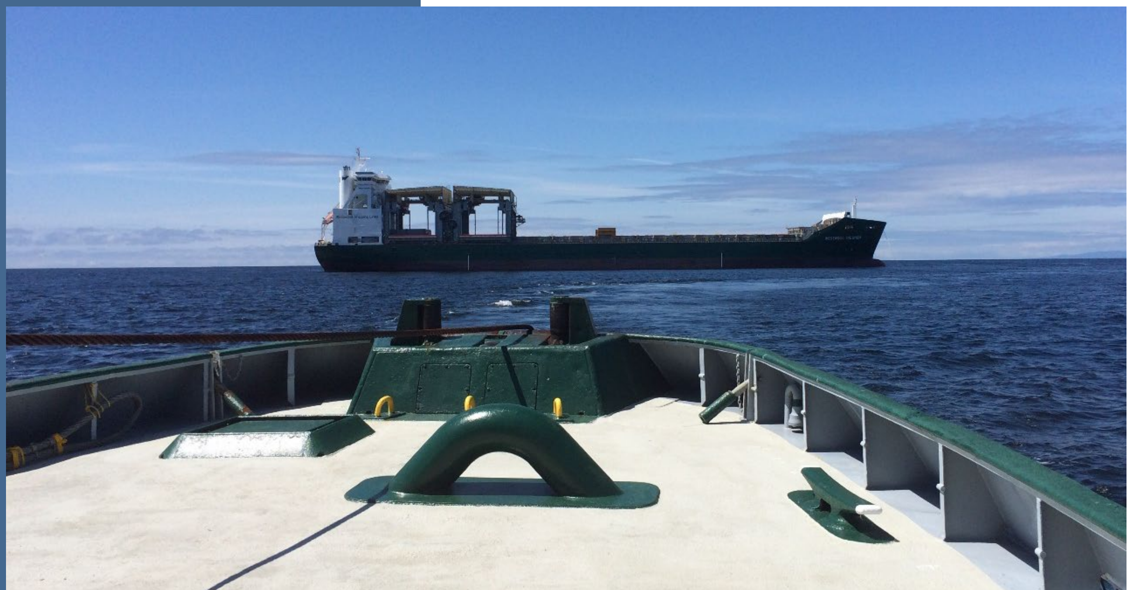

Analysis of an Additional Emergency Response Towing Vessel

Report to the Legislature pursuant to RCW 88.46.250

Spill Prevention, Preparedness, and Response Program

Washington State Department of Ecology

Olympia, Washington

September 2023, Publication 23-08-008

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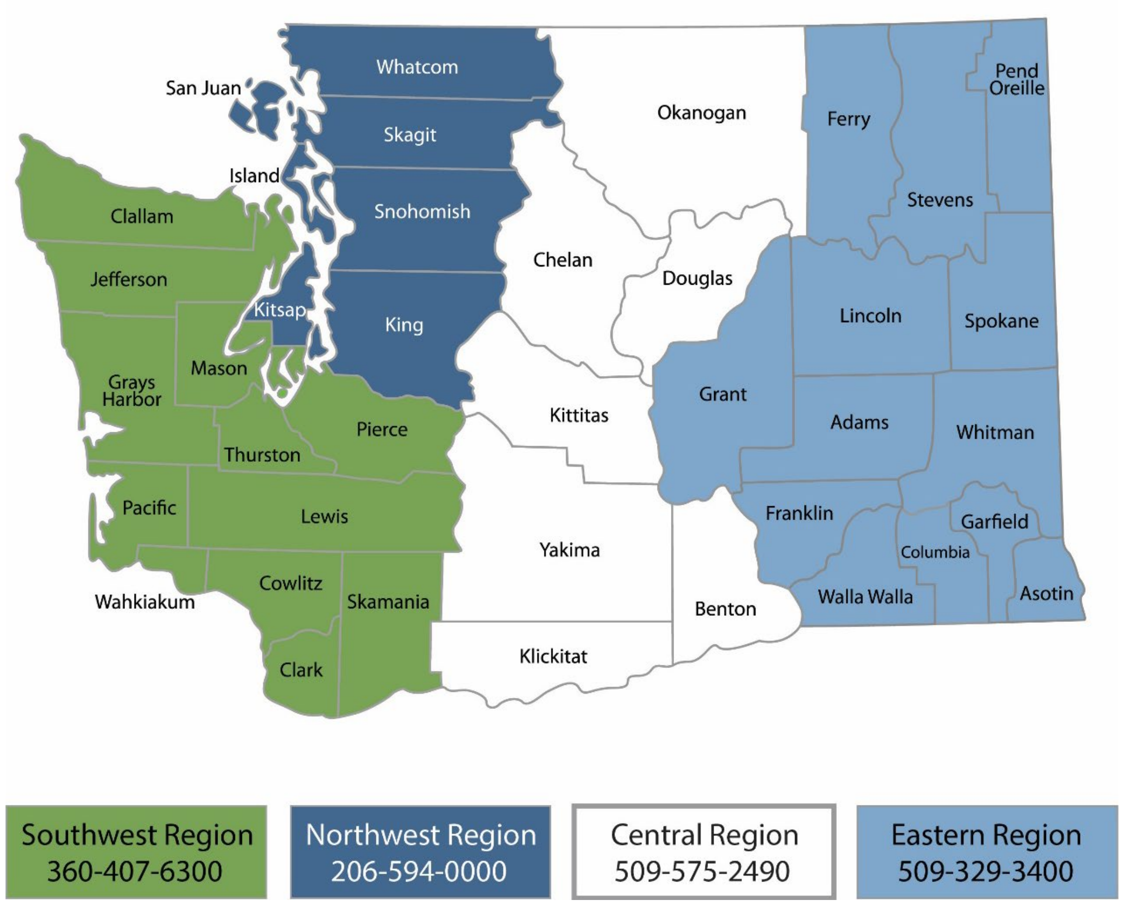
Department of Ecology's Regional Offices

Map of Counties Served



Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	PO Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

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DEPARTMENT OF
ECOLOGY
State of Washington

Table of Contents

List of Figures and Tables

Figures

Tables

Executive Summary

Since 1999, an emergency response towing vessel (ERTV) stationed in Neah Bay has been an important part of the local marine safety system. The ERTV assists vessels that are disabled, have maneuvering problems, or are otherwise in need of assistance. Since its establishment, the Neah Bay ERTV has been called out more than 80 times in response to vessels in distress (Washington State Department of Ecology, 2023). The tug is an important safety net designed to prevent disabled ships and barges from grounding off the outer coast or in the western Strait of Juan de Fuca.

In 2019 the Washington Legislature directed the Department of Ecology (Ecology) to develop an oil spill risk model and use it to conduct an analysis of a potential additional ERTV that would serve Haro Strait, Boundary Pass, Rosario Strait, and connected navigable waterways.

The Spill Prevention, Preparedness, and Response Program at Ecology developed an oil spill risk model and conducted an analysis of seven potential ERTV locations. For each location we evaluated their potential to respond to simulated loss of propulsion incidents for vessel traffic produced by our oil spill risk model. This report summarizes the findings of that analysis.

The objective of our analysis was to quantitatively assess whether an ERTV serving Haro Strait, Boundary Pass, Rosario Strait and connected navigable waterways would reduce oil spill risk from covered vessels. The analysis focused on whether an ERTV can prevent vessels from drifting aground after unexpectedly losing power.

For this study, we simulated vessel traffic patterns based on recent study area traffic data. We also generated loss of propulsion and loss of steering events and evaluated how patterns of drift groundings and subsequent oil spills varied by different potential ERTV locations.

The model includes loss of propulsion frequency and a physics-based drift model that plots the drift paths of vessels that have lost propulsion. The model includes multiple interventions that could prevent a drifting vessel from grounding. Simulated vessels in the model are evaluated for their ability to self-repair and conduct an emergency anchoring following a loss of propulsion. The model also represents tug escorts, the Neah Bay ERTV, and tugs of opportunity.

The analysis study area is bounded on the west by an arc approximately 20 nautical miles past Buoy JA, and to the north with a line from Nanoose Bay to Sechelt. We evaluated seven potential ERTV locations within the study area: Anacortes, Deltaport, Port Angeles, Port Townsend, Roche Harbor, Sidney, and Victoria. Each location could potentially serve the waters of Haro Strait, Boundary Pass, Rosario Strait, and connected waters.

We used three metrics to quantify oil spill risk. The drift grounding metric represents the likelihood of drift groundings. The oil volume at risk metric represents the risk of a maximum potential spill and the oil outflow metric represents the risk of an average potential spill. The metrics are reported as average values per simulation (one year).

Model results indicated an average of 0.3650 drift groundings, an average oil volume at risk of 1,188,025.5 gallons, and an average oil outflow of 104.2 gallons per year. Oil volume at risk and oil outflow should not be understood as spill volume estimates but specific metrics that allow us to compare risk.

When we added potential ERTVs to the simulation, no location produced a large reduction in oil spill risk metrics, but every location provided some benefit. Out of the seven potential locations analyzed, an ERTV in Roche Harbor provided the largest reduction in oil spill risk metrics (around 2-3 percent). An ERTV in Anacortes produced the smallest reduction in oil spill risk.

The ERTV in Roche Harbor resulted in a reduction in drift groundings of 0.0095 per simulation, a reduction in oil volume at risk of 20,858.9 gallons per simulation, and reduction in oil outflow of 2.41 gallons per simulation.

Each potential ERTV location reduced oil spill risk metrics primarily in the zones surrounding their placement. For example, the Roche Harbor ERTV reduced risk in the Eastern Strait of Juan de Fuca, Haro Strait and Boundary Pass, San Juan Islands, Southern Gulf Islands, Strait of Georgia, and Western Strait of Juan de Fuca – but did not reduce risk for Admiralty Inlet, Puget Sound, and Rosario Strait.

Roche Harbor remains the most beneficial ERTV location regardless of different tug escort requirements.[2] When tugs of opportunity were not allowed to intervene we also found that Roche Harbor remained the most beneficial location for an ERTV.

Our analysis also considered whether the additional escort tugs and rescue towing capability associated with the safety measures proposed as part of the Transmountain Expansion Project (TMEP) were complementary to ERTV locations (as in the case of Anacortes and Port Townsend) or redundant (as in the case of Roche Harbor). A reasonable conclusion based on our results is that Roche Harbor would remain most beneficial locations for an ERTV when the TMEP becomes operational.

While our analysis found a small reduction in oil spill risk metrics due to an additional ERTV, these metrics do not represent the full range of possible outcomes from individual drift grounding events. While oil spills from drift groundings are rare events, any drift grounding could result in a large oil spill. Placing an ERTV at one of the seven locations we analyzed would likely offer a small additional level of protection against drift groundings.

[2] See also our report “Summary of Tug Escort Analysis Results,” a report to the legislature pursuant to RCW 88.16.260.

Introduction

Each year, ships traveling on Washington waters carry billions of gallons of oil as cargo and fuel (Spill Prevention, Preparedness, and Response Program, 2022). A catastrophic spill from a ship carrying oil as cargo, or a ship using oil as fuel could cause irreversible damage to endangered Southern Resident Killer Whales and other species, infringe upon tribal treaty rights, damage commercial fishing, and cause severe economic and public health consequences in Washington state. This region's robust marine safety system has evolved over several decades and major oil spills are rare, however the potential for a large spill remains.

Since 1999 an emergency response towing vessel (ERTV) stationed in Neah Bay has been an important part of the local marine safety system. The ERTV assists vessels that are disabled, have maneuvering problems, or are otherwise in need of assistance. Since its establishment, the Neah Bay ERTV has been called out more than 80 times in response to vessels in distress (Washington State Department of Ecology, 2023). The tug plays an important role in preventing disabled ships and barges from grounding off the outer coast or in the western Strait of Juan de Fuca.

Since the establishment of the Neah Bay ERTV, there has been interest in the potential benefit of an ERTV serving the more inland waters of Haro Strait, Boundary Pass and Rosario Strait (see Gray and Hutchison, 2004; Washington State Department of Ecology, 2016; and Van Dorp & Merrick, 2017). In 2019, the Washington Legislature directed the Department of Ecology (Ecology) to develop an oil spill risk model and use that model to conduct an analysis of a potential additional ERTV that would serve Haro Strait, Boundary Pass, Rosario Strait, and connected navigable waterways.

Ecology developed an oil spill risk model and conducted an analysis of seven potential ERTV locations. For each location we evaluated their potential to respond to simulated loss of propulsion incidents for vessel traffic produced by our oil spill risk model. This report summarizes the findings of that analysis.

Legislative direction

In 2019 the Washington state legislature passed Engrossed Substitute House Bill (ESHB) 1578: Reducing Threats to Southern Resident Killer Whales by Improving the Oil Transportation Safety Act. The act amended chapter 88.46 RCW.

RCW 88.46.250(1) states: "The department must develop and maintain a model to quantitatively assess current and potential future risks of oil spills from covered vessels in Washington waters, as it conducts ongoing oil spill risk assessments. The department must consult with the United States coast guard, potentially affected federally recognized Indian treaty fishing tribes, other federally recognized treaty tribes with potentially affected interests, and stakeholders to: Determine model assumptions; develop scenarios to show the likely impacts of changes to model assumptions, including potential changes in vessel traffic, commodities transported, and vessel safety and risk reduction measures; and update the model periodically.

RCW 88.46.250(2) states: “Utilizing the model pursuant to subsection (1) of this section, the department must quantitatively assess whether an emergency response towing vessel serving Haro Strait, Boundary Pass, Rosario Strait, and connected navigable waterways will reduce oil spill risk. The department must report its findings to the legislature by September 1, 2023.”

What is the ERTV analysis?

The objective of our analysis was to quantitatively assess whether an ERTV serving Haro Strait, Boundary Pass, Rosario Strait and connected navigable waterways would reduce oil spill risk from covered vessels.[3] The analysis focused on whether an ERTV can prevent vessels from drifting aground after unexpectedly losing power.

We selected seven potential ERTV locations for evaluation:

- Anacortes, Washington
- Deltaport, British Columbia
- Port Angeles, Washington
- Port Townsend, Washington
- Roche Harbor, Washington
- Sidney, British Columbia
- Victoria, British Columbia

Each location could potentially serve the waters of Haro Strait, Boundary Pass, Rosario Strait, and connected waters. They are shown in Figure 1, along with the location of the existing ERTV in Neah Bay.

Figure 1: Model study area with Neah Bay ERTV and seven potential ERTV locations.

[3] Covered vessels are defined in RCW 88.46.010. "Covered vessel" means a tank vessel, cargo vessel, or passenger vessel. "Tank vessel" means a ship that is constructed or adapted to carry, or that carries, oil in bulk as cargo or cargo residue, and that: (a) Operates on the waters of the state; or (b) Transfers oil in a port or place subject to the jurisdiction of this state. "Cargo vessel" means a self-propelled ship in commerce, other than a tank vessel or a passenger vessel, of three hundred or more gross tons, including but not limited to, commercial fish processing vessels and freighters. "Passenger vessel" means a ship of three hundred or more gross tons with a fuel capacity of at least six thousand gallons carrying passengers for compensation.

An ERTV is not the only way that ships can avoid grounding after losing propulsion. To account for this, the model included the potential for vessels to self-repair or anchor, and the potential for tug escorts and tugs of opportunity to respond to disabled vessels.

The analysis also evaluated a variety of different variables that may affect the utility of different ERTV locations. The variables evaluated include different tug escort requirements, removing the potential for tugs of opportunity to respond to disabled vessels, and the safety measures associated with the projected Trans Mountain Expansion Project (TMEP) (see Trans Mountain, 2013). The report also includes a discussion of how ERTV design characteristics affect oil spill risk.

What is the model?

We used simulation modeling to answer most of the research questions. Simulation models are designed to represent key mechanisms and important processes of a system and can produce informative results even in the absence of extensive underlying data.

For this study, we simulated vessel traffic patterns based on recent study area traffic data. We also generated loss of propulsion and loss of steering events and evaluated how patterns of drift groundings and subsequent oil spills varied by different potential ERTV locations.

The model includes loss of propulsion frequency and a physics-based drift model that plots the drift paths of vessels that have lost propulsion. Self-repair, anchoring, tug escorts, the Neah Bay ERTV, and tugs of opportunity are all included in the model. The model domain is shown in Figure 1.

Model assumptions and parameters are based on research and analysis. For example, we developed a frequency of loss of propulsion, a frequency that tank vessels are laden with oil, a probability of oil outflow per grounding, and others. Details on the methods we used to develop model parameters, and an overview of model structure are located in Appendix B.

Scope of work

The Ecology Spills Program Management Team approved a scope of work for the analysis based on the legislative direction. Elements of the scope of work are described throughout the report, except the research questions which guided analysis and out of scope topics are shown below.

Research questions

How is oil spill risk distributed geographically in the study area and how does an ERTV serving the study area change this risk distribution?

How is oil spill risk distributed across covered vessel types and how does an ERTV serving the study area change this distribution?

How do ERTV stationing locations, tank vessel escort scenarios, and tug of opportunity scenarios change these distributions?

How do key design characteristics of emergency towing vessels affect oil spill risk?

Out of scope topics

Since the legislative direction focused this analysis on the effects on oil spill risks resulting from a potential new ERTV, the following topics were identified as out of scope:

- Consideration of underwater noise
- Consideration of air emissions
- Cost of ERTV provision and funding mechanism
- Cross-border jurisdiction
- Vessel traffic impacts to established treaty fishing areas
- Analysis of the potential fate and effects of oil spill scenarios generated by the model.

Outreach and consultation

From the outset of model development, we prioritized robust outreach and consultation. Our outreach process included learning what potentially affected federally recognized tribes, the U.S. Coast Guard, and what stakeholders wanted to learn from the model. We also asked for their ideas about what should be included in the model, and about concerns they had about model development.

The model development process laid the foundation for the analysis effort. The outreach and consultation that we completed during that time helped determine the structure of the ERTV analysis. We held public events that were open to all interested parties and were designed to be a venue for open dialogue and knowledge sharing.

Between developing the model and the ERTV analysis, we organized more than 25 events attended by more than 200 individual attendees affiliated with over 150 different organizations. At these events, we answered over 300 questions with real time and written responses. A detailed review of our outreach and consultation process is included in Appendix C.

How to use this report

This report is a summary of the analysis. The full details of our analysis, including the underlying model structure, comprehensive results, and supplementary documentation are available in the appendices.

Appendix A includes a comprehensive presentation of results and more details on our methods. Appendix B describes the structure of the model and provides a reference for how we determined model assumptions and parameters. Appendix C describes our outreach and consultation process.

Background

The purpose of an ERTV is to respond to vessels in distress (RCW 88.46.130, 2009). If a vessel suffers a loss of propulsion or steering, an ERTV can control the movement of the disabled ship, thereby avoiding groundings, collisions, and subsequent oil spills.

Drift groundings

Vessels occasionally experience a loss of propulsion. At times, this loss is only partial – a degradation of capability that does not render the vessel completely incapable of propulsion. At other times, the loss is total. The vessel is unable to control its movement and if a shoreline or underwater hazard is present, it may experience a drift grounding.

Drift groundings are a factor in oil spill risk because a grounded ship can release oil cargo or fuel, resulting in environmental damage. Groundings result in spills when the hull and inner tankage is pierced or otherwise opened. The higher the amount of kinetic energy involved, both in the immediate impact, and any subsequent grinding of the vessel on the shoreline, the greater the damage and the higher the potential for a large-scale spill.

The role of emergency towing

The purpose of an ERTV is to provide rescue towing for disabled ships. A successful intervention by an ERTV can prevent a loss of propulsion from turning into a drift grounding.

There are emergency towing operations in place around the world, including in Algeria, Finland, France, Germany, Iceland, the Netherlands, Norway, Poland, South Africa, Spain, Sweden, Turkey, and the United Kingdom (London Offshore Consultants Limited, 2016).

Here in Washington State, we have an ERTV stationed at Neah Bay at the mouth of the Strait of Juan de Fuca that has been operational since 1999. The tug is funded by tank vessels, and cargo and passenger vessels of 300 or more gross tons, that transit to or from Washington ports through the Strait of Juan de Fuca (RCW 88.46.130). The Neah Bay ERTV is intended to be able to support a disabled vessel of 180,000 dead weight tons in severe weather conditions (National Oceanic and Atmospheric Administration, 2022), and conforms to several performance standards (RCW 88.46.435). Since 1999, the Neah Bay ERTV has been called out more than 80 times and has provided towing services more than 20 times (Washington State Department of Ecology, 2023).

There are also two emergency towing vessels leased by the Canadian Coast Guard that are currently serving the Pacific waters off the coast of British Columbia. One vessel patrols a northern area in Canadian waters between Alaska and the northern tip of Vancouver Island, and the other a southern area including the west side of Vancouver Island and the Strait of Juan de Fuca (Bartlett, 2018).

The role of tugs of opportunity

A tug of opportunity is a tug that may respond and assist a vessel that has lost propulsion or is otherwise in distress. It refers to a tug that is not specifically an emergency response vessel, but is otherwise employed in commercial activity, for example as an escort vessel, or harbor assist vessel.

Tugs of opportunity can provide ad hoc response to vessel emergencies. They can be called upon to assist a disabled or otherwise stricken vessel if no dedicated resources are available or nearby. While they may not be specifically designed or equipped for the work of an ERTV, and they are not always available, their presence in an area can help prevent drift groundings.

Most tugs transiting the coastal waters of Washington are engaged in towing, which makes them less available for responding to another vessel (Allan & Phillips, 2013). However, in the inland waters of the Salish Sea, potentially more tugs of opportunity are available (Clear Seas, 2019), such as escort and assist tugs sailing to and from assignments, and tugs operating in ports.

Several tug of opportunity analyses have looked at the number of potentially available tugs that are capable, in terms of bollard pull, of responding to the largest vessels during the worst weather. The naval architecture firm Robert Allan, Ltd reviewed Canadian towing vessels in the Pacific region to assess their capability and found that out of 1,200 tugs, only 32 had the size, horsepower, and bollard pull necessary to be considered candidates for rescue duties (Allan & Phillips, 2013).

Ecology's 2018 review of vessel traffic safety concluded that tugs of opportunity should be considered a contingency strategy, rather than a primary oil spill prevention tool. There are significant uncertainties associated with the availability of a capable tug in the right location, the ability of the towing company to change the tasking of the tug to participate in a rescue attempt, the level of training and proficiency of the crew, and the presence of emergency towing equipment (Spill Prevention, Preparedness and Response Program, 2019).

Other quantitative analyses of ERTVs

Between 2005 and 2017, researchers at George Washington University, Virginia Commonwealth University, and Rensselaer Polytechnic Institute completed a number of simulation-based risk assessments connected to vessel traffic in the Salish Sea (van Dorp et al., 2008; van Dorp and Merrick, 2014; van Dorp and Merrick, 2017).

To approximate an ERTV, one of these risk assessments modeled an escort for all deep draft vessels in Haro Strait and Boundary Pass and found a maximum potential reduction in accidents of 7 percent and a maximum potential reduction in oil loss of 24 percent (van Dorp, 2014, p. 128). Another modeled an ERTV in Sidney and found a potential 2 percent reduction in oil loss (van Dorp and Merrick, 2017, p. 191).

In separate analysis, San Juan County contracted with Nuka Research and Planning Group, LLC to evaluate potential ERTV locations that could serve the waters of Haro Strait and Boundary Pass. Their analysis found that an ERTV located in Roche Harbor or Sidney would be best suited to serving those waterways (San Juan County, 2021).

How to Understand the Results

The results in this report are derived from three different sources:

1. To discuss the relative importance of drift groundings as a contributor to oil spill risk, we reviewed actual vessel incidents.
2. To analyze potential ERTV locations, we used model simulation outputs.
3. For our discussion of ERTV design characteristics, we used a review of technical literature.

Understanding model simulation outputs

This analysis is based on evaluating different ERTV locations. We used a variety of risk metrics to quantify changes in risk for each of those locations. Each metric tells us something different about oil spill risk.

ERTV locations

The effect of the new locations on the oil spill risk profile was determined by calculating the relative changes in oil spill metrics among vessel types and geographic zones with only the Neah Bay ERTV included, and comparing those results with those that included the Neah Bay tug and each of the new locations. This produced seven sets of relative changes, one for each new location.

For each simulation, we first calculated the totals for each oil spill risk metric and the difference in the totals for each oil spill risk metric for each location. Then, we calculated the averages across all simulations for each of those values. Finally, the percent change with new locations was calculated by dividing the average difference between each location by the average total for each location.

The changes in drift grounding rates were calculated by taking the average per simulation of the difference between the drift grounding rate for each location and the drift grounding rate without an additional ERTV. These were calculated for each vessel type, for each geographic zone, and for each scenario.

ERTV location comparison

To assess the effectiveness of each new location, we calculated the relative changes in oil spill metrics for results that included only the Neah Bay tug, and results that also included each of the new locations, for each tug escort scenario. These calculations were done for each vessel type, for each geographic zone, and for each tug escort scenario.

Tug escort scenarios

Our primary evaluation of ERTV locations was completed using a simulation designed to represent current tug escort requirements for study area waters. Current requirements are characterized as Scenario 2 (see below). We also evaluated the potential benefit of each ERTV location under two different tug escort scenarios – Scenario 1 and Scenario 3, below.

Tank vessels in Scenario 1 were simulated using the tug escort requirements in place prior to 2020. Under these requirements, tug escorts are required for laden tank ships over 40,000 deadweight tons (DWT). In Scenario 1, escorts were not simulated for articulated tug and barges (ATBs), tank barges, and tank ships between 5,000 and 40,000 DWT.

Tank vessels in Scenario 2 were simulated using the tug escort requirements established in 2020 (see RCW 88.16.190, 2019). Under these requirements, in addition to the tug escort requirements in place in Scenario 1, tug escorts were required for laden ATBs, tank barges, and tank ships between 5,000 and 40,000 DWT in Rosario Strait and connected waters east.

Tank vessels in Scenario 3 were simulated using a theoretical expansion of tug escort requirements in Washington waters inside a line from New Dungeness Light to Discovery Island Light. In addition to the tug escort requirements in place in Scenario 2, laden ATBs, tank barges, and tank ships between 5,000 and 40,000 DWT were required to take an escort in all other areas inside the referenced line where not previously required.

How we defined risk

In the scope of work for this analysis, we defined risk as the combination of the likelihood of an event and the consequence if the event were to occur. We report one metric that represents likelihood (drift grounding likelihood) and two that represent consequence (oil volume at risk and oil outflow). An additional risk metric representing likelihood (drift grounding rate) is presented in Appendix A.

Drift grounding metric

The drift grounding metric is designed to represent the likelihood of drift groundings, i.e., how likely a grounding is to occur. It is weighted by incident frequency and the overall number of drift groundings identified in model outputs. The purpose of this metric is to compare the potential likelihood of drift groundings, without regard to potential consequence or severity.

Oil volume at risk metric

Oil volume at risk is designed to represent risk of a maximum potential spill. It is based on the fuel and oil cargo capacity of an involved vessel. It is calculated by multiplying the maximum possible volume of oil (in gallons) aboard a simulated vessel, against the incident likelihood. The maximum possible volume is the sum of the fuel capacity and the oil cargo capacity (if laden) of a given simulated vessel. As a result, this is a weighted value and does not reflect exact volumes from any specific incident or collection of incidents. The purpose of this metric is to compare the maximum severity of drift groundings using reliable estimates like fuel and oil cargo capacities.

Oil outflow metric

The oil outflow metric is designed to represent risk of an average potential spill. It doesn't produce specific outflows for individual events. It is based on the historical averages of spill size, and the historical probability of spills per incident, per vessel type. It is calculated by multiplying three values: the average historical spill volume for a vessel type (in gallons), the spill probability per incident, and the incident likelihood. As a result, this is a weighted value and does not reflect exact volumes from any specific incident or collection of incidents. The purpose of this metric is to use historical oil spill volumes to compare average severity of drift groundings.

Presentation of outputs

We used the model to run one thousand simulations. Each simulation produced an equivalent of a year's worth of unique vessel traffic. The results we present are averages per simulation.

We primarily evaluated risk using percentage values, but we also include absolute values where appropriate. Absolute values provide an order of magnitude representation of potential risk in the study area.

To evaluate overall risk in the system we used the relative frequency by zones or by vessel type. Relative frequency is found by converting absolute values into fractions of the whole. These values are presented as percentages.

To compare differences between scenarios we used relative change percentages. Relative change allowed us to evaluate difference between scenarios even when the magnitude of the changes was small.

When communicating percentages, we sometimes use a range from the lowest risk metric value to the highest. For example, when we write that towed oil barges represent 3-10 percent of the oil spill risk in the study area, the range is based off highest and lowest values found among the oil volume at risk, oil outflow and drift grounding metrics. In this case, towed oil barges represented 2.86 percent of the oil volume of risk in the study area, 4.5 percent of the oil outflow, and 9.69 percent of the drift grounding risk. We summarize those values as "towed oil barges represent 3-10 percent of the oil spill risk in the study area."

Study area and geographic zones

The study area is bounded on the west by an arc approximately 20 nautical miles past Buoy JA, and to the north with a line from Nanoose Bay to Sechelt. Interior waterways within the ports of Seattle and Vancouver, such as the Fraser River, portions of the Duwamish River, and Lake Washington, are not included in the study area. The maritime traffic patterns in these areas are either not directly relevant to the scope of our analysis or too complex to simulate effectively as part of this project.

The study area also does not include upper Howe Sound due to a lack of consistent vessel traffic data for that area.

Geographic zones

We evaluated results using geographic zones to provide spatial context for oil spill risk in the study area. The geographic zones consisted of:

- Admiralty Inlet

- Bellingham Channel, Sinclair Island, and waters to the East
- Carr Inlet
- Case Inlet to Oakland Bay
- Colvos Passage
- Dyes Inlet
- Eastern Strait of Juan de Fuca
- Eld Inlet
- Guemes Channel and Saddlebags
- Haro Strait and Boundary Pass
- Hood Canal
- Howe Sound
- Lake Washington Ship Canal
- Nanaimo
- Northern Gulf Islands
- Port Orchard
- Port Susan
- Possession Sound and Saratoga Passage
- Puget Sound
- Rich Passage and Sinclair Inlet
- Rosario Strait
- San Juan Islands
- Skagit Bay
- South Sound to Olympia
- Southern Gulf Islands
- Strait of Georgia
- Strait of Georgia – Below 49th
- Strait of Georgia – North
- Strait of Georgia – South
- Vancouver
- Western Strait of Juan de Fuca

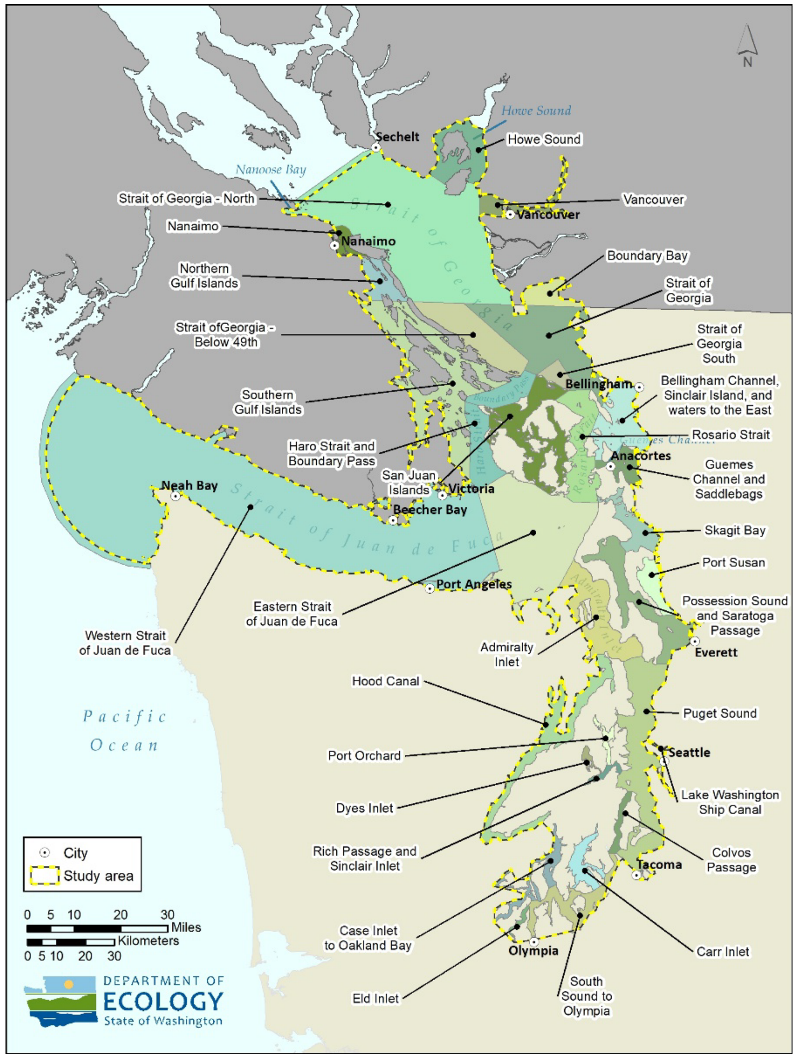

Figure 2: Model zones.

Results

How drift groundings contribute to oil spill risk

Incident data analysis suggests that drift groundings are rare events in the Model Domain (Figure 3) and the Bi-National Area.[4] Drift groundings are a relatively small contributor to the overall number of marine incidents and oil spills. In the Model Domain, we identified 4 drift groundings between 2002 and 2019 (an average of 0.2105 drift groundings per year). None of these resulted in an oil spill. They account for about 2 percent of selected marine incidents involving large commercial vessels.

Figure 3: Model Domain.

When we expanded our review to the much larger Bi-National Area we found 190 drift groundings (an average of 10.5556 per year), of which only 2.6 percent were associated with oil spills.

Our review of historical incidents found that drift groundings are infrequent and do not usually cause large spills. However, we know that even though it may be uncommon, individual drift grounding events can produce large spills. In Washington, there have been at least two large spills resulting from a vessel drifting aground on the outer coast.[5]

[4] The Bi-National Area covers the continental waters of the U.S. and Canada up to 20 miles offshore and continuing inland as far as deep draft traffic regularly calls. The area extends to the north to include Cook Inlet on the west coast, and the northern extent of the Gulf of St. Lawrence on the east coast. See Appendix A, Figure 3 for a map of the area.

[5] Drift groundings associated with large oil spills include the 1964 drift grounding near Moclips, Washington of a towed oil barge after it broke free from its tug and the 1972 drift grounding of a navy ship just south of Cape Flattery. The navy ship broke free while under tow and drifted ashore. Neither event was the result of loss of

For the events we identified in incident databases from 2002-2019, we found spills associated with collisions, allisions, non-drift groundings, and drift groundings that ranged from 1 to 420,000 gallons.

How oil spill risk was distributed based on model outputs

The following sections summarize a selection of model results that do not include oil spill risk from car ferries. Car ferry traffic is so abundant in the study area that it obscures patterns for the vessels and zones we are interested in. Appendix A includes comprehensive model results that include oil spill risk from car ferries.

Model results indicated an average of 0.3650 drift groundings per simulation, an average oil volume at risk of 1,188,025.5 gallons per simulation, and an average oil outflow of 104.2 gallons per simulation.[6] Figure 4 and Figure 5 show how oil spill risk metrics were distributed by vessel type and zones, respectively.

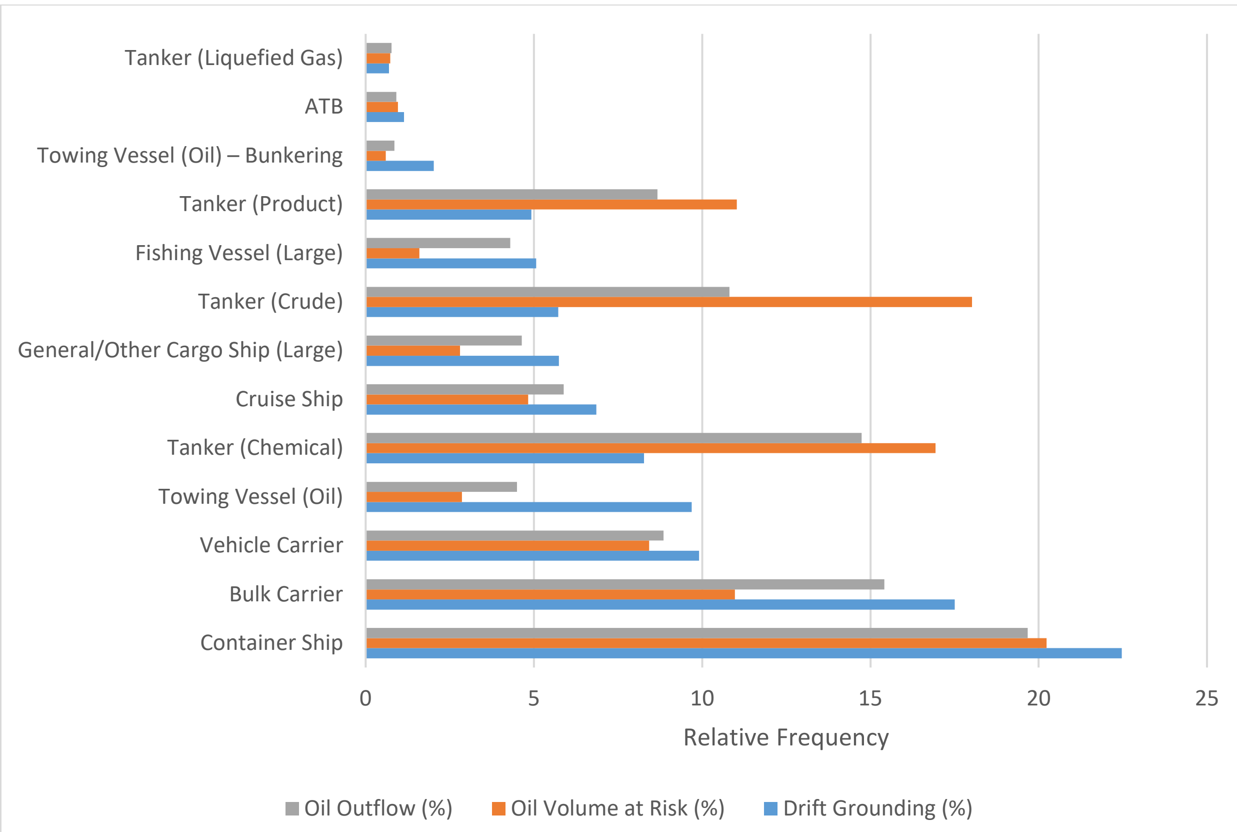

Figure 4: Relative frequency of oil spill risk metrics by vessel type.[7]

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propulsion or loss of steering, and neither event is included in our analysis, as they occurred outside the time period that we used (2002-2019).

[6] These values are from Appendix A, Table 11.

[7] These values are from Appendix A, Table 14.

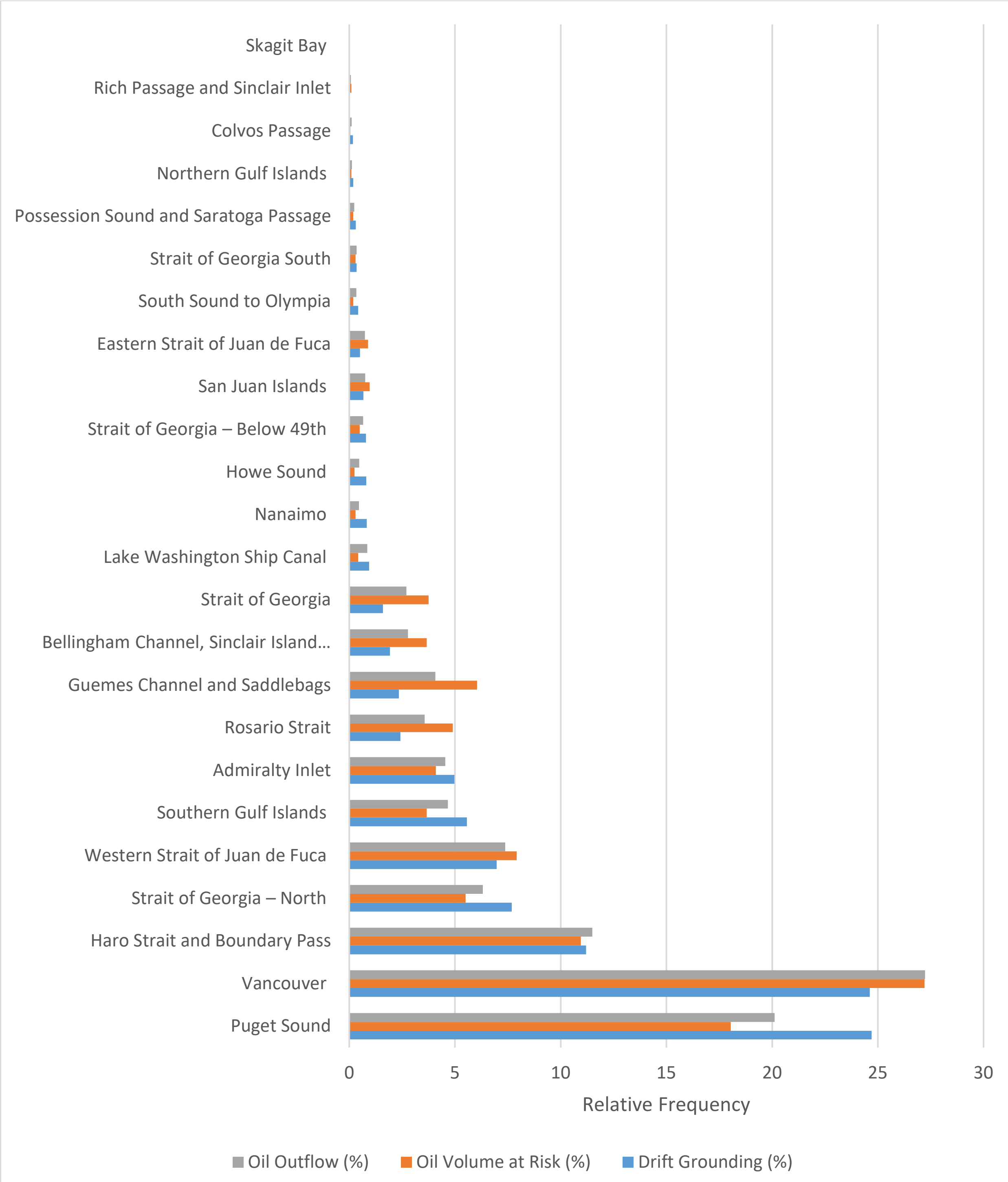

Figure 5: Relative frequency of oil spill risk metrics by zone.[8]

[8] These values are from Appendix A, Table 10. The following zones have zero or close to zero risk metric values and are not included in the figure: Boundary Bay, Carr Inlet, Case Inlet to Oakland Bay, Dyes Inlet, Eld Inlet, Hood Canal, Port Orchard, and Port Susan.

Discussion

We compared the distribution of risk by vessel type and zone against the operational minutes to help us determine which ones represent more risk than would be expected from looking at the time they spent underway.[9]

Some vessel types account for less risk than one would expect given their share of overall operational minutes. For example, ATBs make up 7 percent of the simulated traffic and account for only 1 percent of the oil spill risk. Similarly, bulk carriers account for 28 percent of the simulated traffic, but only 11-18 percent[10] of the risk. Of note, towed oil barges make up 21 percent of the traffic and 3-10 percent of the oil spill risk.

However, other vessels account for more risk than expected given their share of overall operational minutes. Vehicle carriers make up 5 percent of the total simulated traffic but account for 8-10 percent of the oil spill risk.

Just over half of the zones see a relative frequency of oil spill risk that approximates their relative frequency of operational minutes. Three zones account for less risk than might be expected based on their operational minutes. Eastern Strait of Juan de Fuca makes up 12 percent of the simulated traffic but only 2 percent of the oil spill risk. Admiralty Inlet and Strait of Georgia are the other two zones that see less risk that would be suggested by their traffic levels. Three zones account for more risk than their operational minutes would suggest. Haro Strait and Boundary Pass makes up 17 percent of the simulated traffic, but accounts for 22-23 percent of the risk. Guemes Channel and Saddlebags makes up 2 percent of the simulated traffic, but accounts for 5-9 percent of the risk, while Bellingham Channel, Sinclair Island, and Waters to the East makes up 2 percent of the simulated traffic, but accounts for 3-5 percent of the risk.

How oil spill risk changed with the addition of an ERTV

No potential ERTV location produced a large reduction in oil spill risk metrics, but every location provided some benefit. Out of the seven potential locations analyzed, the placement of an ERTV in Roche Harbor provided the largest reduction in oil spill risk metrics (around 2 percent). An ERTV in Anacortes produced the smallest reduction in oil spill risk. See Figure 6.

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[9] Tables showing the distribution of simulated operational minutes by zone and by vessel type are Appendix A Table 6 and Table 7 respectively.

[10] Risk values shown as ranges are based off highest and lowest values between drift grounding metric, oil volume at risk, and oil outflow.

