that estuarine marsh habitat provides.

As described in the previous chapter, all habitats are scaled to estuarine marsh habitat, and the unit cost for estuarine marsh habitat restoration is $110,000 per acre.

Debit

We calculated the area of Columbia River habitat from Bonneville Dam to the mouth of the river using a commonly available U.S. hydrography data layer in GIS. The calculated area of Reach 4 is 880 acres, Reach 3 is 18,392 acres, Reach 2 is 20,556 acres, and Reach 1 is 87,175 acres. The calculated total habitat area for the LCR is 127,003 acres. The vast majority of wetland habitat is in the estuary (Reach 1), with 15,757 acres of wetland. Reach 2 has 395 acres, Reach 3 has 521 acres, and Reach 4 has 14 acres of wetland habitat.

To calculate damages, we assumed that the spill occurs in May 2016 (in the present year, for purposes of discounting). We assumed the following service losses for each habitat in each reach (Table 5.1):

- In Reach 4, where 20,000 bbls of oil will be mixed throughout the water column after going over the dam, we estimated severe impacts, with habitat services declining to 10% of pre-spill conditions. By the end of 2017, services returned to 90%, increasing incrementally each year until reaching 100% in 2025.
- In Reach 3, we estimated habitat services declining to 50% of pre-spill conditions. By the end of 2017, services returned to 90%, increasing incrementally each year until reaching 100% in 2025.
- In Reaches 2 and 1, we estimated habitat services declining to 85% of pre-spill conditions. By the end of 2017, services returned to 95%, increasing incrementally each year until reaching 100% in 2025.

The total HEA debit is 10,135 DSAYs (Table 5.1). The estuary (Reach 1) is two orders of magnitude larger than Reach 4 and contains most of the wetland habitat in the LCR channel; even though the presumed service loss is small in Reach 1, it contributes most of the total debit.

Credit

As discussed in Chapter 4, we assumed that restoration would be completed in 2021, with habitat services increasing linearly by 90% over a 15 year period, with benefits provided for 100 years. The HEA credit for this restoration is 20.5 DSAYs/ac (Table 5.2).

Table 5.1. HEA debit calculations for riverine/subtidal habitat in Reach 1 (A), Reach 2 (B), Reach 3 (C), and Reach 4 (D), as well as debit calculations for wetland habitat in Reach 1 (E), Reach 2 (F), Reach 3 (G), and Reach 4 (H)

A. LCR Reach 1							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Non-wetland (primarily riverine and subtidal)							
	2016	85%	2017	95%	0.1	71,418	2,173
	2018	95%	2025	100%			
B. LCR Reach 2							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Non-wetland (primarily riverine)							
	2016	85%	2017	95%	0.1	20,161	613
	2018	95%	2025	100%			
C. LCR Reach 3							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Non-wetland (primarily riverine)							
	2016	50%	2017	90%	0.1	17,871	1,266
	2018	90%	2025	100%			
D. LCR Reach 4							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Non-wetland (primarily riverine)							
	2016	10%	2017	90%	1.0	866	787
	2018	90%	2025	100%			
E. LCR Reach 1							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Wetland							
	2016	85%	2017	95%	1.0	15,757	4,794
	2018	95%	2025	100%			
F. LCR Reach 2							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Wetland							
	2016	85%	2017	95%	1.0	395	120
	2018	95%	2025	100%			
G. LCR Reach 3							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Wetland							
	2016	50%	2017	90%	1.0	521	369
	2018	90%	2025	100%			
H. LCR Reach 4							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Wetland							
	2016	10%	2017	90%	1.0	14	13
	2018	90%	2025	100%			
Total						127,003	10,135

Table 5.2. Restoration credit per acre restored

Start year	% services	End year	% services	Scalar	Area (ac)	Credit (DSAYs)
2021	10%	2035	100%	1.0	1	20.5
2036	100%	2120	100%			

Quantity and Cost of Restoration Required

With a total calculated debit of 10,135 DSAYs and credit of 20.5 DSAYs/ac, the total quantity of restoration required to offset the injuries to channel habitats in the LCR under this spill scenario is 495 acres. At an average cost of $110,000 per acre, the total damages would be on the order of $54.5 million (Table 5.3).