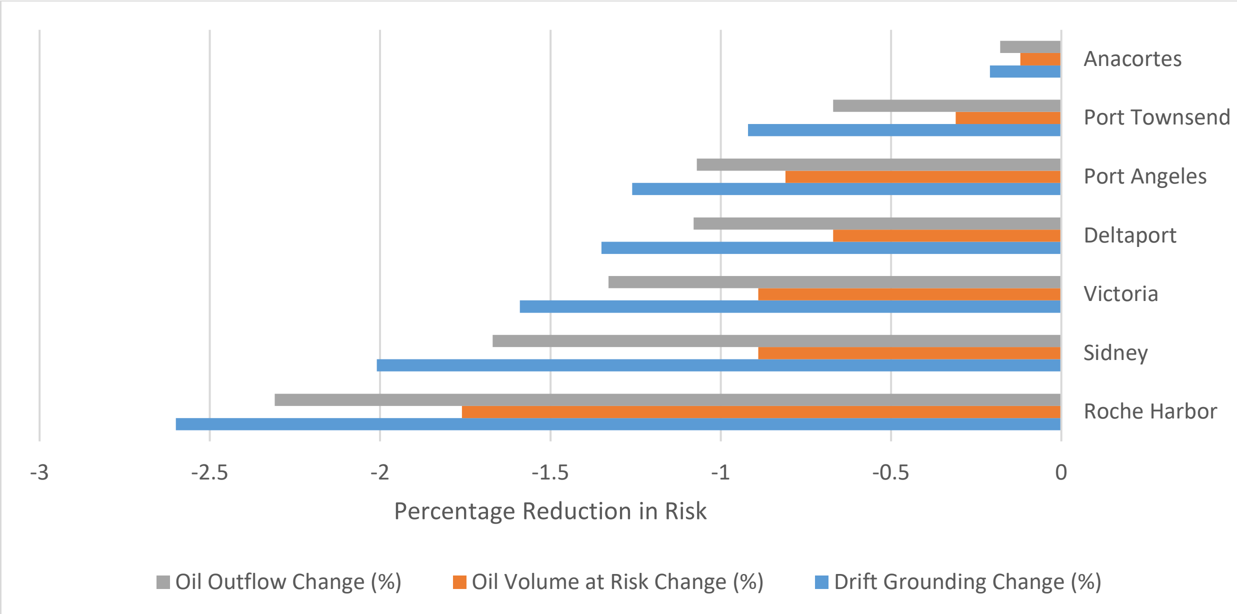

Figure 6: Comparison of ERTV Locations.[11]

In terms of absolute values, an ERTV in Roche Harbor resulted in a reduction in drift groundings of 0.0095 per simulation, a reduction in oil volume at risk of 20,858.9 gallons, and reduction in oil outflow of 2.41 gallons.[12] That represents a 0.0095 reduction in drift groundings per simulation from a total of 0.3650 drift groundings. That amounts to preventing about 1 in 38 drift groundings across the whole study area. See tables 15-28 in Appendix A for absolute values for each location.

Each potential ERTV location reduced oil spill risk metrics primarily in the zones surrounding their placement. For example, the Roche Harbor ERTV reduced risk in the Eastern Strait of Juan de Fuca, Haro Strait and Boundary Pass, San Juan Islands, Southern Gulf Islands, Strait of Georgia (North, Sound, and Below 49th), and Western Strait of Juan de Fuca – but did not reduce risk for Admiralty Inlet, Puget Sound, and Rosario Strait. Table 1 shows summarized results by zone. Zones that saw no detectable changes in oil spill risk metrics are shown in white, zones with detectable changes are shown in grey, and zones with above average detectible changes are shown in black.[13]

[11] These values are from Appendix A, Table 32.
[12] These values are from Appendix A, Table 24.
[13] Table does not include Deltaport ERTV, or zones where there were no changes in oil spill risk metrics: Boundary Bay, Carr Inlet, Case Inlet to Oakland Bay, Colvos Passage, Dyes Inlet, Eld Inlet, Guemes Channel and Saddlebags, Gulf Islands, Hood Canal, Howe Sound, Lake Washington Ship Canal, Nanaimo, Northern Gulf Islands, Port Orchard, Port Susan, Possession Sound and Saratoga Passage, Rich Passage and Sinclair Inlet, Skagit Bay, and South Sound to Olympia. The whole table can be found in Appendix A, Table 59.

Table 1: Changes in all oil spill risk metrics by geographic zone and ERTV location. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.[14]

	Anacortes	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet						
Eastern Strait of Juan de Fuca						
Haro Strait and Boundary Pass						
Puget Sound						
Rosario Strait						
San Juan Islands	Below Average		Below Average		Below Average	Below Average
Southern Gulf Islands						
Strait of Georgia						
Strait of Georgia – Below 49th						
Strait of Georgia – North						
Strait of Georgia South						
Western Strait of Juan de Fuca	Below Average			Below Average	Below Average	

In terms of risk reduction by vessel type, Table 2 shows how different ERTV locations produced reductions in oil spill risk metrics by specific vessel types.

Only one location, Port Townsend, produced a reduction for ATBs. Only three locations, Deltaport, Port Angeles and Victoria, produced a reduction for product tankers. For many vessel types there was at least some reduction in oil spill risk regardless of ERTV location, specifically bulk carriers, cruise ships, LG tankers, towed oil barges, vessels providing bunkering services, and vehicle carriers.

[14] Table excerpted from Appendix A, Table 59.

Table 2: Changes in all oil spill risk metrics by geographic zone and ERTV location. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.[15]

	Anacortes	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
ATB						
Bulk Carrier						
Container Ship						
Cruise Ship						
Fishing Vessel (Large)						
General/Other Cargo Ship						
Tanker (Chemical)						
Tanker (Crude)						
Tanker (Liquefied Gas)						
Tanker (Product)						
Towing Vessel (Oil)						
Towing Vessel (Oil) – Bunkering						
Vehicle Carrier						

For the Roche Harbor location (the location that produces the largest reduction in risk) the percentage reduction in risk varies by vessel type. Vessels moving oil as cargo (ATBs, product tankers, crude tankers, towed oil barges, and vessels engaged in bunkering) see mostly small percentage reductions in oil spill risk metrics (less than 1 percent). The exception is chemical tankers, which see a reduction closer to 2.5-3 percent. Vehicle carriers and bulk carriers see the largest percentage decreases in risk. See Figure 7.

[15] Table excerpted from Appendix A, Table 54.

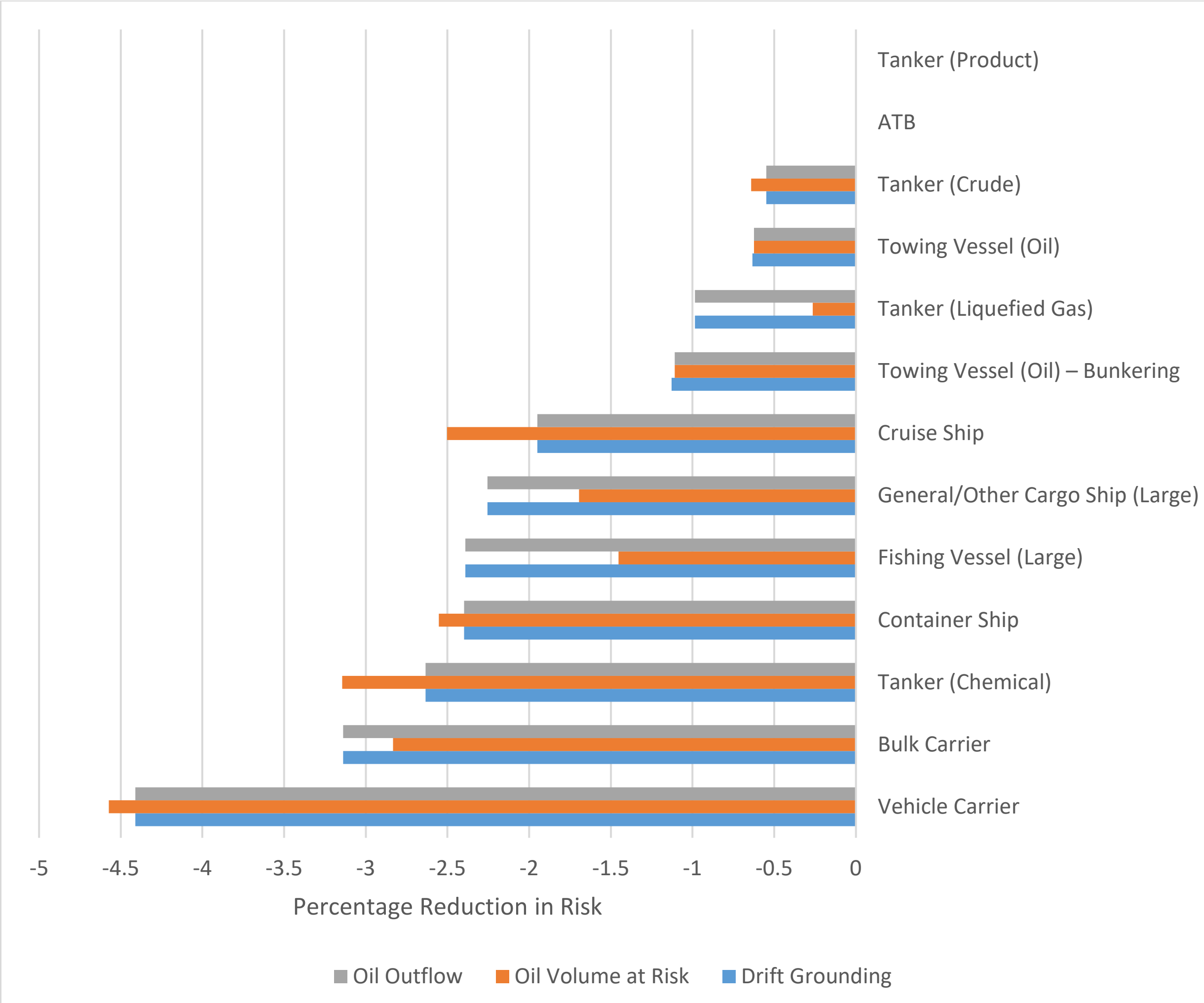

Figure 7: Roche Harbor ERTV percentage reductions in oil spill risk metrics by vessel type.[16]

How different tug escort requirements affect the utility of different ERTV locations

We evaluated each ERTV location against three different tug escort scenarios to determine how changes in the scenario affected the utility of each ERTV location.

Figures 8, 9, and 10 show oil spill risk metrics reductions for each ERTV location, for each tug escort scenario. Roche Harbor remained the most beneficial ERTV location regardless of tug escort scenario.

[16] These values are from Appendix A, Tables 50, 51, and 52.

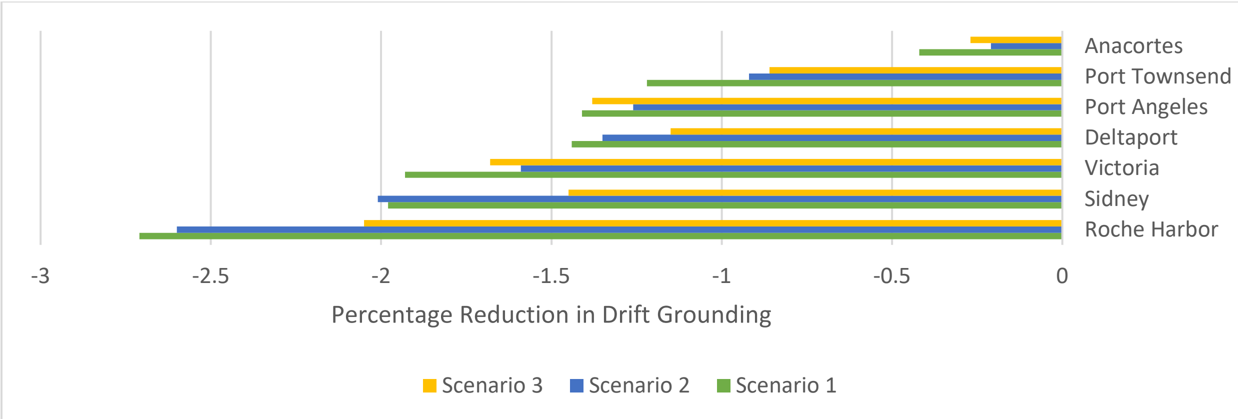

Figure 8: Change in drift groundings for ERTV locations by tug escort scenario.[17]

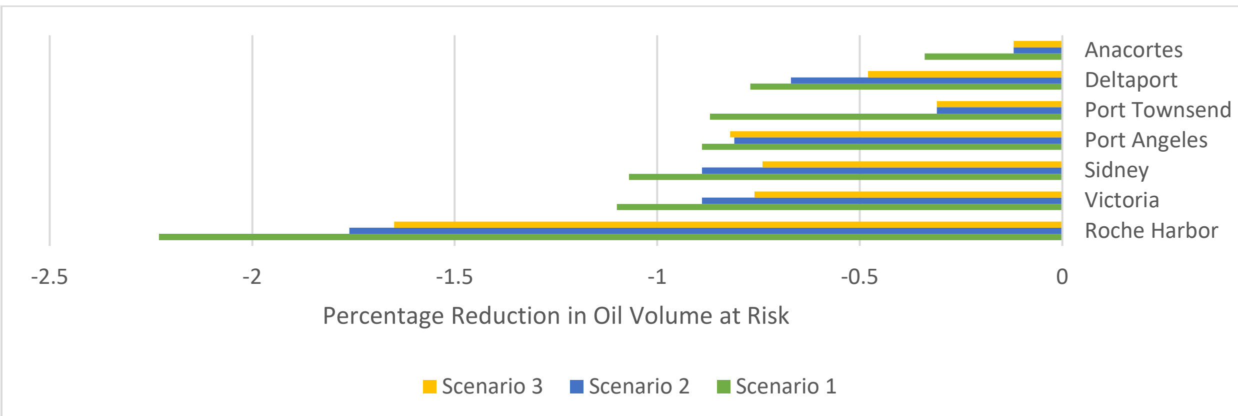

Figure 9: Change in oil volume at risk for ERTV locations by tug escort scenario.[18]

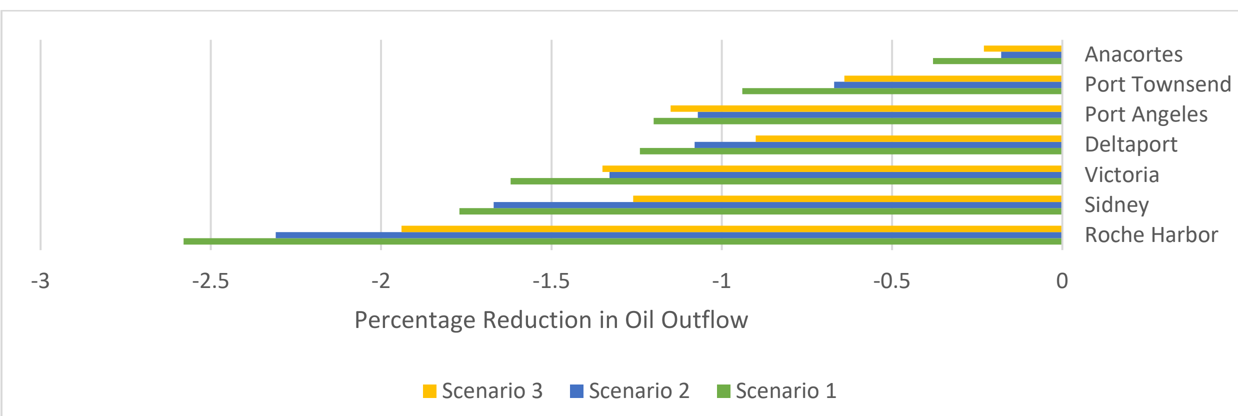

Figure 10: Change in oil outflow for ERTV locations by tug escort scenario.[19]

[17] These values are from Appendix A, Tables 30, 32, and 34.
[18] These values are from Appendix A, Tables 30, 32, and 34.
[19] These values are from Appendix A, Tables 30, 32, and 34.

How the exclusion of tugs of opportunity affects the utility of different ERTV locations

When tugs of opportunity were not allowed to intervene, we found that Roche Harbor remained the most beneficial location for an ERTV.

The removal of tugs of opportunity resulted in an increase in oil spill risk metrics of 9 – 18 percent. The smallest increases in risk were recorded for an ERTV at Roche Harbor. Since Roche Harbor was originally identified as the location that produced the largest risk reduction, it is reasonable to conclude that Roche Harbor is still the most beneficial location for an ERTV even when tugs of opportunity are not included as a potential source of rescue.

How escort traffic from the Trans Mountain Expansion Project (TMEP) affects the utility of different ERTV locations

The TMEP is an expansion of Trans Mountain's pipeline between Alberta and Burnaby, British Columbia. When operational it will substantially increase tank vessel traffic and associated escorts in the study area. The TMEP plan also includes the placement of a vessel that can provide rescue towing in Beecher Bay, B.C. Beecher Bay is located on the southern tip of Vancouver Island, across the Strait of Juan de Fuca from Port Angeles, Washington.

The TMEP proposal estimates that after the approval of the pipeline expansion, there will be an increase of 348 round-trip transits per year to and from the Westridge Terminal in Burnaby, B.C. This would put the total number of round-trip tank ship transits at 408 per year (Trans Mountain, 2013, p. 14). We did not simulate loss of propulsion events for additional TMEP tanker transits, nor did we assess any potential risk that might be produced by those vessels.

Our analysis simulated escort transits to match the TMEP escort plan (Trans Mountain, 2021). This meant that escorts were simulated for laden TMEP tankers all the way to the J Buoy. The escort tugs were dispatched from and returned to Beecher Bay at the end of their escort jobs. We also simulated the planned oil spill response vessel at Beecher Bay as an ERTV with the same call out characteristics that we used for other simulated ERTVs.

Our analysis found that the additional escorts, and the additional rescue towing potential was either complementary to potential ERTV locations (as in the case of Anacortes and Port Townsend) or redundant (as in the case of Roche Harbor). The decreases for Roche Harbor were close to those for Anacortes and Port Townsend. Table A-107 in Appendix A shows the values that support this conclusion.

Considering the previous result that Roche Harbor ERTV location resulted in the largest reductions in all oil spill risk metrics, it is reasonable to conclude that Roche Harbor is still the most beneficial location for ERTVs even considering the additional safety measures associated with the TMEP.

How key design characteristics of ERTVs affect oil spill risk

ERTVs reduce oil spill risk by reducing the chance that a disabling of an underway vessel will result in a grounding. The success of an emergency tow operation depends on several factors:

- the size and configuration of the disabled vessel
- the size and configuration of the rescue vessel
- the equipment available on each vessel
- the knowledge, expertise, and experience of the crew of each vessel
- the environmental conditions at the time of the disabling

The stages of an ERTV response

A 2021 report produced for the Prince William Sound Citizen's Advisory Committee (PWSCAC) established five stages of an ERTV response (Glosten, 2021). Reduced to three here for simplicity, they provide a helpful framework for evaluating the design characteristics of ERTVs that most affect oil spill risk.[20]

Stage 1: transit to the affected vessel

At this stage in the ERTV response, the most important factor is the speed of the responding vessel and its ability to maintain that speed in poor weather. Higher vessel speed can be achieved through various tradeoffs, some of which may compromise other desirable ERTV characteristics. Bollard pull efficiency, maneuverability, and seakeeping are characteristics that may necessitate making compromises on speed.

Stage 2: close-range maneuvering & establishing towing connection

Once the ERTV has reached the disabled vessel, it must maneuver to make a connection. The connection is usually made with a messenger line. To send over the messenger line, the ERTV must be quite close to the disabled vessel. That proximity, particularly in poor weather, can put the ERTV at risk of colliding with the disabled vessel. Maneuvering characteristics of the ERTV are very important during this stage, particularly given the risk to crew exposed on deck during line handling operations.

The required availability and power of directional thrust can be produced by a variety of propulsion systems. Systems that produce omnidirectional thrust, like tractor and rotor tug configurations would be appropriate. The PWSCAC report also describes an example metric for establishing suitable maneuverability the tug should have "the ability to execute a zero speed, 360 degree turn within no more than 150 percent of the vessel's own length, and within no more than 60 seconds" (Glosten, 2021, p. 31).

[20] The five stages described in the report are Stage 1: Transit to the affected vessel; Stage 2: Intercepting and surveying the affected; Stage 3: Close-range maneuvering and establishing towing connection; Stage 4: Towing the affected vessel, and Stage 5: Cessation/handoff of the towing operation.

Stage 3: towing the affected vessel

The PWSCAC report describes the overriding goal of this phase as "maintaining the integrity of the towing connection." While it may be tempting to assume that a large and powerful enough ERTV could tow any vessel, there are additional limiting factors. Even a tug with enough power to overcome the mass of the ship and the forces acting against that mass, is limited by the relative motion between the two vessels. The high loads produced by the relative motion of the vessels make failure of the towing connection quite possible.

Relative motion is managed during tow operations by managing tow line/wire length to lessen strain, and use of a longer and heavier tow wire/line that produces catenary that can reduce surge (National Academy of Sciences, 1994).

While tug power may not be the limiting factor during towing operations, it remains very important. Bollard pull, a measurement of pulling power, needs to be sufficient for the towing forces required. Many different types of propulsion systems can produce the levels of bollard pull required. Tug designs with propulsion systems close to amidships may be preferrable in areas where extremely poor weather could be encountered, as this keeps the propulsion system in the water when the tug is pitching and rolling.

Successful rescue towing also relies heavily on the towing winch. Tow winches used in escorting and assist are not the same as those used for towing astern in an offshore environment. Escort and assist winches are designed for use with synthetic line, while the winches for astern towing suitable for the towing a drifting vessel are compatible with wire ropes. Depending on the expected operational conditions the tug will need a suitable winch sufficient for towing astern.

While dynamic control of winches is essential in escort operations, this can be less crucial when towing astern, as the catenary of the wire provides some shock absorption. The vessel can also slip and/or recover wire as needed since the specific distance between tug and tow is less crucial in open water towing conditions.

Considerations for an ERTV serving Haro Strait, Boundary Pass, Rosario Strait, and connected waters.

Much of the complexity in rescue towing is due to the challenges posed by towing large vessels in extreme weather. Given that the area of operation for an ERTV serving Haro Strait, Boundary Pass, Rosario Strait, and connected waters is less prone to offshore weather extremes, it follows that such an ERTV could have different design priorities.

For instance, it is reasonable to assume that the design characteristics for an ERTV serving more protected inland waters of the Salish Sea might prioritize vessel speed and maneuverability, since there is less space and time available compared to an open ocean rescue. With relatively less focus on seakeeping capability, a faster and more maneuverable ERTV may be able to reduce the time between getting underway and reaching and stabilizing the disabled vessel.

The suitability of a tug for performing the duties of an ERTV is a complex question. Appropriate tug design is essential to safe and effective operation and ability to reduce oil spill risk.

Conclusion

Drift groundings are rare events. Based on our review of historical incidents in the modeled area, we identified 4 drift groundings between 2002 and 2019 (an average of 0.2105 drift groundings per year). None of these resulted in an oil spill. When we expanded our review to the coastal waters of the U.S. and Canada we found 190 drift groundings (an average of 10.5556 per year), of which only 2.6 percent were associated with oil spills.

Though spills associated with drift groundings may be uncommon, they have the potential to be substantial. For the incidents we reviewed (including collisions, allisions, non-drift groundings, and drift groundings), we found spills ranging in size from 1 to 420,000 gallons.

Although drift groundings are not a frequent occurrence and their potential for large scale spills is relatively small, they remain a potential risk for the study area. ERTVs are a well-tested measure for protecting against groundings and other hazards that might occur after loss of propulsion.

Our results show that an ERTV serving Haro Strait, Boundary Pass, Rosario Strait and connected waters would likely reduce oil spill risk beyond safety measures already in place like the ability of the ship to self-repair, the potential for emergency anchoring, and potential rescue by an escort or a tug of opportunity.

With current safety measures in place, model results indicated an average of 0.3650 drift groundings per simulation, an average oil volume at risk of 1,188,025.5 gallons per simulation, and an average oil outflow of 104.2 gallons per simulation.

When we added potential ERTVs to the simulation, no location produced a large reduction in oil spill risk metrics, but every location provided some benefit. Out of the seven potential locations analyzed, the placement of an ERTV in Roche Harbor provided the largest reduction in oil spill risk metrics (around 2 percent). An ERTV in Anacortes produced the smallest reduction in oil spill risk.

We also looked at whether potential changes to the mix of escort tugs in the system would change which ERTV location provided the biggest risk reduction. We found that for different tug escort scenarios results stayed the same – the Roche Harbor location remained the best suited for reducing oil spill risk from drift groundings. When we looked at the additional escorts that may enter the system in conjunction with the Transmountain Expansion Project, as well as the additional potential rescue towing resources that Transmountain plans to place in Beecher Bay, the results stayed the same. The Roche Harbor location was still the best location for an ERTV.

On average, our analysis found small potential reductions in drift grounding from an ERTV that might serve Haro Strait, Boundary Pass, and connected waters. For an ERTV in Roche Harbor, we found a 0.0095 reduction in drift groundings per simulation (from 0.3650 drift groundings). That amounts to preventing about 1 in 38 drift groundings across the whole study area.

While our analysis found a small reduction in oil spill risk metrics due to an additional ERTV, these metrics do not represent the full range of possible outcomes from individual drift grounding events. In other words, any drift grounding could result in a large oil spill. Placing an ERTV at one of the seven locations we analyzed would likely offer a small additional level of protection against drift groundings.

Glossary, Acronyms, and Abbreviations

Glossary

Articulated tug and barge (ATB): A tug-barge combination system capable of operation on the high seas, coastwise and further inland. It combines a normal barge, with a bow resembling that of a ship, but having a deep indent at the stern to accommodate the bow of a tug. The fit is such that the resulting combination behaves almost like a single vessel at sea as well as while maneuvering. In this report, ATBs only refers to tug-barge combinations where the barge is a tank vessel.

Automatic Identification System (AIS): An automatic tracking system used on ships and by vessel traffic services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites.

Bollard pull: The documented maximum continuous pull obtained from a static bollard pull test.

Bunkering: The practice of loading a ship with its fuel.

Buoy J: Strait of Juan de Fuca traffic separation virtual aid to navigation located 12.5 nautical miles northwest of Cape Flattery, at 48°29'36" N 125°00'00" W.

Buoy JA: Strait of Juan de Fuca traffic separation lighted buoy located 6 nautical miles northwest of Cape Flattery, at 48°29'36" N 124°43'38" W.

Catenary: The curve that a chain or wire forms from its own weight.

Covered vessel: Covered vessels are defined in RCW 88.46.010. "Covered vessel" means a tank vessel, cargo vessel, or passenger vessel. "Tank vessel" means a ship that is constructed or adapted to carry, or that carries, oil in bulk as cargo or cargo residue, and that: (a) Operates on the waters of the state; or (b) Transfers oil in a port or place subject to the jurisdiction of this state. "Cargo vessel" means a self-propelled ship in commerce, other than a tank vessel or a passenger vessel, of three hundred or more gross tons, including but not limited to, commercial fish processing vessels and freighters. "Passenger vessel" means a ship of three hundred or more gross tons with a fuel capacity of at least six thousand gallons carrying passengers for compensation. These definitions formed the rationale for vessel inclusion in the model.

Deadweight tonnage (DWT): The carrying capacity of a vessel in tons; the difference between the light and loaded displacement (weight of the ship itself vs. ship plus cargo, fuel, stores and water).

Deep draft vessel: A ship with a draft of over 40 feet.

Department of Ecology (Ecology): A cabinet agency charged with the execution, enforcement, and administration of the laws of the state of Washington and dedicated to preserving and protecting the environment.

Draft: A measure of the depth to which a ship sits below the water surface; the vertical distance between a ship's waterline and the bottom of the hull.

Emergency response towing vessel (ERTV): A rescue tug stationed at a central location with a defined area of operation that has as its primary mission response and assistance to a vessel that has lost steering, propulsion, or is otherwise in distress.

Escort tug: A tugboat designed to accompany specific vessel transits at speeds over 6 knots, while maintaining the ability to effect steering or braking control over that ship in the case of a propulsion or steering failure.

Incident: Any marine occurrence, accident or casualty recorded in the marine casualty databases of the US Coast Guard and the Canadian government.

Laden: A vessel descriptor indicating that the vessel is loaded with cargo.

Loss of propulsion: Failure of the propulsion system to propel the vessel as designed. Includes reductions in propulsion and intentional shutdowns of a vessel's propulsion system when unplanned.

Loss of steering: Failure of the steering system to function as designed.

Model Domain: The model domain is bounded on the west by an arc approximately 20 nautical miles past Buoy JA, and to the north with a line from Nanoose Bay to Sechelt.

Oil: "Oil" as defined in RCW 88.40 and RCW 90.56.

Tank barge: A barge of any tonnage, engaged in the transport of oil, chemicals, tallows, or biologically derived plant oil.

Tank ship: A self-propelled tank vessel of any gross tonnage, engaged in the transport of bulk liquids. In this report tank ships only refer to vessels designed to carry oil, chemicals, tallow, or biologically derived plant oils. It does not include liquified gas tankers.

Tank vessel: A vessel that is constructed or adapted to carry, or that carries oil in bulk as cargo. Articulated tug barges (ATBs), tank barges, and tank ships are tank vessels.

Towed oil barge: A tug and barge operation where the barge is constructed or adapted to carry, or that carries oil in bulk as cargo. Does not include articulated tug barges (ATBs) or tank ships.

Tug of opportunity: A tug of opportunity is a commercial vessel otherwise engaged in commerce that can potentially provide emergency towing assistance on an ad hoc basis. In this report, and in this analysis only vessels capable of service as escort vessels or harbor assist vessels are considered as potential tugs-of-opportunity.

Revised Code of Washington (RCW): The compilation of all permanent Washington State laws now in force.

Salish Sea: The intricate network of coastal waterways located between the southwestern tip of the Canadian province of British Columbia and the northwestern tip of the U.S. state of Washington. Its major bodies of water are the Strait of Georgia, the Strait of Juan de Fuca, and Puget Sound. The Salish Sea reaches from Desolation Sound at the north end of the Strait of Georgia to Oakland Bay at the head of Hammersley Inlet at the south end of Puget Sound. The inland waterways of the Salish Sea are partially separated from the open Pacific Ocean by Vancouver Island and the Olympic Peninsula, and are thus partially shielded from Pacific Ocean storms.

Study Area: The study area is bounded on the west by an arc approximately 20 nautical miles past Buoy JA, and to the north with a line from Nanoose Bay to Sechelt. Interior waterways within the ports of Seattle and Vancouver, such as the Fraser River, portions of the Duwamish River, and Lake Washington, are not included in the study area. The study area also does not include upper Howe Sound.

Trans Mountain Expansion Project (TMEP): An expansion of Trans Mountain’s pipeline between Alberta and Burnaby, British Columbia.

Acronyms and Abbreviations

ATB	Articulated tug and barge
AVIS	Authoritative Vessel Identification Service
BC	British Columbia
CFR	Code of Federal Regulations
DWT	Deadweight tonnage
Ecology	Washington State Department of Ecology
ERTV	Emergency response towing vessel
Gal	Gallon
IMO	International Maritime Organization
LG	Liquified Gas
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas

LLWLT	Lower Low Water Large Tide
LOP	Loss of Propulsion
LOS	Loss of Steering
m	Meters
m^3	Cubic Meters
MARSIS	Marine Safety Information System
MDM	Momentum and Drift Module
MHW	Mean High Water
MISLE	Marine Information for Safety and Law Enforcement
MLLW	Mean Lower Low Water
MMSI	Maritime Mobile Service Identity
MSL	Mean Sea Level
NAVD	North American Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
OSRM	Oil Spill Risk Module
RCW	Revised Code of Washington
RMSE	Root Mean Squared Errors
SQL	Structured Query Language
TSB	Transportation Safety Board of Canada
TMEP	Trans Mountain Expansion Project
VEAT	Vessel Entries and Transits
VDS	Vessel Documentation Service
VMM	Vessel Movement Module
VRAM	Vessel Rescue Analysis Module

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Appendix A: Methods, Results, and Discussion

Methods

Study area

The study area is bounded on the west by an arc approximately 20 nautical miles past Buoy JA, and to the north with a line from Nanoose Bay to Sechelt (Figure A-1).

Interior waterways within the ports of Seattle and Vancouver, such as the Fraser River, portions of the Duwamish River, and Lake Washington, are not included in the study area. The maritime traffic patterns in these areas are either not directly relevant to the scope of our analysis or too complex to simulate effectively as part of this project.

The study area also does not include upper Howe Sound due to a lack of consistent vessel traffic data in that area.

Figure A-1: Study Area.

Geographic zones

We evaluated results using geographic zones to provide spatial context for oil spill risk in the study area (Figure A-1). The geographic zones consisted of:

- Admiralty Inlet
- Bellingham Channel, Sinclair Island, and waters to the East
- Carr Inlet
- Case Inlet to Oakland Bay
- Colvos Passage
- Dyes Inlet
- Eastern Strait of Juan de Fuca
- Eld Inlet
- Guemes Channel and Saddlebags
- Haro Strait and Boundary Pass
- Hood Canal

- Howe Sound
- Lake Washington Ship Canal
- Nanaimo
- Northern Gulf Islands
- Port Orchard
- Port Susan
- Possession Sound and Saratoga Passage
- Puget Sound
- Rich Passage and Sinclair Inlet
- Rosario Strait
- San Juan Islands
- Skagit Bay
- South Sound to Olympia
- Southern Gulf Islands
- Strait of Georgia
- Strait of Georgia – Below 49th
- Strait of Georgia – North
- Strait of Georgia – South
- Vancouver
- Western Strait of Juan de Fuca

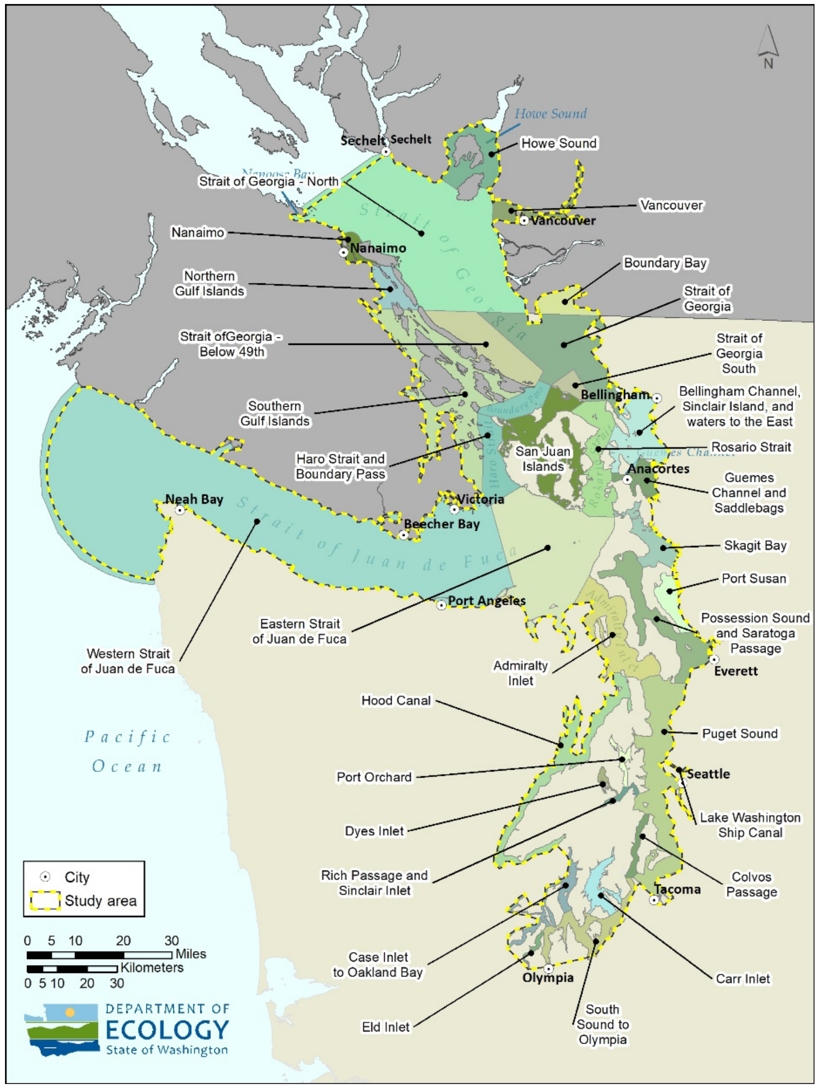

Figure A-2: Model zones.

How we analyzed incident data

We compared the number of drift groundings in vessel incident records against four other incident types: allisions, collisions, non-drift groundings and sinkings. The analysis provides perspective on how common drift groundings are compared to other incidents.

We evaluated vessel incident records in three ways. First, we calculated the relative frequency of incident types by comparing the frequency of each type against the total count of all five incident types. Second, we calculated the relative frequency of each incident with an oil spill by comparing that frequency against the total count of all five incidents with oil spills. Third, we calculated the rate that oil spills occurred for each incident type.

We counted hazards using the U.S. Coast Guard (USCG) Marine Information for Safety and Law Enforcement (MISLE) and Canada's Marine Safety Information System (MARSIS) incident databases. Hazard categories differed in the two databases. To count incidents in each hazard category, we mapped hazard counts in the databases to the categories used in the model. We used the hazard mapping methods described in Appendix B to classify incidents in eight hazard categories. Table A-1 and Table A-2 describe the additional criteria we used to identify drift groundings.

Table A-1: USCG MISLE drift grounding identification.

<table>
<tr><th>Model Hazard Type</th><th>Criteria for Drift Grounding</th></tr>
<tr><td>Loss of Propulsion
Loss of Steering
Loss of Propulsion/Loss of Steering</td><td>Summary contains ground|stuck|stack|strand</td></tr>
<tr><td>Allision
Capsize/Sinking
Collision
Grounding
Other</td><td>Does not meet criteria for drift grounding</td></tr>
</table>

Table A-2: TSB MARSIS drift grounding identification.

<table>
<tr><th>Model Hazard Type</th><th>Additional criteria for drift grounding</th></tr>
<tr><td>Loss of Propulsion</td><td>MARSIS Hazard Type is:
Bottom Contact
GROUNDING - Not under power (includes drifting) (non-intentional)</td></tr>
<tr><td>Loss of Steering</td><td>MARSIS Hazard Type is:
GROUNDING - Under power (non-intentional)</td></tr>
<tr><td>Loss of Propulsion/Loss of Steering</td><td>Summary contains ground|stuck|strand</td></tr>
<tr><td>Allision
Capsize/Sinking
Collision
Grounding
Other</td><td>Does not meet criteria for drift grounding</td></tr>
</table>

We restricted our review of vessel incident records to large commercial vessels. More information on the specific rules we used to identify which vessels to include in our review is available in Appendix B. We looked at vessel incident records for two different geographic areas, the study area (described above and shown in Figure A-1), and a larger area we call the Bi-National area (Figure A-3).

The Bi-National area includes the coastal waters of the U.S. and Canada up to 20 miles from the coast and continuing inland as far as deep draft traffic regularly calls. The area extends to the north to include Cook Inlet on the west coast, and the Gulf of St. Lawrence on the east coast. The Bi-National area does not include inland rivers and lakes, except for the portions that receive significant amounts of deep draft traffic. The Bi-National area includes the following inland waters:

- Fraser River up to New Westminster
- Columbia River up to I-205 bridge
- Willamette River up to Broadway bridge
- Mississippi River up to Baton Rouge
- St. Lawrence River up to Montreal
- Great Lakes, excluding locks

We used vessel incident records from 2002 to 2019 in the USCG MISLE database and Canada's MARSIS database.

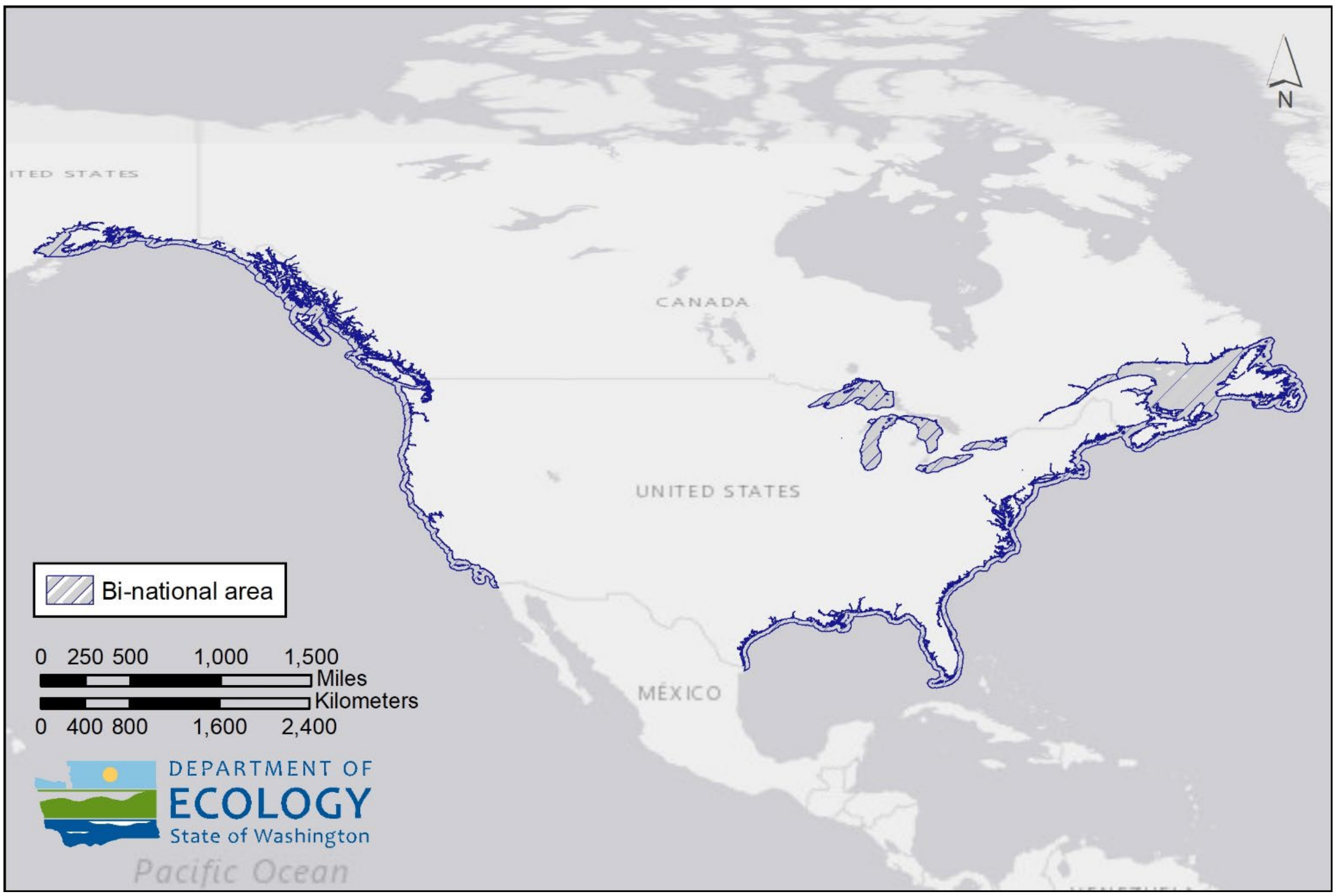

Figure A-3: Bi-National Area

Simulation modeling: model structure and how we analyzed simulation output

Simulation modeling is the main analytical method that we used to evaluate oil spill risk. When data are sparse or unfeasible to collect, simulation modeling allows a hypothetical analysis of a topic of interest.

For this study, we simulated vessel traffic patterns based on recent study area traffic data. Then we analyzed the effect of potential ERTV locations using a variety of risk metrics designed to represent risk of drift groundings and oil spills. To ensure that the simulation model had realistic dynamics, a number of data analyses were performed to inform model development (e.g., analyses of vessel transits to identify laden status). The model that we developed and used is briefly described in this section and described in detail in Appendix B.

General model structure

The objective of the simulation modeling was to generate realistic vessel traffic and movement patterns (including those of escort tugs, assist tugs, and bunkering vessels). The model also generated loss of propulsion events and evaluated how patterns of drift groundings and subsequent oil spills varied by potential ERTV location. The modeling analyses narrowly targeted the effects of vessel actions, such as emergency anchoring and self-repair, and potential rescue by escort tugs, assist tugs, tugs of opportunity and the Neah Bay ERTV. The simulation modeling was not designed to predict future oil outflow volumes or quantify any costs associated with adding an additional ERTV to the system.

Fourteen vessel types are included in the model. The list, with definitions, is included in Appendix B. The vessel types we used are not necessarily easily identifiable using observed AIS data alone. We developed a unique method for typing vessels for this study that is described in Appendix B.

The model consists of five essentially independent components, which we call modules to indicate their independence from the other model components:

- **Vessel Movement Module**: this module generates simulated vessel traffic and movement patterns and includes stays at anchorages, berths, and oil handling facilities.
- **Vessel Accident Module**: this module generates loss of propulsion and loss of steering events. The module determines if each loss of propulsion was a complete loss of propulsion and if so, estimates a potential self-repair time.
- **Momentum and Drift Module**: this module generates drift paths. Each drift path incorporates the effect of an initial turn, residual momentum, and some vessel characteristics. This module also determines the grounding location for drifting vessels.
- **Vessel Rescue Analysis Module**: this module calculates whether a drifting vessel can be reached by tugs of opportunity or by the Neah Bay ERTV before grounding. It also incorporated the effects of emergency anchoring.
- **Oil Spill Risk Module**: this module generates oil spill risk metrics.

Simulation implementation

Using the model, one thousand simulations were run. Each simulation produced an equivalent of a year's worth of unique vessel traffic. All vessel movement (including drifting vessels) were simulated at one-minute intervals.

Unique loss of propulsion events were generated for each simulation using different rates by vessel type. A drift trajectory was simulated for each loss of propulsion event. For each loss of propulsion event, the model recorded a series of attributes. The full list of recorded attributes is in Appendix B.

Once the attributes were recorded, the model determined if each loss of propulsion event ended in a drift grounding. The following criteria must be met for a vessel to be recorded as a drift grounding:

- The vessel's drift trajectory ended in a grounding.
- If the vessel was escorted, the drift duration was less than 30 minutes.[21]
- Vessel experienced a complete loss of propulsion, and the generated self-repair time was greater than the drift duration.
- If the vessel was not a towed oil barge or bunkering barge, a successful emergency anchoring did not occur before vessel grounded. Emergency anchoring results were not included for towed oil barges and bunkering barges since they are often unmanned during transit.
- A tug of opportunity could not rescue vessel before vessel grounded.
- The Neah Bay ERTV could not rescue vessel before vessel grounded.

Figure A-4: ERTV locations.

ERTV locations

We evaluated seven potential ERTV locations: Anacortes, Deltaport, Port Angeles, Port Townsend, Roche Harbor, Sidney, and Victoria (Figure A-4).

[21] Escorted vessels with a drift duration of less than 30 minutes still ground, since model parameters for time to connect and time to control are 15 minutes each.

Tug escort scenarios

Three different escort tug scenarios were examined to assess how past, present, and theoretical future tug escort rules may affect the potential risk reduction benefit of placement of a new ERTV. For each simulated loss of propulsion event, all three tug escort scenarios were simulated to evaluate intervention potential across scenarios.

Tug Escort Scenario 1: pre-2020 requirements

Tank vessels in Tug Escort Scenario 1 are simulated using the tug escort requirements in place prior to 2020. Under these requirements, tug escorts are required for laden tank ships over 40,000 deadweight tons (DWT) in Washington waters inside a line from New Dungeness Light to Discovery Island Light.

Tug Escort Scenario 2: current requirements

Tank vessels in Tug Escort Scenario 2 are simulated using the tug escort requirements established in 2020. Under these requirements, in addition to the tug escort requirements in place in Scenario 1, tug escort are also required for laden articulated tug and barges (ATBs), tank barges, and tank ships between 5,000 and 40,000 DWT in the waters of Rosario Strait and connected waters east.

Tug Escort Scenario 3: escorts required throughout study area

Tank vessels in Tug Escort Scenario 3 are simulated using a theoretical expansion of tug escort requirements in Washington waters inside a line from New Dungeness Light to Discovery Island Light. In addition to the tug escort requirements in place in Scenario 2, laden ATBs, tank barges, and tank ships between 5,000 and 40,000 DWT were required to take an escort in all other areas inside the referenced line where not previously required.

How we simulated escort and assist tugs

The model treats escort and assist tugs as dependent vessels. A portion of their movements are "dependent" on the presence of other vessels. The dependent movements are when an assist tug is called out to assist a vessel to or from a berth, and when an escort tug is called out to escort a laden tank vessel.

The totality of simulated escort and assist tugs movements is made up of dependent movements, plus additional "background" tracks. Background tracks are non-dependent tug movements, pulled directly from observed AIS. The addition of background tracks is required because escort and assist tugs perform work besides escorting and assisting. If we relied solely on dependent movements, we would substantially under-simulate tug traffic in the system.

For each simulation run, the model produces a different set of simulated total tug traffic for each escort scenario, differentiated as dependent assist tracks, dependent escort tracks, and background tracks.

Our simulation approach attempts to hold the overall tug traffic constant across all scenarios. The tug escort rule expansion in Scenarios 2 and 3 increases dependent escort tug traffic for those scenarios. To simulate the same number of tug tracks for each scenario, the number of background tracks is varied. This results in less background tracks simulated in Scenario 2 compared to Scenario 1 and also less background tracks simulated in Scenario 3 compared to Scenario 2. One consequence of this approach is that while the overall tug traffic volume is roughly equivalent between scenarios, the geographic distribution of the simulated traffic increasingly differs from the observed geographic traffic pattern as the numbers of escort tracks increase and background tracks decrease. See Appendix B for a detailed explanation of how the model simulated tug traffic, including descriptions of the three tug track types.

Tug rescues

The model allows drifting vessels to be rescued by tugs of opportunity or ERTVs. The Neah Bay ERTV and all potential ERTVs are modeled with a 20-minute mobilization time, which is based on standards required under Washington state regulations (RCW 88.46.135, 2009). Escort tugs and assist tugs can serve as tugs of opportunity if they are underway at the time of the loss of propulsion. They do not have a mobilization time since they are already underway. All tugs responding to loss of propulsion events travel at 10 knots. When tugs of opportunity or ERTVs respond to loss of propulsion events, they require 15 minutes to connect a towline and 15 minutes to control the drifting vessel.

The time required for a responding tug to reach a disabled vessel is based on the distance from the tug starting point (tug location at time of loss of propulsion event) to the nearest point along the disabled vessel's drift path where the tug and ship intersect. If a tug reaches a drifting vessel with enough time to connect and control before the vessel grounds, a successful rescue is recorded.

All simulated escort and assist tugs are treated as tugs of opportunity. Assist tugs that are engaged in assisting a ship are not simulated in the model. We elected to treat escort and assist tugs as tugs of opportunity because they are tugs that by design and occupation can control the movement of large commercial vessels. There are several other types of tugs that we did not model as potential tugs of opportunity, they include:

- Tugs that engage in ocean and coastal towing.
- Tugs associated within inland towing.
- Other tugs of unidentified occupation.
- Tugs at the dock, whether escort tugs, assist tugs, or any other type.

These tugs are not included for a variety of reasons, including:

- They are usually burdened with a tow and as a result cannot quickly respond to a disabled vessel; or
- They lack sufficient capacity, equipment, and/or training to control the movement of a large commercial vessel.

Evaluation of oil spill risk

In the scope of work for this analysis, we defined risk as the combination of the likelihood of an event and the consequence if the event were to occur. For the analysis, we developed four metrics that each provide a different aspect of oil spill risk from drift groundings. The four metrics are drift grounding rate, drift grounding, oil volume at risk, and oil outflow.

Drift grounding rate

The drift grounding rate is the percentage of simulated loss of propulsion events that result in a drift grounding.

Drift grounding metric

Our drift grounding metric is designed to represent the likelihood of drift groundings. It is weighted by incident likelihood and the overall number of drift groundings identified in model outputs. The purpose of this metric is to compare the potential likelihood of drift groundings, without regard to potential consequence or severity.

The drift grounding rate and drift grounding metric treat all drift groundings equally, regardless of the potential consequence of a grounding. To balance this, we use two other metrics, oil volume at risk and oil outflow to represent potential severity of simulated drift grounding events.

Oil volume at risk metric

Oil volume at risk is designed to represent risk of a maximum potential spill. It is based on the fuel and cargo capacity of an involved vessel. It is calculated by multiplying the maximum volume of oil (in gallons) aboard a simulated vessel, against the incident likelihood. As a result, this is a weighted value and does not reflect exact volumes from any specific incident or collection of incidents. The purpose of this metric is to compare the potential severity of drift groundings using reliable estimates like fuel and oil cargo capacities.

Oil outflow metric

The oil outflow metric is designed to represent risk of an average potential spill. It doesn't produce specific outflows for individual events. It is based on the historical averages of spill size, and the historical rate of spills per incident, per vessel type. It is calculated by multiplying the average historical spill volume (in gallons) for a vessel type, against the spill probability per incident, against the incident likelihood. As a result, this is a weighted value and does not reflect exact volumes from any specific incident or collection of incidents. The purpose of this metric is to use historical oil spill volumes to compare average severity of drift groundings.

Spatial distribution of risk

The model records two sets of geographic coordinates for each loss of propulsion event, the location of loss of propulsion, and the location of the drift grounding. For some loss of propulsion events, the geographic zones for these two locations are different.

Since this analysis focuses on intervening in the accident chain in the moments prior to a grounding event, we elected to assign incident location based on the coordinates of the grounding.

Initial review of simulation results

Before analyzing simulation results, we reviewed the simulated data to identify data that could skew results and potentially lead to inaccurate conclusions. Based on this review, we made a number of adjustments to the initial simulation results. The adjustments and rationale for those adjustments are described below.

Initial Turn

When ships lose propulsion, they can briefly retain the ability to control their heading and avoid hazards using momentum. The model includes a method to incorporate this real-world behavior. Modeled vessels use a 120-degree hazard evaluation area to identify hazards up to 20 minutes ahead based on vessel speed. If hazards are identified the vessel makes one turn towards more open waters. More details on how Initial Turn works can be found in Appendix B.

Based on our evaluation of outputs, we determined that the Initial Turn function was not working as expected. The hazard identification rules captured too many hazards and led to more initial turns than anticipated. Only a very small portion of the turns were useful for avoiding an immediate hazard. The large number of turns introduced extensive noise into the drift data. As a result, we did not include initial turn results in the analysis.

Short drift durations

In our initial review of drift results, we found that roughly 25 percent of the drift trajectories had drift durations of 5 minutes or less. Many of them were taking place near berths. For some of these loss of propulsion events, it is likely that the vessel would normally be under the control of one or more assist tugs. For others, it’s likely that they were at a berth, but variability in source Global Positioning System (GPS) data made them appear like they were moving. Low GPS accuracy can produce erratic ship position data that can appear to show movement while a vessel is functionally stationary. Based on the existence of these relatively simple explanations for the phenomenon, and our concern that the volume of these events would likely skew our summary statistics, we created a filtering approach to remove these from the analysis.

Assist filter

We established a 400-meter assist zone around deep-draft vessel berths to remove loss of propulsion events from analysis where a vessel was likely under the control of one or more assist tugs. This assumed that the assisting tugs are fully in control of the vessel at that distance to the berth. We applied this filter for vessel types that take assist tugs. A list of those vessel types can be found in Appendix B.

Issues and exceptions to the assist filter

The 400-meter radius for assists worked well in harbors like the Port of Seattle and the Port of Tacoma. It did not work as well for Guemes Channel and Burrard Inlet where some berths are close enough to the traffic lane. In those areas, the 400-meter zone was incorrectly capturing passing vessels that were not heading to berth. To address this, we modified the filter so that it was not applied in Burrard Inlet or Guemes Channel.

Berth filter

To remove loss of propulsion events from analysis where a vessel was likely at a berth, we established a 50-meter berth zone around all vessel berths. This filter was applied to all simulated vessel types. For loss of propulsions within 50 meters of a berth, that event was not considered a candidate for drift grounding, under the assumption that the vessel is likely at the berth and/or with lines on, at the time of loss of propulsion.

Speed filter

In addition to the locational filters, we established a 1-knot filter for all simulated vessel types. We assumed that if a vessel is traveling less than 1 knot at the time of a loss of propulsion, then the vessel is under the control of an assist tug, engaged in dropping or retrieving an anchor, or otherwise not in danger from an abrupt loss of power. At speeds less than 1 knot the vessel would not have steering due to inadequate flow over the rudder. The vessel is thus engaged in an activity where a loss of propulsion does not create a hazardous condition that benefits from inclusion in the analysis.

Momentum and drift stabilization time

Our review also determined that the momentum and drift module can produce irregular results during the first minute or two of drift trajectory. In recognition of this, we established filtering approach to drift paths of extremely short duration.

Stabilization filter

Loss of propulsion events that have a drift duration of less than 2 minutes are not considered in simulation analysis.

Current oil spill risk profile

We characterized the current oil spill risk profile by calculating the relative frequency of oil spill metrics for each vessel type and for each geographical zone. We used data from Tug Escort Scenario 2, which represent current escort requirements, for these calculations. All of the relative frequency calculations followed the following procedure:

For each simulation, the totals for each oil spill risk metric for all vessel types and zones were calculated. Then, the total for each oil spill risk metric for each vessel type or geographic zone were calculated. The relative frequencies for a simulation were found by dividing the totals for each vessel type or geographic zone by the total for all vessels and zones. Finally, the average relative frequencies for each vessel type and geographic zone across all simulations were calculated. Drift groundings rates were calculated by taking the average of the drift grounding rates for each simulation. We also performed these steps with the results from car ferries excluded.

Changes between ERTV locations

The characterization of the effect of the new ERTV locations on the oil spill risk profile was provided by calculating the relative changes in oil spill metrics among vessel types and geographic zones between results with only the Neah Bay ERTV included, and results with the Neah Bay ERTV and each of the new ERTV locations. This produced seven sets of relative changes, one for each new ERTV location. The calculations were done for each tug escort scenario as well.

For each simulation, we first calculated the totals for each oil spill risk metric and the difference in the totals for each oil spill risk metric between ERTV location on/off results. Then, we calculated the averages across all simulations for each of those values. Finally, the overall percent change with new ERTV locations on/off were calculated by dividing the average difference between ERTV location on/off results to the average total of the ERTV location off results. The changes in drift groundings rates were calculated by taking the average per simulation of the difference in the drift grounding rates between ERTV location on/off results. These were calculated for each vessel type, for each geographic zone, and for each scenario.

ERTV location comparison

To assess the new ERTV location effects, we calculated relative changes in oil spill metrics among vessel types and geographic zones between results with only the Neah Bay ERTV included and results with the Neah Bay ERTV and each of the new ERTV locations for each scenario were compared.

Influence of tugs of opportunity

The characterization of the effect of the tug of opportunity and the proposed ERTV locations on the oil spill profile was provided by calculating the relative changes in oil spill metrics among vessel types and geographic zones between results with the Neah Bay ERTV and each of the proposed ERTV locations included with the tug of opportunity option turned on and off. The calculations were done for each scenario. The calculations for the influence of tugs of opportunity followed a similar approach to how changes between ERTV locations were evaluated.

Trans Mountain Expansion Project

An additional simulation analysis was performed to evaluate the effects of the additional tug traffic associated with Trans Mountain Expansion Project (TMEP) on potential benefits from new ERTV locations. This analysis required adding additional simulated transits to the traffic simulation produced for Scenario 2. The tug escorts assigned to these new transits are consistent with the TMEP proposal, and in accordance with Pacific Pilotage Authority rules (Pacific Pilotage Authority, 2019).

The TMEP proposal estimates that after the approval of the pipeline expansion, there will be 408 (an increase of 348) round-trip transits per year to and from the Westridge Terminal in Burnaby, B.C. (Trans Mountain, 2013, p. 14). The model assumes inbound traffic is unladen and unescorted while outbound tankers are laden and escorted. Escorting responsibilities are shared by two different tugs with a hand-off at Race Rocks. Escort tugs originate at Beecher Bay when heading to an escort job and return there when the job is complete. The escort ends at the J buoy, where the tug stands by for one hour before returning to Beecher Bay. The TMEP proposal includes the placement in Beecher Bay of an oil spill response vessel (OSRV) that can respond to disabled vessels and provide assistance towing.

We simulated additional escort transits that reflected the TMEP proposal for each simulation. The rescue tug analysis was repeated with the additional TMEP tugs of opportunity, and the Beecher Bay OSRV included as an additional ERTV.

Relative changes in oil spill metrics overall and among vessel types and geographic regions were calculated to compare oil spill metrics following addition tug of opportunity traffic resulting from the TMEP escort requirements. We did not assess any potential risk that might be produced by additional TMEP tanker transits. Calculation steps were similar to those described for evaluating changes between ERTV locations.

Results

This section covers the results of our analysis of incident data, traffic data, and simulation data.

Our analysis of incident data

In the study area, we identified 27 large commercial vessel groundings and four large commercial vessel drift groundings[22] between 2002 and 2019. None of these incidents were associated with an oil spill. In the Bi-National Area (Figure A-3), 5,071 covered vessel groundings were identified; 0.91 percent of these groundings were associated with an oil spill. There were 190 covered vessel drift groundings identified, of which 2.63 percent were associated with an oil spill.

The biggest spill associated with the drift groundings was 335,732 gallons and the mean spill size was 1,047 gallons.

Drift groundings make up 2.1 percent of the casualties in the Model Domain, and 1.7 percent of the incidents in the Bi-National Area. Drift groundings make up only 2.39 percent of incidents associated with an oil spill.

Table A-3: Count and relative frequency of vessel incident types in the study area and the Bi-National Area.

Incident Type	Study Area (Count)	Study Area (%)	Bi-National Area (Count)	Bi-National Area (%)
Allision	127	65.5	4531	39.8
Collision	40	20.6	1654	14.5
Sinking	0	0	115	1.0
Non-drift Grounding	23	11.9	4881	42.9
Drift Grounding	4	2.1	190	1.7
Total	194	100.00	11371	100.00

Table A-4: Count and relative frequency of incident type with an oil spill in the study area and Bi-National Area.

Incident Type	Study Area	Bi-National Area Count	Bi-National Area (%)
Allision (with spill)	No reported spills	80	38.28

[22] The four records we identified as potential large commercial vessel drift groundings in the study area follow:

- February 6, 2004 propulsion failure and grounding of fishing vessel ALASKA MIST (8836259) near Shilshole Bay.
- June 30, 2005 loss of propulsion of car ferry QUEEN OF OAK BAY (7902283). The vessel struck 28 berthed pleasure craft before grounding.
- December 23, 2008 blackout aboard the car ferry QUEEN OF NANAIMO (6404375). The vessel anchored in Long Harbour, B.C. for repairs. The vessel did not ground.
- March 27, 2018 propulsion failure of the container ship SEAMAX NORWALK (9290464) in Haro Strait. The vessel anchored to avoid grounding.

Incident Type	Study Area	Bi-National Area Count	Bi-National Area (%)
Collision (with spill)	No reported spills	55	26.32
Sinking (with spill)	No reported spills	28	13.40
Non-drift Grounding (with spill)	No reported spills	41	19.62
Drift Grounding (with spill)	No reported spills	4	2.39
All Incident Types	No reported spills	208	100.00

Of all drift grounding, 2.63 percent result in oil spills. Drift groundings have the third highest oil spill rate per incident, after sinking and collision.

Table A-5: Relative frequency of an oil spill per incident, by incident type, in the study area and Bi-National Area.

Incident Type	Study Area Spills Per Incident (%)	US and Canada Spills Per Incident (%)
Allision	No reported spills	1.77
Collision	No reported spills	3.33
Sinking	No reported spills	24.35
Non-drift Grounding	No reported spills	0.84
Drift Grounding	No reported spills	2.63

Our analysis of simulated output

Our analysis of simulated vessel traffic

Vessel underway minutes (i.e., vessel traffic) within the study area varied strongly across geographic zones and vessel types. These non-uniform patterns were seen in the observed historical vessel traffic and in the simulated vessel traffic. Simulated traffic patterns closely matched observed data (less than 1 percent difference from observed percentages for most zones and vessel types).

More than 50 percent of simulated traffic occurred in three zones: Western Strait of Juan de Fuca, Puget Sound, and Strait of Georgia - North. With car ferry traffic removed, those zones accounted for around 65 percent of traffic in the study area.

Bulk carriers and car ferries were the two busiest vessel types. They made up nearly 65 percent of the vessel traffic. Towed oil barges came in third in terms of underway time in the study area. With car ferry traffic removed, bulk carriers made up around 28.39 percent of the traffic. Towed oil barges and container ships are the next highest at 21.32 percent and 14.86 percent respectively. Table A-6 and Table A-7 shows the relative vessel traffic for all geographic zones and vessel types in the study area with car ferry traffic included and excluded.

Table A-6: Relative frequency of total simulated vessel traffic (underway minutes) by geographic zone.

Geographic Zone	Relative Frequency (%)	Relative Frequency Excluding Ferries (%)
Admiralty Inlet	3.40	4.40
Bellingham Channel, Sinclair Island, and waters to the East	0.37	0.66
Boundary Bay	0.00	0.00
Carr Inlet	0.00	0.00
Case Inlet to Oakland Bay	0.38	0.00
Colvos Passage	0.08	0.14
Dyes Inlet	0.00	0.00
Eastern Strait of Juan de Fuca	2.13	4.19
Eld Inlet	0.00	0.00
Guemes Channel and Saddlebags	1.19	0.62
Haro Strait and Boundary Pass	3.08	5.96
Hood Canal	0.00	0.00
Howe Sound	2.83	0.50
Lake Washington Ship Canal	0.11	0.22
Nanaimo	2.57	0.71
Northern Gulf Islands	0.06	0.12
Port Orchard	0.00	0.00
Port Susan	0.00	0.00
Possession Sound and Saratoga Passage	1.80	0.18
Puget Sound	16.46	12.65
Rich Passage and Sinclair Inlet	1.23	0.00
Rosario Strait	2.20	2.11
San Juan Islands	3.71	0.01
Skagit Bay	0.00	0.00
South Sound to Olympia	1.13	0.17
Southern Gulf Islands	10.80	1.92
Strait of Georgia	4.46	4.39
Strait of Georgia – Below 49^{th}	2.54	1.31
Strait of Georgia – North	15.33	13.42
Strait of Georgia – South	0.11	0.18
Vancouver	4.13	8.15
Western Strait of Juan de Fuca	19.98	37.97
All Zones	100.00	100.00

Table A-7: Relative frequency of simulated vessel traffic (underway minutes) by vessel type.

Vessel Type	Relative Frequency (%)	Relative Frequency Excluding Ferries (%)
ATB	3.40	6.74
Bulk Carrier	14.33	28.39

Vessel Type	Relative Frequency (%)	Relative Frequency Excluding Ferries (%)
Container Ship	7.50	14.86
Cruise Ship	1.89	3.76
Ferry (Car)	49.54	NA
Fishing Vessel (Large)	1.70	3.38
General/Other Cargo Ship (Large)	2.24	4.43
Tanker (Chemical)	1.96	3.89
Tanker (Crude)	1.23	2.43
Tanker (Liquefied Gas)	0.14	0.27
Tanker (Product)	1.18	2.34
Towing Vessel (Oil)	10.76	21.32
Towing Vessel (Oil) – Bunkering	1.56	3.09
Vehicle Carrier	2.57	5.10
All Vessel Types	100.00	100.00

Current oil spill risk profile

Geographic distribution: study area

Primary risk metrics

All three primary oil spill risk metrics varied spatially across the study area (Table A-8). Over 50 percent of all drift groundings occurred in only three geographic zones: Puget Sound (22.20 percent), Southern Gulf Islands (17.19 percent), and Vancouver (10.99 percent). The geographic distribution of oil volume at risk differed from drift groundings. The top three zones in terms of oil volume at risk represented almost 50 percent of the total volume: Vancouver (22.61 percent), Puget Sound (18.06 percent), and Haro Strait and Boundary Pass (9.15 percent). The top three zones for oil outflow represented almost 50 percent of total oil outflow risk: Puget Sound (20.12 percent), Southern Gulf Islands (16.11 percent), and Vancouver (13.24 percent).

Zones with zero or near-zero values for the primary risk metrics were Boundary Bay, Carr Inlet, Case Inlet to Oakland Bay, Dyes Inlet, Eld Inlet, Gulf Islands, Hood Canal, Port Orchard, Port Susan, and Skagit Bay.

Drift grounding rates

The overall drift grounding rate for all vessel types was 2.88 percent. The zones with the three highest grounding rates were Lake Washington Ship Canal (21.36 percent), Nanaimo (14.14 percent), Rich Passage and Sinclair Inlet (12.43), and Vancouver (12.18 percent).

Table A-8: Relative frequency of oil spill risk metrics for Scenario 2 by geographic zone.

Geographic Zone	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate
Admiralty Inlet	3.57	3.50	3.36	1.75
Bellingham Channel, Sinclair Island, and waters to the East	0.77	3.22	1.36	4.13
Boundary Bay	0.00	0.00	0.00	0.00

Geographic Zone	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate
Carr Inlet	0.00	0.00	0.00	0.00
Case Inlet to Oakland Bay	0.00	0.00	0.00	0.00
Colvos Passage	0.16	0.05	0.14	5.52
Dyes Inlet	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	0.26	0.80	0.38	0.31
Eld Inlet	0.00	0.00	0.00	NA
Guemes Channel and Saddlebags	1.10	5.59	2.01	10.42
Haro Strait and Boundary Pass	5.55	9.15	6.05	5.15
Hood Canal	0.00	0.00	0.00	0.00
Howe Sound	3.61	1.30	3.32	8.09
Lake Washington Ship Canal	0.31	0.06	0.23	21.36
Nanaimo	3.72	1.26	3.24	14.14
Northern Gulf Islands	0.06	0.04	0.03	7.59
Port Orchard	0.00	0.00	0.00	0.00
Port Susan	0.00	0.00	0.00	0.00
Possession Sound and Saratoga Passage	3.06	1.10	2.92	9.66
Puget Sound	22.20	18.06	20.12	6.46
Rich Passage and Sinclair Inlet	2.06	0.83	2.01	12.43
Rosario Strait	2.19	4.87	3.09	2.67
San Juan Islands	5.53	1.61	5.21	2.86
Skagit Bay	0.01	0.00	0.00	2.47
South Sound to Olympia	0.78	0.25	0.78	5.72
Southern Gulf Islands	17.19	7.93	16.11	8.34
Strait of Georgia	1.77	3.28	1.98	1.96
Strait of Georgia – Below 49th	2.49	1.53	2.44	1.39
Strait of Georgia – North	8.26	6.21	7.25	2.46
Strait of Georgia – South	0.12	0.25	0.13	1.15
Vancouver	10.99	22.61	13.24	12.18
Western Strait of Juan de Fuca	4.23	6.50	4.60	0.40
All Vessels - All Zones	100.00	100.00	100.00	2.88

In terms of absolute values, the model produced an average of 1.48 drift groundings, 1,287,277 gallons of oil volume at risk, and 331.96 gallons of oil outflow per simulation (Table A-9).

Table A-9: Mean values per simulation for Scenario 2 by geographic zone.

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Admiralty Inlet	0.0440	38,744.6828	9.5361
Bellingham Channel, Sinclair Island, and waters to the East	0.0051	69,400.7413	2.9887
Boundary Bay	0.0000	0.0000	0.0000

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Carr Inlet	0.0000	0.0000	0.0000
Case Inlet to Oakland Bay	0.0000	0.0000	0.0000
Colvos Passage	0.0018	754.4342	0.3650
Dyes Inlet	0.0000	0.0000	0.0000
Eastern Strait of Juan de Fuca	0.0011	14,196.8573	0.5874
Eld Inlet	0.0000	0.0000	0.0000
Guemes Channel and Saddlebags	0.0153	111,866.9261	5.5595
Gulf Islands	0.0000	0.0000	0.0000
Haro Strait and Boundary Pass	0.0548	116,569.9535	14.1574
Hood Canal	0.0000	0.0000	0.0000
Howe Sound	0.0709	8,313.2259	15.0988
Lake Washington Ship Canal	0.0023	294.4680	0.4919
Nanaimo	0.0685	7,023.2328	12.6605
Northern Gulf Islands	0.0007	322.2020	0.1379
Port Orchard	0.0000	0.0000	0.0000
Port Susan	0.0000	0.0000	0.0000
Possession Sound and Saratoga Passage	0.0607	7,713.2775	12.9697
Puget Sound	0.2981	167,993.0537	63.5865
Rich Passage and Sinclair Inlet	0.0404	4,250.4583	8.6744
Rosario Strait	0.0263	92,184.3714	7.9642
San Juan Islands	0.1120	16,215.5154	24.2329
Skagit Bay	0.0001	6.4775	0.0109
South Sound to Olympia	0.0142	1,297.4372	3.0403
Southern Gulf Islands	0.3207	58,257.7071	67.6057
Strait of Georgia	0.0264	70,121.0172	4.8646
Strait of Georgia - Below 49th	0.0548	11,427.6153	11.7361
Strait of Georgia - North	0.1267	68,888.8685	24.0117
Strait of Georgia South	0.0008	2,711.5649	0.2103
Vancouver	0.0935	331,922.3442	31.9834
Western Strait of Juan de Fuca	0.0367	86,800.7209	9.4852
Total	1.4756	1,287,277.1530	331.9589

Geographic distribution: study area excluding car ferries

Primary risk metrics

With car ferries removed, the top three zones for drift groundings in the study area were: Puget Sound (24.70 percent), Vancouver (24.62 percent), and Haro Strait and Boundary Pass (11.20 percent). These three zones accounted for about 60 percent of the total drift groundings. The top three zones for oil volume at risk were Vancouver (27.21 percent), Puget Sound (18.05 percent), and Haro Strait and Boundary Pass (10.95 percent). In total they make up about 56 percent of the oil volume at risk. Oil outflow was similarly distributed. Vancouver (27.23 percent), Puget Sound (20.12 percent), and Haro

Strait and Boundary Pass (11.5 percent) made up about 59 percent of the total oil outflow (Table A-10).

Zones with zero or near-zero values for the primary risk metrics were Boundary Bay, Carr Inlet, Case Inlet to Oakland Bay, Dyes Inlet, Eld Inlet, Gulf Islands, Hood Canal, Port Orchard, Port Susan, and Skagit Bay.

Drift grounding rates

The overall drift grounding rate for all vessel types (excluding car ferries) was 2.55 percent. The zones with the three highest grounding rates were Lake Washington Ship Canal (21.36 percent), Nanaimo (15.26 percent), and Vancouver (12.23 percent).

Table A-10: Relative frequency of oil spill risk metrics for Scenario 2 by geographic zone, excluding car ferries.

Geographic Zone	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate
Admiralty Inlet	4.97	4.10	4.54	1.64
Bellingham Channel, Sinclair Island, and waters to the East	1.92	3.67	2.78	4.18
Boundary Bay	0.00	0.00	0.00	0.00
Carr Inlet	0.00	0.00	0.00	NA
Case Inlet to Oakland Bay	0.00	0.00	0.00	0.00
Colvos Passage	0.17	0.05	0.11	6.12
Dyes Inlet	0.00	0.00	0.00	NA
Eastern Strait of Juan de Fuca	0.51	0.89	0.74	0.32
Eld Inlet	0.00	0.00	0.00	NA
Guemes Channel and Saddlebags	2.35	6.04	4.07	10.83
Haro Strait and Boundary Pass	11.20	10.95	11.50	5.21
Hood Canal	0.00	0.00	0.00	0.00
Howe Sound	0.80	0.25	0.47	6.39
Lake Washington Ship Canal	0.94	0.42	0.85	21.36
Nanaimo	0.83	0.30	0.46	15.26
Northern Gulf Islands	0.18	0.10	0.12	8.41
Port Orchard	0.00	0.00	0.00	0.00
Port Susan	0.00	0.00	0.00	0.00
Possession Sound and Saratoga Passage	0.31	0.18	0.24	4.42
Puget Sound	24.70	18.05	20.12	6.29
Rich Passage and Sinclair Inlet	0.03	0.10	0.08	5.56
Rosario Strait	2.42	4.90	3.56	2.43
San Juan Islands	0.67	0.96	0.75	0.54
Skagit Bay	0.01	0.00	0.00	2.50
South Sound to Olympia	0.42	0.19	0.33	9.18

Geographic Zone	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate
Southern Gulf Islands	5.56	3.66	4.66	6.65
Strait of Georgia	1.59	3.75	2.70	1.73
Strait of Georgia – Below 49th	0.79	0.50	0.66	0.57
Strait of Georgia – North	7.68	5.50	6.31	2.32
Strait of Georgia South	0.35	0.30	0.35	1.18
Vancouver	24.62	27.21	27.23	12.23
Western Strait of Juan de Fuca	6.97	7.92	7.38	0.39
No Ferries – All Zones	100.00	100.00	100.00	2.55

In terms of absolute values, with car ferry traffic removed, the model produced an average of 0.36 drift groundings, 1,188,025 gallons of oil volume at risk, and 104.20 gallons of oil outflow per simulation (Table A-11).

Table A-11: Mean values per simulation for Scenario 2 by geographic zone, excluding car ferries.

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Admiralty Inlet	0.0193	38,146.4748	4.2611
Bellingham Channel, Sinclair Island, and waters to the East	0.0038	69,294.7199	2.7036
Boundary Bay	0.0000	0.0000	0.0000
Carr Inlet	0.0000	0.0000	0.0000
Case Inlet to Oakland Bay	0.0000	0.0000	0.0000
Colvos Passage	0.0013	742.2822	0.2581
Dyes Inlet	0.0000	0.0000	0.0000
Eastern Strait of Juan de Fuca	0.0011	14,196.8573	0.5874
Eld Inlet	0.0000	0.0000	0.0000
Guemes Channel and Saddlebags	0.0048	111,409.4274	4.0624
Gulf Islands	0.0000	0.0000	0.0000
Haro Strait and Boundary Pass	0.0529	116,423.1505	13.7654
Hood Canal	0.0000	0.0000	0.0000
Howe Sound	0.0017	805.9589	0.3073
Lake Washington Ship Canal	0.0023	294.4680	0.4919
Nanaimo	0.0026	1,465.1423	0.4705
Northern Gulf Islands	0.0007	322.2020	0.1379
Port Orchard	0.0000	0.0000	0.0000
Port Susan	0.0000	0.0000	0.0000
Possession Sound and Saratoga Passage	0.0018	2,164.1928	0.3880
Puget Sound	0.0829	146,001.9803	17.5724
Rich Passage and Sinclair Inlet	0.0000	1,110.1453	0.0490
Rosario Strait	0.0040	90,341.9411	3.1881
San Juan Islands	0.0030	10,354.8077	0.9229
Skagit Bay	0.0001	6.4775	0.0109

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
South Sound to Olympia	0.0019	1,008.3359	0.4028
Southern Gulf Islands	0.0220	31,649.6476	5.2111
Strait of Georgia	0.0034	68,533.0665	2.3342
Strait of Georgia - Below 49th	0.0033	4,399.2275	0.7227
Strait of Georgia - North	0.0345	58,893.9507	7.5579
Strait of Georgia South	0.0008	2,711.5649	0.2103
Vancouver	0.0935	331,922.3442	31.9834
Western Strait of Juan de Fuca	0.0232	85,827.1144	6.5981
Total	0.3649	1,188,025.4797	104.1974

Vessel type distribution: study area including car ferries

Primary risk metrics

The top three vessel types for drift groundings were car ferries (53.42 percent of all drift groundings), container ships (12.23 percent), and bulk carriers (10.42 percent). The top three vessel types for oil volume at risk were container ships (18.50 percent), car ferries (17.78 percent), and chemical tankers (15.19 percent). The top three vessel types for oil outflow risk were car ferries (49.70 percent), container ships (11.17 percent) and bulk carriers (9.48 percent).

ATBs, liquefied gas tankers, and bunkering barges had the lowest values for the primary risk metrics.

Drift grounding rates

The three vessel types with the highest drift grounding rates were car ferries (7.68 percent), bunkering barges (6.60 percent), and oil-towing barges (5.59 percent). See Table A-12 for full results.

Table A-12: Relative frequency of oil spill risk metrics for Scenario 2 by vessel type.

Vessel Type	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate
ATB	0.41	0.27	0.28	1.64
Bulk Carrier	10.42	9.34	9.48	2.23
Container Ship	12.23	18.50	11.17	2.98
Cruise Ship	2.89	2.79	2.58	1.87
Ferry (Car)	53.42	17.78	49.70	7.68
Fishing Vessel (Large)	1.77	0.60	1.54	1.38
General/Other Cargo Ship (Large)	2.35	1.62	2.02	1.77
Tanker (Chemical)	3.52	15.19	7.58	2.14
Tanker (Crude)	2.48	16.92	5.44	1.89
Tanker (Liquefied Gas)	0.15	0.10	0.13	0.83
Tanker (Product)	1.67	10.19	4.09	1.86
Towing Vessel (Oil)	3.80	1.14	1.84	5.59
Towing Vessel (Oil) – Bunkering	0.68	0.16	0.25	6.60

Vessel Type	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate
Vehicle Carrier	4.23	5.39	3.89	2.23

In terms of absolute values, the model produced an average of 1.11 drift grounding per simulation for car ferries. On average, car ferries produced 99,251.67 gallons of oil volume at risk, and 227.76 gallons of oil outflow per simulation (Table A-13). Looking beyond car ferries, the model produced an average of around 0.14 drift groundings per simulation for bulk carriers. Other leading vessel types include crude tankers, which produced an average of 369,415 gallons of oil volume at risk, and bulk carriers, which produced an average of 28.89 gallons of oil outflow per simulation (Table A-13).

Table A-13: Mean values per simulation for Scenario 2 by vessel type.

Vessel Type	Drift Groundings	Oil Volume at Risk	Oil Outflow
ATB	0.0010	141.5994	0.1122
Bulk Carrier	0.1351	94,933.5287	28.8860
General/Other Cargo Ship (Large)	0.0142	6,709.0301	3.0333
Tanker (Chemical)	0.0177	237,245.5784	17.3528
Container Ship	0.1209	279,096.8309	25.8548
Tanker (Crude)	0.0097	369,415.6543	9.5316
Cruise Ship	0.0116	8,072.8326	2.4864
Ferry (Car)	1.1107	99,251.6732	227.7616
Fishing Vessel (Large)	0.0126	1,955.9532	2.6839
Tanker (Liquified Gas)	0.0005	155.0850	0.1084
Tanker (Product)	0.0095	171,291.9078	9.2787
Towing Vessel (Oil) – Bunkering	0.0018	7.9070	0.0577
Towing Vessel (Oil)	0.0103	71.1453	0.5188
Vehicle Carrier	0.0201	18,928.4272	4.2927

Vessel type distribution: excluding car ferries

Primary risk metrics

The top three vessel types for drift groundings in the study area excluding car ferries were container ships (22.47 percent), bulk containers (17.50 percent), and vehicle ships (9.91 percent). The top three vessel types for oil volume at risk were container ships (20.23 percent), crude tankers (18.02 percent), and chemical tankers (16.93 percent). The top three vessel types for oil outflow were container ships (19.67 percent), bulk carriers (15.41 percent), and chemical tankers (14.74 percent).

Drift grounding rates

The top three vessel types (excluding ferries) for drift grounding rates were towed bunkering barges (6.60 percent), towed oil barges (5.59 percent), and container ships (2.98 percent). See Table A-14 for full results.

Table A-14: Relative frequency of oil spill risk metrics for Scenario 2 by vessel type, excluding car ferries.

Vessel Type	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate
ATB	1.14	0.96	0.91	1.64
Bulk Carrier	17.50	10.97	15.41	2.23
Container Ship	22.47	20.23	19.67	2.98
Cruise Ship	6.85	4.83	5.88	1.87
Fishing Vessel (Large)	5.07	1.60	4.30	1.38
General/Other Cargo Ship (Large)	5.74	2.80	4.64	1.77
Tanker (Chemical)	8.27	16.93	14.74	2.14
Tanker (Crude)	5.72	18.02	10.81	1.89
Tanker (Liquefied Gas)	0.69	0.73	0.77	0.83
Tanker (Product)	4.92	11.03	8.67	1.86
Towing Vessel (Oil)	9.69	2.86	4.50	5.59
Towing Vessel (Oil) – Bunkering	2.02	0.60	0.85	6.60
Vehicle Carrier	9.91	8.42	8.85	2.23

Changes in risk by ERTV location

Changes in risk by ERTV location was evaluating by comparing results with only the Neah Bay ERTV included to the results including an additional ERTV location. Comparisons were also made for each tug escort scenario.

Anacortes

The simulation results indicated a potential average of 1.4666 – 1.4762 drift groundings per simulated year (including ferries), and a potential average of 0.3585 – 0.3699 drift groundings per simulated year (excluding car ferries). Overall, the change in the primary risk metrics was small regardless of the scenario. In average, an Anacortes ERTV may prevent about 1 in 923 to 1 in 1845 drift groundings for all vessel types, and about 1 in 231 to 1 in 456 drift groundings of non-ferries vessel types, depending on the scenario.

Table A-15: Overall changes in oil spill risk metrics for the Anacortes ERTV for each tug escort scenario.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Anacortes ERTV	1.4762	1.4756	1.4666
Change in drift groundings with Anacortes ERTV	-0.0016	-0.0008	-0.0010
Percent change in drift groundings with Anacortes ERTV	-0.11	-0.05	-0.07
Oil volume at risk per simulation without Anacortes ERTV	1,303,683.1762	1,287,277.1530	1,280,512.6504

Category Description	Scenario 1	Scenario 2	Scenario 3
Change in oil volume at risk with Anacortes ERTV	-4,082.7689	-1,401.8179	-1,453.1685
Percent change in oil volume at risk with Anacortes ERTV	-0.31	-0.11	-0.11
Oil outflow per simulation without Anacortes ERTV	332.2809	331.9589	330.2013
Change in total oil outflow with Anacortes ERTV	-0.3973	-0.1922	-0.2386
Percent change in oil outflow with Anacortes ERTV	-0.12	-0.06	-0.07
Drift grounding rate without Anacortes ERTV	2.94	2.88	2.73
Change in grounding rate with Anacortes ERTV	-0.01	-0.01	-0.01

Table A-16: Overall changes in oil spill risk metrics for the Anacortes ERTV for each tug escort scenario, excluding car ferries.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Anacortes ERTV	0.3699	0.3650	0.3585
Change in drift groundings with Anacortes ERTV	-0.0016	-0.0008	-0.0010
Percent change in drift groundings with Anacortes ERTV	-0.42	-0.21	-0.27
Oil volume at risk per simulation without Anacortes ERTV	1,204,946.7835	1,188,025.4798	1,181,290.8965
Change in oil volume at risk with Anacortes ERTV	-4,082.7689	-1,401.8179	-1,453.1685
Percent change in oil volume at risk with Anacortes ERTV	-0.34	-0.12	-0.12
Oil outflow per simulation without Anacortes ERTV	105.5370	104.1973	102.9743
Change in total oil outflow with Anacortes ERTV	-0.3973	-0.1922	-0.2386
Percent change in oil outflow with Anacortes ERTV	-0.38	-0.18	-0.23
Drift grounding rate without Anacortes ERTV	2.61	2.55	2.39
Change in grounding rate with Anacortes ERTV	-0.01	-0.01	-0.01

Deltaport

Overall, the change in the primary risk metrics were small regardless of the scenario. On average, a Deltaport ERTV may prevent about 1 in 155 to 1 in 244 drift groundings for all vessel types, and about 1 in 70 to 1 in 87 drift groundings of non-ferries vessel types, depending on the scenario.

Table A-17: Overall changes in oil spill risk metrics for the Deltaport ERTV for each tug escort scenario.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Deltaport ERTV	1.4762	1.4756	1.4666
Change in drift groundings with Deltaport ERTV	-0.0095	-0.0078	-0.0060
Percent change in drift groundings with Deltaport ERTV	-0.64	-0.53	-0.41
Oil volume at risk per simulation without Deltaport ERTV	1,303,683.1762	1,287,277.1530	1,280,512.6504
Change in oil volume at risk with Deltaport ERTV	-9,946.9878	-8,514.0538	-6,068.1530
Percent change in oil volume at risk with Deltaport ERTV	-0.76	-0.66	-0.47
Oil outflow per simulation without Deltaport ERTV	332.2809	331.9589	330.2013
Change in total oil outflow with Deltaport ERTV	-2.1996	-1.7333	-1.3205
Percent change in oil outflow with Deltaport ERTV	-0.66	-0.52	-0.40
Drift grounding rate without Deltaport ERTV	2.94	2.88	2.73
Change in grounding rate with Deltaport ERTV	-0.02	-0.02	-0.01

Table A-18: Overall changes in oil spill risk metrics for the Deltaport ERTV for each tug escort scenario, excluding car ferries.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Deltaport ERTV	0.3699	0.3650	0.3585
Change in drift groundings with Deltaport ERTV	-0.0053	-0.0049	-0.0041
Percent change in drift groundings with Deltaport ERTV	-1.44	-1.35	-1.15
Oil volume at risk per simulation without Deltaport ERTV	1,204,946.7835	1,188,025.4798	1,181,290.8965
Change in oil volume at risk with Deltaport ERTV	-9,282.9721	-7,961.6048	-5,710.6860
Percent change in oil volume at risk with Deltaport ERTV	-0.77	-0.67	-0.48
Oil outflow per simulation without Deltaport ERTV	105.5370	104.1973	102.9743
Change in total oil outflow with Deltaport ERTV	-1.3086	-1.1274	-0.9285
Percent change in oil outflow with Deltaport ERTV	-1.24	-1.08	-0.90
Drift grounding rate without Deltaport ERTV	2.61	2.55	2.39

Category Description	Scenario 1	Scenario 2	Scenario 3
Change in grounding rate with Deltaport ERTV	-0.02	-0.01	-0.01

Port Angeles

Overall, the change in the primary risk metrics were small regardless of the scenario. In average, a Port Angeles ERTV may prevent about 1 in 284 to 1 in 321 drift groundings for all vessel types, and about 1 in 71 to 1 in 79 drift groundings of non-ferries vessel types, depending on the scenario.

Table A-19: Overall changes in oil spill risk metrics for the Port Angeles ERTV for each tug escort scenario.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Port Angeles ERTV	1.4762	1.4756	1.4666
Change in drift groundings with Port Angeles ERTV	-0.0052	-0.0046	-0.0049
Percent change in drift groundings with Port Angeles ERTV	-0.35	-0.31	-0.34
Oil volume at risk per simulation without Port Angeles ERTV	1,303,683.1762	1,287,277.1530	1,280,512.6504
Change in oil volume at risk with Port Angeles ERTV	-10,681.3248	-9,611.9213	-9,660.4915
Percent change in oil volume at risk with Port Angeles ERTV	-0.82	-0.75	-0.75
Oil outflow per simulation without Port Angeles ERTV	332.2809	331.9589	330.2013
Change in total oil outflow with Port Angeles ERTV	-1.2661	-1.1188	-1.1840
Percent change in oil outflow with Port Angeles ERTV	-0.38	-0.34	-0.36
Drift grounding rate without Port Angeles ERTV	2.94	2.88	2.73
Change in grounding rate with Port Angeles ERTV	-0.02	-0.02	-0.02

Table A-20: Overall changes in oil spill risk metrics for the Port Angeles ERTV for each tug escort scenario, excluding car ferries.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Port Angeles ERTV	0.3699	0.3650	0.3585
Change in drift groundings with Port Angeles ERTV	-0.0052	-0.0046	-0.0049
Percent change in drift groundings with Port Angeles ERTV	-1.41	-1.26	-1.38
Oil volume at risk per simulation without Port Angeles ERTV	1,204,946.7835	1,188,025.4798	1,181,290.8965

Category Description	Scenario 1	Scenario 2	Scenario 3
Change in oil volume at risk with Port Angeles ERTV	-10,681.3248	-9,611.9213	-9,660.4915
Percent change in oil volume at risk with Port Angeles ERTV	-0.89	-0.81	-0.82
Oil outflow per simulation without Port Angeles ERTV	105.5370	104.1973	102.9743
Change in total oil outflow with Port Angeles ERTV	-1.2661	-1.1188	-1.1840
Percent change in oil outflow with Port Angeles ERTV	-1.20	-1.07	-1.15
Drift grounding rate without Port Angeles ERTV	2.61	2.55	2.39
Change in grounding rate with Port Angeles ERTV	-0.02	-0.02	-0.02

Port Townsend

Overall, the change in the primary risk metrics were small regardless of the scenario. In average, a Port Townsend ERTV may prevent about 1 in 207 to 1 in 328 drift groundings for all vessel types, and about 1 in 82 to 1 in 116 drift groundings of non-ferries vessel types, depending on the scenario.