Table 5.3. Estimated cost to restore habitat sufficient to offset injuries in the LCR

Debit (DSAYs)	Credit (DSAYs/acre)	Restoration required (acres)	Unit cost ($/acre)	Total
10,135	20.5	495	$110,000	$54.5 million

5.4.5 Restoration-Based Damages: Wildlife Refuges

To account for injuries to birds and riverbank/floodplain habitat, we conducted a separate HEA for wetlands in the 100-year floodplain that are not in the designated channel of the Columbia River. Some of these wetlands can be found in the four refuges described previously for Reaches 1 and 2, as well as the three refuges between Vancouver and Bonneville Dam (Pierce, Franz Lake, and Steigerwald NWRs; see Figure 4.4). The combined area of these floodplain wetland habitats in Reaches 1 through 4 is 32,055 acres.

Debit

To calculate damages, we assumed the following service losses for each reach (Table 5.4):

- In Reach 4, we estimated habitat services declining to 25% of pre-spill conditions in 2016. By the end of 2017, services returned to 75%, increasing incrementally each year until reaching 100% in 2025.
- In Reach 3, we estimated habitat services declining to 75% of pre-spill conditions. By the end of 2017, services returned to 90%, increasing incrementally each year until reaching 100% in 2025.
- In Reaches 2 and 1, we estimated habitat services declining to 90% of pre-spill conditions. By the end of 2017, services returned to 98%, increasing incrementally each year until reaching 100% in 2025.
- The total HEA debit for estimated service losses in floodplain wetland habitat for all four reaches is 5,643 DSAYs (Table 5.4).

Table 5.4. HEA debit calculations for floodplain habitat in Reach 1 (A), Reach 2 (B), Reach 3 (C), and Reach 4 (D). Numbers may not sum due to rounding.

A. LCR Reach 1							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Floodplain wetland							
	2016	90%	2017	98%	1.0	16,108	2,282
	2018	98%	2025	100%			
B. LCR Reach 2							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Floodplain wetland							
	2016	90%	2017	98%	1.0	13,759	1,949
	2018	98%	2025	100%			
C. LCR Reach 3							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Floodplain wetland							
	2016	75%	2017	90%	1.0	2,045	1,193
	2018	90%	2025	100%			
D. LCR Reach 4							
Habitat	Start year	% services	End year	% services	Scalar	Area (ac)	Debit (DSAYs)
Floodplain wetland							
	2016	25%	2017	75%	1.0	144	219
	2018	75%	2025	100%			
Total						32,055	5,643

Credit

We used the same credit calculation here as we did for the river habitat; the calculated HEA credit is 20.5 DSAYs/acre (see Table 5.2).

Quantity and Cost of Restoration Required

With a total calculated debit of 5,643 DSAYs and credit of 20.5 DSAYs/ac, the total quantity of restoration required to offset the injuries to floodplain wetland habitat and biota is 276 acres. At a cost of $110,000 per acre, the total damages would be on the order of $30.4 million (Table 5.5).

Table 5.5. Estimated cost to restore habitat sufficient to offset floodplain habitat injuries in the LCR

Debit (DSAYs)	Credit (DSAYs/acre)	Restoration required (acres)	Unit cost ($/acre)	Total
5,643	20.5	276	$110,000	$30.4 million

5.4.6 Summary

Damages estimates presented in this section are summarized in Table 5.6. The estimates from scaling past damages calculations based on unit cost per volume of oil spilled do not account for specific natural resource injuries that may occur; instead, they are based on damages that occurred in similar habitats or on similar scales as the effective WCD spill.

Table 5.6. Summary of damages estimates for the effective WCD spill in the LCR

Method	Damages estimate
Range-finding based on past major spills ($/bbl)[a]	$48 million to $122 million
Range-finding based on past incidents in the Columbia River ($/gallon)[a]	$24.4 million
Cost to restore injured river habitat + cost to restore injured floodplain wetland habitat (HEA)	$54.5 million + $30.4 million = $84.9 million

a. Settlements from other spills in other locations are generally not scalable, but they can be used to suggest a potential range of damages.

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