Table A-21: Overall changes in oil spill risk metrics for the Port Townsend ERTV for each tug escort scenario.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Port Townsend ERTV	1.4762	1.4756	1.4666
Change in drift groundings with Port Townsend ERTV	-0.0045	-0.0060	-0.0071
Percent change in drift groundings with Port Townsend ERTV	-0.31	-0.41	-0.48
Oil volume at risk per simulation without Port Townsend ERTV	1,303,683.1762	1,287,277.1530	1,280,512.6504
Change in oil volume at risk with Port Townsend ERTV	-10,435.8473	-3,919.9452	-4,085.8777
Percent change in oil volume at risk with Port Townsend ERTV	-0.80	-0.30	-0.32
Oil outflow per simulation without Port Townsend ERTV	332.2809	331.9589	330.2013
Change in total oil outflow with Port Townsend ERTV	-0.9956	-1.2682	-1.5126
Percent change in oil outflow with Port Townsend ERTV	-0.30	-0.38	-0.46
Drift grounding rate without Port Townsend ERTV	2.94	2.88	2.73
Change in grounding rate with Port Townsend ERTV	-0.03	-0.03	-0.01

Table A-22: Overall changes in oil spill risk metrics for the Port Townsend ERTV for each tug escort scenario, excluding car ferries.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Port Townsend ERTV	0.3699	0.3650	0.3585
Change in drift groundings with Port Townsend ERTV	-0.0045	-0.0034	-0.0031
Percent change in drift groundings with Port Townsend ERTV	-1.22	-0.92	-0.86
Oil volume at risk per simulation without Port Townsend ERTV	1,204,946.7835	1,188,025.4798	1,181,290.8965
Change in oil volume at risk with Port Townsend ERTV	-10,435.8473	-3,715.5332	-3,708.1684
Percent change in oil volume at risk with Port Townsend ERTV	-0.87	-0.31	-0.31
Oil outflow per simulation without Port Townsend ERTV	105.5370	104.1973	102.9743
Change in total oil outflow with Port Townsend ERTV	-0.9956	-0.6979	-0.6572
Percent change in oil outflow with Port Townsend ERTV	-0.94	-0.67	-0.64
Drift grounding rate without Port Townsend ERTV	2.61	2.55	2.39
Change in grounding rate with Port Townsend ERTV	-0.03	-0.03	-0.01

Roche Harbor

Overall, the change in the primary risk metrics were small regardless of the scenario. In average, a Roche Harbor ERTV may prevent about 1 in 104 to 1 in 159 drift groundings for all vessel types, and about 1 in 37 to 1 in 49 drift groundings of non-ferries vessel types, depending on the scenario.

Table A-23: Overall changes in oil spill risk metrics for the Roche Harbor ERTV for each tug escort scenario.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Roche Harbor ERTV	1.4762	1.4756	1.4666
Change in drift groundings with Roche Harbor ERTV	-0.0142	-0.0118	-0.0092
Percent change in drift groundings with Roche Harbor ERTV	-0.96	-0.80	-0.63
Oil volume at risk per simulation without Roche Harbor ERTV	1,303,683.1762	1,287,277.1530	1,280,512.6504
Change in oil volume at risk with Roche Harbor ERTV	-27,195.9061	-21,200.3633	-19,686.0872
Percent change in oil volume at risk with Roche Harbor ERTV	-2.09	-1.65	-1.54

Category Description	Scenario 1	Scenario 2	Scenario 3
Oil outflow per simulation without Roche Harbor ERTV	332.2809	331.9589	330.2013
Change in total oil outflow with Roche Harbor ERTV	-3.5242	-2.9104	-2.3922
Percent change in oil outflow with Roche Harbor ERTV	-1.06	-0.88	-0.72
Drift grounding rate without Roche Harbor ERTV	2.94	2.88	2.73
Change in grounding rate with Roche Harbor ERTV	-0.05	-0.04	-0.04

Table A-24: Overall changes in oil spill risk metrics for the Roche Harbor ERTV for each tug escort scenario, excluding car ferries.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Roche Harbor ERTV	0.3699	0.3650	0.3585
Change in drift groundings with Roche Harbor ERTV	-0.0100	-0.0095	-0.0073
Percent change in drift groundings with Roche Harbor ERTV	-2.71	-2.60	-2.05
Oil volume at risk per simulation without Roche Harbor ERTV	1,204,946.7835	1,188,025.4798	1,181,290.8965
Change in oil volume at risk with Roche Harbor ERTV	-26,829.6461	-20,858.8533	-19,442.0682
Percent change in oil volume at risk with Roche Harbor ERTV	-2.23	-1.76	-1.65
Oil outflow per simulation without Roche Harbor ERTV	105.5370	104.1973	102.9743
Change in total oil outflow with Roche Harbor ERTV	-2.7243	-2.4114	-2.0001
Percent change in oil outflow with Roche Harbor ERTV	-2.58	-2.31	-1.94
Drift grounding rate without Roche Harbor ERTV	2.61	2.55	2.39
Change in grounding rate with Roche Harbor ERTV	-0.05	-0.04	-0.04

Sidney

Overall, the change in the primary risk metrics were small regardless of the scenario. On average, a Sidney ERTV may prevent about 1 in 81 to 1 in 107 drift groundings for all vessel types, and about 1 in 49 to 1 in 70 drift groundings of non-ferries vessel types, depending on the scenario.

Table A-25: Overall changes in oil spill risk metrics for the Sidney ERTV for each tug escort scenario.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Sidney ERTV	1.4762	1.4756	1.4666

Category Description	Scenario 1	Scenario 2	Scenario 3
Change in drift groundings with Sidney ERTV	-0.0182	-0.0164	-0.0137
Percent change in drift groundings with Sidney ERTV	-1.23	-1.11	-0.93
Oil volume at risk per simulation without Sidney ERTV	1,303,683.1762	1,287,277.1530	1,280,512.6504
Change in oil volume at risk with Sidney ERTV	-13,483.1066	-11,109.0692	-9,217.0707
Percent change in oil volume at risk with Sidney ERTV	-1.03	-0.86	-0.72
Oil outflow per simulation without Sidney ERTV	332.2809	331.9589	330.2013
Change in total oil outflow with Sidney ERTV	-3.8941	-3.4611	-2.9160
Percent change in oil outflow with Sidney ERTV	-1.17	-1.04	-0.88
Drift grounding rate without Sidney ERTV	2.94	2.88	2.73
Change in grounding rate with Sidney ERTV	-0.04	-0.03	-0.03

Table A-26: Overall changes in oil spill risk metrics for the Sidney ERTV for each tug escort scenario, excluding car ferries.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Sidney ERTV	0.3699	0.3650	0.3585
Change in drift groundings with Sidney ERTV	-0.0073	-0.0074	-0.0052
Percent change in drift groundings with Sidney ERTV	-1.98	-2.01	-1.45
Oil volume at risk per simulation without Sidney ERTV	1,204,946.7835	1,188,025.4798	1,181,290.8965
Change in oil volume at risk with Sidney ERTV	-12,885.5826	-10,536.2952	-8,741.7877
Percent change in oil volume at risk with Sidney ERTV	-1.07	-0.89	-0.74
Oil outflow per simulation without Sidney ERTV	105.5370	104.1973	102.9743
Change in total oil outflow with Sidney ERTV	-1.8673	-1.7352	-1.2970
Percent change in oil outflow with Sidney ERTV	-1.77	-1.67	-1.26
Drift grounding rate without Sidney ERTV	2.61	2.55	2.39
Change in grounding rate with Sidney ERTV	-0.03	-0.03	-0.03

Victoria

Overall, the change in the primary risk metrics were small regardless of the scenario. On average, a Victoria ERTV may prevent about 1 in 208 to 1 in 254 drift groundings for all vessel types, and about 1 in 52 to 1 in 63 drift groundings of non-ferries vessel types, depending on the scenario.

Table A-27: Overall changes in oil spill risk metrics for the Victoria ERTV for each tug escort scenario.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Victoria ERTV	1.4762	1.4756	1.4666
Change in drift groundings with Victoria ERTV	-0.0071	-0.0058	-0.0060
Percent change in drift groundings with Victoria ERTV	-0.48	-0.39	-0.41
Oil volume at risk per simulation without Victoria ERTV	1,303,683.1762	1,287,277.1530	1,280,512.6504
Change in oil volume at risk with Victoria ERTV	-13,254.3178	-10,579.6303	-9,018.9250
Percent change in oil volume at risk with Victoria ERTV	-1.02	-0.82	-0.70
Oil outflow per simulation without Victoria ERTV	332.2809	331.9589	330.2013
Change in total oil outflow with Victoria ERTV	-1.7082	-1.3867	-1.3918
Percent change in oil outflow with Victoria ERTV	-0.51	-0.42	-0.42
Drift grounding rate without Victoria ERTV	2.94	2.88	2.73
Change in grounding rate with Victoria ERTV	-0.03	-0.03	-0.03

Table A-28: Overall changes in oil spill risk metrics for the Victoria ERTV for each tug escort scenario, excluding car ferries.

Category Description	Scenario 1	Scenario 2	Scenario 3
Drift groundings per simulation without Victoria ERTV	0.3699	0.3650	0.3585
Change in drift groundings with Victoria ERTV	-0.0071	-0.0058	-0.0060
Percent change in drift groundings with Victoria ERTV	-1.93	-1.59	-1.68
Oil volume at risk per simulation without Victoria ERTV	1,204,946.7835	1,188,025.4798	1,181,290.8965
Change in oil volume at risk with Victoria ERTV	-13,254.3178	-10,579.6303	-9,018.9250
Percent change in oil volume at risk with Victoria ERTV	-1.10	-0.89	-0.76
Oil outflow per simulation without Victoria ERTV	105.5370	104.1973	102.9743

Category Description	Scenario 1	Scenario 2	Scenario 3
Change in total oil outflow with Victoria ERTV	-1.7082	-1.3867	-1.3918
Percent change in oil outflow with Victoria ERTV	-1.62	-1.33	-1.35
Drift grounding rate without Victoria ERTV	2.61	2.55	2.39
Change in grounding rate with Victoria ERTV	-0.03	-0.03	-0.03

Comparing changes in risk by ERTV Location

Overall comparison of ERTV locations

Overall, ERTVs located in Roche Harbor and Sidney provide the largest reductions in drift groundings, oil volumes at risk, and oil outflows regardless of the scenario. Roche Harbor resulted in the largest reductions in the oil volume at risk and grounding rates, while Sidney resulted in the largest reductions in drift groundings and oil outflows. Regardless of the ERTV location, these reductions were modest (less than 2.1 percent).

When car ferries are excluded, ERTVs located in Roche Harbor provide the largest reductions in drift groundings, oil volumes at risk, and oil outflows regardless of the scenario. Sidney ERTV resulted in the second largest reduction in drift groundings in all scenarios and second largest reduction in oil outflow in Scenario 1 and 2, Victoria ERTV location resulted in the second largest reduction in oil volume at risk in all scenarios and second largest reduction in oil outflow in Scenario 3. Regardless of the ERTV location, these reductions were modest (less than 2.7 percent).

Table A-29: Comparison of oil spill risk metrics by ERTV locations for Scenario 1.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	-0.11	-0.31	-0.12	2.94	-0.01
Deltaport	-0.64	-0.76	-0.66	2.94	-0.02
Port Angeles	-0.35	-0.82	-0.38	2.94	-0.02
Port Townsend	-0.31	-0.80	-0.30	2.94	-0.03
Roche Harbor	-0.96	-2.09	-1.06	2.94	-0.05
Sidney	-1.23	-1.03	-1.17	2.94	-0.04
Victoria	-0.48	-1.02	-0.51	2.94	-0.03

Table A-30: Comparison of oil spill risk metrics by ERTV locations for Scenario 1, excluding car ferries.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	-0.42	-0.34	-0.38	2.61	-0.01

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Deltaport	-1.44	-0.77	-1.24	2.61	-0.02
Port Angeles	-1.41	-0.89	-1.20	2.61	-0.02
Port Townsend	-1.22	-0.87	-0.94	2.61	-0.03
Roche Harbor	-2.71	-2.23	-2.58	2.61	-0.05
Sidney	-1.98	-1.07	-1.77	2.61	-0.03
Victoria	-1.93	-1.10	-1.62	2.61	-0.03

Table A-31: Comparison of oil spill risk metrics by ERTV locations for Scenario 2.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	-0.05	-0.11	-0.06	2.88	-0.01
Deltaport	-0.53	-0.66	-0.52	2.88	-0.02
Port Angeles	-0.31	-0.75	-0.34	2.88	-0.02
Port Townsend	-0.41	-0.30	-0.38	2.88	-0.03
Roche Harbor	-0.80	-1.65	-0.88	2.88	-0.04
Sidney	-1.11	-0.86	-1.04	2.88	-0.03
Victoria	-0.39	-0.82	-0.42	2.88	-0.03

Table A-32: Comparison of oil spill risk metrics by ERTV locations for Scenario 2, excluding car ferries.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	-0.21	-0.12	-0.18	2.55	-0.01
Deltaport	-1.35	-0.67	-1.08	2.55	-0.01
Port Angeles	-1.26	-0.81	-1.07	2.55	-0.02
Port Townsend	-0.92	-0.31	-0.67	2.55	-0.03
Roche Harbor	-2.60	-1.76	-2.31	2.55	-0.04
Sidney	-2.01	-0.89	-1.67	2.55	-0.03
Victoria	-1.59	-0.89	-1.33	2.55	-0.03

Table A-33: Comparison of oil spill risk metrics by ERTV locations for Scenario 3.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	-0.06	-0.11	-0.07	2.73	-0.01
Deltaport	-0.41	-0.47	-0.40	2.73	-0.01

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Port Angeles	-0.34	-0.75	-0.36	2.73	-0.02
Port Townsend	-0.48	-0.32	-0.46	2.73	-0.01
Roche Harbor	-0.63	-1.54	-0.72	2.73	-0.04
Sidney	-0.93	-0.72	-0.88	2.73	-0.03
Victoria	-0.41	-0.70	-0.42	2.73	-0.03

Table A-34: Comparison of oil spill risk metrics by ERTV locations for Scenario 3, excluding car ferries.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	-0.27	-0.12	-0.23	2.39	-0.01
Deltaport	-1.15	-0.48	-0.90	2.39	-0.01
Port Angeles	-1.38	-0.82	-1.15	2.39	-0.02
Port Townsend	-0.86	-0.31	-0.64	2.39	-0.01
Roche Harbor	-2.05	-1.65	-1.94	2.39	-0.04
Sidney	-1.45	-0.74	-1.26	2.39	-0.03
Victoria	-1.68	-0.76	-1.35	2.39	-0.03

Detailed comparison of ERTV locations by vessel type and by zone for Scenario 1

Vessel type risk

For drift groundings:

- ATBs benefit the most from ERTVs located in Anacortes or Roche Harbor.
- Bulk carriers, chemical tankers, container ships, crude tanker, and vehicle carriers benefit the most from ERTV located in Roche Harbor.
- Largo cargo vessels and cruise ships benefit the most from ERTV located in Victoria.
- Car ferries benefit the most from ERTV located in Sidney.
- Large fishing vessels and towed oil barges benefit the most from ERTV located in Port Townsend.
- Liquid gas carriers benefit the most from ERTV located in Port Angeles.
- Product tankers benefit the most from ERTVs located in Deltaport, Port Angeles, or Victoria.
- Towed bunkering barges benefit the most from ERTVs located in Sidney or Victoria.

For oil volume at risk:

- ATBs, bulk carriers, chemical tankers, container ships, and crude tankers benefit the most from ERTVs located in Roche Harbor.
- Large cargo vessels, cruise ships, and towed bunkering barges benefit the most from ERTV located in Victoria.

- Car ferries benefit the most from ERTV located in Deltaport.
- Large fishing vessels benefit the most from ERTVs located in Port Angeles or Victoria.
- Liquid gas carriers benefit the most from ERTV located in Port Angeles.
- Product tankers benefit the most from ERTV located in Deltaport.
- Towed oil barges benefit the most from ERTV located in Port Townsend.
- Vehicle carriers benefit the most from ERTV located in Sidney.

For oil outflow:

- ATBs benefit the most from ERTVs located in Anacortes or Roche Harbor.
- Bulk carriers, chemical tankers, container ships, and crude tankers benefit the most from ERTV located in Roche Harbor.
- Large cargo vessels, cruise ships, and towed bunkering barges benefit the most from ERTV located in Victoria.
- Car ferries and vehicle carriers benefit the most from ERTV located in Sidney.
- Large fishing vessels and towed oil barges benefit the most from ERTV located in Port Townsend.
- Liquid gas carriers benefit the most from ERTV located in Port Angeles.
- Product tankers benefit the most from ERTVs located in Deltaport, Port Angeles, or Victoria.

Changes in groundings rates per vessel type were small regardless of the ERTV locations, ranging from -0.09 percent to 0.00 percent.

Table A-35 to Table A-38 summarize the changes in oil spill metrics for each vessel type and ERTV location.

Table A-35: Relative change in drift grounding by vessel type and ERTV location for Scenario 1.

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
ATB	-0.70	0.00	0.00	-0.35	-0.70	-0.35	0.00
Bulk Carrier	-0.83	-2.55	-1.69	-0.83	-3.17	-2.70	-2.97
Container Ship	0.00	-0.66	-0.99	-1.48	-2.39	-1.65	-0.91
Cruise Ship	-0.34	-0.34	-0.68	-1.82	-1.03	-0.46	-2.05
Ferry (Car)	0.00	-0.38	0.00	0.00	-0.38	-0.98	0.00
Fishing Vessel (Large)	-0.81	-1.61	-4.44	-4.84	-3.23	-3.23	-4.44
General/Other Cargo Ship (Large)	0.00	-1.61	-1.72	-1.23	-1.61	-0.54	-2.20
Tanker (Chemical)	-0.07	-0.81	-0.44	0.00	-3.47	-1.99	-0.59
Tanker (Crude)	-0.93	-0.40	-0.80	-0.93	-1.34	-0.53	-0.93

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Tanker (Liquefied Gas)	-1.00	0.00	-1.99	0.00	0.00	0.00	-1.00
Tanker (Product)	0.00	-0.53	-0.53	0.00	-0.27	0.00	-0.53
Towing Vessel (Oil)	-0.80	-0.46	-0.28	-2.03	-0.83	-0.58	-0.32
Towing Vessel (Oil) – Bunkering	-0.23	0.00	-0.46	-0.93	-0.93	-1.16	-1.16
Vehicle Carrier	-0.28	-1.16	-2.61	-1.15	-5.40	-2.85	-2.61

Table A-36: Relative change in oil volume at risk by vessel type and ERTV location for Scenario 1.

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
ATB	-0.68	0.00	0.00	-0.39	-0.74	-0.37	0.00
Bulk Carrier	-0.76	-2.76	-1.60	-1.09	-3.00	-2.63	-2.97
Container Ship	0.00	-0.36	-0.89	-1.73	-2.54	-1.38	-0.82
Cruise Ship	-0.55	-0.40	-0.89	-1.84	-1.32	-0.71	-2.38
Ferry (Car)	0.00	-0.67	0.00	0.00	-0.37	-0.61	0.00
Fishing Vessel (Large)	-0.48	-1.05	-2.50	-2.25	-2.01	-1.94	-2.50
General/Other Cargo Ship (Large)	0.00	-1.93	-1.49	-0.90	-1.25	-0.50	-2.14
Tanker (Chemical)	-0.08	-0.71	-0.48	0.00	-3.88	-1.48	-0.62
Tanker (Crude)	-0.80	-0.47	-0.82	-1.06	-1.53	-0.58	-1.06
Tanker (Liquefied Gas)	-0.26	0.00	-5.69	0.00	0.00	0.00	-5.43
Tanker (Product)	0.00	-1.00	-0.98	0.00	-0.20	0.00	-0.98
Towing Vessel (Oil)	-0.77	-0.39	-0.21	-1.96	-0.78	-0.48	-0.26
Towing Vessel (Oil) – Bunkering	-0.14	0.00	-0.52	-0.92	-0.89	-1.15	-1.17
Vehicle Carrier	-0.29	-1.19	-2.52	-1.16	-5.49	-2.99	-2.51

Table A-37: Relative change in oil outflow by vessel type and ERTV location for Scenario 1.

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
ATB	-0.70	0.00	0.00	-0.35	-0.70	-0.35	0.00
Bulk Carrier	-0.83	-2.55	-1.69	-0.83	-3.17	-2.70	-2.97
Container Ship	0.00	-0.66	-0.99	-1.48	-2.39	-1.65	-0.91
Cruise Ship	-0.34	-0.34	-0.68	-1.82	-1.03	-0.46	-2.05
Ferry (Car)	0.00	-0.39	0.00	0.00	-0.35	-0.89	0.00
Fishing Vessel (Large)	-0.81	-1.61	-4.44	-4.84	-3.23	-3.23	-4.44
General/Other Cargo Ship (Large)	0.00	-1.61	-1.72	-1.23	-1.61	-0.54	-2.20
Tanker (Chemical)	-0.07	-0.81	-0.44	0.00	-3.47	-1.99	-0.59
Tanker (Crude)	-0.93	-0.40	-0.80	-0.93	-1.34	-0.53	-0.93
Tanker (Liquefied Gas)	-1.00	0.00	-1.99	0.00	0.00	0.00	-1.00
Tanker (Product)	0.00	-0.53	-0.53	0.00	-0.27	0.00	-0.53
Towing Vessel (Oil)	-0.77	-0.39	-0.21	-1.96	-0.78	-0.48	-0.26
Towing Vessel (Oil) – Bunkering	-0.14	0.00	-0.52	-0.92	-0.89	-1.15	-1.17
Vehicle Carrier	-0.28	-1.16	-2.61	-1.15	-5.40	-2.85	-2.61

Table A-38: Change in grounding rate by vessel type and ERTV Location for Scenario 1.

Vessel Type [original grounding rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
ATB [1.83]	-0.01	0.00	0.00	-0.01	-0.01	-0.01	0.00
Bulk Carrier [2.27]	-0.01	-0.05	-0.03	-0.02	-0.09	-0.07	-0.05
Container Ship [2.98]	0.00	-0.02	-0.02	-0.04	-0.08	-0.06	-0.03
Cruise Ship [1.88]	-0.01	-0.01	-0.02	-0.03	-0.03	-0.01	-0.04
Ferry (Car) [7.68]	0.00	-0.04	0.00	0.00	-0.04	-0.06	0.00
Fishing Vessel (Large) [1.36]	-0.01	-0.02	-0.07	-0.06	-0.04	-0.04	-0.07
General/Other Cargo Ship (Large) [1.85]	0.00	-0.02	-0.04	-0.04	-0.02	-0.01	-0.04
Tanker (Chemical) [2.18]	0.00	-0.02	-0.01	0.00	-0.08	-0.05	-0.02

Vessel Type [original grounding rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Tanker (Crude) [1.94]	-0.02	-0.01	-0.01	-0.02	-0.03	-0.01	-0.02
Tanker (Liquefied Gas) [0.83]	-0.01	0.00	-0.01	0.00	0.00	0.00	-0.01
Tanker (Product) [1.85]	0.00	-0.01	-0.01	0.00	-0.01	0.00	-0.01
Towing Vessel (Oil) [5.97]	-0.04	-0.04	-0.02	-0.12	-0.06	-0.05	-0.02
Towing Vessel (Oil) – Bunkering [6.43]	-0.01	0.00	-0.05	-0.06	-0.05	-0.06	-0.08
Vehicle Carrier [2.20]	0.00	-0.02	-0.05	-0.02	-0.09	-0.05	-0.05

Table A-39 summarizes per vessel type the ERTV locations resulting in no detectable changes in oil spill risk metrics (white), detectable changes in all oil spill risk metrics for each vessel type (grey), the above average detectable changes in oil spill risk metrics for each vessel type (black).

Table A-39: Changes in all oil spill risk metrics by vessel type and ERTV location for Scenario 1. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.

Vessel Type	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
ATB							
Bulk Carrier							
Container Ship							
Cruise Ship							
Ferry (Car)							
Fishing Vessel (Large)							
General/Other Cargo Ship (Large)							
Tanker (Chemical)							
Tanker (Crude)							
Tanker (Liquefied Gas)							
Tanker (Product)							

Vessel Type	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Towing Vessel (Oil)							
Towing Vessel (Oil) – Bunkering							
Vehicle Carrier							

Zone risk

Table A-40 and Table A-41 show the mean values per simulation, for each risk metric, by geographic zone, for Scenario 1.

Table A-40: Mean values per simulation for Scenario 1 by geographic zone.

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Admiralty Inlet	0.0432	40921.96	9.3628
Bellingham Channel, Sinclair Island, and waters to the East	0.0053	73175.07	3.1438
Boundary Bay	0	0	0
Carr Inlet	0	0	0
Case Inlet to Oakland Bay	0	0	0
Colvos Passage	0.0018	754.3532	0.3644
Dyes Inlet	0	0	0
Eastern Strait of Juan de Fuca	0.0012	17137.63	0.638
Eld Inlet	0	0	0
Guemes Channel and Saddlebags	0.0153	112003.7	5.5751
Gulf Islands	0	0	0
Haro Strait and Boundary Pass	0.0549	117735.3	14.242
Hood Canal	0	0	0
Howe Sound	0.0703	7940.256	14.9676
Lake Washington Ship Canal	0.0023	294.468	0.4919
Nanaimo	0.068	6574.375	12.5418
Northern Gulf Islands	0.0007	322.202	0.1379
Port Orchard	0	0	0
Port Susan	0	0	0
Possession Sound and Saratoga Passage	0.0607	7713.278	12.9697
Puget Sound	0.3006	170696.1	64.1438
Rich Passage and Sinclair Inlet	0.0372	4086.495	7.9972
Rosario Strait	0.0268	97052.78	8.2003
San Juan Islands	0.1125	18316.75	24.3727
Skagit Bay	0.0001	6.4775	0.0109

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
South Sound to Olympia	0.0142	1297.501	3.0407
Southern Gulf Islands	0.3226	58554.6	67.9476
Strait of Georgia	0.0252	69894.14	4.6069
Strait of Georgia - Below 49th	0.0548	11427.62	11.7362
Strait of Georgia - North	0.1263	70098.75	24.0296
Strait of Georgia - South	0.0013	2978.129	0.2958
Vancouver	0.0939	330778.1	31.9747
Western Strait of Juan de Fuca	0.0371	83923.09	9.4895

Table A-41: Mean values per simulation for Scenario 1 by geographic zone, excluding car ferries.

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Admiralty Inlet	0.0199	40354.86	4.3729
Bellingham Channel, Sinclair Island, and waters to the East	0.004	73069.05	2.8586
Boundary Bay	0	0	0
Carr Inlet	0	0	0
Case Inlet to Oakland Bay	0	0	0
Colvos Passage	0.0013	742.2012	0.2575
Dyes Inlet	0	0	0
Eastern Strait of Juan de Fuca	0.0012	17137.63	0.638
Eld Inlet	0	0	0
Guemes Channel and Saddlebags	0.0048	111546.2	4.078
Gulf Islands	0	0	0
Haro Strait and Boundary Pass	0.0531	117588.5	13.85
Hood Canal	0	0	0
Howe Sound	0.0011	432.9893	0.1761
Lake Washington Ship Canal	0.0023	294.468	0.4919
Nanaimo	0.0021	1016.284	0.3518
Northern Gulf Islands	0.0007	322.202	0.1379
Port Orchard	0	0	0
Port Susan	0	0	0
Possession Sound and Saratoga Passage	0.0018	2164.193	0.388
Puget Sound	0.0858	148680.9	18.201
Rich Passage and Sinclair Inlet	0.0001	1110.145	0.049
Rosario Strait	0.0045	95210.35	3.4242
San Juan Islands	0.0035	12456.04	1.0627
Skagit Bay	0.0001	6.4775	0.0109
South Sound to Olympia	0.0019	1008.399	0.4032

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Southern Gulf Islands	0.0221	31921.79	5.2521
Strait of Georgia	0.0035	68592.25	2.3616
Strait of Georgia - Below 49th	0.0033	4399.235	0.7227
Strait of Georgia - North	0.0341	60186.86	7.5758
Strait of Georgia - South	0.0013	2978.129	0.2958
Vancouver	0.0939	330778.1	31.9747
Western Strait of Juan de Fuca	0.0236	82949.48	6.6025

There were several zones where there were no changes in drift groundings, oil volume at risk, and oil outflows for all ERTV locations for Scenario 1. They include Boundary Bay, Carr Inlet, Case Inlet to Oakland Bay, Colvos Passage, Dyes Inlet, Eld Inlet, Gulf Islands, Hood Canal, Howe Sound, Lake Washington Ship Canal, Nanaimo, Northern Gulf Islands, Port Orchard, Port Susan, Possession Sound and Saratoga Passage, Rich Passage and Sinclair Inlet, Skagit Bay, and South Sound to Olympia. For improved readability, those zones are omitted in the following tables.

Table A-42: Mean change in absolute values for drift grounding by geographic zone and ERTV location for Scenario 1.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	0	0	0	-0.0033	0	0	0
Bellingham Channel, Sinclair Island, and waters to the East	0	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-0.0002	-0.0001	-0.0002	-0.0003	-0.0003	-0.0001	-0.0003
Guemes Channel and Saddlebags	0	0	0	0	0	0	0
Haro Strait and Boundary Pass	-0.0001	-0.0001	0	0	-0.0051	-0.0036	-0.0006
Puget Sound	0	0	0	-0.0003	0	0	0
Rosario Strait	-0.0001	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-0.0024	0	0
Southern Gulf Islands	0	-0.0001	0	0	-0.0039	-0.0119	-0.0001
Strait of Georgia	0	-0.0022	0	0	0	0	0
Strait of Georgia - Below 49th	-0.0006	-0.0011	-0.0006	-0.0006	-0.0011	-0.0011	-0.0006
Strait of Georgia - North	0	-0.0054	0	0	-0.0001	-0.0001	0
Strait of Georgia - South	-0.0006	-0.0006	0	0	-0.0006	-0.0006	-0.0006
Vancouver	0	0	0	0	0	0	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Western Strait of Juan de Fuca	-0.0001	-0.0001	-0.0043	-0.0001	-0.0007	-0.0007	-0.0049

Table A-43: Relative change in drift grounding by geographic zone and ERTV location for Scenario 1.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	0.00	0.00	0.00	-7.53	0.00	0.00	0.00
Bellingham Channel, Sinclair Island, and waters to the East	-0.17	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-12.50	-8.15	-19.56	-23.91	-23.68	-11.41	-27.48
Guemes Channel and Saddlebags	-0.14	-0.09	-0.09	-0.09	-0.09	-0.09	-0.09
Haro Strait and Boundary Pass	-0.10	-0.10	-0.07	0.00	-9.22	-6.63	-1.15
Puget Sound	0.00	0.00	0.00	-0.10	0.00	0.00	0.00
Rosario Strait	-0.33	0.00	0.00	0.00	-.0.06	0.00	0.00
San Juan Islands	-0.01	0.00	0.00	-0.01	-2.17	-0.01	-0.01
Southern Gulf Islands	0.00	-0.02	0.00	0.00	-1.22	-3.70	-0.02
Strait of Georgia	0.00	-8.65	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-1.04	-1.97	-1.04	-1.04	-1.96	-1.96	-1.04
Strait of Georgia - North	0.00	-4.25	0.00	0.00	-0.07	-0.07	0.00
Strait of Georgia South	-45.55	-45.55	0.00	0.00	-45.55	-45.55	-45.55
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	-0.15	-0.15	-11.66	-0.18	-1.81	-1.81	-13.29

Table A-44: Mean change in absolute values for oil volume at risk by geographic zone and ERTV location for Scenario 1.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	0	0	0	-5902.4	0	0	0
Bellingham Channel, Sinclair Island, and	-0.4151	0	0	0	0	0	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
waters to the East							
Eastern Strait of Juan de Fuca	-1790.64	-8.8762	-1798.38	-3632.45	-3708.25	-1790.54	-3677.46
Guemes Channel and Saddlebags	-0.0838	-0.0247	-0.0247	-0.0247	-0.0247	-0.0247	-0.0247
Haro Strait and Boundary Pass	-233.362	-54.7559	-44.6298	0	-12718.3	-5061.68	-673.663
Puget Sound	-0.1057	0	-0.1057	-123.459	-0.1057	0	-0.1057
Rosario Strait	-854.917	0	0	0	-0.7006	0	0
San Juan Islands	-414.564	0	0	-414.564	-4754.64	-414.564	-414.564
Southern Gulf Islands	0	-180.085	0	0	-3635.34	-3837.73	-180.127
Strait of Georgia	0	-4269.27	0	0	0	0	0
Strait of Georgia - Below 49th	-300.727	-398.258	-300.727	-300.727	-398.226	-398.226	-300.727
Strait of Georgia - North	0	-4547.74	0	0	-631.872	-631.872	0
Strait of Georgia - South	-433.2	-433.2	0	0	-433.2	-433.2	-433.2
Vancouver	0	-0.0317	0	0	0	0	0
Western Strait of Juan de Fuca	-54.7509	-54.7509	-8537.45	-62.2204	-915.274	-915.274	-7574.45

Table A-45: Relative change in oil volume at risk by geographic zone and ERTV location for Scenario 1.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	0.00	0.00	0.00	-14.42	0.00	0.00	0.00
Bellingham Channel, Sinclair Island, and waters to the East	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-10.45	-0.05	-10.49	-21.20	-21.64	-10.45	-21.46

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.20	-0.05	-0.04	0.00	-10.80	-4.30	-0.57
Puget Sound	0.00	0.00	0.00	-0.08	0.00	0.00	0.00
Rosario Strait	-0.88	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	-2.26	0.00	0.00	-2.26	-25.96	-2.26	-2.26
Southern Gulf Islands	0.00	-0.31	0.00	0.00	-6.21	-6.55	-0.31
Strait of Georgia	0.00	-6.11	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-2.63	-3.49	-2.63	-2.63	-3.48	-3.48	-2.63
Strait of Georgia - North	0.00	-6.49	0.00	0.00	-0.90	-0.90	0.00
Strait of Georgia South	-14.55	-14.55	0.00	0.00	-14.55	-14.55	-14.55
Western Strait of Juan de Fuca	-0.07	-0.07	-10.17	-0.07	-1.09	-1.09	-9.03

Table A-46: Mean change in absolute values for oil outflow by geographic zone and ERTV location for Scenario 1.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	0	0	0	-0.6639	0	0	0
Bellingham Channel, Sinclair Island, and waters to the East	-0.0011	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-0.0613	-0.0214	-0.0819	-0.1219	-0.1234	-0.0606	-0.1333
Guemes Channel and Saddlebags	-0.0006	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002
Haro Strait and Boundary Pass	-0.0216	-0.0122	-0.0086	0	-1.3449	-0.8702	-0.1455
Puget Sound	-0.0008	0	-0.0008	-0.0604	-0.0008	0	-0.0008
Rosario Strait	-0.0422	0	0	0	-0.0012	0	0
San Juan Islands	-0.0131	0	0	-0.0131	-0.6116	-0.0131	-0.0131
Southern Gulf Islands	0	-0.0216	0	0	-0.8816	-2.3896	-0.0219
Strait of Georgia	0	-0.5351	0	0	0	0	0
Strait of Georgia - Below 49th	-0.1222	-0.2294	-0.1222	-0.1222	-0.2292	-0.2292	-0.1222

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Strait of Georgia - North	0	-1.2451	0	0	-0.0663	-0.0663	0
Strait of Georgia - South	-0.1222	-0.1222	0	0	-0.1222	-0.1222	-0.1222
Vancouver	0	-0.0002	0	0	0	0	0
Western Strait of Juan de Fuca	-0.0122	-0.0122	-1.0525	-0.0139	-0.1429	-0.1429	-1.149

Table A-47: Relative change in oil outflow by geographic zone and ERTV location for Scenario 1.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	0.00	0.00	0.00	-7.09	0.00	0.00	0.00
Bellingham Channel, Sinclair Island, and waters to the East	-0.04	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-9.61	-3.35	-12.84	-19.10	-19.34	-9.49	-20.90
Guemes Channel and Saddlebags	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.15	-0.09	-0.06	0.00	-9.44	-6.11	-1.02
Puget Sound	0.00	0.00	0.00	-0.09	0.00	0.00	0.00
Rosario Strait	-0.51	0.00	0.00	0.00	-0.01	0.00	0.00
San Juan Islands	-0.05	0.00	0.00	-0.05	-2.51	-0.05	-0.05
Southern Gulf Islands	0.00	-0.03	0.00	0.00	-1.30	-3.52	-0.03
Strait of Georgia	0.00	-11.61	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-1.04	-1.95	-1.04	-1.04	-1.95	-1.95	-1.04
Strait of Georgia - North	0.00	-5.18	0.00	0.00	-0.28	-0.28	0.00
Strait of Georgia South	-41.31	-41.31	0.00	0.00	-41.31	-41.31	-41.31
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	-0.13	-0.13	-11.09	-0.15	-1.51	-1.51	-12.11

Table A-48: Change in grounding rate by geographic zone and ERTV location for Scenario 1.

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet [1.85]	0.00	0.00	0.00	-0.37	0.00	0.00	0.00

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Bellingham Channel, Sinclair Island, and waters to the East [4.44]	-0.08	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca [0.34]	-0.02	-0.01	-0.02	-0.03	-0.04	-0.01	-0.04
Guemes Channel and Saddlebags [10.77]	-0.16	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
Haro Strait and Boundary Pass [5.22]	-0.05	-0.01	-0.03	0.00	-0.66	-0.42	-0.09
Puget Sound [6.41]	-0.01	0.00	-0.01	-0.03	-0.01	0.00	-0.01
Rosario Strait [3.09]	-0.07	0.00	0.00	0.00	-0.02	0.00	0.00
San Juan Islands [3.13]	-0.05	0.00	0.00	-0.05	-0.38	-0.05	-0.05
Southern Gulf Islands [8.50]	0.00	-0.03	0.00	0.00	-0.33	-0.45	-0.06
Strait of Georgia [2.05]	0.00	-0.12	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th [1.40]	-0.01	-0.06	-0.01	-0.01	-0.04	-0.04	-0.01
Strait of Georgia – North [2.55]	0.00	-0.09	0.00	0.00	-0.01	-0.01	0.00
Strait of Georgia South [1.41]	-0.03	-0.03	0.00	0.00	-0.03	-0.03	-0.03
Vancouver [12.28]	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca [0.41]	0.00	0.00	-0.05	0.00	-0.01	-0.01	-0.05

Table A-49 summarizes the ERTV locations resulting in no detectable changes in oil spill risk metrics (white), detectable changes in all oil spill risk metrics for each vessel type (grey), the above average detectable changes in oil spill risk metrics for each vessel type (black).

Table A-49: Changes in all oil spill risk metrics (rounded to the nearest 0.01) by geographic zone and ERTV location for Scenario 1. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet							
Eastern Strait of Juan de Fuca							
Haro Strait and Boundary Pass							

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Puget Sound							
Rosario Strait							
San Juan Islands							
Southern Gulf Islands							
Strait of Georgia							
Strait of Georgia – Below 49th							
Strait of Georgia – North							
Strait of Georgia South							
Western Strait of Juan de Fuca							

Table A-50: Mean change in absolute values for drift groundings by zone and ERTV location for Scenario 1, excluding car ferries.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	0	0	0	-0.0033	0	0	0
Bellingham Channel, Sinclair Island, and waters to the East	0	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-0.0002	-0.0001	-0.0002	-0.0003	-0.0003	-0.0001	-0.0003
Guemes Channel and Saddlebags	0	0	0	0	0	0	0
Haro Strait and Boundary Pass	-0.0001	-0.0001	0	0	-0.0046	-0.0031	-0.0006
Puget Sound	0	0	0	-0.0003	0	0	0
Rosario Strait	-0.0001	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-0.0011	0	0
Southern Gulf Islands	0	-0.0001	0	0	-0.0021	-0.0021	-0.0001
Strait of Georgia	0	-0.0008	0	0	0	0	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Strait of Georgia - Below 49th	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006
Strait of Georgia - North	0	-0.003	0	0	-0.0001	-0.0001	0
Strait of Georgia - South	-0.0006	-0.0006	0	0	-0.0006	-0.0006	-0.0006
Vancouver	0	0	0	0	0	0	0
Western Strait of Juan de Fuca	-0.0001	-0.0001	-0.0043	-0.0001	-0.0007	-0.0007	-0.0049

Table A-51: Relative change in drift grounding by geographic zone and ERTV location for Scenario 1, excluding car ferries.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	0.00	0.00	0.00	-16.37	0.00	0.00	0.00
Bellingham Channel, Sinclair Island, and waters to the East	-0.22	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-12.50	-8.15	-19.56	-23.91	-23.68	-11.41	-27.48
Guemes Channel and Saddlebags	-0.44	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28
Haro Strait and Boundary Pass	-0.10	-0.11	-0.08	0.00	-8.59	-5.92	-1.19
Puget Sound	-0.02	0.00	-0.02	-0.35	-0.02	0.00	-0.02
Rosario Strait	-1.96	0.00	0.00	0.00	-0.39	0.00	0.00
San Juan Islands	-0.38	0.00	0.00	-0.38	-31.77	-0.38	-0.38
Southern Gulf Islands	0.00	-0.24	0.00	0.00	-9.59	-9.57	-0.28
Strait of Georgia	0.00	-23.99	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-17.26	-17.51	-17.26	-17.26	-17.39	-17.39	-17.26
Strait of Georgia - North	0.00	-8.88	0.00	0.00	-0.25	-0.25	0.00
Strait of Georgia South	-45.55	-45.55	0.00	0.00	-45.55	-45.55	-45.55
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	-0.24	-0.24	-18.35	-0.28	-2.85	-2.85	-20.90

Table A-52: Mean change in absolute values for oil volume at risk by zone and ERTV location for Scenario 1, excluding car ferries.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	0	0	0	-5902.4	0	0	0
Bellingham Channel, Sinclair Island, and waters to the East	-0.4151	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-1790.64	-8.8762	-1798.38	-3632.45	-3708.25	-1790.54	-3677.46
Guemes Channel and Saddlebags	-0.0838	-0.0247	-0.0247	-0.0247	-0.0247	-0.0247	-0.0247
Haro Strait and Boundary Pass	-233.362	-54.7559	-44.6298	0	-12620.8	-4964.19	-673.663
Puget Sound	-0.1057	0	-0.1057	-123.459	-0.1057	0	-0.1057
Rosario Strait	-854.917	0	0	0	-0.7006	0	0
San Juan Islands	-414.564	0	0	-414.564	-4608.11	-414.564	-414.564
Southern Gulf Islands	0	-180.085	0	0	-3610.59	-3435.19	-180.127
Strait of Georgia	0	-4009.29	0	0	0	0	0
Strait of Georgia - Below 49th	-300.727	-300.767	-300.727	-300.727	-300.735	-300.735	-300.727
Strait of Georgia - North	0	-4241.19	0	0	-631.872	-631.872	0
Strait of Georgia - South	-433.2	-433.2	0	0	-433.2	-433.2	-433.2
Vancouver	0	-0.0317	0	0	0	0	0
Western Strait of Juan de Fuca	-54.7509	-54.7509	-8537.45	-62.2204	-915.274	-915.274	-7574.45

Table A-53: Relative change in oil volume at risk by geographic zone and ERTV location for Scenario 1, excluding car ferries.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	0.00	0.00	0.00	-14.63	0.00	0.00	0.00
Bellingham Channel, Sinclair Island, and waters to the East	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-10.45	-0.05	-10.49	-21.20	-21.64	-10.45	-21.46
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.20	-0.05	-0.04	0.00	-10.73	-4.22	-0.57
Puget Sound	0.00	0.00	0.00	-0.08	0.00	0.00	0.00
Rosario Strait	-0.90	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	-3.33	0.00	0.00	-3.33	-37.00	-3.33	-3.33
Southern Gulf Islands	0.00	-0.56	0.00	0.00	-11.31	-10.76	-0.56
Strait of Georgia	0.00	-5.85	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-6.84	-6.84	-6.84	-6.84	-6.84	-6.84	-6.84
Strait of Georgia - North	0.00	-7.05	0.00	0.00	-1.05	-1.05	0.00
Strait of Georgia South	-14.55	-14.55	0.00	0.00	-14.55	-14.55	-14.55
Western Strait of Juan de Fuca	-0.07	-0.07	-10.29	-0.08	-1.10	-1.10	-9.13

Table A-54: Mean change in absolute values for oil outflow by zone and ERTV location for Scenario 1, excluding car ferries.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	0	0	0	-0.6639	0	0	0
Bellingham Channel, Sinclair Island, and waters to the East	-0.0011	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-0.0613	-0.0214	-0.0819	-0.1219	-0.1234	-0.0606	-0.1333

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Guemes Channel and Saddlebags	-0.0006	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002
Haro Strait and Boundary Pass	-0.0216	-0.0122	-0.0086	0	-1.238	-0.7633	-0.1455
Puget Sound	-0.0008	0	-0.0008	-0.0604	-0.0008	0	-0.0008
Rosario Strait	-0.0422	0	0	0	-0.0012	0	0
San Juan Islands	-0.0131	0	0	-0.0131	-0.3265	-0.0131	-0.0131
Southern Gulf Islands	0	-0.0216	0	0	-0.5806	-0.5766	-0.0219
Strait of Georgia	0	-0.2499	0	0	0	0	0
Strait of Georgia - Below 49th	-0.1222	-0.1225	-0.1222	-0.1222	-0.1223	-0.1223	-0.1222
Strait of Georgia - North	0	-0.7461	0	0	-0.0663	-0.0663	0
Strait of Georgia - South	-0.1222	-0.1222	0	0	-0.1222	-0.1222	-0.1222
Vancouver	0	-0.0002	0	0	0	0	0
Western Strait of Juan de Fuca	-0.0122	-0.0122	-1.0525	-0.0139	-0.1429	-0.1429	-1.149

Table A-55: Relative change in oil outflow by geographic zone and ERTV location for Scenario 1, excluding car ferries.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	0.00	0.00	0.00	-15.18	0.00	0.00	0.00
Bellingham Channel, Sinclair Island, and waters to the East	-0.04	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-9.61	-3.35	-12.84	-19.11	-19.34	-9.49	-20.90
Guemes Channel and Saddlebags	-0.02	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.16	-0.09	-0.06	0.00	-8.94	-5.51	-1.05
Puget Sound	0.00	0.00	0.00	-0.33	0.00	0.00	0.00
Rosario Strait	-1.23	0.00	0.00	0.00	-0.04	0.00	0.00

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
San Juan Islands	-1.23	0.00	0.00	-1.23	-30.72	-1.23	-1.23
Southern Gulf Islands	0.00	-0.41	0.00	0.00	-11.06	-10.98	-0.42
Strait of Georgia	0.00	-10.58	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-16.91	-16.95	-16.91	-16.91	-16.92	-16.92	-16.91
Strait of Georgia - North	0.00	-9.85	0.00	0.00	-0.88	-0.88	0.00
Strait of Georgia South	-41.31	-41.31	0.00	0.00	-41.31	-41.31	-41.31
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	-0.19	-0.19	-15.94	-0.21	-2.17	-2.17	-17.40

Table A-56: Change in grounding rate by geographic zone and ERTV location for Scenario 1, excluding car ferries.

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet [1.76]	0.00	0.00	0.00	-0.39	0.00	0.00	0.00
Bellingham Channel, Sinclair Island, and waters to the East [4.50]	-0.08	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca [0.35]	-0.02	-0.01	-0.02	-0.04	-0.04	-0.01	-0.04
Guemes Channel and Saddlebags [11.33]	-0.30	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14
Haro Strait and Boundary Pass [5.28]	-0.05	-0.01	-0.03	0.00	-0.64	-0.41	-0.09
Puget Sound [6.23]	-0.01	0.00	-0.01	-0.04	-0.01	0.00	-0.01
Rosario Strait [2.88]	-0.07	0.00	0.00	0.00	-0.03	0.00	0.00
San Juan Islands [0.94]	-0.05	0.00	0.00	-0.05	-0.42	-0.05	-0.05
Southern Gulf Islands [6.89]	0.00	-0.05	0.00	0.00	-0.49	-0.55	-0.08
Strait of Georgia [1.84]	0.00	-0.12	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th [0.59]	-0.01	-0.05	-0.01	-0.01	-0.03	-0.03	-0.01
Strait of Georgia – North [2.42]	0.00	-0.09	0.00	0.00	-0.02	-0.02	0.00
Strait of Georgia South [1.44]	-0.03	-0.03	0.00	0.00	-0.03	-0.03	-0.03

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Vancouver [12.34]	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca [0.39]	0.00	0.00	-0.05	0.00	-0.01	-0.01	-0.05

Table A-57 summarizes the ERTV locations resulting in no detectable changes in oil spill risk metrics, detectable changes in all oil spill risk metrics for each vessel type, the above average detectable changes in oil spill risk metrics for each vessel type.

Table A-57: Changes in all oil spill risk metrics (values rounded to the nearest 0.01) by geographic zone and ERTV location for Scenario 1, excluding car ferries. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet							
Eastern Strait of Juan de Fuca							
Haro Strait and Boundary Pass							
Puget Sound							
Rosario Strait							
San Juan Islands							
Southern Gulf Islands							
Strait of Georgia							
Strait of Georgia – Below 49th							
Strait of Georgia – North							
Strait of Georgia South							
Western Strait of Juan de Fuca							

Detailed comparison of ERTV locations by vessel type and by zone for Scenario 2

Vessel type risk

For drift groundings:

- ATBs, large fishing vessels, towed bunkering and oil barges benefit the most from ERTVs located in Port Townsend.

- Bulk carriers, large cargo vessels, chemical tankers, container ships, and vehicle carriers benefit the most from ERTV located in Roche Harbor.
- Crude tankers benefit the most from ERTVs located in Deltaport or Roche Harbor.
- Cruise ships benefit the most from ERTVs located in Roche Harbor or Victoria.
- Car ferries benefit the most from ERTV located in Sidney.
- Liquid gas carriers benefit the most from ERTV located in Port Angeles.
- Product tankers benefit the most from ERTVs located in Deltaport, Port Angeles, or Victoria.

For oil volume at risk:

- ATBs, large fishing vessels, towed bunkering and oil barges benefit the most from ERTVs located in Port Townsend.
- Bulk carriers, large cargo vessels, chemical tankers, container ships, cruise ships, and vehicle carriers benefit the most from ERTV located in Roche Harbor.
- Crude tankers benefit the most from ERTVs located in Deltaport or Roche Harbor.
- Car ferries benefit the most from ERTV located in Sidney.
- Liquid gas carriers benefit the most from ERTV located in Port Angeles.
- Product tankers benefit the most from ERTV located in Deltaport.

For oil outflow:

- ATBs, large fishing vessels, towed bunkering and oil barges benefit the most from ERTVs located in Port Townsend.
- Bulk carriers, large cargo vessels, chemical tankers, container ships, and vehicle carriers benefit the most from ERTV located in Roche Harbor.
- Crude tankers benefit the most from ERTVs located in Deltaport or Roche Harbor.
- Cruise ships benefit the most from ERTVs located in Roche Harbor or Victoria.
- Car ferries benefit the most from ERTV located in Sidney.
- Liquid gas carriers benefit the most from ERTV located in Port Angeles.
- Product tankers benefit the most from ERTVs located in Deltaport, Port Angeles, or Victoria.

Changes in groundings rates per vessel type were small regardless of the ERTV locations, ranging from -0.09 percent to 0.00 percent.

Table A-58 to Table A-61 summarizes the changes in oil spill metrics for each vessel type and ERTV location.

Table A-58: Relative change in drift grounding by vessel type and ERTV location for Scenario 2.

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
ATB	0.00	0.00	0.00	-0.39	0.00	0.00	0.00
Bulk Carrier	-0.42	-2.60	-1.27	-0.85	-3.14	-2.69	-2.12
Container Ship	0.00	-0.66	-1.32	-0.74	-2.40	-1.99	-1.24
Cruise Ship	-0.46	-0.34	-1.26	-1.38	-1.95	-1.49	-1.95

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Ferry (Car)	0.00	-0.26	0.00	-0.24	-0.21	-0.81	0.00
Fishing Vessel (Large)	0.00	-0.80	-3.59	-4.38	-2.39	-2.39	-3.59
General/Other Cargo Ship (Large)	0.00	-1.13	-0.68	-1.24	-2.26	-0.56	-1.18
Tanker (Chemical)	-0.08	0.00	-0.53	0.00	-2.63	-1.20	-0.60
Tanker (Crude)	-0.41	-0.55	-0.41	0.00	-0.55	-0.14	-0.41
Tanker (Liquefied Gas)	-2.76	-0.99	-2.96	-0.99	-0.99	-0.99	-1.97
Tanker (Product)	0.00	-0.53	-0.53	0.00	0.00	0.00	-0.53
Towing Vessel (Oil)	-0.43	-0.32	-0.21	-1.03	-0.63	-0.37	-0.21
Towing Vessel (Oil) – Bunkering	-0.68	-0.23	-0.68	-1.58	-1.13	-1.35	-1.35
Vehicle Carrier	-0.02	-0.87	-1.81	-1.48	-4.41	-2.38	-1.81

Table A-59: Relative change in oil volume at risk by vessel type and ERTV location for Scenario 2.

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
ATB	0.00	0.00	0.00	-0.45	0.00	0.00	0.00
Bulk Carrier	-0.32	-2.68	-1.13	-1.11	-2.83	-2.48	-2.05
Container Ship	0.00	-0.37	-1.31	-0.78	-2.55	-1.80	-1.24
Cruise Ship	-0.66	-0.50	-1.36	-1.20	-2.50	-2.02	-2.27
Ferry (Car)	0.00	-0.56	0.00	-0.21	-0.34	-0.58	0.00
Fishing Vessel (Large)	0.00	-0.55	-1.92	-2.16	-1.45	-1.39	-1.92
General/Other Cargo Ship (Large)	0.00	-1.68	-0.61	-0.89	-1.70	-0.52	-1.29
Tanker (Chemical)	-0.08	0.00	-0.57	0.00	-3.14	-0.78	-0.65
Tanker (Crude)	-0.23	-0.64	-0.37	0.00	-0.64	-0.16	-0.37
Tanker (Liquefied Gas)	-0.74	-0.27	-5.94	-0.27	-0.27	-0.27	-5.68
Tanker (Product)	0.00	-0.99	-0.97	0.00	0.00	0.00	-0.97
Towing Vessel (Oil)	-0.42	-0.37	-0.21	-1.03	-0.62	-0.35	-0.22
Towing Vessel (Oil) – Bunkering	-0.63	-0.24	-0.75	-1.75	-1.11	-1.36	-1.38
Vehicle Carrier	-0.02	-0.88	-1.70	-1.51	-4.57	-2.55	-1.64

Table A-60: Relative change in oil outflow by vessel type and ERTV location for Scenario 2.

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
ATB	0.00	0.00	0.00	-0.39	0.00	0.00	0.00
Bulk Carrier	-0.42	-2.60	-1.27	-0.85	-3.14	-2.69	-2.12
Container Ship	0.00	-0.66	-1.32	-0.74	-2.40	-1.99	-1.24
Cruise Ship	-0.46	-0.34	-1.26	-1.38	-1.95	-1.49	-1.95
Ferry (Car)	0.00	-0.27	0.00	-0.25	-0.22	-0.76	0.00
Fishing Vessel (Large)	0.00	-0.80	-3.59	-4.38	-2.39	-2.39	-3.59
General/Other Cargo Ship (Large)	0.00	-1.13	-0.68	-1.24	-2.26	-0.56	-1.18
Tanker (Chemical)	-0.08	0.00	-0.53	0.00	-2.63	-1.20	-0.60
Tanker (Crude)	-0.41	-0.55	-0.41	0.00	-0.55	-0.14	-0.41
Tanker (Liquefied Gas)	-2.76	-0.99	-2.96	-0.99	-0.99	-0.99	-1.97
Tanker (Product)	0.00	-0.53	-0.53	0.00	0.00	0.00	-0.53
Towing Vessel (Oil)	-0.42	-0.37	-0.21	-1.03	-0.62	-0.35	-0.22
Towing Vessel (Oil) - Bunkering	-0.63	-0.24	-0.75	-1.75	-1.11	-1.36	-1.38
Vehicle Carrier	-0.02	-0.87	-1.81	-1.48	-4.41	-2.38	-1.81

Table A-61: Change in grounding rate by vessel type and ERTV location for Scenario 2.

Vessel Type [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
ATB [1.64]	0.00	0.00	0.00	-0.01	0.00	0.00	0.00
Bulk Carrier [2.23]	-0.01	-0.04	-0.02	-0.02	-0.07	-0.06	-0.03
Container Ship [2.98]	0.00	-0.02	-0.03	-0.02	-0.08	-0.07	-0.04
Cruise Ship [1.87]	-0.01	-0.01	-0.04	-0.03	-0.04	-0.03	-0.05
Ferry (Car) [7.68]	0.00	-0.03	0.00	-0.01	-0.02	-0.05	0.00
Fishing Vessel (Large) [1.38]	0.00	-0.01	-0.06	-0.06	-0.03	-0.03	-0.06
General/Other Cargo Ship (Large) [1.77]	0.00	-0.01	-0.02	-0.03	-0.03	-0.01	-0.02
Tanker (Chemical) [2.14]	0.00	0.00	-0.02	0.00	-0.05	-0.04	-0.02
Tanker (Crude) [1.89]	-0.01	-0.01	-0.01	0.00	-0.02	-0.01	-0.01
Tanker (Liquefied Gas) [0.83]	-0.02	-0.01	-0.02	-0.01	-0.01	-0.01	-0.02
Tanker (Product) [1.86]	0.00	-0.01	-0.01	0.00	0.00	0.00	-0.01

Vessel Type [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Towing Vessel (Oil) [5.59]	-0.02	-0.02	-0.01	-0.06	-0.03	-0.03	-0.01
Towing Vessel (Oil) – Bunkering [6.60]	-0.05	-0.01	-0.06	-0.09	-0.07	-0.08	-0.10
Vehicle Carrier [2.23]	-0.01	-0.02	-0.04	-0.04	-0.09	-0.05	-0.04

Table A-62 summarizes per vessel type the ERTV locations resulting in no detectable changes in oil spill risk metrics, detectable changes in all oil spill risk metrics for each vessel type, the above average detectable changes in oil spill risk metrics for each vessel type.

Table A-62: Changes in all oil spill risk metrics (rounded to the nearest 0.01) by vessel type and ERTV location for Scenario 2. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.

Vessel Type	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
ATB							
Bulk Carrier							
Container Ship							
Cruise Ship							
Ferry (Car)							
Fishing Vessel (Large)							
General/Other Cargo Ship (Large)							
Tanker (Chemical)							
Tanker (Crude)							
Tanker (Liquefied Gas)							
Tanker (Product)							
Towing Vessel (Oil)							
Towing Vessel (Oil) – Bunkering							

Vessel Type	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Vehicle Carrier							

Zone risk

For the mean values per simulation for each risk metric by geographic zone, for Scenario 2, see Table A-9 and Table A-11.

There were several zones where there were no changes in drift groundings, oil volume at risk, and oil outflows for all ERTV locations for Scenario 2. They include Boundary Bay, Carr Inlet, Case Inlet to Oakland Bay, Colvos Passage, Dyes Inlet, Eld Inlet, Guemes Channel and Saddlebags, Gulf Islands, Hood Canal, Howe Sound, Lake Washington Ship Canal, Nanaimo, Northern Gulf Islands, Port Orchard, Port Susan, Possession Sound and Saratoga Passage, Rich Passage and Sinclair Inlet, Skagit Bay, and South Sound to Olympia. For improved readability, those zones are omitted in the following tables.

Table A-63: Mean change in absolute values for drift grounding by geographic zone and ERTV location for Scenario 2.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	0	0	0	-0.0036	0	0	0
Bellingham Channel, Sinclair Island, and waters to the East	0	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	0	0	-0.0001	-0.0002	-0.0001	0	-0.0001
Guemes Channel and Saddlebags	0	0	0	0	0	0	0
Haro Strait and Boundary Pass	-0.0001	-0.0001	0	0	-0.005	-0.0037	-0.0006
Puget Sound	0	0	0	-0.0016	0	0	0
Rosario Strait	-0.0001	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-0.002	0	0
Skagit Bay	0	0	0	0	0	0	0
Southern Gulf Islands	0	-0.0001	0	0	-0.0021	-0.0101	0
Strait of Georgia	0	-0.0021	0	0	0	0	0
Strait of Georgia - Below 49th	-0.0006	-0.0011	-0.0006	-0.0006	-0.0011	-0.0011	-0.0006
Strait of Georgia - North	0	-0.0044	0	0	-0.0006	-0.0006	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Strait of Georgia - South	0	0	0	0	-0.0001	0	0
Vancouver	0	0	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-0.0039	0	-0.001	-0.001	-0.0045

Table A-64: Relative change in drift grounding by geographic zone and ERTV location for Scenario 2.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.03	0.00	-0.03	-8.27	-0.03	0.00	-0.03
Bellingham Channel, Sinclair Island, and waters to the East	-0.43	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-2.01	0.00	-10.70	-15.80	-5.04	0.00	-10.70
Guemes Channel and Saddlebags	-0.03	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.11	-0.11	-0.08	-0.01	-9.08	-6.67	-1.16
Puget Sound	0.00	0.00	0.00	-0.55	0.00	0.00	0.00
Rosario Strait	-0.22	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
San Juan Islands	0.00	0.00	0.00	0.00	-1.76	0.00	0.00
Southern Gulf Islands	0.00	-0.02	0.00	0.00	-0.65	-3.14	0.00
Strait of Georgia	0.00	-8.09	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-1.04	-1.96	-1.04	-1.04	-1.95	-1.95	-1.04
Strait of Georgia - North	0.00	-3.50	0.00	0.00	-0.46	-0.46	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-9.60	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-10.50	-0.05	-2.67	-2.66	-12.19

Table A-65: Mean change in absolute values for oil volume at risk by geographic zone and ERTV location for Scenario 2.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-0.0916	0	-0.0916	-3272.08	-0.0916	0	-0.0916
Bellingham Channel, Sinclair	-0.4855	0	0	0	0	0	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Island, and waters to the East							
Eastern Strait of Juan de Fuca	-13.0417	0	-16.7326	-26.9175	-38.6393	0	-16.7326
Guemes Channel and Saddlebags	-0.0201	0	0	0	0	0	0
Haro Strait and Boundary Pass	-233.774	-55.1674	-45.0413	-0.4116	-12635.6	-5065.25	-674.075
Puget Sound	-0.0275	0	-0.0275	-312.322	0	0	0
Rich Passage and Sinclair Inlet	0	0	0	0	0	0	0
Rosario Strait	-853.651	-0.019	-0.019	-0.019	-0.019	-0.019	-0.019
San Juan Islands	0	0	0	0	-2653.51	0	0
Southern Gulf Islands	0	-647.301	0	0	-3159.02	-3361.31	-0.0423
Strait of Georgia	0	-4245.67	0	0	0	0	0
Strait of Georgia - Below 49th	-300.727	-398.25	-300.727	-300.727	-398.218	-398.218	-300.727
Strait of Georgia - North	0	-3167.61	0	0	-300.833	-300.833	0
Strait of Georgia - South	0	0	0	0	-26.0753	0	0
Vancouver	0	-0.0317	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-9249.28	-7.4696	-1988.33	-1983.45	-9587.94

Table A-66: Relative change in oil volume at risk by geographic zone and ERTV Location for Scenario 2.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	0.00	0.00	0.00	-8.45	0.00	0.00	0.00
Bellingham Channel, Sinclair Island, and waters to the East	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Eastern Strait of Juan de Fuca	-0.09	0.00	-0.12	-0.19	-0.27	0.00	-0.12
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.20	-0.05	-0.04	0.00	-10.84	-4.35	-0.58
Puget Sound	0.00	0.00	0.00	-0.19	0.00	0.00	0.00
Rosario Strait	-0.93	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-16.36	0.00	0.00
Southern Gulf Islands	0.00	-1.11	0.00	0.00	-5.42	-5.77	0.00
Strait of Georgia	0.00	-6.05	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-2.63	-3.48	-2.63	-2.63	-3.48	-3.48	-2.63
Strait of Georgia - North	0.00	-4.60	0.00	0.00	-0.44	-0.44	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-0.96	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-10.66	-0.01	-2.29	-2.29	-11.05

Table A-67: Mean change in absolute values for oil outflow by geographic zone and ERTV location for Scenario 2.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-0.0007	0	-0.0007	-0.7578	-0.0007	0	-0.0007
Bellingham Channel, Sinclair Island, and waters to the East	-0.0017	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-0.0046	0	-0.0242	-0.0358	-0.0114	0	-0.0242
Guemes Channel and Saddlebags	-0.0001	0	0	0	0	0	0
Haro Strait and Boundary Pass	-0.0227	-0.0133	-0.0096	-0.0011	-1.3261	-0.8721	-0.1466
Puget Sound	-0.0002	0	-0.0002	-0.3494	0	0	0
Rich Passage and Sinclair Inlet	0	0	0	0	0	0	0
Rosario Strait	-0.0401	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
San Juan Islands	0	0	0	0	-0.4726	0	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Southern Gulf Islands	0	-0.0216	0	0	-0.5218	-2.0291	-0.0003
Strait of Georgia	0	-0.5257	0	0	0	0	0
Strait of Georgia - Below 49th	-0.1222	-0.2294	-0.1222	-0.1222	-0.2291	-0.2291	-0.1222
Strait of Georgia - North	0	-0.943	0	0	-0.123	-0.123	0
Strait of Georgia - South	0	0	0	0	-0.0171	0	0
Vancouver	0	-0.0002	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-0.9617	-0.0017	-0.2085	-0.2077	-1.0925

Table A-68: Relative change in oil outflow by geographic zone and ERTV Location for Scenario 2.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.01	0.00	-0.01	-7.95	-0.01	0.00	-0.01
Bellingham Channel, Sinclair Island, and waters to the East	-0.06	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-0.78	0.00	-4.13	-6.09	-1.94	0.00	-4.13
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.16	-0.09	-0.07	-0.01	-9.37	-6.16	-1.04
Puget Sound	0.00	0.00	0.00	-0.55	0.00	0.00	0.00
Rosario Strait	-0.50	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-1.95	0.00	0.00
Southern Gulf Islands	0.00	-0.03	0.00	0.00	-0.77	-3.00	0.00
Strait of Georgia	0.00	-10.81	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-1.04	-1.95	-1.04	-1.04	-1.95	-1.95	-1.04
Strait of Georgia - North	0.00	-3.93	0.00	0.00	-0.51	-0.51	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-8.14	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-10.14	-0.02	-2.20	-2.19	-11.52

Table A-69: Change in grounding rate by geographic zone and ERTV Location for Scenario 2.

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet [1.75]	-0.01	0.00	-0.01	-0.31	-0.01	0.00	-0.01
Bellingham Channel, Sinclair Island, and waters to the East [4.13]	-0.11	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca [0.31]	-0.02	0.00	-0.02	-0.03	-0.01	0.00	-0.02
Guemes Channel and Saddlebags [10.42]	-0.04	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass [5.15]	-0.06	-0.02	-0.04	-0.01	-0.64	-0.45	-0.11
Puget Sound [6.46]	-0.01	0.00	-0.01	-0.04	0.00	0.00	0.00
Rosario Strait [2.67]	-0.04	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
San Juan Islands [2.86]	0.00	0.00	0.00	0.00	-0.16	0.00	0.00
Southern Gulf Islands [8.34]	0.00	-0.02	0.00	0.00	-0.30	-0.40	-0.03
Strait of Georgia [1.96]	0.00	-0.10	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th [1.39]	-0.01	-0.04	-0.01	-0.01	-0.03	-0.03	-0.01
Strait of Georgia – North [2.46]	0.00	-0.08	0.00	0.00	-0.01	-0.01	0.00
Strait of Georgia South [1.15]	0.00	0.00	0.00	0.00	-0.07	0.00	0.00
Vancouver [12.18]	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca [0.40]	0.00	0.00	-0.04	0.00	-0.01	-0.01	-0.05

Table A-70 summarizes the ERTV locations resulting in no detectable changes in oil spill risk metrics, detectable changes in all oil spill risk metrics for each vessel type, the above average detectable changes in oil spill risk metrics for each vessel type.

Table A-70: Changes in all oil spill risk metrics by geographic zone and ERTV location for Scenario 2. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet							
Eastern Strait of Juan de Fuca							
Haro Strait and Boundary Pass							
Puget Sound							
Rosario Strait							
San Juan Islands							
Southern Gulf Islands							
Strait of Georgia							
Strait of Georgia – Below 49th							
Strait of Georgia – North							
Strait of Georgia South							
Western Strait of Juan de Fuca							

Table A-71: Change in absolute values for drift groundings by geographic zone and ERTV location for Scenario 2, excluding car ferries.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	0	0	0	-0.0023	0	0	0
Bellingham Channel, Sinclair Island, and waters to the East	0	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	0	0	-0.0001	-0.0002	-0.0001	0	-0.0001
Guemes Channel and Saddlebags	0	0	0	0	0	0	0
Haro Strait and Boundary Pass	-0.0001	-0.0001	0	0	-0.0045	-0.0032	-0.0006

Puget Sound	0	0	0	-0.0003	0	0	0
Rich Passage and Sinclair Inlet	0	0	0	0	0	0	0
Rosario Strait	-0.0001	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-0.0006	0	0
Southern Gulf Islands	0	-0.0001	0	0	-0.0021	-0.0021	0
Strait of Georgia	0	-0.0008	0	0	0	0	0
Strait of Georgia - Below 49th	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006
Strait of Georgia - North	0	-0.0034	0	0	-0.0006	-0.0006	0
Strait of Georgia - South	0	0	0	0	-0.0001	0	0
Vancouver	0	0	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-0.0039	0	-0.001	-0.001	-0.0045

Table A-72: Relative change in drift grounding by geographic zone and ERTV location for Scenario 2, excluding car ferries.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.07	0.00	-0.07	-11.94	-0.07	0.00	-0.07
Bellingham Channel, Sinclair Island, and waters to the East	-0.59	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-2.01	0.00	-10.70	-15.80	-5.04	0.00	-10.70
Guemes Channel and Saddlebags	-0.08	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.11	-0.12	-0.09	-0.01	-8.45	-5.96	-1.21
Puget Sound	0.00	0.00	0.00	-0.37	0.00	0.00	0.00
Rosario Strait	-1.43	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
San Juan Islands	0.00	0.00	0.00	0.00	-21.32	0.00	0.00
Southern Gulf Islands	0.00	-0.24	0.00	0.00	-9.47	-9.39	-0.04
Strait of Georgia	0.00	-23.66	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-17.28	-17.41	-17.28	-17.28	-17.28	-17.28	-17.28
Strait of Georgia - North	0.00	-9.93	0.00	0.00	-1.69	-1.69	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-9.60	0.00	0.00

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-16.62	-0.03	-4.22	-4.21	-19.29

Table A-73: Mean change in absolute values for oil volume at risk by zone and ERTV location for Scenario 2, excluding car ferries.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-0.0916	0	-0.0916	-3240.96	-0.0916	0	-0.0916
Bellingham Channel, Sinclair Island, and waters to the East	-0.4855	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-13.0417	0	-16.7326	-26.9175	-38.6393	0	-16.7326
Guemes Channel and Saddlebags	-0.0201	0	0	0	0	0	0
Haro Strait and Boundary Pass	-233.774	-55.1674	-45.0413	-0.4116	-12538.1	-4967.76	-674.075
Puget Sound	-0.0275	0	-0.0275	-139.025	0	0	0
Rich Passage and Sinclair Inlet	0	0	0	0	0	0	0
Rosario Strait	-853.651	-0.019	-0.019	-0.019	-0.019	-0.019	-0.019
San Juan Islands	0	0	0	0	-2506.98	0	0
Southern Gulf Islands	0	-647.301	0	0	-3159.02	-2983.51	-0.0423
Strait of Georgia	0	-3985.7	0	0	0	0	0
Strait of Georgia - Below 49th	-300.727	-300.759	-300.727	-300.727	-300.727	-300.727	-300.727
Strait of Georgia - North	0	-2972.63	0	0	-300.833	-300.833	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Strait of Georgia - South	0	0	0	0	-26.0753	0	0
Vancouver	0	-0.0317	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-9249.28	-7.4696	-1988.33	-1983.45	-9587.94

Table A-74: Relative change in oil volume at risk by geographic zone and ERTV Location for Scenario 2, excluding car ferries.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	0.00	0.00	0.00	-8.50	0.00	0.00	0.00
Bellingham Channel, Sinclair Island, and waters to the East	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-0.09	0.00	-0.12	-0.19	-0.27	0.00	-0.12
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.20	-0.05	-0.04	0.00	-10.77	-4.27	-0.58
Puget Sound	0.00	0.00	0.00	-0.10	0.00	0.00	0.00
Rosario Strait	-0.94	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-24.21	0.00	0.00
Southern Gulf Islands	0.00	-2.05	0.00	0.00	-9.98	-9.43	0.00
Strait of Georgia	0.00	-5.82	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-6.84	-6.84	-6.84	-6.84	-6.84	-6.84	-6.84
Strait of Georgia - North	0.00	-5.05	0.00	0.00	-0.51	-0.51	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-0.96	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-10.78	-0.01	-2.32	-2.31	-11.17

Table A-75: Mean change in absolute values for oil outflow by zone and ERTV location for Scenario 2, excluding car ferries.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-0.0007	0.0000	-0.0007	-0.4727	-0.0007	0.0000	-0.0007

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Bellingham Channel, Sinclair Island, and waters to the East	-0.0017	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eastern Strait of Juan de Fuca	-0.0046	0.0000	-0.0242	-0.0358	-0.0114	0.0000	-0.0242
Guemes Channel and Saddlebags	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gulf Islands	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Haro Strait and Boundary Pass	-0.0227	-0.0133	-0.0096	-0.0011	-1.2192	-0.7652	-0.1466
Puget Sound	-0.0002	0.0000	-0.0002	-0.0643	0.0000	0.0000	0.0000
Rosario Strait	-0.0401	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
San Juan Islands	0.0000	0.0000	0.0000	0.0000	-0.1875	0.0000	0.0000
Southern Gulf Islands	0.0000	-0.0216	0.0000	0.0000	-0.5218	-0.5170	-0.0003
Strait of Georgia	0.0000	-0.2405	0.0000	0.0000	0.0000	0.0000	0.0000
Strait of Georgia - Below 49th	-0.1222	-0.1224	-0.1222	-0.1222	-0.1222	-0.1222	-0.1222
Strait of Georgia - North	0.0000	-0.7291	0.0000	0.0000	-0.1230	-0.1230	0.0000
Strait of Georgia South	0.0000	0.0000	0.0000	0.0000	-0.0171	0.0000	0.0000
Vancouver	0.0000	-0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
Western Strait of Juan de Fuca	0.0000	0.0000	-0.9617	-0.0017	-0.2085	-0.2077	-1.0925

Table A-76: Relative change in oil outflow by geographic zone and ERTV Location for Scenario 2, excluding car ferries.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.02	0.00	-0.02	-11.09	-0.02	0.00	-0.02
Bellingham Channel, Sinclair Island, and waters to the East	-0.06	0.00	0.00	0.00	0.00	0.00	0.00

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Eastern Strait of Juan de Fuca	-0.78	0.00	-4.13	-6.09	-1.94	0.00	-4.13
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.16	-0.10	-0.07	-0.01	-8.86	-5.56	-1.06
Puget Sound	0.00	0.00	0.00	-0.37	0.00	0.00	0.00
Rosario Strait	-1.26	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-20.31	0.00	0.00
Southern Gulf Islands	0.00	-0.41	0.00	0.00	-10.01	-9.92	-0.01
Strait of Georgia	0.00	-10.30	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-16.91	-16.94	-16.91	-16.91	-16.91	-16.91	-16.91
Strait of Georgia - North	0.00	-9.65	0.00	0.00	-1.63	-1.63	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-8.14	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-14.58	-0.03	-3.16	-3.15	-16.56

Table A-77: Change in grounding rate by geographic zone and ERTV Location for Scenario 2, excluding car ferries.

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet [1.64]	-0.01	0.00	-0.01	-0.31	-0.01	0.00	-0.01
Bellingham Channel, Sinclair Island, and waters to the East [4.18]	-0.11	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca [0.32]	-0.02	0.00	-0.02	-0.03	-0.01	0.00	-0.02
Guemes Channel and Saddlebags [10.83]	-0.05	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass [5.21]	-0.06	-0.02	-0.04	-0.01	-0.63	-0.43	-0.11
Puget Sound [6.29]	-0.01	0.00	-0.01	-0.04	0.00	0.00	0.00

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Rosario Strait [2.43]	-0.04	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
San Juan Islands [0.54]	0.00	0.00	0.00	0.00	-0.13	0.00	0.00
Southern Gulf Islands [6.65]	0.00	-0.02	0.00	0.00	-0.44	-0.49	-0.03
Strait of Georgia [1.73]	0.00	-0.09	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th [0.57]	-0.01	-0.03	-0.01	-0.01	-0.01	-0.01	-0.01
Strait of Georgia – North [2.32]	0.00	-0.08	0.00	0.00	-0.01	-0.01	0.00
Strait of Georgia South [1.18]	0.00	0.00	0.00	0.00	-0.07	0.00	0.00
Vancouver [12.23]	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca [0.39]	0.00	0.00	-0.04	0.00	-0.01	-0.01	-0.05

Table A-78: Changes in all oil spill risk metrics by geographic zone and ERTV location for Scenario 2, excluding car ferries. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet							
Eastern Strait of Juan de Fuca							
Haro Strait and Boundary Pass							
Puget Sound							
Rosario Strait							
San Juan Islands							
Southern Gulf Islands							
Strait of Georgia							
Strait of Georgia – Below 49th							
Strait of Georgia – North							

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Strait of Georgia South							
Western Strait of Juan de Fuca							

Detailed comparison of ERTV locations by vessel type and by zone for Scenario 3

Vessel type risk

For drift groundings:

- Bulk carriers and cruise ships benefit the most from an ERTV located in Victoria.
- Large cargo vessels, chemical tankers, container ships, crude tankers, and vehicle carriers benefit the most from an ERTV located in Roche Harbor.
- Car ferries benefit the most from an ERTV located in Sidney.
- Liquified gas carriers benefit the most from an ERTV located in Port Angeles.
- Product tankers benefit the most from ERTVs located in Deltaport, Port Angeles, or Victoria.
- Towed bunkering barges benefit the most from ERTVs located in Roche Harbor and Victoria.
- Towed oil barges benefit the most from an ERTV located in Anacortes.
- ATBs do not benefit from any ERTV locations under Scenario 3.

For oil volume at risk:

- Bulk carriers and product tankers benefit the most from an ERTV located in Deltaport.
- Large cargo vessels, cruise ships, and large fishing vessels benefit the most from ERTV located in Victoria.
- Chemical tankers, container ships, crude tankers, and vehicle carriers benefit the most from ERTV located in Roche Harbor.
- Car ferries and towed bunkering barges benefit the most from ERTV located in Sidney.
- Liquified gas carriers benefit the most from ERTV located in Port Angeles.
- Towed oil barges benefit the most from ERTV located in Anacortes.

For oil outflow:

- Bulk carriers and cruise ships benefit the most from ERTVs located in Victoria.
- Large cargo vessels, chemical tankers, container ships, crude tankers, and vehicle carriers benefit the most from ERTV located in Roche Harbor.
- Car ferries and towed bunkering barges benefit the most from ERTV located in Sidney.
- Large fishing vessels benefit the most from ERTV located in Port Townsend.
- Liquid gas carriers benefit the most from ERTV located in Port Angeles, product tankers from ERTVs located in Deltaport, Port Angeles, or Victoria.
- Towed oil barges benefit the most from ERTV located in Anacortes.

Changes in groundings rates per vessel type were small regardless of the ERTV locations, ranging from -0.08 percent to 0.00 percent.

Table A-79, Table A-80, Table A-81, and Table A-82 summarize the changes in oil spill metrics for each vessel type and ERTV location. Table A-83 summarizes by vessel type the ERTV locations that result in no detectable changes in oil spill risk metrics (white), detectable changes in oil spill risk metrics (grey), and the above average detectable changes in oil spill risk metrics (black).

Table A-79: Relative change in drift grounding frequency by vessel type and ERTV location for Scenario 3.

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
ATB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulk Carrier	-0.43	-2.20	-1.29	-0.86	-1.86	-1.41	-2.14
Container Ship	0.00	-0.67	-1.34	-0.75	-2.09	-1.67	-1.17
Cruise Ship	-0.71	-0.12	-1.19	-0.95	-1.43	-1.31	-2.38
Ferry (Car)	0.00	-0.17	0.00	-0.36	-0.17	-0.77	0.00
Fishing Vessel (Large)	-1.61	-0.80	-5.22	-5.62	-4.02	-4.02	-5.22
General/Other Cargo Ship (Large)	0.00	-0.56	-1.18	-0.68	-2.26	-0.56	-1.75
Tanker (Chemical)	-0.08	0.00	-0.46	0.00	-2.82	-1.37	-0.53
Tanker (Crude)	-0.41	-0.14	-0.41	0.00	-0.55	-0.14	0.00
Tanker (Liquefied Gas)	-1.78	0.00	-1.98	0.00	0.00	0.00	-0.99
Tanker (Product)	0.00	-0.53	-0.53	0.00	-0.27	0.00	-0.53
Towing Vessel (Oil)	-0.32	-0.10	0.00	0.00	-0.19	-0.14	-0.10
Towing Vessel (Oil) - Bunkering	-0.46	-0.23	-0.46	-0.46	-1.16	-1.39	-1.16
Vehicle Carrier	-0.02	-0.61	-2.49	-0.65	-3.94	-1.54	-2.17

Table A-80: Relative change in oil volume at risk by vessel type and ERTV Location for Scenario 3.

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
ATB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulk Carrier	-0.32	-2.38	-1.14	-1.12	-1.65	-1.29	-2.07
Container Ship	0.00	-0.37	-1.36	-0.86	-2.25	-1.48	-1.19
Cruise Ship	-0.80	-0.10	-1.30	-0.64	-1.68	-1.49	-2.23
Ferry (Car)	0.00	-0.36	0.00	-0.38	-0.25	-0.48	0.00
Fishing Vessel (Large)	-2.34	-0.48	-4.35	-4.01	-3.86	-3.79	-4.35
General/Other Cargo Ship (Large)	0.00	-0.30	-1.07	-0.69	-1.72	-0.53	-1.84

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Tanker (Chemical)	-0.08	0.00	-0.49	0.00	-3.37	-0.99	-0.57
Tanker (Crude)	-0.23	-0.16	-0.35	0.00	-0.64	-0.16	0.00
Tanker (Liquefied Gas)	-0.47	0.00	-5.68	0.00	0.00	0.00	-5.42
Tanker (Product)	0.00	-1.00	-0.98	0.00	-0.20	0.00	-0.98
Towing Vessel (Oil)	-0.30	-0.11	0.00	0.00	-0.18	-0.12	-0.11
Towing Vessel (Oil) - Bunkering	-0.40	-0.26	-0.52	-0.52	-1.15	-1.41	-1.16
Vehicle Carrier	-0.02	-0.62	-2.39	-0.67	-4.02	-1.62	-2.11

Table A-81: Relative change in oil outflow by vessel type and ERTV Location for Scenario 3.

Vessel Type	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
ATB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulk Carrier	-0.43	-2.20	-1.29	-0.86	-1.86	-1.41	-2.14
Container Ship	0.00	-0.67	-1.34	-0.75	-2.09	-1.67	-1.17
Cruise Ship	-0.71	-0.12	-1.19	-0.95	-1.43	-1.31	-2.38
Ferry (Car)	0.00	-0.17	0.00	-0.38	-0.17	-0.71	0.00
Fishing Vessel (Large)	-1.61	-0.80	-5.22	-5.62	-4.02	-4.02	-5.22
General/Other Cargo Ship (Large)	0.00	-0.56	-1.18	-0.68	-2.26	-0.56	-1.75
Tanker (Chemical)	-0.08	0.00	-0.46	0.00	-2.82	-1.37	-0.53
Tanker (Crude)	-0.41	-0.14	-0.41	0.00	-0.55	-0.14	0.00
Tanker (Liquefied Gas)	-1.78	0.00	-1.98	0.00	0.00	0.00	-0.99
Tanker (Product)	0.00	-0.53	-0.53	0.00	-0.27	0.00	-0.53
Towing Vessel (Oil)	-0.30	-0.11	0.00	0.00	-0.18	-0.12	-0.11
Towing Vessel (Oil) - Bunkering	-0.40	-0.26	-0.52	-0.52	-1.15	-1.41	-1.16
Vehicle Carrier	-0.02	-0.61	-2.49	-0.65	-3.94	-1.54	-2.17

Table A-82: Change in grounding rate by vessel type and ERTV Location for Scenario 3.

Vessel Type [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
ATB [1.55]	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Vessel Type [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Bulk Carrier [2.22]	-0.01	-0.04	-0.02	-0.02	-0.05	-0.04	-0.03
Container Ship [2.94]	0.00	-0.02	-0.04	-0.02	-0.08	-0.06	-0.04
Cruise Ship [1.82]	-0.01	-0.01	-0.03	-0.02	-0.03	-0.03	-0.05
Ferry (Car) [7.65]	0.00	-0.02	0.00	-0.02	-0.02	-0.04	0.00
Fishing Vessel (Large) [1.37]	-0.02	-0.01	-0.08	-0.07	-0.05	-0.05	-0.08
General/Other Cargo Ship (Large) [1.77]	0.00	-0.01	-0.02	-0.03	-0.03	-0.01	-0.03
Tanker (Chemical) [2.09]	0.00	0.00	-0.01	0.00	-0.04	-0.03	-0.01
Tanker (Crude) [1.91]	-0.01	-0.01	-0.01	0.00	-0.02	-0.01	0.00
Tanker (Liquefied Gas) [0.83]	-0.02	0.00	-0.01	0.00	0.00	0.00	-0.01
Tanker (Product) [1.86]	0.00	-0.01	-0.01	0.00	-0.01	0.00	-0.01
Towing Vessel (Oil) [4.54]	-0.01	-0.01	0.00	0.00	-0.02	-0.02	-0.01
Towing Vessel (Oil) – Bunkering [6.39]	-0.04	-0.02	-0.05	-0.03	-0.07	-0.08	-0.08
Vehicle Carrier [2.14]	-0.01	-0.01	-0.06	-0.02	-0.07	-0.03	-0.05

Table A-83: Changes in all oil spill risk metrics by vessel type and ERTV location for Scenario 3. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.

Vessel Type	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
ATB							
Bulk Carrier							
Container Ship							
Cruise Ship							
Ferry (Car)							
Fishing Vessel (Large)							
General/Other Cargo Ship (Large)							

Vessel Type	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Tanker (Chemical)							
Tanker (Crude)							
Tanker (Liquefied Gas)							
Tanker (Product)							
Towing Vessel (Oil)							
Towing Vessel (Oil) – Bunkering							
Vehicle Carrier							

Zone risk

Table A-84 and Table A-85 show the mean values per simulation, for each risk metric, by geographic zone, for Scenario 3.

Table A-84: Mean values per simulation for Scenario 3 by geographic zone.

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Admiralty Inlet	0.0442	37439.65	9.6128
Bellingham Channel, Sinclair Island, and waters to the East	0.0051	69400.74	2.9887
Boundary Bay	0	0	0
Carr Inlet	0	0	0
Case Inlet to Oakland Bay	0	0	0
Colvos Passage	0.0017	754.0158	0.3619
Dyes Inlet	0	0	0
Eastern Strait of Juan de Fuca	0.0011	14183.22	0.594
Eld Inlet	0	0	0
Guemes Channel and Saddlebags	0.0153	111867.5	5.5599
Gulf Islands	0	0	0
Haro Strait and Boundary Pass	0.0551	115981.6	14.1968
Hood Canal	0	0	0
Howe Sound	0.0684	7765.421	14.571
Lake Washington Ship Canal	0.0023	294.468	0.4919
Nanaimo	0.0684	7022.891	12.658
Northern Gulf Islands	0.0007	322.1946	0.1378
Port Orchard	0	0	0

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Port Susan	0	0	0
Possession Sound and Saratoga Passage	0.0607	7707.29	12.9697
Puget Sound	0.3003	168069.4	64.2315
Rich Passage and Sinclair Inlet	0.0386	4155.532	8.2823
Rosario Strait	0.0266	95349.84	8.1162
San Juan Islands	0.112	16562.45	24.2574
Skagit Bay	0.0001	6.4775	0.0109
South Sound to Olympia	0.0147	1309.074	3.147
Southern Gulf Islands	0.3156	56542.9	66.5745
Strait of Georgia	0.0263	67436.6	4.768
Strait of Georgia - Below 49th	0.0541	11215.16	11.5934
Strait of Georgia - North	0.1248	68771.02	23.6613
Strait of Georgia - South	0.0009	2715.849	0.231
Vancouver	0.0929	329598.3	31.7608
Western Strait of Juan de Fuca	0.0366	86041.03	9.4245

Table A-85: Mean values per simulation for Scenario 3 by geographic zone, excluding car ferries.

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Admiralty Inlet	0.0182	36668.15	4.0526
Bellingham Channel, Sinclair Island, and waters to the East	0.0038	69294.72	2.7036
Boundary Bay	0	0	0
Carr Inlet	0	0	0
Case Inlet to Oakland Bay	0	0	0
Colvos Passage	0.0012	741.8638	0.255
Dyes Inlet	0	0	0
Eastern Strait of Juan de Fuca	0.0011	14183.22	0.594
Eld Inlet	0	0	0
Guemes Channel and Saddlebags	0.0048	111410	4.0628
Gulf Islands	0	0	0
Haro Strait and Boundary Pass	0.0533	115834.8	13.8047
Hood Canal	0	0	0
Howe Sound	0.001	432.3644	0.1716
Lake Washington Ship Canal	0.0023	294.468	0.4919
Nanaimo	0.0026	1464.801	0.468
Northern Gulf Islands	0.0007	322.1946	0.1378
Port Orchard	0	0	0

Geographic Zone	Mean Drift Groundings	Mean Oil Volume at Risk	Mean Oil Outflow
Port Susan	0	0	0
Possession Sound and Saratoga Passage	0.0018	2164.193	0.388
Puget Sound	0.082	145601.8	17.5403
Rich Passage and Sinclair Inlet	0.0001	1110.145	0.049
Rosario Strait	0.0043	93507.41	3.3402
San Juan Islands	0.003	10701.74	0.9474
Skagit Bay	0.0001	6.4775	0.0109
South Sound to Olympia	0.0019	1008.304	0.4025
Southern Gulf Islands	0.0193	30148.51	4.6789
Strait of Georgia	0.0033	65848.65	2.2376
Strait of Georgia - Below 49th	0.0031	4284.261	0.6869
Strait of Georgia - North	0.0337	58881.18	7.4213
Strait of Georgia - South	0.0009	2715.849	0.231
Vancouver	0.0929	329598.3	31.7608
Western Strait of Juan de Fuca	0.0231	85067.43	6.5375

There were several zones where there were no changes in drift groundings, oil volume at risk, and oil outflows for all ERTV locations for Scenario 3. They include Boundary Bay, Carr Inlet, Case Inlet to Oakland Bay, Colvos Passage, Dyes Inlet, Eld Inlet, Guemes Channel and Saddlebags, Gulf Islands, Hood Canal, Howe Sound, Lake Washington Ship Canal, Nanaimo, Northern Gulf Islands, Port Orchard, Port Susan, Possession Sound and Saratoga Passage, Rich Passage and Sinclair Inlet, Skagit Bay, and South Sound to Olympia. For improved readability, those zones are omitted in the following tables.

Table A-86: Mean change in absolute values for drift groundings by geographic zone and ERTV location for Scenario 3.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-0.0001	0	-0.0001	-0.0049	-0.0001	-0.0001	-0.0001
Bellingham Channel, Sinclair Island, and waters to the East	0	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-0.0001	-0.0001	-0.0002	-0.0002	-0.0002	-0.0001	-0.0002
Guemes Channel	0	0	0	0	0	0	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
and Saddlebags							
Haro Strait and Boundary Pass	-0.0001	-0.0001	0	0	-0.005	-0.0036	-0.0006
Puget Sound	0	0	0	-0.0013	0	0	0
Rosario Strait	-0.0001	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-0.002	0	0
Southern Gulf Islands	0	0	0	0	-0.0007	-0.0087	0
Strait of Georgia	0	-0.0021	0	0	0	0	0
Strait of Georgia - Below 49th	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006
Strait of Georgia - North	0	-0.0031	0	0	0	0	0
Strait of Georgia - South	0	0	0	0	-0.0001	0	0
Vancouver	0	0	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-0.004	0	-0.0006	-0.0006	-0.0045

Table A-87: Relative change in drift grounding frequency by geographic zone and ERTV location for Scenario 3.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.23	0.00	-0.23	-11.14	-0.23	-0.23	-0.23
Bellingham Channel, Sinclair Island, and waters to the East	-0.43	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-13.78	-9.31	-18.62	-22.71	-14.65	-13.03	-22.71
Guemes Channel and Saddlebags	-0.03	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.10	-0.10	-0.07	0.00	-9.06	-6.59	-1.14

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Howe Sound	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Puget Sound	0.00	0.00	0.00	-0.45	0.00	0.00	0.00
Rosario Strait	-0.20	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-1.78	0.00	0.00
Southern Gulf Islands	0.00	-0.01	0.00	0.00	-0.22	-2.75	-0.01
Strait of Georgia	0.00	-8.12	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-1.06	-1.06	-1.06	-1.06	-1.06	-1.06	-1.06
Strait of Georgia - North	0.00	-2.45	0.00	0.00	0.00	0.00	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-8.64	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-10.95	-0.02	-1.58	-1.57	-12.15

Table A-88: Mean change in absolute values for oil volume at risk by geographic zone and ERTV location for Scenario 3.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-34.7122	0	-34.7122	-3561.74	-34.7122	-34.7122	-34.7122
Bellingham Channel, Sinclair Island, and waters to the East	-0.4855	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-30.2298	-8.8762	-16.7221	-37.7522	-40.983	-26.0748	-33.9524
Guemes Channel and Saddlebags	-0.0201	0	0	0	0	0	0
Haro Strait and Boundary Pass	-233.362	-54.7559	-44.6298	0	-12687.8	-5062.84	-669.9
Howe Sound	0	-0.0317	0	0	0	0	0
Puget Sound	0	0	0	-178.184	0	0	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Rosario Strait	-853.632	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-3000.45	0	0
Southern Gulf Islands	0	-614.394	0	0	-2372.29	-2574.58	-7.7916
Strait of Georgia	0	-2499.44	0	0	0	0	0
Strait of Georgia - Below 49th	-300.727	-300.727	-300.727	-300.727	-300.727	-300.727	-300.727
Strait of Georgia - North	0	-2589.89	0	0	0	0	0
Strait of Georgia - South	0	0	0	0	-26.0753	0	0
Vancouver	0	-0.0317	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-9263.7	-7.4696	-1223.01	-1218.13	-7971.84

Table A-89: Relative change in oil volume at risk by geographic zone and ERTV location for Scenario 3.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.09	0.00	-0.09	-9.51	-0.09	-0.09	-0.09
Bellingham Channel, Sinclair Island, and waters to the East	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-0.21	-0.06	-0.12	-0.27	-0.29	-0.18	-0.24
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.20	-0.05	-0.04	0.00	-10.94	-4.37	-0.58
Howe Sound	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Puget Sound	0.00	0.00	0.00	-0.11	0.00	0.00	0.00
Rosario Strait	-0.90	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-18.12	0.00	0.00
Southern Gulf Islands	0.00	-1.09	0.00	0.00	-4.20	-4.55	-0.01
Strait of Georgia	0.00	-3.71	0.00	0.00	0.00	0.00	0.00

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Strait of Georgia - Below 49th	-2.68	-2.68	-2.68	-2.68	-2.68	-2.68	-2.68
Strait of Georgia - North	0.00	-3.77	0.00	0.00	0.00	0.00	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-0.96	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-10.77	-0.01	-1.42	-1.42	-9.27

Table A-90: Mean change in absolute values for oil outflow by geographic zone and ERTV location for Scenario 3

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-0.0214	0	-0.0214	-1.0505	-0.0214	-0.0214	-0.0214
Bellingham Channel, Sinclair Island, and waters to the East	-0.0017	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-0.0317	-0.0214	-0.0428	-0.0522	-0.033	-0.0299	-0.0516
Guemes Channel and Saddlebags	-0.0001	0	0	0	0	0	0
Haro Strait and Boundary Pass	-0.0216	-0.0122	-0.0086	0	-1.3232	-0.8578	-0.1447
Howe Sound	0	-0.0002	0	0	0	0	0
Puget Sound	0	0	0	-0.286	0	0	0
Rosario Strait	-0.0399	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-0.4971	0	0
Southern Gulf Islands	0	-0.0161	0	0	-0.2552	-1.7625	-0.0032
Strait of Georgia	0	-0.495	0	0	0	0	0
Strait of Georgia - Below 49th	-0.1222	-0.1222	-0.1222	-0.1222	-0.1222	-0.1222	-0.1222
Strait of Georgia - North	0	-0.6532	0	0	0	0	0
Strait of Georgia - South	0	0	0	0	-0.0171	0	0
Vancouver	0	-0.0002	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-0.9891	-0.0017	-0.123	-0.1221	-1.0489

Table A-91: Relative change in oil outflow by geographic zone and ERTV Location for Scenario 3

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.22	0.00	-0.22	-10.93	-0.22	-0.22	-0.22
Bellingham Channel, Sinclair Island, and waters to the East	-0.06	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-5.33	-3.60	-7.20	-8.78	-5.56	-5.04	-8.68
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.15	-0.09	-0.06	0.00	-9.32	-6.04	-1.02
Howe Sound	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Puget Sound	0.00	0.00	0.00	-0.45	0.00	0.00	0.00
Rosario Strait	-0.49	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-2.05	0.00	0.00
Southern Gulf Islands	0.00	-0.02	0.00	0.00	-0.38	-2.65	0.00
Strait of Georgia	0.00	-10.38	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-1.05	-1.05	-1.05	-1.05	-1.05	-1.05	-1.05
Strait of Georgia - North	0.00	-2.76	0.00	0.00	0.00	0.00	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-7.41	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-10.50	-0.02	-1.31	-1.30	-11.13

Table A-92: Change in grounding rate by geographic zone and ERTV Location for Scenario 3

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet [1.46]	-0.01	0.00	-0.01	-0.17	-0.01	-0.01	-0.01
Bellingham Channel, Sinclair Island, and waters to the East [4.13]	-0.11	0.00	0.00	0.00	0.00	0.00	0.00
Colvos Passage [3.92]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca [0.29]	-0.03	-0.01	-0.02	-0.03	-0.03	-0.01	-0.03

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Guemes Channel and Saddlebags [10.46]	-0.04	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass [5.06]	-0.05	-0.01	-0.03	0.00	-0.60	-0.41	-0.08
Howe Sound [7.41]	0.00	-0.03	0.00	0.00	0.00	0.00	0.00
Puget Sound [5.80]	0.00	0.00	0.00	-0.01	0.00	0.00	0.00
Rosario Strait [2.72]	-0.03	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands [2.90]	0.00	0.00	0.00	0.00	-0.20	0.00	0.00
Southern Gulf Islands [7.86]	0.00	-0.03	0.00	0.00	-0.18	-0.28	-0.04
Strait of Georgia [1.94]	0.00	-0.10	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th [1.30]	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Strait of Georgia – North [2.30]	0.00	-0.03	0.00	0.00	0.00	0.00	0.00
Strait of Georgia South [1.14]	0.00	0.00	0.00	0.00	-0.07	0.00	0.00
Vancouver [11.89]	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca [0.40]	0.00	0.00	-0.05	0.00	-0.01	-0.01	-0.05

Table A-93 summarizes the ERTV locations resulting in no detectable changes in oil spill risk metrics, detectable changes in all oil spill risk metrics for each vessel type, the above average detectable changes in oil spill risk metrics for each vessel type.

Table A-93: Changes in all oil spill risk metrics by geographic zone and ERTV location for Scenario 3. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet							
Eastern Strait of Juan de Fuca							
Haro Strait and Boundary Pass							
Puget Sound							
Rosario Strait							

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
San Juan Islands							
Southern Gulf Islands							
Strait of Georgia							
Strait of Georgia – Below 49th							
Strait of Georgia – North							
Strait of Georgia South							
Western Strait of Juan de Fuca							

Table A-94: Mean change in absolute values for drift groundings by geographic zone and ERTV location for Scenario 3, excluding car ferries.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-0.0001	0	-0.0001	-0.0023	-0.0001	-0.0001	-0.0001
Bellingham Channel, Sinclair Island, and waters to the East	0	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-0.0001	-0.0001	-0.0002	-0.0002	-0.0002	-0.0001	-0.0002
Guemes Channel and Saddlebags	0	0	0	0	0	0	0
Haro Strait and Boundary Pass	-0.0001	-0.0001	0	0	-0.0045	-0.0031	-0.0006
Puget Sound	0	0	0	0	0	0	0
Rosario Strait	-0.0001	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-0.0007	0	0
Southern Gulf Islands	0	0	0	0	-0.0007	-0.0007	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Strait of Georgia	0	-0.0008	0	0	0	0	0
Strait of Georgia - Below 49th	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006	-0.0006
Strait of Georgia - North	0	-0.0026	0	0	0	0	0
Strait of Georgia - South	0	0	0	0	-0.0001	0	0
Vancouver	0	0	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-0.004	0	-0.0006	-0.0006	-0.0045

Table A-95: Relative change in drift grounding frequency by geographic zone and ERTV location for Scenario 3, excluding car ferries.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.55	0.00	-0.55	-12.39	-0.55	-0.55	-0.55
Bellingham Channel, Sinclair Island, and waters to the East	-0.59	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-13.78	-9.31	-18.62	-22.71	-14.65	-13.03	-22.71
Guemes Channel and Saddlebags	-0.08	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.10	-0.11	-0.08	0.00	-8.44	-5.88	-1.18
Howe Sound	0.00	-0.39	0.00	0.00	0.00	0.00	0.00
Puget Sound	0.00	0.00	0.00	-0.01	0.00	0.00	0.00
Rosario Strait	-1.24	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-21.97	0.00	0.00
Southern Gulf Islands	0.00	-0.16	0.00	0.00	-3.56	-3.47	-0.11
Strait of Georgia	0.00	-24.23	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-18.24	-18.24	-18.24	-18.24	-18.24	-18.24	-18.24
Strait of Georgia - North	0.00	-7.59	0.00	0.00	0.00	0.00	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-8.64	0.00	0.00

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-17.39	-0.04	-2.50	-2.48	-19.25

Table A-96: Mean change in absolute values for oil volume at risk by zone and ERTV location for Scenario 3, excluding car ferries.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-34.7122	0	-34.7122	-3357.33	-34.7122	-34.7122	-34.7122
Bellingham Channel, Sinclair Island, and waters to the East	-0.4855	0	0	0	0	0	0
Eastern Strait of Juan de Fuca	-30.2298	-8.8762	-16.7221	-37.7522	-40.983	-26.0748	-33.9524
Guemes Channel and Saddlebags	-0.0201	0	0	0	0	0	0
Haro Strait and Boundary Pass	-233.362	-54.7559	-44.6298	0	-12590.3	-4965.35	-669.9
Howe Sound	0	-0.0317	0	0	0	0	0
Puget Sound	0	0	0	-4.8868	0	0	0
Rosario Strait	-853.632	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-2853.92	0	0
Southern Gulf Islands	0	-614.394	0	0	-2372.29	-2196.79	-7.7916
Strait of Georgia	0	-2239.47	0	0	0	0	0
Strait of Georgia - Below 49th	-300.727	-300.727	-300.727	-300.727	-300.727	-300.727	-300.727
Strait of Georgia - North	0	-2492.4	0	0	0	0	0
Strait of Georgia - South	0	0	0	0	-26.0753	0	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Vancouver	0	-0.0317	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-9263.7	-7.4696	-1223.01	-1218.13	-7971.84

Table A-97: Relative change in oil volume at risk by geographic zone and ERTV Location for Scenario 3, excluding car ferries.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.10	0.00	-0.10	-9.16	-0.10	-0.10	-0.10
Bellingham Channel, Sinclair Island, and waters to the East	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-0.21	-0.06	-0.12	-0.27	-0.29	-0.18	-0.24
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass	-0.20	-0.05	-0.04	0.00	-10.87	-4.29	-0.58
Howe Sound	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Puget Sound	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rosario Strait	-0.91	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-26.67	0.00	0.00
Southern Gulf Islands	0.00	-2.04	0.00	0.00	-7.87	-7.29	-0.03
Strait of Georgia	0.00	-3.40	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-7.02	-7.02	-7.02	-7.02	-7.02	-7.02	-7.02
Strait of Georgia - North	0.00	-4.23	0.00	0.00	0.00	0.00	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-0.96	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-10.89	-0.01	-1.44	-1.43	-9.37

Table A-98: Mean change in absolute values for oil outflow by zone and ERTV location for Scenario 3, excluding car ferries.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet	-0.0214	0	-0.0214	-0.4803	-0.0214	-0.0214	-0.0214
Bellingham Channel,	-0.0017	0	0	0	0	0	0

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Sinclair Island, and waters to the East							
Eastern Strait of Juan de Fuca	-0.0317	-0.0214	-0.0428	-0.0522	-0.033	-0.0299	-0.0516
Eld Inlet	0	0	0	0	0	0	0
Guemes Channel and Saddlebags	-0.0001	0	0	0	0	0	0
Haro Strait and Boundary Pass	-0.0216	-0.0122	-0.0086	0	-1.2162	-0.7508	-0.1447
Howe Sound	0	-0.0002	0	0	0	0	0
Puget Sound	0	0	0	-0.0009	0	0	0
Rosario Strait	-0.0399	0	0	0	0	0	0
San Juan Islands	0	0	0	0	-0.212	0	0
Southern Gulf Islands	0	-0.0161	0	0	-0.2552	-0.2505	-0.0032
Strait of Georgia	0	-0.2099	0	0	0	0	0
Strait of Georgia - Below 49th	-0.1222	-0.1222	-0.1222	-0.1222	-0.1222	-0.1222	-0.1222
Strait of Georgia - North	0	-0.5462	0	0	0	0	0
Strait of Georgia - South	0	0	0	0	-0.0171	0	0
Vancouver	0	-0.0002	0	0	0	0	0
Western Strait of Juan de Fuca	0	0	-0.9891	-0.0017	-0.123	-0.1221	-1.0489

Table A-99: Relative change in oil outflow by geographic zone and ERTV Location for Scenario 3, excluding car ferries.

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Admiralty Inlet	-0.53	0.00	-0.53	-11.85	-0.53	-0.53	-0.53
Bellingham Channel, Sinclair Island, and waters to the East	-0.06	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca	-5.33	-3.60	-7.20	-8.79	-5.56	-5.04	-8.68
Guemes Channel and Saddlebags	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Geographic Zone	Anacortes (%)	Deltaport (%)	Port Angeles (%)	Port Townsend (%)	Roche Harbor (%)	Sidney (%)	Victoria (%)
Haro Strait and Boundary Pass	-0.16	-0.09	-0.06	0.00	-8.81	-5.44	-1.05
Howe Sound	0.00	-0.14	0.00	0.00	0.00	0.00	0.00
Puget Sound	0.00	0.00	0.00	-0.01	0.00	0.00	0.00
Rosario Strait	-1.20	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands	0.00	0.00	0.00	0.00	-22.37	0.00	0.00
Southern Gulf Islands	0.00	-0.34	0.00	0.00	-5.46	-5.35	-0.07
Strait of Georgia	0.00	-9.38	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th	-17.79	-17.79	-17.79	-17.79	-17.79	-17.79	-17.79
Strait of Georgia - North	0.00	-7.36	0.00	0.00	0.00	0.00	0.00
Strait of Georgia South	0.00	0.00	0.00	0.00	-7.41	0.00	0.00
Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca	0.00	0.00	-15.13	-0.03	-1.88	-1.87	-16.04

Table A-100: Change in grounding rate by geographic zone and ERTV Location for Scenario 3, excluding car ferries.

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet [1.34]	-0.01	0.00	-0.01	-0.17	-0.01	-0.01	-0.01
Bellingham Channel, Sinclair Island, and waters to the East [4.18]	-0.11	0.00	0.00	0.00	0.00	0.00	0.00
Colvos Passage [4.31]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Strait of Juan de Fuca [0.29]	-0.03	-0.01	-0.02	-0.03	-0.03	-0.02	-0.03
Guemes Channel and Saddlebags [10.86]	-0.05	0.00	0.00	0.00	0.00	0.00	0.00
Haro Strait and Boundary Pass [5.12]	-0.05	-0.01	-0.03	0.00	-0.59	-0.40	-0.08
Howe Sound [5.59]	0.00	-0.09	0.00	0.00	0.00	0.00	0.00
Puget Sound [5.53]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rosario Strait [2.48]	-0.03	0.00	0.00	0.00	0.00	0.00	0.00
San Juan Islands [0.58]	0.00	0.00	0.00	0.00	-0.16	0.00	0.00

Geographic Zone [Original Grounding Rate]	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Southern Gulf Islands [5.94]	0.00	-0.04	0.00	0.00	-0.27	-0.31	-0.05
Strait of Georgia [1.72]	0.00	-0.09	0.00	0.00	0.00	0.00	0.00
Strait of Georgia - Below 49th [0.49]	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Strait of Georgia – North [2.15]	0.00	-0.03	0.00	0.00	0.00	0.00	0.00
Strait of Georgia South [1.17]	0.00	0.00	0.00	0.00	-0.07	0.00	0.00
Vancouver [11.94]	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Western Strait of Juan de Fuca [0.39]	0.00	0.00	-0.05	0.00	-0.01	-0.01	-0.05

Table A-101 summarizes the ERTV locations resulting in no detectable changes in oil spill risk metrics, detectable changes in all oil spill risk metrics for each vessel type, the above average detectable changes in oil spill risk metrics for each vessel type.

Table A-101: Changes in all oil spill risk metrics by geographic zone and ERTV location for Scenario 3, excluding car ferries. White cells indicate detectable changes in oil spill risk metrics, grey cells indicate detectable changes, and black cells indicate above average detectible changes.

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Admiralty Inlet							
Eastern Strait of Juan de Fuca							
Haro Strait and Boundary Pass							
Howe Sound							
Rosario Strait							
San Juan Islands							
Southern Gulf Islands							
Strait of Georgia							
Strait of Georgia – Below 49th							
Strait of Georgia – North							
Strait of Georgia South							

Geographic Zone	Anacortes	Deltaport	Port Angeles	Port Townsend	Roche Harbor	Sidney	Victoria
Western Strait of Juan de Fuca							

Influence of tugs of opportunity

The previous comparisons for each ERTV location are repeated here with the tugs of opportunity option turned off and only looking at Scenario 2.

Table A-102 summarizes the overall changes in oil spill metrics for each ERTV locations. The detailed results are discussed in detail in the following sections.

Table A-102: Overall changes in oil spill risk metrics per ERTV location without tugs of opportunity.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	9.31	9.99	9.19	2.88	0.50
Deltaport	8.17	8.93	7.98	2.87	0.47
Port Angeles	10.03	10.78	9.98	2.86	0.53
Port Townsend	9.44	10.21	9.44	2.86	0.48
Roche Harbor	8.17	8.01	7.98	2.84	0.46
Sidney	8.20	8.64	8.07	2.85	0.48
Victoria	9.25	9.45	9.14	2.86	0.50

Table A-103: Overall changes in oil spill risk metrics per ERTV location without tugs of opportunity, excluding car ferries.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	16.83	10.16	13.89	2.54	0.50
Deltaport	14.98	9.12	12.08	2.54	0.47
Port Angeles	18.45	10.95	15.42	2.53	0.53
Port Townsend	17.43	10.39	14.73	2.53	0.48
Roche Harbor	14.42	8.08	11.55	2.51	0.46
Sidney	14.74	8.76	11.94	2.52	0.48
Victoria	16.69	9.58	13.77	2.52	0.50

This analysis investigated the effects of the absence of tugs of opportunity as an intervention on the oil spill metrics. Thus, as expected, it resulted in overall increases in all oil spill metrics, regardless of the ERTV location. Each ERTV location can compensate for the absence of tugs of opportunities to some extent. However, the ERTV locations with the lowest increase in oil spill metrics are the ones that provide the highest benefit, in the absence of tugs of opportunity as an intervention option.

Trans Mountain Expansion Project traffic

This section reviews the outcomes of a traffic simulation that included projected levels of round-trip tank ship transits associated with the Trans Mountain Expansion Project. The simulated transits run from the J-Buoy at the entrance to the Strait of Juan de Fuca to Westridge Terminal in Burnaby, B.C. The outbound laden transit is escorted. The inbound unladen transit is unescorted. The research questions associated with this secondary analysis were assessed against current tug escort requirements (Scenario 2).

Table A-104 summarizes the overall effects of TMEP for each ERTV location.

Table A-104: Overall changes in oil spill risk metrics per ERTV location for the TMEP.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	-0.84	-1.34	-0.89	2.88	-0.05
Deltaport	-0.77	-1.28	-0.82	2.87	-0.05
Port Angeles	-0.61	-0.71	-0.62	2.86	-0.03
Port Townsend	-0.84	-1.36	-0.89	2.86	-0.05
Roche Harbor	-0.63	-0.99	-0.66	2.84	-0.04
Sidney	-0.55	-0.99	-0.60	2.85	-0.04
Victoria	-0.56	-0.62	-0.57	2.86	-0.03

Table A-105: Overall changes in oil spill risk metrics per ERTV location for the TMEP, excluding car ferries.

ERTV Location	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Change in Grounding Rate
Anacortes	-2.55	-1.43	-2.24	2.54	-0.05
Deltaport	-2.41	-1.38	-2.13	2.54	-0.05
Port Angeles	-1.61	-0.75	-1.41	2.53	-0.03
Port Townsend	-2.55	-1.45	-2.25	2.53	-0.05
Roche Harbor	-1.70	-1.06	-1.54	2.51	-0.04
Sidney	-1.73	-1.06	-1.55	2.52	-0.04
Victoria	-1.40	-0.65	-1.24	2.52	-0.03

This analysis did not investigate the effects of additional tank vessels traffic from the TMEP on the overall oil spill risk. It only looked at potential benefits of additional tugs of opportunity from the TMEP escorted vessels in conjunction with ERTV locations, to the current vessel traffic in the study area. Thus, as expected, the additional tugs of opportunities from TMEP as an intervention option resulted in overall decreases in all oil spill metrics, regardless of the ERTV location. However, tugs of opportunity and ERTVs are overlapping interventions. The benefits of ERTVs are higher if tugs of opportunities are not available. Therefore, the ERTV locations with the highest decrease in oil spill metrics are the ones that provide the highest benefit in conjunction with the additional TMEP tugs of opportunity.

Discussion

Simulation modeling

A note about car ferries

The overwhelming volume of car ferry traffic in our simulated outputs put us at risk of missing important patterns for vessel types of interest. With that in mind, we evaluated all outputs both with and without ferry traffic included. This discussion section only reviews the portion of the results that excluded car ferry traffic. Results with ferry traffic included are available for review in the results section.

Simulated vessel traffic data

Vessel traffic was unevenly distributed among zones. This can be attributed to the large differences in the size of the zones, and the fact that some zones contain major commercial traffic routes to ports.

The presence of major commercial routes explains why about 83 percent of the traffic is in Admiralty Inlet, Eastern Strait of Juan de Fuca, Haro Strait and Boundary Pass, Puget Sound, Strait of Georgia, Strait of Georgia – North, Vancouver, and Western Strait of Juan de Fuca. Zones that account for the least traffic, such as Carr Inlet, Colvos Passage, Port Orchard, and Skagit Bay, are small zones that don't include major traffic routes.

Towed oil barges, bulk carriers, and container ships make up almost 65 percent of underway minutes. ATBs and towed oil barges account for over 31 percent of all traffic and oil tankers a bit less than 5 percent.

Current oil spill risk profile

The simulation modeling provided insight on how oil spill risk due to loss of propulsion events and subsequent drift groundings varies across geographic zones and vessel types. For a given vessel type, area and time period, loss of propulsion frequency is a function of vessel traffic intensity and the probability of loss of propulsion events.

For the most part, the spatial distribution of the oil spill risk metrics reflected traffic volume patterns. While there are several contributing factors to a loss of propulsion event becoming a drift grounding (wind and current conditions, vessel characteristics, proximity to shoreline, shoreline characteristics, etc.), the results for the geographic distribution of oil risk support a common-sense insight: high traffic regions with restricted waterways have the highest oil spill risk. For example, Puget Sound accounts for nearly 13 percent of the traffic and about 20 percent of the oil spill risk. A high traffic zone that is a less restricted waterway, the Western Strait of Juan de Fuca, accounts for over 40 percent of the traffic but only around 7-8 percent of the overall oil spill risk. Conversely, areas with very little traffic had zero or near-zero oil spill risk metric values (e.g., Boundary Bay, Carr Inlet, Case Inlet to Oakland Bay, Dyes Inlet, Eld Inlet, Gulf Islands, Hood Canal, Port Orchard, Port Susan, or Skagit Bay).

Based on drift grounding rate, Lake Washington Ship Canal has the highest potential drift grounding risk (grounding rate of 21.36 percent). This high rate is likely due to the Lake Washington Ship Canal being a narrow waterway. Vessels are always near the shoreline. If a loss of propulsion takes place, there is little time for any intervention to prevent a drift grounding. Although the grounding rate for the Lake Washington Ship Canal is very high, the relative contribution to oil risk metrics in the study area was very low compared with other zones, since the traffic volumes are comparably small (<0.1 percent).

When considering risk by vessel type, oil spill risk metrics also follow traffic volumes. This is similar to what we saw when comparing by zone. Bulk carriers and container ships are the biggest contributors to the drift groundings and oil outflow among all the vessels. This is not surprising since they account for about 43 percent of the traffic in the study area.

Looking at the grounding rates, bunkering barges and towed oil barges have the highest values: 6.60 percent and 5.59 percent, respectively.

Changes between ERTV locations

The model results suggest that, regardless of the scenario, when car ferries are excluded, ERTVs located in Roche Harbor provide the largest reductions in drift groundings, oil volumes at risk, and oil outflows regardless of the scenario.

An ERTV in Sidney resulted in the second largest reduction in drift groundings in all scenarios and second largest reduction in oil outflow in Scenario 1 and 2, while Victoria ERTV location resulted in the second largest reduction in oil volume at risk in all scenarios and second largest reduction in oil outflow in Scenario 3. Regardless of the ERTV location, these reductions were modest (up to < 2.7 percent).

All vessel types benefited from the presence of an ERTV in all scenarios. Non-tank vessels benefited more from ERTVs than tank vessels, probably since tank vessels are sometimes escorted.

In all scenarios, Roche Harbor benefited vehicle carriers the most. With the order depending on the scenario, Roche Harbor also benefited large fishing vessels, bulk carriers, chemical tankers, and container ships. Depending on the scenario, bulk carriers – the largest traffic contributors in the area - benefited the most from ERTV located in Deltaport, Roche Harbor, Sidney, and Victoria.

The geographic zones most benefited by a Roche Harbor ERTV were Eastern Strait of Juan de Fuca, Haro Strait and Boundary Pass, San Juan Island, Southern Gulf Islands, Strait of Georgia - Below 49^{th}, Strait of Georgia South, and Western Strait of Juan de Fuca.

Vessel types primarily benefit from ERTVs located near their typical routes. For example, bulk carriers often travel close by to most ERTV locations. Not surprisingly, they benefit from the presence of an ERTV regardless of its location.

Similarly, zones benefit from ERTVs stationed nearby. For example, Haro Strait and Boundary Pass benefited the most from ERTVs located in Roche Harbor, Sidney, and Victoria and less or not at all from ERTVs located in Anacortes, Deltaport, Port Angeles, and Port Townsend.

Zone size and characteristics are important since they might dictate the drift duration. Thus, vessels will potentially drift longer in large, open zones, allowing for ERTVs from most locations to intervene.

This may be why Eastern Strait of Juan de Fuca, for example, systematically recorded some of the highest reductions in oil spill risk metrics, regardless of the ERTV location and scenario.

Zones farther away from the locations of the ERTVs, smaller in size, and with restricted waters were less likely to benefit from the presence of ERTVs. Zones with large relative changes in metrics may also be smaller zones with little traffic, in which a small absolute change results in a large relative change.

Tug escort requirement effect on ERTV locations

We evaluated each ERTV location against three different tug escort scenarios to determine if tug escort scenarios change which ERTV location provided the highest oil spill risk reduction benefit. Roche Harbor remained the most beneficial ERTV location regardless of tug escort scenario.

Influence of tugs of opportunity

The removal of tugs of opportunity resulted in an increase of about 9 to 18 percent in oil spill risk metrics. The smallest increases were recorded for Roche Harbor locations for all oil spill metrics. Considering the previous result that Roche Harbor ERTV location resulted in the largest reductions in all oil spill risk metrics, it is reasonable to conclude that Roche Harbor is still the most beneficial location for ERTVs even in the absence of tugs of opportunity.

Overall, tugs of opportunity appear to have a greater effect on oil spill risk than an additional ERTV. The removal of tugs of opportunity resulted in an increase in oil spill metrics of about 18 percent regardless of the ERTV location. Roche Harbor is still the most beneficial locations for ERTVs even in the absence of tugs of opportunity.

Influence of the Trans Mountain Expansion Project traffic

In general, the model results indicated a slight decrease for all ERTV locations in overall oil spill risk due to the additional tug rescue options associated with the TMEP (about -0.6 to -1.3 percent in oil spill risk metrics). The largest decreases were recorded for Anacortes and Port Townsend ERTV locations, while the decreases for Sidney were smaller. Overall, this is because the TMEP increases the number of potential tugs of opportunity on the waterways and adds a new rescue tug at Beecher Bay. However, the benefit of the increase is either complementary to the ERTV benefits (as in the case of Anacortes and Port Townsend), or more redundant (as in the case of Roche Harbor).

The decreases for Roche Harbor were close to those for Anacortes and Port Townsend. Therefore, considering the previous result that Roche Harbor ERTV location resulted in the largest reductions in all oil spill risk metrics, it is reasonable to conclude that Roche Harbor is still the most beneficial locations for ERTVs even considering the TMEP.

Sources of uncertainty

The estimation of loss of propulsion probabilities for the vessel types used in the model was an original analysis. While estimates for these probabilities were implemented in the model, they had substantial uncertainty. For example, loss of propulsions for ferries may have a higher reporting rate than other vessel types, but the rates for total losses of propulsion were primarily based on commercial deep draft vessels. Ferries are more likely to have redundant propulsion systems and likely experience total losses of propulsion at rates lower than were simulated.

However, since the goal of the analysis was focused on relative differences among contributing factors to oil spill risk rather than predicting loss of propulsion events, the importance of these uncertainties was minimized in assessing relative differences between vessel types. The focus of this study on relative differences in oil spill risk also minimizes the importance of the overall accuracy of the estimated probabilities.

The drift and momentum module determines a path for a vessel after a propulsion loss by incorporating basic physical forces to determine the resulting drift trajectory and speed. The study area has complex currents and wind patterns resulting from tidal influences, landforms, and other physical features of the area. While the drift and momentum module produced plausible results, the hydrodynamics of the region are complex. Since, the model relied upon many general assumptions, simulated trajectories should be considered coarse representations of actual drift trajectories.

Our simulation design produced notable differences between observed and simulated volumes of escort and assist tugs.

Our tug simulation approach attempted to keep overall tug traffic constant across all three scenarios, but the implementation of Scenario 3 often required increasing tug traffic volumes for the other two scenarios. The simulated results also showed us that escort traffic tends to result in more underway time compared to other tasks performed by those vessels. All of this supports a common-sense conclusion that rules requiring tug escorts lead to an increase in tug traffic.

Another important source of uncertainty in the modeling was the assignment of laden status to tank vessels. The vessel traffic data that we used to model vessel movement do not contain reliable information regarding laden status. While information from Ecology’s Advance Notice of Oil Transfers System was a valuable source of information, its utility was limited. As explained in Appendix B a set of rules was developed for each tank vessel type that determined whether a tank vessel was laden with cargo for specific parts of the vessel’s journey. While we tried to develop rules that accurately represent when vessels are laden, the lack of data meant that we were forced to make a number of assumptions. Thus, some uncertainty exists about when such vessels are actually laden.

Additional sources of uncertainty come from the time to connect and control, tug speed and tug success rate model parameters. The estimates used for those parameters were chosen based on the best knowledge in the field, in consultation with our stakeholders. They were not based on data since such records are scarce and difficult to obtain. The relationship between these parameters and oil spill metrics does not seem linear, which highlight the importance of re-visiting the estimation of these parameters if more data becomes available.

Summary

Drift groundings are rare events. Based on our review of historical incidents in the study area, we identified 4 drift groundings between 2002 and 2019 (an average of 0.2105 drift groundings per year).

None of these resulted in an oil spill. When we expanded our review to a much larger area (the Bi-National area), we found 190 drift groundings (an average of 10.5556 per year), of which only 2.6 percent were associated with oil spills.

However, the spills associated with those drift groundings have the potential to be substantial. For the incidents we reviewed (including collisions, allisions, non-drift groundings, and drift groundings), spills ranging in size from 1 to 420,000 gallons were found. Depending on vessel type, the median spill size ranged from 75 to 1,000 gallons and the mean spill size ranged from 14,212 to 46,732 gallons.[23]

On average, our analysis found small potential reductions in drift groundings due to ERTVs. For Scenario 2, excluding car ferries, they were -0.0008 for Anacortes, -0.0034 for Port Townsend, -0.0046 for Port Angeles, -0.0049 for Deltaport, -0.0058 for Victoria, -0.0074 for Sidney, and -0.0095 for Roche Harbor. This is equivalent for the ERTVs under Scenario 2 being able to prevent about 1 in 456 drift groundings (Anacortes ERTV), 1 in 107 drift groundings (Port Townsend ERTV), 1 in 79 drift groundings (Port Angeles ERTV), 1 in 74 drift groundings (Deltaport ERTV), 1 in 63 drift groundings (Victoria ERTV), 1 in 49 drift groundings (Sidney ERTV), and 1 in 38 drift groundings (Roche Harbor ERTV).

The potential average reduction in oil volume at risk and oil outflows associated with these reductions is also small. Yet, the risk metrics do not speak to whether the specific drift groundings prevented by the new ERTVs have large or small spills associated with them. Individual spill outcomes present in incident databases are a reminder that while most drift groundings aren’t associated with spills, large spills remain a possibility. It follows that while our risk metrics show small average reductions in risk, the prevention of an individual drift grounding could potentially be preventing a large spill.

[23] For more information on oil spill data analysis, see Appendix B – Oil Spill Volumes.

Appendix B: Rescue Tug Analysis Model Description

Overview

The Rescue Tug Analysis Model (model) is a set of tools used to perform the tug escort and ERTV analyses (Figure B-1). The objective of the model is to test, through simulations, the impacts of different tug escort and ERTVs scenarios on drift groundings. Simulation modeling is a common approach to generate data when experimentation is not possible, cost prohibitive, or time-consuming.

The objective of the model was to generate realistic vessel traffic and movement patterns (including escort tugs, assist tugs, and bunkering vessels), generate loss of propulsion and loss of steering events, and evaluate how patterns of drift groundings and potential oil spills varied under different scenarios.

Each simulation in the model follows the same general approach. At every minute, each vessel moves following trajectories based on the historical traffic data. Loss of propulsion and loss of steering events occur with given probabilities. Vessel drift trajectories from the loss of propulsion incidents are generated. Then, the model evaluates actions and interventions for preventing a drift grounding and generates oil spill risk metrics for each simulated drift grounding.

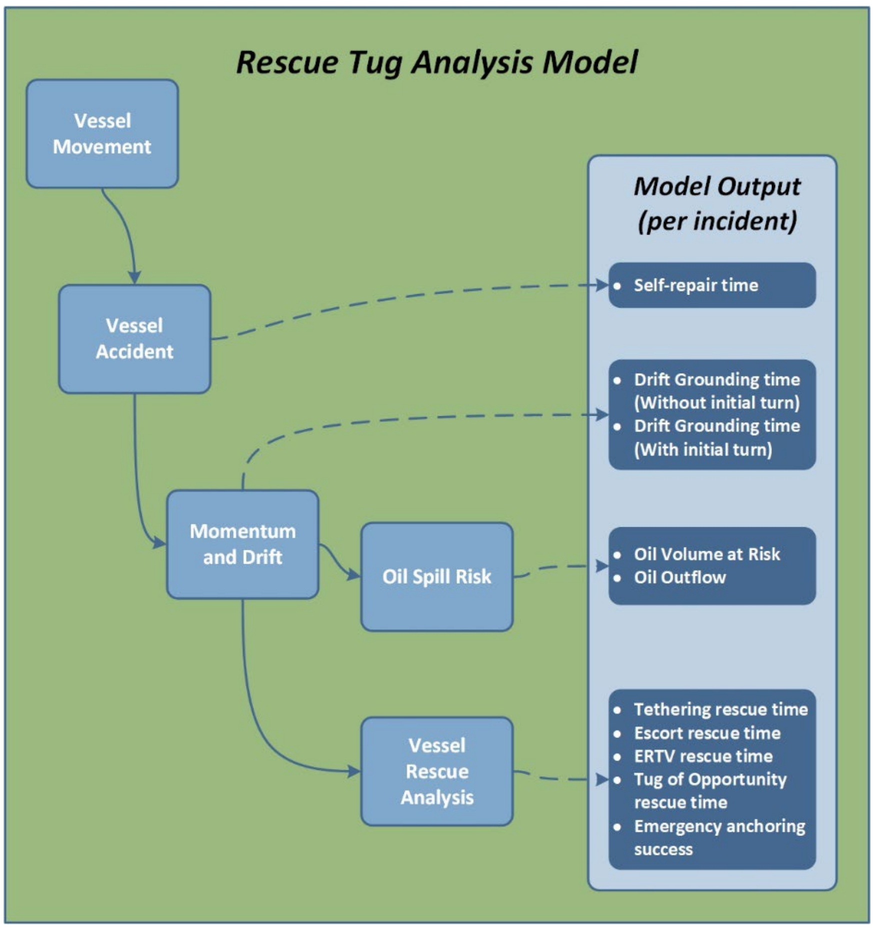

Figure B-1: Rescue Tug Analysis Model.

The model is structured as five discrete modules: Vessel Movement, Vessel Accident, Momentum and Drift, Oil Spill Risk, and Vessel Rescue Analysis. The Vessel Movement Module generates similar vessel traffic levels to what was observed but allows for unique combinations of vessel routes and travel times not observed.

Using probabilities based on existing data, the Vessel Accident Module generates loss of propulsion and loss of steering incidents, identifying the time and location for the incident for a simulated vessel. The Vessel Accident Module also determines an amount of time for the crew to self-repair.

The Momentum and Drift Module plots a drift trajectory and a drift grounding location for a simulated ship that loses propulsion, based on vessel characteristics, wind and current data, and bathymetry. For each loss of propulsion event, the Momentum and Drift Module plots two drift trajectories. One trajectory includes an initial turn to avoid readily apparent grounding hazards and another drift trajectory without an initial turn.

For each drift grounding, the Oil Spill Risk Module generates three oil spill risk metric values. The risk metrics represent the frequency of a drift grounding, the maximum amount of potential oil on board the simulated vessel (oil volume at risk) and an oil spill volume. The oil spill risk metric values are weighted by the probability of a loss of propulsion occurring for that vessel type. The Oil Spill Risk Module generates the oil outflow risk value using data from historical spills.

The Vessel Rescue Analysis Module evaluates a vessel drift trajectory for successful emergency anchoring, Emergency Response Towing Vessel (ERTV) rescue, and tug of opportunity rescue. The Vessel Rescue Analysis Module also evaluates the immediate benefits of escorting and tethering for an adrift vessel. This model structure allows us to independently assess the relative impacts of ship actions and interventions, including self-repair, emergency anchoring, escort tugs, tugs of opportunity, and ERTVs, to prevent drift groundings.

Figure B-2: Model domain.

Model domain

The model domain is bounded on the west by an arc approximately 20 nautical miles past Buoy JA, and to the north with a line from Nanoose Bay to Sechelt (Figure B-2).

Interior waterways within the ports of Seattle and Vancouver, such as the Fraser River, portions of the Duwamish River, and Lake Washington, are outside the model domain. The maritime traffic patterns in these areas are either not directly relevant to the scope of our analysis or too complex to simulate effectively.

Additionally, the model domain is restricted in the north to include only lower Howe Sound due to a lack of consistent vessel traffic data in the upper portion.

Data processing and analysis

All the Model's components, mechanisms, and tools are based on data. We used data to build the foundation for the Model's vessel traffic simulation, for defining key model parameters, and for analysis to inform model rules. In many cases, the data underwent significant processing and analysis. We primarily acquired data from government agencies through public data portals or Freedom of Information Act requests. When necessary, we acquired proprietary datasets to supplement our existing data. Our general approach to data processing was to transform and modify source data as little as possible to still meet the needs of the Model. Similarly, when analyzing data, we relied upon empirical results as much as possible and attempted to minimize our use of derived values or "rules of thumb."

AIS data

Automatic Identification System (AIS) is an automatic tracking system used on ships and by vessel traffic services for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites.

AIS transmissions include a ship's position along with other information, such as speed, course, status, and heading. AIS transmitters also broadcast additional vessel details, including Maritime Mobile Service Identity number (MMSI), vessel type, International Maritime Organization (IMO) number, call sign, and vessel dimensions. Vessels transmit this information with different frequency ranging from a few seconds to several minutes. The frequency depends on the type of AIS unit, vessel status, course, and speed. Most commercial vessels are required to carry AIS under United States Coast Guard (USCG), IMO, and Transport Canada regulations. Only vessels that carry AIS are represented in the Model.

For this analysis, the project team acquired AIS data from MarineCadastre.gov for the years 2015 through 2019. MarineCadastre.gov, a partnership between National Oceanic and Atmospheric Administration (NOAA) and the Bureau of Ocean Energy Management, provides AIS data received by land-based antennas from the USCG's national network of receivers. MarineCadastre.gov filters the raw AIS messages to one minute. Beginning in 2015, MarineCadastre.gov used the USCG's Authoritative Vessel Identification Service (AVIS) to correct static vessel information for fields with missing or inaccurate values.

The project team developed several scripts and transfer tools to handle the AIS data. A Python script selected AIS messages within a bounding box encompassing the model domain. Custom data transfer tools imported these AIS messages into a Microsoft SQL Server 2016 database and then split into two tables. One table included dynamic movement information (latitude, longitude, speed, course, heading, and navigation status). The other contained static vessel information (MMSI, vessel name, IMO number, call sign, vessel type, length, width, and draft). Database scripts split the dynamic movement data into separate tables for each model vessel type (see *Vessel Types*) and year.

Environmental data

Bathymetry

The model uses bathymetry data for determining drift groundings and the potential for emergency anchoring. We acquired bathymetry data from NOAA and the Canadian Hydrographic Service. The bathymetry layer used in the model was a composite dataset stitched together from multiple bathymetric products to provide coverage for the entire model domain. The list of bathymetric data sources is listed below:

Table B-1: Bathymetry data sources.

Dataset	Year	Horizontal Resolution	Vertical Datum for Source Bathymetry[24]
Continuously Updated Digital Elevation Model (CUDEM) – 1/9 Arc-Second Resolution Bathymetric-Topographic Tiles	(downloaded 2021)	1/9 arc-seconds (approximately 3 m)	MHW
Strait of Juan de Fuca 1/3 arc-second NAVD 88 Coastal Digital Elevation Model	2015	1/3 arc-seconds (approximately 10 m)	MHW
Puget Sound 1/3 arc-second NAVD 88 Coastal Digital Elevation Model	2014	1/3 arc-seconds (approximately 10 m)	MHW
Port Townsend, Washington 1/3 Arc-second NAVD 88 Coastal Digital Elevation Model	2011	1/3 arc-seconds (approximately 10 m)	MHW
British Columbia 3 arc-second Bathymetric Digital Elevation Model	2013	3 arc-seconds (approximately 90 m)	MLLW, LLWLT, MSL, or assumed MSL (no common vertical datum reference due to large cell size)
Canadian Hydrographic Service Non-Navigational (NONNA) Bathymetric Data	2022	Varies (100 m for entire area, 10 m for selected areas	No common vertical datum

[24] Mean lower low water (MLLW), Lower Low Water Large Tide (LLWLT), Mean sea level (MSL), and Mean high water (MHW) are local referenced tidal datums and are transformed to a standard vertical datum (NAVD 88) for consistency of elevation values within and across bathymetric datasets.

There was overlapping spatial coverage for the datasets. When creating the composite bathymetry dataset preference, elevations for overlapping area were selected by first prioritizing greater horizontal resolution, then year of publication (Figure B-3). Elevation values for the different bathymetry sources were converted to water depth values for the model area.

Wind and current data

The model uses hindcast wind and current data from LiveOcean to determine vessel drift trajectories. LiveOcean is a computer model simulating ocean properties and is integrated with Weather Research and Forecasting (WRF) wind data (MacCready et al. 2021). Dr. Parker MacCready of the University of Washington Coastal Modeling Group provided LiveOcean data and the WRF wind input data from 2017 to 2021.

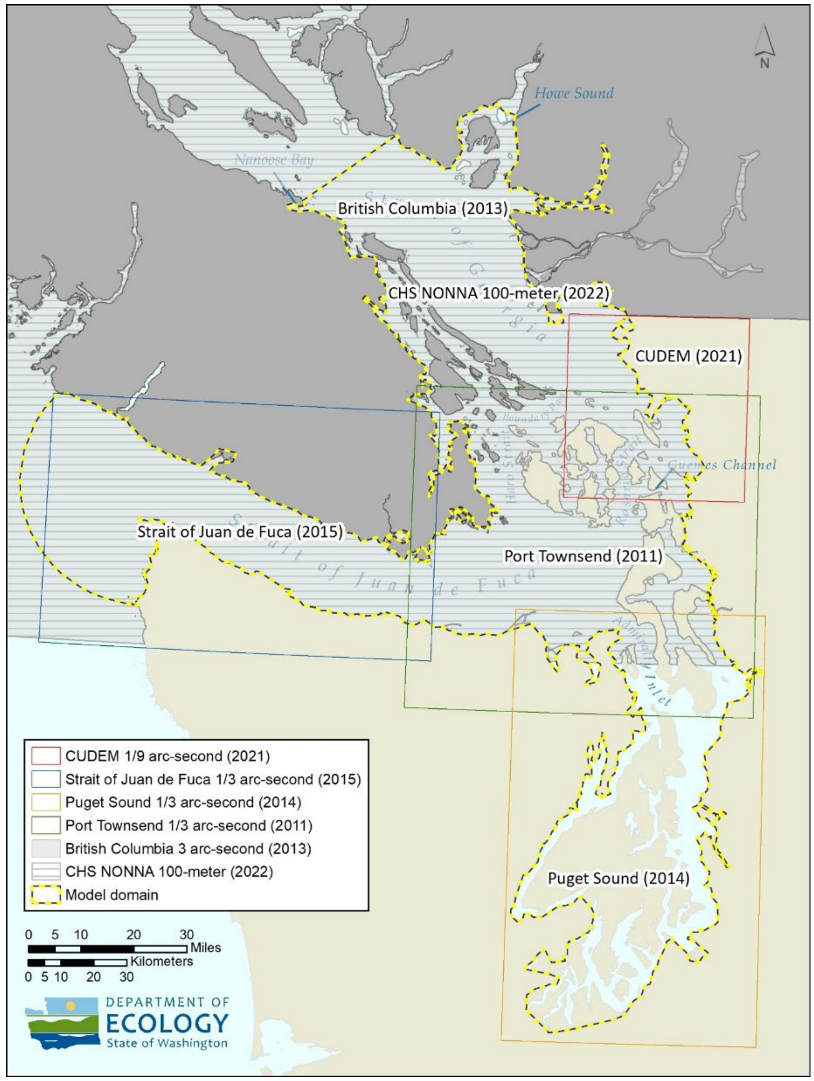

Figure B-3: Bathymetry sources.

Vessel data

The model simulates vessels based on AIS messages transmitted within the model domain from 2015 to 2019. Vessel attribute data used in the model came from four databases: IHS-Markit Seaweb, USCG's Vessel Documentation System (VDS), the Transportation Safety Board of Canada's Marine Safety Information System (MARSIS), and the USCG's AVIS. Information from company and industry websites supplemented the vessel database sources.

Vessel types

The model simulates movement for three broad sets of vessels: route based, dependent, and ferries. These vessel sets are distinguished by their behavior. Route based vessels predominantly operate on a set of common routes throughout the system and contain most deep draft commercial vessels. Dependent vessels' movements rely on the presence of another vessel. For instance, vessels providing escort, assist, or bunkering services. The third general group is ferries which exclusively includes car ferries.

Route based vessel types

The model simulates the following vessel types as route-based:

Table B-2: Definitions of route-based vessel types.

Model Vessel Type	Definition
ATB	Tugs that almost exclusively travel with a linked tank barge.
Bulk Carrier	A commercial ship that carries bulk (non-liquid) cargo.
Container Ship	A commercial ship that carries containerized cargo.
Cruise Ship	A large overnight passenger vessel with a tonnage over 2000 ITC.
Fishing Vessel (Large)	A commercial fishing vessel over 40 meters
General/Other Cargo Ship (Large)	A commercial ship that carries cargo and is more than 100 meters long. This category includes break-bulk cargo vessels, mixed containerized and bulk ships, and others.
Tanker (Chemical)	A tank ship that carries oil (or substances defined as oil) as cargo, and could carry non-oil liquid cargo
Tanker (Crude)	A crude tanker is designed to carry unrefined oil.
Tanker (Liquefied Gas)	A commercial ship that carries liquefied gas, including natural gas (LNG) and liquefied petroleum gas (LPG).
Tanker (Product)	A tank ship that carries refined oil in bulk.
Towing Vessel (Oil)	Tugs that generally operate with a tow (ahead or astern) that contains oil as cargo.
Vehicle Carrier	A commercial ship that carries vehicles as cargo and loads and discharges via a ramp.

Ferry vessels

In the Model, Ferry (Car) is the only vessel type is this category. These vessels carry vehicles and passengers on set routes between established ferry terminals. This category also includes the Seaspan Intermodal Ferries, which include a few ATBs that run intermodal cargo (not oil) on set runs.

Dependent vessels

The model simulates the following vessel types as dependent vessels:

Table B-3: Definitions of dependent vessel types.

Model Vessel Type	Definition
Towing Vessel (Oil) – Bunkering	Tugs that generally operate with a tow (ahead or astern) that contains oil as cargo and engage in bunkering of other vessels. This category does include one self-propelled bunkering vessel.

Model Vessel Type	Definition
Tug (Assist & Escort)	Tugs that generally do not operate with a tow. These tugs assist/escort other vessels. Generally over 50 feet long.

Vessel categorization

Traffic patterns vary by vessel type within the system. In order to represent this in our simulation, it was necessary to establish a vessel categorization system. Though many maritime datasets organize vessels into categories based on vessel type, there is no unifying typology. None of the existing categorization systems were ideal for the needs of the Model. As a result, the project team created a vessel taxonomy. The new vessel taxonomy first classified vessels based on a list of individually classified vessels before using existing classifications and vessel length found in IHS-Markit Seaweb, VDS, MARSIS, and AVIS.

Vessel categorization algorithm

1) Manual assignment to a vessel category.
    a) For all vessel types, we built a table for manual identification. For any vessel that was uniquely identifiable based on organizational or expert knowledge, we assigned a type in these tables.
    b) For a subset of vessel types that were too specific to be identified using vessel databases, we used these tables exclusively. Those vessel types included Towing Vessel (Oil), Towing Vessel (Oil) – Bunkering, and Tug (Assist & Escort).
2) Vessels assigned to a model category based on specific IHS-Markit vessel categories.

Table B-4: IHS-Markit vessel category groupings.

IHS-Markit Vessel Category	Model Vessel Type
Passenger/Ro-Ro Ship (Vehicles)	Ferry (Car)
Articulated Pusher Tug	ATB
Bulk Carrier Bulk Carrier, Laker Only Bulk Carrier, Self-discharging Bulk Carrier, Self-discharging, Laker Bulk/Caustic Soda Carrier (CABU) Open Hatch Cargo Ship Wood Chips Carrier	Bulk Carrier
Container ship (Fully Cellular)	Container Ship
Crude Oil Tanker Asphalt/Bitumen Tanker	Tanker (Crude)
LNG Tanker LPG Tanker	Tanker (Liquefied Gas)

IHS-Markit Vessel Category	Model Vessel Type
Vehicles Carrier	Vehicle Carrier
Crude/Oil Products Tanker Products Tanker Replenishment Tanker	Tanker (Product)
Chemical/Products Tanker	Tanker (Chemical)

3) Based on specific IHS-Markit vessel categories and additional criteria

Table B-5: IHS-Markit vessel category groupings with additional criteria.

IHS-Markit Vessel Category	Additional criteria	Model Vessel Type
Passenger/Cruise Cruise Ship, Inland Waterways	Gross tonnage (ITC) >= 2000	Cruise Ship
Fish Factory Ship Fishery Research Vessel Fishery Support Vessel	Vessel length > 40 m	Fishing Vessel (Large)
General Cargo Ship General Cargo Ship (with Ro-Ro facility) Heavy Load Carrier, semi-submersible Hospital Vessel Landing Craft Livestock Carrier Rail Vehicles Carrier Refrigerated Cargo Ship Ro-Ro Cargo Ship	Vessel length > 100 m	General/Other Cargo Ship (Large)

4) Based on a specific type in the Marine Exchange, Chamber of Shipping (British Columbia), or Transportation Safety Board (TSB) of Canada.

Table B-6: Marine Exchange, the Chamber of Shipping, and TSB vessel category groupings.

Vessel Category [Source]	Model Vessel Type
Bulk Carrier [Marine Exchange, TSB] Wood-chip [Marine Exchange] Barge Carrier [Marine Exchange]	Bulk Carrier
Container [Marine Exchange]	Container Ship

Vessel Category [Source]	Model Vessel Type
General Cargo with Container Capacity [Marine Exchange] Container Ship (Fully Cellular) [Marine Exchange] Container Ship [TSB]	
Car Carrier [Marine Exchange, Chamber of Shipping] Vehicle Carrier [Marine Exchange, Chamber of Shipping] Vehicles [Marine Exchange, Chamber of Shipping]	Vehicle Carrier

5) Based on a specific type in the Marine Exchange or USCG's VDS and additional criteria.

Table B-7: Marine Exchange and VDS vessel category groupings with additional criteria.

Vessel Category [Source]	Additional criteria	Model Vessel Type
General Cargo [Marine Exchange] Catamaran Tug [Marine Exchange] Freight ship [VDS]	Vessel length > 100 m	General/Other Cargo Ship (Large)
Fishing [Marine Exchange] Commercial Fishing Vessel [VDS] Fishery Support Vessel [VDS]	Vessel length > 40 m	Fishing Vessel (Large)

6) Based on AIS vessel type and additional criteria, in some cases.

Table B-8: AIS vessel type code groupings.

AIS Vessel Type Code	Additional criteria	Model Vessel Type
80 to 89	No additional criteria	Tanker (Chemical)
70 to 79	Vessel length > 100 m	General/Other Cargo Ship (Large)
30	Vessel length > 40 m	Fishing Vessel (Large)

Vessel attributes

The model requires specific vessel attributes to simulate vessel momentum and drift and for generating oil spill risk outputs. We populated vessel attributes from previously mentioned data sources. Complete sets of attributes were not available for all vessels. We performed regression analysis based on known values to fill data gaps for displacement tonnage and fuel capacity. Where insufficient data existed to perform regression analysis, default values were assigned.

Each vessel type uses the following attributes:

Table B-9: Required vessel attributes.

Model Vessel Type	Length	Width	Draft	Fuel Capacity	Cargo Capacity	Tons (DWT)	Tons (displacement)
ATB (Tug Only)	Yes	Yes	Yes	Yes	No	Yes	Yes
Bulk Carrier	Yes	Yes	Yes	Yes	No	Yes	Yes
Container Ship	Yes	Yes	Yes	Yes	No	Yes	Yes
Cruise Ship	Yes	Yes	Yes	Yes	No	Yes	Yes
Ferry (Car)	Yes	Yes	Yes	Yes	No	Yes	Yes
Fishing Vessel (Large)	Yes	Yes	Yes	Yes	No	Yes	Yes
General/Other Cargo Ship (Large)	Yes	Yes	Yes	Yes	No	Yes	Yes
Tanker (Chemical)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tanker (Crude)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tanker (Liquefied Gas)	Yes	Yes	Yes	Yes	No	Yes	Yes
Tanker (Product)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Towing Vessel (Oil) (Tug Only)	Yes	Yes	Yes	No	No	No	No
Towing Vessel (Oil) – Bunkering (Tug Only)	Yes	Yes	Yes	No	No	No	No
Tug (Assist & Escort)	Yes	Yes	Yes	Yes	No	No	No
Vehicle Carrier	Yes	Yes	Yes	Yes	No	Yes	Yes

Barge attributes are also required to supplement vessel characteristics for towing vessels. The model uses the following attributes for the barges associated with ATBs, Towing Vessels (Oil), and Towing Vessels (Oil) – Bunkering vessels:

- Barge length
- Barge width
- Barge draft
- Barge cargo capacity
- Barge dead weight tonnage
- Barge displacement

Barge attributes

For barge attributes, we primarily used known values. When known values were not available, we used the default values shown in Table B-10.

Table B-10: Barge attributes.

Barge Attribute	ATB	Towing Vessel (Oil)	Towing Vessel (Oil) - Bunkering
Length (m)	150	125	80
Width (m)	22	30	18
Draft (m)	N/A; use tug draft	6.5	5.5
Cargo capacity (m^3)	26,402	14,024	6,713

If barge displacement was not known, we used the following formula:

Equation 1

$$C = L \cdot W \cdot D \cdot c_b \cdot \rho$$

Where:

- C – vessel cargo capacity;
- L – vessel length;
- W – vessel width;
- D – vessel draft,
- $c_b = 0.90$ – block coefficient;
- $\rho = 1.025\ t/m^3$- seawater density

The estimated value for block coefficient is based on the maximum block coefficient for tankers listed in Elements of Modern Ship Construction (House 2010).

Displacement tonnage calculations

We used regression analysis based on deadweight tonnage to fill data gaps for displacement tonnage. We considered several regression models and chose the zero-intercept polynomial regression model. This model had the smallest Root Mean Squared Errors (RMSE). RMSE measures how far from the regression line the data points are and the model with the smallest RMSE is generally the one with the best predictive power.

Zero-intercept polynomial regression model for displacement tonnage:

Equation 2

$$D = \beta_1 W + \beta_2 W^2$$

Where:

- D – vessel displacement;
- W – vessel DWT;
- β_1 and β_2 - regression coefficients.

The following table shows the coefficients for the zero-intercept polynomial regression models:

Table B-11: Regression coefficients for vessel displacement using DWT.

Model Vessel Type	β_1	β_2
ATB	3.09	-8.53×10^{-4}
Bulk Carrier	1.19	-3.28×10^{-7}
Container Ship	1.36	-4.25×10^{-7}
Cruise Ship	5.64	6.87×10^{-6}
Ferry (Car)	3.68	1.23×10^{-4}
Fishing Vessel (Large)	3.14	-1.87×10^{-4}
General/Other Cargo Ship (Large)	1.74	-7.91×10^{-6}
Tanker (Chemical)	1.28	-1.15×10^{-6}
Tanker (Crude)	1.20	-1.59×10^{-7}
Tanker (Liquefied Gas)	1.35	2.36×10^{-7}
Tanker (Product)	1.24	-6.70×10^{-7}
Vehicle Carrier	2.04	-9.67×10^{-6}

Fuel capacity calculations

We used regression analysis based on vessel length to fill data gaps for fuel capacity. We examined three models: linear, zero-intercept linear, and the zero-intercept polynomial. Following the same criteria as for the displacement regression models (*Displacement Tonnage Calculations*), the zero-intercept polynomial models were chosen.

Zero-intercept polynomial regression model for fuel capacity:

Equation 3

$$F = \beta_1 L + \beta_2 L^2$$

Where:

- F – vessel fuel capacity;
- L – vessel length;
- β_1 and β_2 - regression coefficients.

The following table shows the coefficients for the zero-intercept polynomial regression models:

Table B-12: Regression coefficients for fuel capacity using vessel length.

Model Vessel Type	β_1	β_2
ATB	-5.65	0.48
Bulk Carrier	-1.84	0.06
Container Ship	-13.11	0.14
Cruise Ship	3.02	0.03
Ferry (Car)	-0.41	0.03
Fishing Vessel (Large)	-2.18	0.14
General/Other Cargo Ship (Large)	0.21	0.06
Tanker (Chemical)	5.49	0.02
Tanker (Crude)	-10.96	0.10
Tanker (Liquefied Gas)	-14.19	0.13
Tanker (Product)	2.48	0.04
Tug (Assist & Escort)	-1.20	0.22
Vehicle Carrier	2.77	0.08

Laden status determination

Determining whether a tank ship or oil barge is carrying oil or liquefied gas (LG) is a critical component of the Model, as it allows the model to know when an escort tug may be required. The project team examined historical transits for model vessel types known to transport oil as cargo or LG. To develop rules that we used in the Model, we used visits to facilities handling oil, the type of facility visited, and in some cases, the presence or absence of a tug escort.

Six model vessel types regularly require an escort while they are in the system. They are as follows: ATB, Tanker (Chemical), Tanker (Crude), Tanker (Liquefied gas), Tanker (Product), and Towing Vessel (Oil). There is one additional type that transports oil as cargo but does not require an escort: Towing Vessel (Oil) - Bunkering.

For vessels that have historically used escorts while laden with oil, like Tanker (Chemical), Tanker (Crude), and Tanker (Product) vessels, we used the presence or absence of an escort while in an escort zone as a proxy for laden status. Liquefied gas tankers are also required to use escorts while laden, and we used the same approach for them as well.

ATBs and towed tank barges have been required to use escorts while laden since late 2020. However, we did not have processed AIS data from that period, so we were not able to use the same method that we used for tankers to estimate whether they were laden or not. In addition, the area where escorts are required for ATB and towed tank barges is a small part of the overall system, and it would be problematic to extrapolate the data from that area to the whole system, even if the data was available. Additional details on ATB and towed tank barge laden status determination in *ATBs and towed oil barges*.

Oil handling facilities

We identified the names and locations of oil handling facilities operating from 2015 to 2019 based on Ecology facility records, aerial imagery, and publicly available company documentation. Figure B-4 shows the locations of oil handling facilities used in the model. We categorized facilities as:

- Refinery
- Canadian export facility (Westridge Marine Terminal)
- Liquefied gas facility
- Oil terminal

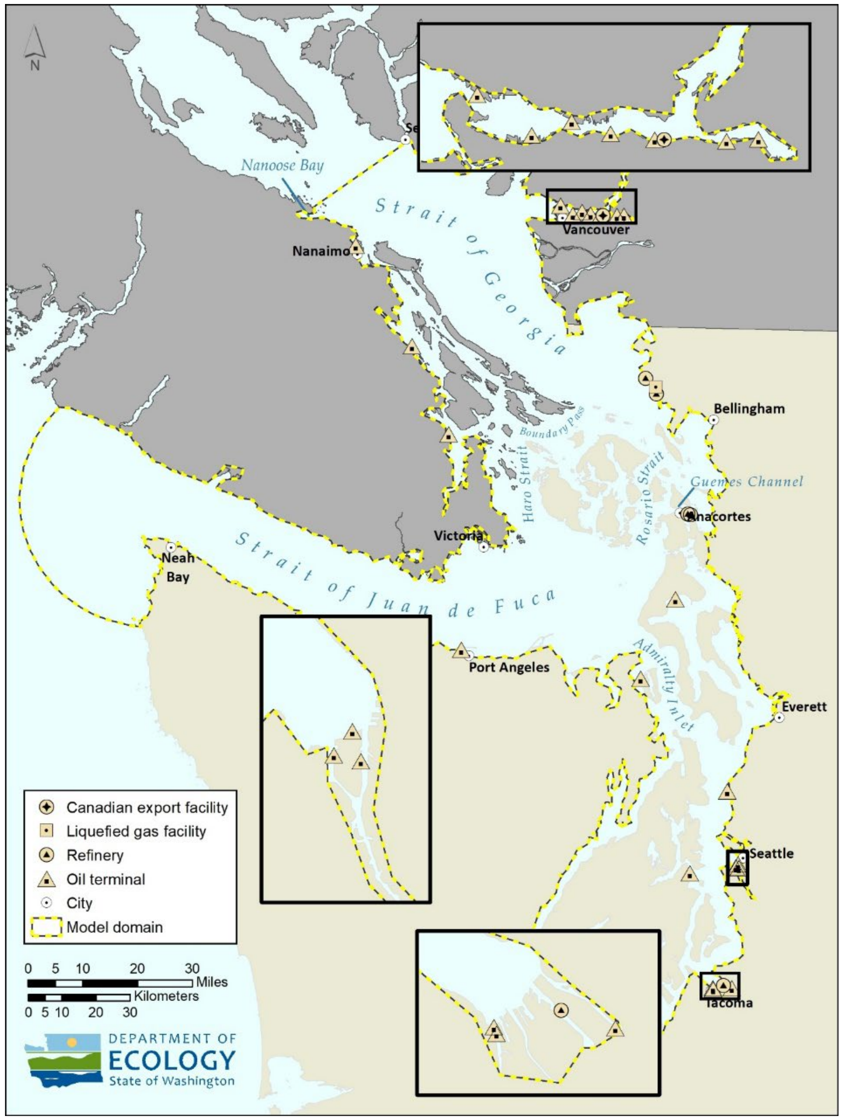

Figure B-4: Oil handling facilities.

Liquefied gas, product, chemical, and crude tankers

Using 2018 AIS data, we identified 200 entries into the study area by chemical tankers, 185 entries by crude tankers, 182 entries into the system by product tankers and 19 by liquefied gas (LG) tankers. Some of the entries were relatively simple, with just one port of call before departing again. Other ships visited multiple facilities before departing.

To support our estimation of how likely tankers are to be laden, we grouped their transits based on their behavior in the system. Options include facilities visited, first facility visited, last facility visited, facility and type visited.

Based on a review of those options, we characterized LG, product, and crude tanker visits by "first facility visited." Grouping the tanker visits in this way gives us enough visibility into where they are going but is not so granular as to eliminate our chance to use a sampling approach to the review of data.

For chemical tankers we characterized their visits based on whether they called on a Canadian Export Facility, a Refinery, or an “other” berth at any time during their visit.

For each sampled entry, project team members independently determined the laden status of its inbound and outbound transits, using a historical replay of AIS information to identify if the transits were escorted. Escorted transits were determined based not only on proximity of an escort tug but also its behavior before during and after the escorted transit. After making initial determinations, the team reviewed any mismatches and selected a consensus answer.

We visually inspected all transits for vessel types with less than 20 transits. For vessel types with more than 20 transits, we visually examined a simple random sample of 20 transits.

To facilitate our sampling approach, we grouped the possible “first facilities” into our facility types.

Under that categorization, we saw the following number of transits from outside of the system to a facility type.

Table B-13: First facility visited.

Vessel Type	Refinery	Canadian Export Facility	LG Facility	Other Berths (including Oil Terminal)
Product Tanker	115	30	0	11
Crude Tanker	148	17	0	2
LG Tanker	0	0	19	0

For chemical tankers we grouped possible visits using our facility types. We saw the following number of transits from outside the system for each visit category.

Table B-14: Chemical tanker facility visits.

Vessel Type	Refinery	Canadian Export Facility	LG Facility	Other Berths (including Oil Terminal)
Chemical Tanker	67	5	0	144

Review of inbound and outbound transits

The following set of estimates for percentage laden per vessel type, per route type were established. Percentages refer to the percentage of vessels that are laden not the percentage of cargo aboard a vessel.

The following table specifies the percent of transits laden with oil cargo on the inbound leg of a journey.

Table B-15: Inbound laden transits, percentage of vessels that are laden.

Vessel Type	Refinery	Canadian Export Facility	LG Facility	Other (including Oil Terminal)
Product Tanker	55%	35%	N/A	N/A
Crude Tanker	100%	0%	N/A	N/A
Chemical Tanker	45%	100%	N/A	5%
LG Tanker	N/A	N/A	0%	N/A

The following table specifies the percent of transits laden with oil cargo on the outbound leg of a journey.

Table B-16: Outbound laden transits, percentage of vessels that are laden.

Vessel Type	Refinery	Canadian Export Facility	LG Facility	Other (including Oil Terminal)
Product Tanker	85%	84%	N/A	N/A
Crude Tanker	43%	100%	N/A	N/A
Chemical Tanker	80%	40%	N/A	10%
LG Tanker	N/A	N/A	100%	N/A

Other transit types

There were transits that could not be grouped by the first facility visited. They include:

- Where crude or product tanker visits an "other berth" on their entry or exit from the system
- Internal transits
- Transits that do not call on a facility
- Partial journeys

Crude and product tanker visits to "other berths"

Of the 367 combined product and crude tanker entries in the system, 13 went first to an "other berth." These berths were generally oil terminals. Instead of a data-based approach for these visits, we established a set of basic assumptions based on an understanding of the role of oil terminals in petroleum transportation.

- Inbound to oil terminal – 100 percent are laden
- Outbound from oil terminal – 0 percent are laden

Crude and product tanker internal transits

Due to the complexity of the movements, and the presence of too many confounding vessels, the escort status of internal transits (movements between berths, anchorages, and between berths and anchorages) could not be determined visually. Using escorts as a proxy for laden status works best when target vessels are transiting relatively open waters within an escort area. An open stretch of water allows the reviewer a clear area for review that is free from confounding vessels like assist tugs or transiting tugs. These confounding vessels are much harder to deal with when trying to evaluate short transits between berths or between anchorages and berths. This means internal transits (movements between berths, anchorages, and between berths and anchorages) require a different approach.

Instead of a data-based approach for these internal transits, we established a set of assumptions on laden status:

- From refinery/Canadian export facility to refinery/Canadian export facility/oil terminal – 100 percent are laden
- From oil terminal to oil terminal – 100 percent are laden
- From oil terminal to refinery/Canadian export facility – 0 percent are laden

Crude and product tanker transits that do not visit a facility

Some tankers entering the system only visit Port Angeles anchorage before departure. Since their entry does not cross any areas where laden tankers are required to take an escort, we cannot use our established method for determining their laden status. To address this, we established a set of assumptions on laden status for this type of movement. Although there is the potential for lightering activity during these types of calls, most of these trips are associated with bunkering. As such we established the following rule:

- From system edge to Port Angeles and back – 100 percent are laden

Crude and product tanker partial journeys

For some tankers, their historical visit may have been split across calendar years resulting in “partial journeys.” A partial journey is a vessel movement that does not start and end at the edge of the study area. Instead, it may start or end, or start *and* end at locations within the study area. Since our laden status determinations are all based on knowing either the destination or the origin of a given transit, partial journeys present a problem. Some partial journeys may not contain enough information to allow us to use our determination rules. With that in mind, we established the following rules:

- Partial journeys for product and crude tankers – 100 percent are laden

Chemical tanker transits

The laden status of chemical tankers presents an interesting problem. Chemical tankers move a wider variety of products, not all of which are oil, and they do not only call on facilities that handle oil. Their unique behaviors led us to develop a unique approach for the determination of laden status for this vessel type.

Chemical tanker journeys that include a refinery, Canadian export facility, or other berth are broken into two portions, the portion preceding the visit to the refinery, export facility or “other” berth, and the portion following. The preceding portion is assigned a laden or unladen status using the probability for inbound transits for that visit type (see Table B-15). The portion of the journey following the visit is assigned a laden or unladen status using the probability for outbound transits for that visit type.

Any internal transit, or partial journey follows the same rules. If the chemical tanker does not visit a refinery, Canadian export facility, or other berth during their journey, the entire transit is marked as unladen.

ATBs and towed oil barges

The laden status of ATBs and towed oil barges is difficult to determine from existing data. Since barges do not carry separate AIS transmitters, determining if a tug was burdened presented an additional difficulty. As a result, we adopted rules of thumb based on a general understanding of how those vessel types transport oil within the system. For ATBs and towed tank barges, we established the following rules:

- Inbound to first facility – 0 percent are laden
- Internal transits, partial journeys, and any other journey that is not the initial inbound journey to the first facility – 100 percent are laden

Hazard probabilities

The Vessel Accident Module requires hazard probabilities to identify when and where a loss of propulsion or loss of steering occurs. To estimate a probability, two measures are required, the number of observed occurrences and an exposure variable. For these analyses, the project team used operating minutes underway as our exposure variable.

Hazard vessel types

Not every model vessel type has been assigned its own unique hazard probability. Due to a limited number of observed hazards, we consolidated some model vessel types. We consolidated Cruise and Ferry vessel types, as well as General Cargo and Vehicle Carrier vessel types, because the incident databases did not differentiate them sufficiently to allow for separate hazard counts. The following table indicates the relationship between hazard vessel types and model vessel types.

Table B-17: Vessel types for hazard probability calculations.

Hazard Vessel Type	Model Vessel Types
Tank Ship	Tanker (Chemical), Tanker (Crude), Tanker (Liquefied Gas), Tanker (Product)
Tank Barge and ATB	ATB, Towing Vessel (Oil), Towing Vessel (Oil) - Bunkering
Passenger Ship (Cruise & Ferry)	Cruise Ship, Ferry (Car)
Container Ship	Container Ship
General Cargo Ship	General/Other Cargo Ship (Large), Vehicle Carrier
Bulk Carrier	Bulk Carrier

Hazard Vessel Type	Model Vessel Types
Large Fishing Vessel	Fishing (Large)
Escort Tugs	Tug (Assist & Escort)

MISLE categorizes vessels by vessel class and a more specific vessel type. We mapped MISLE vessel categories to the model hazard vessel types according to the following table.

Table B-18: Mapping MISLE vessel types to model hazard vessel types.

Hazard Vessel Type	MISLE Vessel Class	MISLE Vessel Type	Additional Criteria
Tank Ship	Tank Ship	All Types	
	Bulk Carrier	Combination Carrier (e.g. OBO)	
Tank Barge and ATB	Barge	Bulk Liquid Cargo (Tank) Barge	
	Towing Vessel	Articulated Tug and Barge (Tug)	
Passenger Ship (Cruise & Ferry)	Passenger Ship	All Types	Gross Tonnage over 300
Container Ship	Container Ship	All Types	
General Cargo Ship	General Dry Cargo Ship	All Types	
	Refrigerated Cargo Ship	All Types	
	Ro-Ro Cargo Ship	All Types	
Bulk Carrier	Bulk Carrier	Cement Carrier, General, Ore Carrier, Woodchips Carrier	
Large Fishing Vessel	Fishing Vessel	All Types	Gross Tonnage over 300
Escort Tugs	Towing Vessel	General, Harbor/Ship Assist (Tug), Pushing Ahead (Towboat), Pushing Ahead/hauling alongside, Ship/Harbor Assist, Towing Astern, Towing Behind (Tug)	Vessel Length over 50 feet

Similar to MISLE, MARSIS includes two levels of vessel categorization, Type and Subtype. We mapped MARSIS vessel categorizes into the model hazard vessel types according to the following table.

Table B-19: Mapping MARSIS vessel types to model hazard vessel types.

Hazard Vessel Type	MARSIS Vessel Types	MARSIS Vessel Subtypes	Additional Criteria
Tank Ship	CARGO - LIQUID	CHEMICAL TANKER, COMBINATION CARRIER (OBO), CRUDE TANKER (INCL BITUMEN/ASPHALT), LIQUIFIED GAS CARRIER, PRODUCT TANKER, PRODUCT/CHEMICAL TANKER	
	TANKER - CHEMICAL/ORE/OIL/CRUDE	All Subtypes	
	TANKER - OTHER	All Subtypes	
Tank Barge and ATB	BARGE - LIQUID CARGO	All Subtypes	
Passenger Ship (Cruise & Ferry)	FERRY	All Subtypes	Gross Tonnage over 300
	PASSENGER	All Subtypes	
Container Ship	CARGO - SOLID	CONTAINER SHIP	
	SERVICE SHIP	CONTAINER SHIP	
General Cargo Ship	CARGO - SOLID	GENERAL CARGO, HEAVY LOAD CARRIER, REFRIGERATED CARGO	
Bulk Carrier	CARGO - SOLID	BULK CARRIER	
Large Fishing Vessel	FISHING	All Subtypes	Gross Tonnage over 300
Escort Tugs	TUG	All Subtypes	Vessel length over 50 feet

Calculated hazard probabilities for simulated vessels

Hazard probabilities are expressed as occurrences per minute underway. Note that $1x10^{-6}$ is 0.000001 or one occurrence per million minutes. Loss of propulsion/Loss of steering events are incidents described in accident databases where we were unable to determine if the hazard was a Loss of Propulsion or a Loss of Steering. Additional information on this topic can be found in *Methods and Hazard Mapping*.

The following table displays the probabilities for loss of propulsion, loss of steering, and loss of propulsion/loss of steering events.

Table B-20: Loss of propulsion and loss of steering probabilities.

Hazard Vessel Type	Probability (Loss of Propulsion)	Probability (Loss of Steering)	Probability (Loss of Propulsion/Loss of Steering)
Tank Ship	1.90×10^{-6}	5.27×10^{-8}	3.16×10^{-7}
Tank Barge and ATB	7.13×10^{-8}	4.28×10^{-8}	2.85×10^{-8}
Passenger Ship (Cruise & Ferry)	1.46×10^{-6}	2.96×10^{-7}	2.79×10^{-7}
Container Ship	2.75×10^{-6}	6.41×10^{-8}	2.88×10^{-7}
General Cargo Ship	1.78×10^{-6}	1.49×10^{-7}	7.43×10^{-8}
Bulk Carrier	2.19×10^{-6}	1.00×10^{-7}	8.37×10^{-8}
Large Fishing Vessel	2.45×10^{-6}	N/A*	5.26×10^{-7}

*No loss of steering events were identified for this vessel type in MISLE or MARSIS.

The following table displays the hazard probabilities for escort tugs.

Table B-21: Escort tug hazard probabilities.

Hazard Type	Probability	Confidence Interval (lower bound)	Confidence Interval (upper bound)
Allisions/Collisions	2.31×10^{-7}	1.73×10^{-7}	3.03×10^{-7}
Groundings	7.12×10^{-8}	4.07×10^{-8}	1.16×10^{-7}
Sinking/Capsize	1.78×10^{-8}	4.85×10^{-9}	4.56×10^{-8}
Other	1.09×10^{-6}	9.54×10^{-7}	1.23×10^{-6}

Hazard counts

We counted hazards using the USCG's MISLE and Canada's MARSIS incident databases looking at incidents that occurred between 2002 and 2019 in the model domain (Figure B-2). Loss of propulsion events and loss of steering events were identified using the hazard mapping methods described in *Methods and Hazard Mapping.*

Our hazard mapping methods found incidents where we were unable to determine whether the event was a loss of propulsion or a loss of steering – although we could tell that it was at least one of those. We categorized this subset of events as LOP/LOS. The Table B-22 shows the loss of propulsion counts, the loss of steering counts, and the LOP/LOS counts, arranged by vessel type.

All of the LOP/LOS events come from the MISLE database and include an incident description of "Loss/Reduction of Vessel Propulsion/Steering." Rather than assume these were loss of propulsion events, we established a third probability, for this indeterminate hazard. The probability of LOP/LOS can be reviewed in Table B-20.

Table B-22: Loss of propulsion, loss of steering, and loss of propulsion/loss of steering incident counts by vessel type.

Hazard Vessel Type	Counts (LOP)	Counts (LOS)	Counts (LOP/LOS)
Tank Ship	32	3	6
Tank Barge and ATB	5	2	2
Passenger Ship (Cruise & Ferry)	214	56	51
Container Ship	73	2	9
General Cargo Ship	21	2	1
Bulk Carrier	86	8	5
Large Fishing Vessel	12	1	3

The following table includes hazard counts for escort tugs (see Table B-18 and Table B-19 for which vessel types from MISLE and MARSIS are included).

Table B-23: Hazard counts for escort tug hazard probabilities.

Hazard Type	Counts
Allisions/Collisions	52
Groundings	16
Sinking/Capsize	4
Other	244

Methods and hazard mapping

Hazard categories differed in the two databases. To count incidents in each hazard category, we mapped hazard counts in the databases to the categories used in the model.

The MARSIS dataset assigns each occurrence one accident or incident type, while the MISLE dataset assigns each occurrence one or more event types. Information about incidents is also available in various free-text fields in both databases. We also processed IHS incident descriptions to help with the mapping.

We generally accepted the MARSIS assigned accident type and MISLE primary event type as the primary hazard for the purposes of hazard counting. However, since there was no specific MARSIS category for loss of propulsion or loss of steering, they were linked in the database to other hazards.

We used information in the summary field to identify which hazards also included loss of propulsion and loss of steering events.

Since MISLE used multiple event types for some incidents, we reviewed every event type associated with a given incident to determine if they referenced other hazards of interest. While only loss of propulsion or loss of steering hazard probabilities are used in the model simulation, the tug escort analysis requires a review of additional hazard types for a supplemental analysis of risk presented by additional tug escorts.

The full list of hazard types counted is listed below.

- Allision
- Capsize/Sinking
- Collision
- Loss of Propulsion (LOP)
- Loss of Steering (LOS)
- Loss of Propulsion/Loss of Steering
- Other
- Grounding

MISLE (Marine Information for Safety and Law Enforcement)

Our incident mapping process first queries incidents by Initial Event Type. For some Initial Event Types, we applied additional criteria to determine the model hazard type. When possible, we consolidated information from event type, case title, and activity title fields in MISLE and from incident description fields in IHS-Markit databases. We populated a “Summary” field with the consolidated information from both databases. When possible, we employed direct categorization from the Initial Event Type field to the Model Hazard Type. When direct categorization was not possible, we used keyword searches of the “Summary” field to determine a Model Hazard Type. Table B-24 displays the field mapping strategy. Table B-25 contains the keyword search criteria for each model hazard type. The keyword searches include misspellings and word fragments present in the databases.

Table B-24: USCG MISLE database query parameters.

MISLE Initial Event Type	Additional Criteria	Model Hazard Type
Abandonment	Direct categorization	Other
Capsize	Direct categorization	Capsize/Sinking
Grounding	Direct categorization	Grounding
Loss of Electrical Power	Direct categorization	Loss of Propulsion
Sinking	Direct categorization	Sinking
Allision	Direct categorization	Allision
Collision	Direct categorization	Collision

MISLE Initial Event Type	Additional Criteria	Model Hazard Type
Loss/Reduction of Vessel Propulsion/Steering	See keyword search criteria for Loss of Propulsion	Loss of Propulsion
Loss/Reduction of Vessel Propulsion/Steering	See keyword search criteria for Loss of Steering	Loss of Steering
Loss/Reduction of Vessel Propulsion/Steering	Does not meet keyword search criteria for Loss of Propulsion or Loss of Steering	Loss of Propulsion/Loss of Steering
Set Adrift	See keyword search for Capsize/Sinking	Capsize/Sinking
Set Adrift	Does not meet keyword search criteria for Capsize/Sinking	Other
Cargo/Fuel Transfer/Shift Damage to Cargo Discharge/Release - Pollution Explosion Fire - Initial Fire - Reflash Flooding - Initial Flooding - Progressive Fouling Implosion Loss of Stability Material Failure/Malfunction Vessel Manuever (sic) Vessel Yaw/Pitch/Roll/Heel Wave(s) Strikes/Impacts	See keyword search criteria for Loss of Propulsion	Loss of Propulsion
Cargo/Fuel Transfer/Shift Damage to Cargo Discharge/Release - Pollution Explosion Fire - Initial Fire - Reflash	See keyword search criteria for Loss of Steering	Loss of Steering

MISLE Initial Event Type	Additional Criteria	Model Hazard Type
Flooding - Initial Flooding - Progressive Fouling Implosion Loss of Stability Material Failure/Malfunction Vessel Manuever (sic) Vessel Yaw/Pitch/Roll/Heel Wave(s) Strikes/Impacts		
Cargo/Fuel Transfer/Shift Damage to Cargo Discharge/Release - Pollution Explosion Fire - Initial Fire - Reflash Flooding - Initial Flooding - Progressive Fouling Implosion Loss of Stability Material Failure/Malfunction Vessel Manuever (sic) Vessel Yaw/Pitch/Roll/Heel Wave(s) Strikes/Impacts	See keyword search criteria for Allision	Allision
Cargo/Fuel Transfer/Shift Damage to Cargo Discharge/Release - Pollution Explosion Fire - Initial	See keyword search criteria for Collision	Collision

MISLE Initial Event Type	Additional Criteria	Model Hazard Type
Fire - Reflash Flooding - Initial Flooding - Progressive Fouling Implosion Loss of Stability Material Failure/Malfunction Vessel Manuever (sic) Vessel Yaw/Pitch/Roll/Heel Wave(s) Strikes/Impacts		
Cargo/Fuel Transfer/Shift Damage to Cargo Discharge/Release - Pollution Explosion Fire - Initial Fire - Reflash Flooding - Initial Flooding - Progressive Fouling Implosion Loss of Stability Material Failure/Malfunction Vessel Manuever (sic) Vessel Yaw/Pitch/Roll/Heel Wave(s) Strikes/Impacts	See keyword search criteria for Grounding	Grounding
Cargo/Fuel Transfer/Shift Damage to Cargo Discharge/Release - Pollution Explosion	See keyword search criteria for Capsize/Sinking	Capsize/Sinking

MISLE Initial Event Type	Additional Criteria	Model Hazard Type
Fire - Initial Fire - Reflash Flooding - Initial Flooding - Progressive Fouling Implosion Loss of Stability Material Failure/Malfunction Vessel Manuever (sic) Vessel Yaw/Pitch/Roll/Heel Wave(s) Strikes/Impacts		
Cargo/Fuel Transfer/Shift Damage to Cargo Discharge/Release - Pollution Explosion Fire - Initial Fire - Reflash Flooding - Initial Flooding - Progressive Fouling Implosion Loss of Stability Material Failure/Malfunction Vessel Manuever (sic) Vessel Yaw/Pitch/Roll/Heel Wave(s) Strikes/Impacts	Does not meet keyword search criteria for Loss of Propulsion, Loss of Steering, Allision, Collision, Grounding, or Capsize/Sinking	Other

Table B-25: Keyword search criteria for MISLE.

Model Hazard Type	Keyword Search Criteria
Allision	Summary contains: *allision*

Model Hazard Type	Keyword Search Criteria
Capsize/Sinking	Summary contains: *capsiz*| *sink*| *sunk*| *sank*| *submerge*
Collision	Summary contains*: collision*| *collid*
Grounding	Summary contains*: ground*
Loss of Propulsion	Summary contains: *lop*| *loss of electrical power*| *loss of propulsion*| *loss of propolusion*| *propulsion loss*| *loss of prop*| *propulsion failure*| *loss of power*| *propulsion casualty*| *disabled*| *drifting*| *drifted*| *reduced propulsion*| *propulsion m equipment failure*| *damage to propeller*| *propulsion problems*| *reduced speed*| *loss of cp* | *main engine problems*
Loss of Steering	Summary contains: *steering loss*| *loss of steering*| *steering failure*| *steering casualty*| *loss of electrical power/steering*| *reduced steering*| *steering system malfunction*| *steering gear ms equipment failure*

MARSIS (Marine Safety Information System)

For each incident, the MARSIS database records a primary hazard. Our incident mapping process started by querying incidents by the primary Incident Type. For each MARSIS hazard, we checked if the recorded hazard was preceded by a different hazard or if it was the "final" hazard associated with a given event. The full mapping strategy and keyword search criteria are displayed in Table B-26 and Table B-27. The keyword searches include misspellings and word fragments present in the databases.

Table B-26: TSB MARSIS database query parameters.

MARSIS Hazard Type	Additional Criteria	Model Hazard Type
COLLISION - Struck by vessel COLLISION - With another vessel or other floating object	Direct categorization	Collision
STRIKING - Allision with a fixed object (striking - includes berthed/docked vessels)	Direct categorization	Allision
GROUNDING - Not under power (includes drifting) (non-intentional)	See keyword search criteria for Loss of Propulsion	Loss of Propulsion
GROUNDING - Not under power (includes drifting) (non-intentional)	See keyword search criteria for Loss of Steering	Loss of Steering
GROUNDING - Under power (non-intentional)	See keyword search criteria for Loss of Steering	Loss of Steering

MARSIS Hazard Type	Additional Criteria	Model Hazard Type
GROUNDING - Under power (non-intentional)	Does not meet keyword search criteria	Grounding
Bottom Contact	See keyword search criteria for Loss of Steering	Loss of Steering
Bottom Contact	See keyword search criteria for Loss of Propulsion	Loss of Propulsion
Bottom Contact	Does not meet keyword search criteria for Loss of Propulsion or Loss of Steering	Grounding
Capsizes	See keyword search criteria for Loss of Propulsion	Loss of Propulsion
Capsizes	See keyword search criteria for Loss of Steering	Loss of Steering
Capsizes	Does not meet keyword search criteria for Loss of Propulsion or Loss of Steering	Capsize/Sinking
SANK - Flooding SANK - Founders (taking on water above the waterline)	See keyword search criteria for Loss of Propulsion	Loss of Propulsion
SANK - Flooding SANK - Founders (taking on water above the waterline)	See keyword search criteria for Loss of Steering	Loss of Steering
SANK - Flooding SANK - Founders (taking on water above the waterline)	Does not meet keyword search criteria for loss of propulsion nor for loss of steering	Capsize/Sinking
Abandoned CARGO SHIFT/CARGO LOSS - Cargo lost overboard CARGO SHIFT/CARGO LOSS - Cargo shifted DANGEROUS GOODS RELEASED - From the ship DANGEROUS GOODS RELEASED - On board ship EXPLOSION FIRE	See keyword search criteria for Loss of Propulsion	Loss of Propulsion

MARSIS Hazard Type	Additional Criteria	Model Hazard Type
FOULS UNDERWATER OBJECT INTENTIONAL BEACHING/GROUNDING/ ANCHORING to avoid occurrence SUSTAINS DAMAGE RENDER UNSEAWORTHY/ UNFIT FOR PURPOSE - Unfit for purpose - ice, weather, etc. TOTAL FAILURE OF ANY MACHINERY OR TECHNICAL SYSTEM		
Abandoned CARGO SHIFT/CARGO LOSS - Cargo lost overboard CARGO SHIFT/CARGO LOSS - Cargo shifted DANGEROUS GOODS RELEASED - From the ship DANGEROUS GOODS RELEASED - On board ship EXPLOSION FIRE FOULS UNDERWATER OBJECT INTENTIONAL BEACHING/GROUNDING/ ANCHORING to avoid occurrence SUSTAINS DAMAGE RENDER UNSEAWORTHY/ UNFIT FOR PURPOSE - Unfit for purpose - ice, weather, etc. TOTAL FAILURE OF ANY MACHINERY OR TECHNICAL SYSTEM	See keyword search criteria for Loss of Steering	Loss of Steering
Abandoned CARGO SHIFT/CARGO LOSS - Cargo lost overboard CARGO SHIFT/CARGO LOSS - Cargo shifted DANGEROUS GOODS RELEASED - From the ship DANGEROUS GOODS RELEASED - On board ship EXPLOSION FIRE FOULS UNDERWATER OBJECT INTENTIONAL BEACHING/GROUNDING/ ANCHORING to avoid occurrence SUSTAINS DAMAGE RENDER UNSEAWORTHY/ UNFIT FOR PURPOSE - Unfit for purpose - ice, weather, etc.	Does not meet keyword search criteria for Loss of Propulsion or Loss of Steering	Other

MARSIS Hazard Type	**Additional Criteria**	**Model Hazard Type**
TOTAL FAILURE OF ANY MACHINERY OR TECHNICAL SYSTEM		

Table B-27: Keyword search criteria for MARSIS.

Model Hazard Type	**Keyword Search Criteria**
Allision	Summary contains: *allision* *OR* *hard landing* *OR* *struck*| *strik*| *hit AND* wharf| *berth*| *moor*| *terminal*| *dock*| *platform*| *pier*| *crane*
Capsize/Sinking	Summary contains: *capsiz*| *sink*| *sunk*| *sank*| *submerge*
Collision	Summary contains*: collision*| *collid*
Grounding	Summary contains*: ground*
Loss of Propulsion	Summary contains: *lop*| *drift*| *broken down*| *unable to build speed*| *starting error*| *brownout* *OR* *los*| *casualty*| *fail*| *engine*| *no*| *issue*| *shutdown*| *repairs*| *shut down*| *breakdown*| *disable AND power*| *propul* *OR* *engine*| *Right Angle Drives*| *fuel pump*| *turbo charger*| *fuel injection AND break*| *broke*| *issue*| *failure*| *problem*| *shut down* | *inoperative*| *not operational*| *difficulties*| *malfunction*| *seizure*| *los*| *fire*| *insufficient control*| *overheating*| *disable* *OR* failure| foul| off-line AND *propeller* *OR*

Model Hazard Type	Keyword Search Criteria
	blackout| black-out| black out| reduced speed| towed| assisted| taken out of service| contaminated fuel| disabled AND machinery failure| mechanical failure| propulsion machinery| complete| loss of power *OR* *crank case| crankcase| crank-case AND explosion* *OR* *failure| shut down AND shaft* *OR* *fuel filter| short circuit| leakage| machinery failure| anchor| blackout| assist tug| fuel issues | fuel system AND disable*
Loss of Steering	Summary contains: *damaged navigation* *OR* *steering| steerage AND broke| jam| trouble| los| casualty| issue| leak| difficulty| disable OR* *mechanical | rudder| steering AND* failure| *malfunction | hydraulic leak*

Exposure counts

We used AIS data from 2018 to count minutes underway for each vessel type. Due to the inconsistency or lack of AIS data for the entirety of the temporal range (2002-2019) we used an estimation approach to adjust 2018 counts for other years.

Specifically, we used Vessel Entries and Transits (VEAT) data from 2002-2019 to create annual multipliers based on the percent difference in traffic levels for each year compared to 2018 levels.[25] This relies on the assumption that exposure counts for each vessel type are proportional to overall traffic levels captured in the VEAT data.

For example, we found that overall traffic captured in VEAT in 2008 was 95 percent of that in 2018. The exposure counts from 2018 AIS data for each vessel category are multiplied by 0.95 to estimate exposures for 2008. We summed these estimated exposures for the period 2002-2019 to create the total exposure minutes for that vessel type. Overall traffic levels captured in VEAT remained fairly static over the period 2002-2019 as can be seen in table below.

[25] Vessel Entries And Transits (VEAT) data is offered by the Washington State Department of Ecology in response to public requests for information about commercial vessel traffic in Washington waters. The data identifies vessels tracked by Ecology. These include cargo and passenger vessels 300 gross tons and larger and tank ships and tank barges, transporting oil, of any tonnage. Starting in 2007, VEAT data classifies tankers carrying edible oil or tallow as tank ships and not cargo & passenger (C&P) vessels. This change reflects the change in the definition of "oil" under Washington State law. VEAT lists data by vessel destination and vessel type and does not reflect specific products or commodities transported or delivered.

Table B-28: Annual vessel traffic multipliers.

Year	Percent of 2018 Traffic	Year	Percent of 2018 Traffic
2002	99.2	2011	98.7
2003	99.7	2012	100.0
2004	99.2	2013	100.3
2005	99.3	2014	99.9
2006	99.8	2015	100.2
2007	99.2	2016	100.4
2008	94.9	2017	99.7
2009	97.7	2018	100.0
2010	98.9	2019	100.5

Total calculated exposure counts for model vessel types for 2002-2019:

Table B-29: Exposure counts by vessel type.

Vessel Categories	Counts (minutes underway)
Tank Ship	18,961,115
Tank Barge and ATB	70,127,573
Passenger Ship (Cruise & Ferry)	195,577,926
Container Ship	31,222,345
General Cargo Ship	13,456,884
Bulk Carrier	59,704,524
Large Fishing Vessel	5,708,788

The following table includes calculated exposure counts for escort tugs:

Table B-30: Exposure counts for escort tugs.

Vessel Category	Counts (minutes underway)
Tug (Assist & Escort)	224,757,316

Self-repair analysis

We developed this probability distribution function by reviewing loss of propulsion incidents from two datasets: the Washington Board of Pilotage Commissioners Marine Safety Occurrence records from 2007-2020, and Neah Bay ERTV callout records from 1999-2017. In our review of these two datasets, we identified 103 events that involved a vessel in the Salish Sea or the entrance to the Strait of Juan de Fuca that met our definition of any reduction in propulsion that affects maneuverability.

Our review of associated investigation reports, class reports, and contemporaneous notes allowed us to develop two estimates: first, the likelihood that a given reduction in propulsion event was a "complete" loss of propulsion that would produce a drifting vessel, and second, the duration of that complete disablement. We were able to find values for 98 of those 103 incidents. For incidents where propulsion was never restored, we used a duration of 24 hours (1440 minutes). From that dataset, we reviewed the goodness of fit of four distributions: Log Normal, Weibull, Gamma, and Exponential. The Log Normal distribution does the best job of representing the bimodal aspect of the dataset. The Log Normal function is unbounded in its upper range and can theoretically generate infinitely high predicted values.

Table B-31 shows the observed durations found in our incident review, as well as the times predicted by the Log Normal distribution. Twenty-five percent of the values fall below the 1st quartile. Fifty percent of the values fall below the median, and 75 percent of the values fall below the 3rd quartile. Predicted values are the summary of 100,000 predicted values generated from the Log Normal function.

Table B-31: Loss of propulsion durations.

Loss of Propulsion Duration (min.)	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Observed	2	8	36	266	325	1,440
Predicted	0	12	47	364	181	740,656

Oil spill probabilities

The model uses oil spill probabilities as part of the calculation of the oil outflow metric. To estimate a probability, two measures are required, the number of observed occurrences and an exposure variable. For these analyses, the project team used the number of groundings as our exposure variable.

We estimated oil spills probabilities using the USCG's MISLE and Canada's MARSIS incident databases. We looked at incidents that occurred between 2000 and 2020 in both databases. To ensure that we would find enough oil spills, we consolidated vessel types. The mapping followed the procedures used in the hazard counts estimation (see *Hazard Counts*).

The table below includes the consolidated vessel types for oil spill probabilities from groundings, as well as the observed counts of groundings, observed counts of oil spills, and the probabilities of oil spills from groundings. For the count of groundings, we used the sum of all groundings identified using the hazard mapping method described in *Methods and Hazard Mapping*, as well as any groundings that were proceeded by an LOP, LOS, or LOP/LOS (which would have been categorized as LOP, LOS, or LOP/LOS respectively under that method).

Table B-32: Oil spills from groundings.

Oil Outflow Vessel Type	Model Vessel Types	Count of Groundings	Count of Oil Spills	Probability of an Oil Spill Per Grounding
Non-Tank Commercial Ship	Cruise Ship, Ferry (Car), Container Ship, General/Other Cargo Ship (Large), Bulk Carrier, Fishing (Large), Vehicle Carrier	1727	21	0.0122
Tank Ship	Tanker (Chemical), Tanker (Crude), Tanker (Liquefied Gas), Tanker (Product)	413	3	0.0073
Tank Barge and ATB	ATB, Towing Vessel (Oil), Towing Vessel (Oil) - Bunkering	3017	22	0.0073

Oil spill volumes

The model uses observed oil spill volumes, and observed oil spill probabilities, as part of the process to generate oil outflow risk values. See *Oil Outflow* for additional details on how this data is used by the Model. We looked at incidents that occurred between 2000 and 2020 in USCG's MISLE and Canada's MARSIS incident databases. We did not apply any geographic filter. To ensure that we would find enough oil spills per vessel type, we consolidated vessel types and used oil spills observed in the database for all incident types associated with collisions, groundings, and allisions. For collision and allision incident that involved vessels of more than one vessel type, oil outflow volumes were assigned to all vessel types involved in the incident. The mapping followed the procedures used in the hazard counts estimation (see *Methods and Hazard Mapping*).

The table below includes the consolidated vessel types for oil spill probabilities from groundings, as well as summary statistics of the observed oil spills in gallons.

Table B-33: Oil outflow volumes (in gallons).

Oil Outflow Vessel Type	Count	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Non-Tank Commercial Ship	65	1	10	75	14,212	811	420,000
Tank Ship	17	21	110	1,000	46,732	4,600	420,000
Tank Barge and ATB	100	1	26	100	25,787	10,000	420,000

Tug escort scenarios

This analysis includes three tug escort scenarios:

- Tank vessels in Scenario 1 are simulated using the tug escort requirements in place prior to 2020. Under these requirements, tug escorts are required for laden tank ships over 40,000 DWT throughout the study area.
- Tank vessels in Scenario 2 are simulated using the tug escort requirements established in 2020. Under these requirements, in addition to the tug escort requirements in place in Scenario 1, tug escorts are also required for laden articulated tug and barges (ATBs), tank barges, and tank ships between 5,000 and 40,000 DWT in Rosario Strait and connected waters east.
- Tank vessels in Scenario 3 are simulated using a theoretical expansion of tug escort requirements to the entire study area. In addition to the tug escort requirements in place in Scenario 2, laden ATBs, tank barges, and tank ships between 5,000 and 40,000 DWT are required to take an escort in all other portions of the study area where not previously required.

The tables below elaborate on the specific tug escort requirements under each scenario:

Table B-34: Tug escort scenarios applicability.

Location	**Laden Tank Ships (including LPG and LNG ships) over 40,000 DWT**	**Laden Tank Ships (including LPG and LNG ships) between 5,000 and 40,000 DWT**	**Laden Towed Tank Barges over 5,000 DWT**	**Laden ATBs over 5,000 DWT**
Admiralty Inlet	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Boundary Pass	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Colvos Passage	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Eastern Strait of Juan de Fuca	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Guemes Channel and Saddlebags	Scenario 1 Scenario 2 Scenario 3	Scenario 2 Scenario 3	Scenario 2 Scenario 3	Scenario 2 Scenario 3

Location	Laden Tank Ships (including LPG and LNG ships) over 40,000 DWT	Laden Tank Ships (including LPG and LNG ships) between 5,000 and 40,000 DWT	Laden Towed Tank Barges over 5,000 DWT	Laden ATBs over 5,000 DWT
Haro Strait	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Possession Sound and Saratoga Passage	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Puget Sound	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Rich Passage and Sinclair Inlet	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Rosario Strait	Scenario 1 Scenario 2 Scenario 3	Scenario 2 Scenario 3	Scenario 2 Scenario 3	Scenario 2 Scenario 3
South Sound to Olympia	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Strait of Georgia	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3
Waters East (Of Rosario)	Scenario 1 Scenario 2 Scenario 3	Scenario 2 Scenario 3	Scenario 2 Scenario 3	Scenario 2 Scenario 3
Other WA Waters Inside Line from Discovery Island Light to New Dungeness Light	Scenario 1 Scenario 2 Scenario 3	Scenario 3	Scenario 3	Scenario 3

Vessel Movement Module

The Vessel Movement Module (VMM) generates marine traffic based on historical vessel movement observed in Automatic Identification System (AIS) data. The module simulates the equivalent of multiple years of vessel traffic data. Each year is unique but based on observed patterns such as the mix of vessel types, berth and anchorage use, and daily traffic levels. The objective of the VMM is to simulate different random traffic configurations that reproduce the macro-characteristics of the system (such as vessel traffic volume by vessel characteristics and waterway characteristics) while changing various micro-characteristics, such as timing and speed of individual vessel journeys.

Simulating vessel movement

This section describes vessel movements by covering the components of a movement, the process for creating tracks out of raw AIS data, and the process for identification and assignment of vessel attributes.

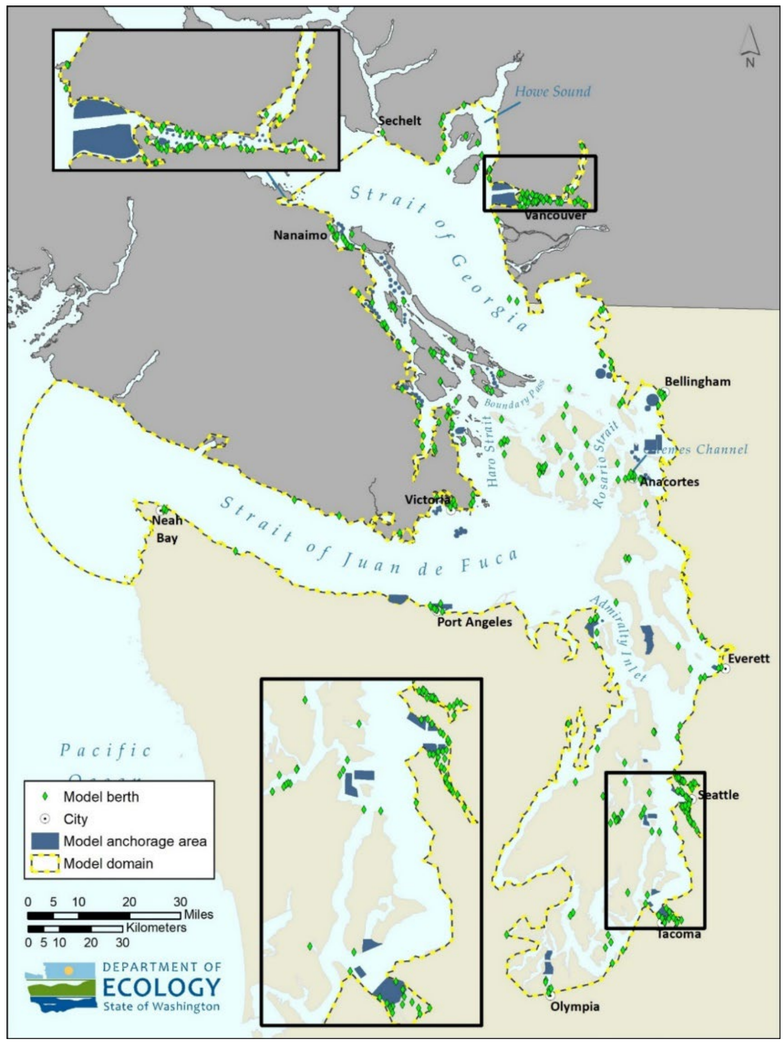

Figure B-5: Model berths and anchorages.

Vessel journeys

A journey is a vessel's entire visit to the Model Domain. For example, a typical journey for a crude tanker would start at the western entrance to the Strait of Juan de Fuca. The journey would continue as it transits the Salish Sea, calls at a berth, or visits an anchorage. The tanker's journey ends when it departs the Salish Sea. For the Model, a journey translates to the collection of vessel tracks that represent a vessel's trip in the system. A track is the collection of AIS messages (in chronological order) for one vessel for one route. A route is a direction of travel between model locations or nodes. The model identifies routes with a starting and ending node. Another component of a journey is a stay. A stay is the time a vessel spends at a node.

Nodes

Nodes are locations that represent the start or end of a route. Berths, anchorages, waypoints, edge of model areas, escort areas, and extended study areas are all types of nodes.

Berths

A berth is a node defined by one or more spatial points. Berths typically refer to specific terminals or docks. We identified berth locations from existing Ecology datasets, through visual inspection of aerial imagery, port maps, and AIS data.

Anchorages

Anchorages are defined by a spatial polygon. Model anchorages include official and unofficial anchorage areas used by deep draft commercial vessels. We identified official anchorages from the Puget Sound Harbor Safety Plan and the Pacific Pilotage Authority. We identified unofficial anchorages through a visual review of AIS data. Each model anchorage can only be used by one deep draft vessel at a time.

We created anchorage groups for areas where multiple individual anchorages are available. We assigned maximum occupancy values to these groups based on local rules. The model combines anchorages into anchorage groups for selecting routes. If a first-choice anchorage group is fully occupied, the next preferred anchorage groups are called Alternative Anchorages. The only model anchorage areas that can take more than one vessel at a time are the tug and barge anchorages.

Waypoints

Waypoints are virtual lines within waterways. They are used to split tracks and provide more flexibility for simulating a diversity of vessel routes and incorporating some model components. We defined waypoints based on a review of AIS traffic.

Edge of model areas

Edge of model areas are locations where the model domain ends. There are two edge of model areas. One is the arc 20 miles west of the JA Buoy at the western entrance to the Strait of Juan de Fuca and one is in the Strait of Georgia, at the line from Nanoose Bay to Sechelt.

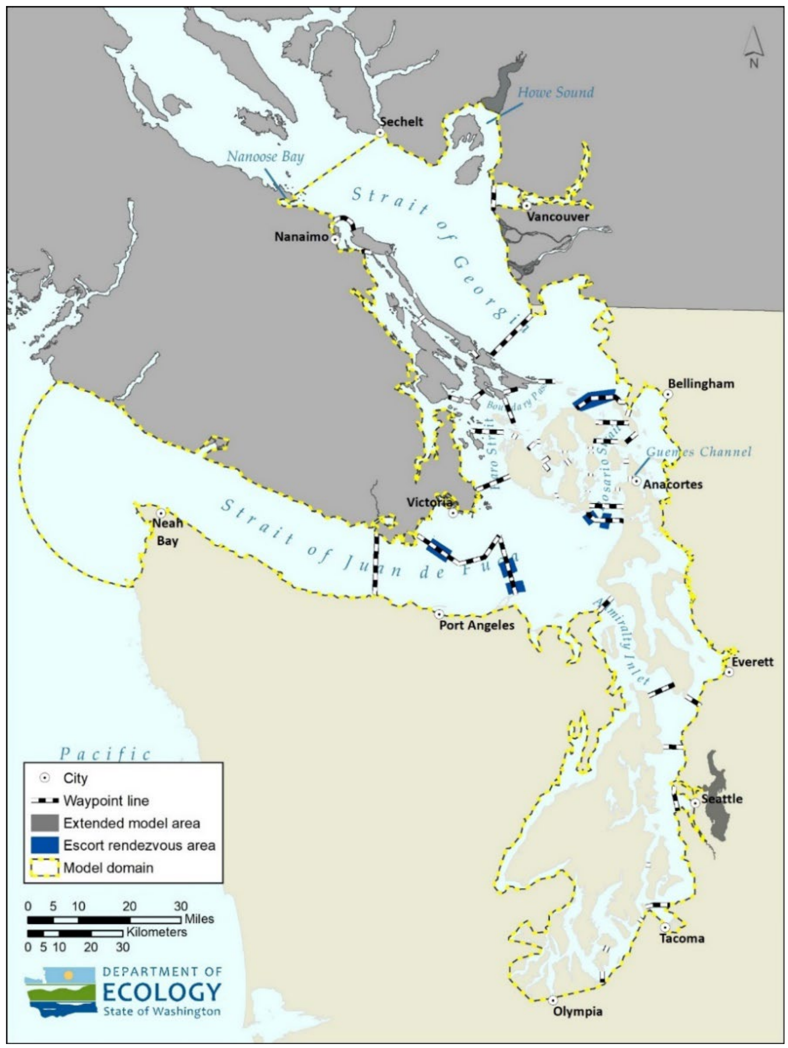

Figure B-6: Model waypoints, escort rendezvous areas, and extended model areas.

Escort rendezvous areas

Escort rendezvous areas are delineated by a spatial polygon. Escort rendezvous areas are where escort tugs either meet or leave laden underway tank vessels. We identified escort rendezvous areas through an examination of tug escort requirements, and a review of AIS.

Extended model areas

Extended model areas are located adjacent to the model domain and the model does not simulate traffic within them. The model treats these areas like berths for track, route, and stay length purposes. These areas include interior waterways within the ports of Seattle and Vancouver, such as the Fraser River and the Duwamish River. Other examples include Upper Howe Sound, Fraser River North, Fraser River South, Duwamish River, and Lake Washington.

AIS track creation

The first step in the track creation process for all vessel types was selecting AIS messages whose position was within the model domain. The AIS message selection was expanded to include AIS messages immediately outside the model domain. Including these AIS messages was useful when creating tracks near the margins of the model domain.

Route-based vessels

After selecting AIS messages within the model domain, messages were associated with nodes. We performed spatial comparisons to identify the closest berth or anchorage within 500 meters. For each unique MMSI, AIS messages were connected chronologically to create a line. Virtual AIS messages were created at the intersection of any line segment with a waypoint line, edge of model area, and extended study area. The virtual AIS messages were associated with the node feature that prompted their creation. Lines were split into vessel tracks when one of the following conditions were met:

- an AIS message was associated with a node;
- the reported vessel speed decreased below 0.2 knots;
- the reported vessel speed increased above 0.2 knots;
- the calculated vessel speed was less than 0.25 meters per second (approximately 0.5 knots);
- the calculated vessel speed was greater than 50 meters per second (approximately 100 knots);
- the distance to previous AIS message was greater than 5 km;
- the duration since last AIS message was greater than 10 minutes;

For AIS messages associated with berths or anchorages, the final node selection was done as follows:

1) If AIS message is within 200 meters of berth, then the final node selection is a berth.
2) If AIS message is more than 200 meters from a berth, then the final node is whichever is closer, the berth or anchorage node.

The result was a series of tracks with starting and ending nodes. AIS messages were then generated at one-minute intervals along the track.

Dependent vessels

Tug (Assist & Escort)

We processed AIS messages and created tracks following two different procedures to meet the simulation needs of the VMM. The VMM generates separate sets of traffic for Tug (Assist & Escort) vessels for each tug escort scenario.

The track creation for escort and assist vessels used the same procedure as with route-based vessels, but with a different set of nodes. For escort tracks, the nodes used for the spatial comparisons were berths, anchorages, and escort rendezvous areas. After lines were created for each unique MMSI connecting the AIS messages in chronological order, they were split into vessel tracks using the same conditions as with route-based vessels. The assignment of starting and ending nodes for tracks also follows the same steps as with route-based vessels. AIS messages were then generated at one-minute intervals along each track.

The majority of the observed vessel tracks for this vessel type do not follow a clear pattern of traveling from node to node. In an attempt to account for this irregular movement, underway tracks were created for each vessel. An underway track was defined as all AIS messages for a given vessel while it was underway. An underway track ends when the vessel's reported speed is less than or equal to 0.2 knots. A new underway track starts when the vessel's reported speed is greater than 0.2 knots. The initial AIS processing step was to remove all AIS messages with a reported vessel speed less than or equal to 0.2 knots. The remaining AIS messages were rounded to the nearest minute. Any temporal gaps (no messages for any 1-minute increment) less than or equal to 10 minutes were filled in by repeating the previous AIS message. Any temporal gaps greater than 10 minutes would mark the end of one underway track. The next AIS message with a reported speed greater than 0.2 knots marks the start of the next underway track. This track creation process would be repeated until there were no more AIS messages for a particular vessel.

Towing Vessel (Oil) – Bunkering

For this vessel type, AIS messages were only associated with berths or anchorages. The rest of the track creation process was the same as with route-based vessels, including generating AIS messages at one-minute intervals along each track.

Ferry (Car)

Underway tracks were created for this vessel category. First, all AIS messages with a reported vessel speed less than or equal to 0.2 knots were removed. Remaining AIS messages were rounded to the nearest minute. Any temporal gaps (no messages for any 1-minute increment) less than or equal to 10 minutes were filled in by repeating the previous AIS message. Any temporal gaps greater than 10 minutes would mark the end of one underway track. The next AIS message with a reported speed greater than 0.2 knots marks the start of the next underway track. This track creation process was repeated until all AIS messages were processed for a particular vessel.

Simulating Movements for route-based vessels

When a route-based vessel visits the system, it follows a series of routes that combine to form a journey. A vessel's journey starts with its appearance at a node. A vessel selects a route from that node based on the distribution of observed tracks from that node. When selecting routes, the model factors in the previous two nodes visited to prevent vessels from becoming trapped in loops. A vessel continues to select routes until it leaves the system or the model year ends. Route-based vessels travel between berths, anchorages, waypoints, edge of model areas, and extended model areas.

Vessel journey starts

A vessel journey starts with a vessel's appearance in the Model. This is determined from the observed AIS. In the observed AIS, a vessel journey start occurs when a vessel track starts at the edge of model area or when the first valid track is observed for that vessel for that year. A valid track has a start and end node.

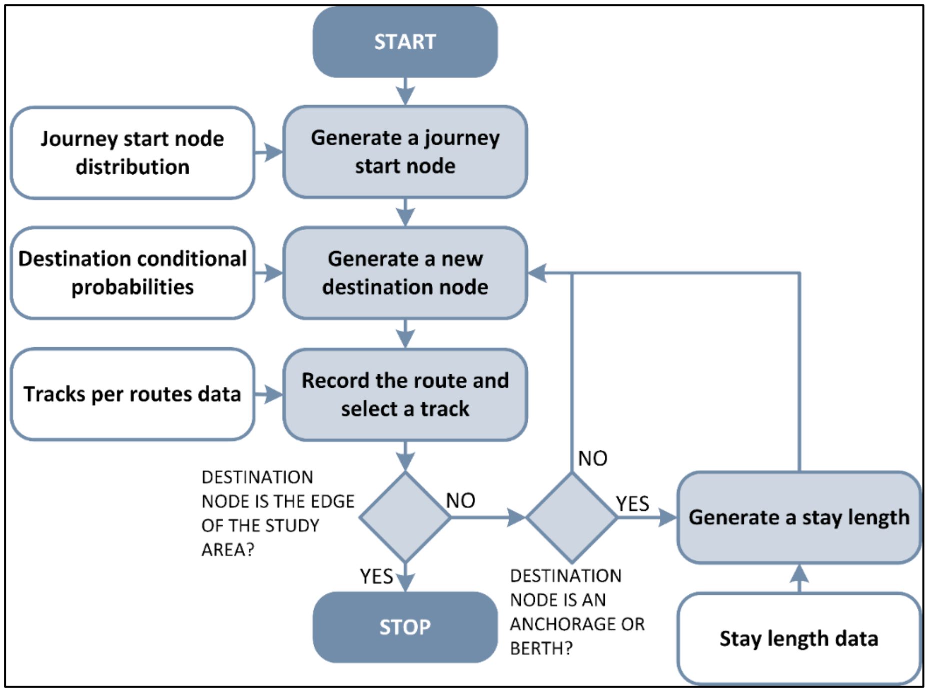

Figure B-7: Route generation process (simplified).

Simulating journeys

The first step in simulating vessel traffic for route-based vessels is determining how many vessel journeys to simulate for a model year. This is determined by randomly selecting a number for each vessel type between the annual minimum number of observed vessel journeys and the annual maximum number of observed vessel journeys across all years of data. That number of journey starts is then selected from the distribution of journey start locations and times (month, day, and time).

Next, a starting track is selected from a distribution of tracks starting from the journey start location. A set of vessel attributes is randomly selected for that vessel type from the model vessels dataset. Once the initial track is selected, the model selects subsequent tracks factoring in the vessel's previous two destinations. Subsequent routes and tracks are selected until a vessel leaves the model domain or the model year is over.

Berths, including extended model areas

When vessels travel to berths or extended model areas, the module must determine how long the vessel will remain at that location. Stay length is determined by selecting from the observed stay lengths for that location. The module does not track berth occupancy, so there is no restriction on the number of vessels that could be at a berth or extended model area at the same time. The module does not track vessel location while at berths or extended model areas.

Anchorages

In the VMM, there are two types of anchorages, standard anchorages and tug and barge anchorages. Standard anchorages in the model are common anchorages primarily used by commercial, deep-draft vessels. The following route-based model vessel types visit them:

- ATB
- Bulk Carrier
- Container Ship
- Cruise Ship
- General/Other Cargo Ship (Large)
- Tanker (Chemical)
- Tanker (Crude)
- Tanker (Liquefied Gas)
- Tanker (Product)
- Vehicle Carrier

Tug and barge anchorages are anchorages specially designated for use by tugs and barges. The following route-based model vessel types visit them:

- ATB
- Towing Vessel (Oil)

Similar to berths, when a vessel travels to an anchorage, the VMM determines how long the vessel will remain at that location. Occupancy is tracked for standard anchorages and each anchorage group has a maximum occupancy based on local rules or regulations. If a vessel route is selected for an anchorage group that cannot accommodate an additional vessel, a new vessel route is selected to an alternative anchorage group. Each anchorage group has been assigned one or more alternative anchorage groups. Occupancy is not restricted for tug and barge anchorages.

The VMM simulates the location and movement of vessels while at anchor. Stay duration and vessel movement at anchor is determined by selecting an observed vessel track for that anchorage location.

Vessels that take escorts

A laden tank vessel may require escort tugs for portions of its journey. The rules defined in tug escort scenarios (see *Tug* **Escort Scenarios**) determine the portions of journeys that require tug escorts. The following model vessel types may have tug escorts:

- ATB
- Tanker (Chemical)
- Tanker (Crude)
- Tanker (Liquefied Gas)
- Tanker (Product)
- Towing Vessel (Oil)

Vessels that use assist tugs

Some vessels require assist tugs when arriving or leaving a berth. ATBs use one assist tug. All other vessel types use two assist tugs. The following model vessel types use tug assists:

- ATB
- Bulk Carrier
- Container Ship
- General/Other Cargo Ship (Large)
- Tanker (Chemical)
- Tanker (Crude)
- Tanker (Liquefied Gas)
- Tanker (Product)
- Vehicle Carrier

Vessels that use bunkering services

The VMM determines if a vessel will receive fuel from bunkering vessels at berths and anchorages. Bunkering vessels can provide fuel to the following route-based vessels at some berths and anchorages.

- ATB
- Bulk Carrier
- Container Ship
- Cruise Ship
- General/Other Cargo Ship (Large)
- Tanker (Chemical)
- Tanker (Crude)
- Tanker (Liquefied Gas)
- Tanker (Product)
- Vehicle Carrier

The project team identified berths and anchorages where bunkering is allowed and those locations where it is prohibited. We used the following criteria to determine that a location allows vessel to vessel bunkering:

- It is a berth or anchorage where bunkering is specifically allowed by that port authority.
- It is a Washington location where a vessel-to-vessel transfer has been recorded in Ecology's Advance Notice of Oil Transfer System (ANTS).
- It is a Puget Sound VTS Anchorage.
- It is a berth that is otherwise not specifically prohibited from allowing bunkering.

We used the following criteria to determine that a location does not allow vessel to vessel bunkering:

- Bunkering is functionally or actually prohibited at that location by port authority.
- It is a ferry dock or fuel dock.

- It is a non-Puget Sound VTS anchorage.
- It is a refinery berth.
- It is a WA berth where no vessel-to-vessel transfers has been recorded in in Ecology's Advance Notice of Oil Transfer System (ANTS).
- It is an exposed anchorage.

Bunkering frequency was determined by reviewing oil transfer data for 2018 from Ecology's Advance Notice of Oil Transfer System (ANTS) and berth and anchorage visits (stays) observed in AIS. We only counted stays at Washington locations where we determined bunkering is allowed. The bunkering rate is the number of vessel-to-vessel transfers divided by the number of stays at berths and anchorages where bunkering is allowed. In 2018, the counts were 1,564 transfers and 3,943 stays. The rate was 0.397 transfers per stay. If bunkering occurs, it begins when the ship arrives at the berth or anchorage. Each transfer is instantaneous for simulation purposes.

Simulating movements for dependent vessels

In the Model, dependent vessels are vessels that perform some support function for route-based vessels. This includes assist, escort, and bunkering vessels. When required, dependent vessels travel to the location where the dependent activity begins. When the dependent activity has concluded, the dependent vessel leaves. Dependent vessels are available on demand. They "appear" in the system when needed and then "disappear" after their dependent activity is concluded.

Simulating movements for Tug (Assist & Escort)

This category includes vessels that are engaged in two different behaviors, escorting and assisting. The VMM simulates these vessels both as dependent journeys and as background traffic. The number of dependent escort and assist tracks simulated for each model year is recorded and subtracted from the overall number of background traffic tracks that will be simulated. Background traffic is simulated using the underway tracks described in *AIS Track Creation – Dependent vessels – Tug (Assist & Escort)* . A separate set of simulated traffic (dependent and background) is created for each tug escort scenario for each simulation.

Tug escorts

When the need for an escort is identified (see *Determining Need for Escort*), a track is selected from the distribution of observed Tug (Assist & Escort) tracks traveling to the location where the escort job begins. The movement of the tug while escorting is simulated by replicating the movement of the route-based vessel from the rendezvous location to the end of the escort job. The start time for the escorting tug track is delayed by one minute. At the end of the escort job, a track is selected from the distribution of observed Tug (Assist & Escort) tracks traveling from the location where it ends. Escort jobs can begin or end at berths, extended study areas, anchorages, and escort rendezvous areas.

Tug assists

When a tug assist is required, the VMM first evaluates if the vessel is escorted. If the vessel is escorted, the escort tug is assumed to provide assist services reducing the number of assist tugs required by one. To simulate tug assists, the required number of assist tracks are selected from the distribution of observed Tug (Assist & Escort) tracks traveling to the berth visited by the route-based vessel. The start time for the tug assist track is modified so it arrives at the berth at the same time as the route-based vessel. The movement of the dependent vessel while assisting is not simulated. Once the assist tug arrives at the berth, it immediately departs.

The return trip for tug assists is simulated by selecting from the observed Tug (Assist & Escort) tracks traveling from the berth visited by the route-based vessel. When the route-based vessel leaves from the berth, the VMM selects tracks for the assist tugs from the distribution of tracks to the berth. The subsequent return trip for the assist tugs begins one hour after the route-based vessel leaves the berth. The VMM selects return tracks for assist tugs from the distribution of tracks from that berth. If the route-based vessel requires an escort tug when leaving the berth, then the number of assist tugs required is reduced by one.

Simulating movements for Towing Vessel (Oil) - Bunkering

Based on the rate of bunkering per stay at berth or anchorage described in *Vessels that use bunkering services*, the VMM simulates the movement of Towing Vessel (Oil) – Bunkering vessels to the bunkering location and from the bunkering location. The VMM simulates movement to the bunkering location by selecting a track from the distribution of observed Towing Vessel (Oil) – Bunkering tracks to the bunkering location. The return trip begins immediately after arriving at the bunkering location (bunkering is instantaneous in the Model) and is simulated by selecting a track from the distribution of observed Towing Vessel (Oil) – Bunkering tracks from the bunkering location. If there is not an observed track to or from the bunkering location, then bunkering does not occur.

Simulating movements for Ferry (Car)

Ferry (Car) movements are simulated by replicating an entire year of Ferry (Car) underway tracks. For the VMM, each simulation will choose at random a year of traffic from the available years of AIS data (2015 to 2019).

Implemented Rules for laden status

For purposes of coding, we used the following set of rules to establish laden or unladen status for tank vessels based on tank vessel type, destination, and origin.

Tanker (Chemical)

- If visits Canadian export facility, then:
  - Transit before Canadian export facility visit – 100 percent are laden
  - Transit after Canadian export facility visit – 40 percent are laden
- If does not visit Canadian export facility and does visit refinery, then:
  - Transit before refinery visit – 45 percent are laden
  - Transit after refinery visit – 80 percent are laden
- If does not visit Canadian export facility and does not visit refinery, then:
  - Transit before other berth – 5 percent are laden
  - Transit after other berth – 10 percent are laden

Tanker (Crude)

- Inbound to Canadian export facility – 0 percent are laden
- Inbound to refinery – 100 percent are laden
- Outbound from Canadian export facility – 100 percent are laden
- Outbound from refinery – 43 percent are laden
- Inbound to oil terminal - 100 percent are laden
- From refinery/Canadian export facility to oil terminal – 100 percent are laden
- From oil terminal to oil terminal – 100 percent are laden
- From Refinery/Canadian export facility to refinery/Canadian export facility – 100 percent are laden
- Outbound from oil terminal – 0 percent are laden
- From oil terminal to refinery/Canadian export facility – 0 percent are laden
- Does not call on an oil handling berth - 100 percent are laden

Tanker (Liquefied Gas)

- Inbound to Ferndale facility – 0 percent are laden
- Outbound from Ferndale facility – 100 percent are laden
- Ferndale facility to Ferndale facility – 100 percent are laden
- Outbound from anchorage – 100 percent are laden
- Anchorage to Ferndale facility – 0 percent are laden

Tanker (Product)

- Inbound to Canadian export facility – 35 percent are laden
- Inbound to refinery – 55 percent are laden
- Outbound from Canadian export facility – 84 percent are laden
- Outbound from refinery – 85 percent are laden
- Inbound to oil terminal – 100 percent are laden
- From refinery/Canadian export facility to oil terminal – 100 percent are laden
- From oil terminal to oil terminal – 100 percent are laden
- From refinery/Canadian export facility to refinery/Canadian export facility – 100 percent are laden
- Does not call on an oil handling berth - 100 percent are laden
- Outbound from oil terminal – 0 percent are laden
- From oil terminal to refinery/Canadian export facility – 0 percent are laden

ATB and Towing Vessel (Oil)

- Enter the system unladen
- Exit the system laden
- Considered laden after first visit to oil terminal
- If vessel does not leave the system, all subsequent transits are laden

Towing Vessel (Oil) - Bunkering

- Laden from appearance to bunkering rendezvous
- Unladen for return trip after completing the bunkering job

Determining need for escort

Whether a laden vessel requires a tug escort is dictated by the rules associated with a given tug escort scenario. In the VMM, the escort zones (areas of the waterways where escort requirements apply) are identified by the routes where escort rendezvous areas are located. Any simulated vessel route is considered to be within the escort zone if it occurs after a route where a tug escort would join and before a route where a tug escort would leave. Slight modifications of these general rules were required during implementation to ensure that vessels with partial journeys took escorts where appropriate.

Vessel Accident Module

The Vessel Accident Module generates marine incidents for further analysis. The model applies a probability of loss of propulsion (LOP) and loss of steering (LOS) on a minute-by-minute basis to the simulated traffic from the Vessel Movement Module. Hazard probabilities are based on observed occurrences in the USCG Marine Information for Safety and Law Enforcement (MISLE) and Transportation Safety Board of Canada's Marine Safety Information System (MARSIS).

Application of hazard probabilities

We established probabilities for loss of propulsion (LOP) and loss of steering (LOS) per operating minute as described in *Calculated Hazard Probabilities for Simulated Vessels*. We multiplied the calculated probability for each vessel type in order to simulate a much larger number of loss of propulsion and loss of steering incidents for each vessel type than what the original hazard rates would produce. As described in *Oil Spill Risk Module*, the hazard rate modifier for each vessel type and for each hazard is included in calculation of oil spill risk metrics. Using the modified probabilities, the model evaluates each simulated track to determine if a hazard occurs and at what 1-minute time step it occurs. If one of these hazards occurs, the model logs the incident time and location for subsequent analysis.

Self-repair

When a simulated vessel experiences a loss of propulsion event, the model first determines if the loss of propulsion was total. To do so, the model applies a probability of 0.347 that the event resulted in a complete loss of propulsion. Then, for ships that experience a total loss of propulsion, the model selects a duration without propulsion using the following probability distribution function.

Equation 4

$$X \sim Lognormal(meanlog = 3.834073, sdlog = 2.03378)$$

The *Self-Repair Analysis* section describes the self-repair function in more detail.

Momentum and Drift Module

The Momentum and Drift Module (MDM) plots a drift trajectory for a simulated ship that loses propulsion. The model incorporates vessel dimensions and characteristics, wind and current data, and bathymetry. For each loss of propulsion event, the MDM identifies a drift duration, speed, and location of grounding.

Data inputs

The MDM uses simulated vessel movement and attributes along with wind, current, and bathymetry data to calculate a drift trajectory. The vessel movement data is fed from the Vessel Accident Module that includes information about the time and location of the loss of propulsion event. The Vessel Accident Module also identifies the simulated vessel involved allowing the MDM to bring in relevant vessel attributes, such as displacement tonnage and dimensions.

Initial Turn application

When ships lose propulsion, they can briefly retain the ability to control their heading and avoid hazards using momentum. We incorporated this real-world behavior into the MDM with these steps:

1) Create a 120-degree hazard evaluation area centered on the vessel's coordinates and using the vessel speed to determine radius of the arc.
    a) The radius of the arc corresponds to the distance that vessel will travel at its current speed in 20 minutes.
2) Divide the 120-degree hazard evaluation area into 10 equal wedges.
3) Evaluate wedges for potential grounding hazards.
    a) If the water depth is equal to or less than the draft of the vessel anywhere within the wedge, then a hazard is identified.
4) Select the largest group of contiguous wedges without hazards.
5) If there are multiple groups of the same number, select the wedge group closest to the original course.
6) Set new course to the middle of the selected wedge group.

For each vessel that loses power, a drift trajectory is first calculated without applying the initial turn. If for that same vessel an initial turn was required, an additional drift trajectory is calculated after applying the initial turn course change.

Drift modeling

No existing drift model fully met our requirements. We developed a new drift model to account for the vessel momentum, vessel type, wind, current, and wave effects. For Towing Vessel (Oil) and Towing Vessel (Oil) – Bunkering vessels, only the barge is modeled for drifting.

Drift modeling approach

The drift modeling process has three main objectives:

1) To include the major environmental forces acting on a ship (wind, current, and waves) in a generalized form;
2) To account for the vessel momentum as a potential influencing force in restricted waters;
3) To account for vessel type where possible.

To achieve this, the drift model balances ship momentum with environmental drag forces:

Equation 5

$$(m + m')\frac{dv}{dt} = F_{res,air} + F_{res,water} + F_{wind} + F_{current} + F_{wave}$$

Where:

- m is vessel mass
- m' is added mass from acceleration of water particles along the hull
- $\frac{dv}{dt}$ is vessel acceleration
- $F_{res,air}$, $F_{res,water}$ are the air and water resistance opposed to the direction of vessel movement
- F_{wind}, $F_{current}$, F_{wave} are the wind drag force acting on the vessel, the current drag force acting on the vessel, and the wave drag force acting on the vessel

The forces are generally proportional to the velocity of the object in a fluid. This function depends on the vessel characteristics and its speed relative to the external forces. In general, the drag force is exponentially proportional to speed (Ni et al. 2010). As an approximation, the generic formulas for the air and water resistance forces and the drag wind, current and wave drag forces are:

Equation 6

$$F_{res,air} = \frac{1}{2} c_{air} \rho_{air} A_{air} {v_{ship}}^2$$

$$F_{current} = \frac{1}{2} c_{water} \rho_{water} A_{water} {v_{ship}}^2$$

$$F_{wind} = \frac{1}{2} c_{air} \rho_{air} A_{air} {v_{air}}^2$$

$$F_{current} = \frac{1}{2} c_{water} \rho_{water} A_{water} {v_{water}}^2$$

$$F_{wave} = \frac{1}{2} c_{wave} \rho_{water} g L a^2$$

Where:

- c_{air}, c_{water}, c_{wave} are the drag coefficients for air, water, and waves
- ρ_{air}, ρ_{water} are the air and water densities
- A_{air}, A_{water} are the areas exposed to wind and water

- v_{ship}, v_{air}, v_{water} are the ship's velocity, the relative wind velocity, and the relative current velocity
- g is the Earth's gravitational acceleration
- L is the length of the waterline
- a is the wave amplitude (1/2 of the wave length)

Inclusion of vessel momentum

In the restricted waters considered in our analyses, the early moments after a loss of propulsion are important. Over this period, a vessel could travel $1\ nm$ or more after losing propulsion. The inertial stopping distance could be longer, depending on the vessel type, size, and speed. Moreover, this is the period of time when the pilot maneuvering the ship could influence the direction of the vessel trajectory. For these reasons, we deemed vessel momentum as an essential component of our drift model.

Input parameters

There are a number of parameters required by our approach. The assumed model structure is as described by Equation 5 and Equation 6 and requires the following inputs:

- Vessel location
- Course
- Speed
- Time of the loss-of-propulsion event
- Vessel characteristics
- Wind and current speed and direction
- Wave direction and amplitude

The MDM also requires estimates for five vessel-dependent parameters: air drag, water drag, wave drag, added mass, ratio of wind to air exposed areas. Discussion for calculating these five parameters follows.

Wind drag coefficients

Wind drag forces depend on the angle of attack (angle between vessel heading and wind direction), wind speed, and vessel characteristics. Many studies have focused on estimation of the wind drag forces or wind drag coefficients for various vessel types.

There are three types of wind drag models documented in the literature: experimental, statistical, and mathematical. After review, we selected a mathematical model based on the Helmholtz-Kischhoff plate theory as used by Blenderman (1994).

Blenderman (1994) applied a load concept to compute wind coefficients. The wind load functions use four parameters: longitudinal resistance CD_l, transversal resistance CD_t, the cross-force parameter δ, and the rolling moment factor K.

Current drag coefficients

The current drag coefficients depend on the angle of attack (relative angle between vessel heading and current direction), current speed relative to the vessel, vessel characteristics, vessel orientation into the current (port or starboard), and the ratio of water depth to vessel draft.

There are few studies dedicated to the estimation of the current drag forces or current drag coefficients than wind drag. A 1994 study by Oil Companies International Marine Forum (OCIMF 1994) provides the only approach to estimating current drag forces based on extensive research, and it was ultimately chosen for the MDM.

The formulas are designed to estimate current force on stationary objects. In our model the relative current speeds may be higher than the ones for which the OCIMF study was built, but only for a short period of time when the vessel still has momentum and is not fully driven by the wind and current velocity vectors combined.

Wave drag coefficients

In Equation 6, wave force requires the calculation of a wave-drag coefficient, of the length of the waterline, and the wave amplitude. The most common approach in drift modeling is to ignore wave effects. For example, Breivik and Allen (2008) assumed that wave drag forces are negligible for the objects modeled, and already captured by the regression coefficients since wave direction predominantly followed the direction of the wind.

Ni and others (2010) showed that the wave effects can be ignored if the wave amplitude is less than 1/30th of the length of the vessel. Yang and others (2018) showed the maximum wave height in the Salish Sea is about 2.5 m with most frequent wave heights being between 0.25 – 0.5 m. The most common wave amplitudes in Salish Sea are therefore 0.125 – 0.25 m, with maximum of approximately 1.25 m. Wave forces are therefore negligible in terms of their influence on drift path for vessels longer than 37.5 m under virtually all conditions. As a result, we determined that wave action in the study area likely has no significant impact on drift for covered vessels and therefore excluded it.

Estimating "added mass"

A vessel accelerating or decelerating in a fluid accelerates or deflects some volume of surrounding fluid as it moves. This is typically modeled as a volume of fluid moving with the vessel, which effectively increases the vessel inertia. This effect is called the added mass (Breivik and Allen 2008).

There are many approaches for calculating added mass. Tveitnes (2001) conducted an extensive review of the historical approaches. There are 36 components of the added mass which correspond to combinations of the six vessel movements: surge, sway, heave, roll, pitch, and yaw. In the MDM, we are only interested in the added mass for surge, the longitudinal motion along the x-axis, because only the forward momentum is modeled and the vessel heading is approximated by the course over ground.

Zhang and others (2019) indicate that the longitudinal added mass coefficient is small compared with the mass of the ship – about 0.02 to 0.07. They also suggest that for simplicity or in case of absence of detailed vessel information a value of 0.05 can be used. Following that rationale, the MDM uses a value of 0.05 multiplied by the vessel's displacement to approximate added mass.

Estimating "water-exposed vessel area" and "wind-exposed vessel area"

To estimate the water exposed area and the wind exposed area, the model relies on the approach by Jurdzinski (2020). This is the assumption that the general ratio of above to below the waterline area is 5:1 for vessel types with large windage areas and 1:5 for vessel types that have low freeboard.

The vessel area exposed to the current is calculated first as the product of the vessel draft and the vessel length for longitudinal area, and the product of the vessel draft and vessel beam for the lateral area. This is an overestimate of the true values.

The wind exposed area will be five times larger than the current exposed area for vessels with large windage areas and $1/5^{th}$ of the current exposed area for vessels with low free board. The modeled vessel types are classified as high and low windage as follows.

Table B-35: Windage classification.

Model Vessel Type	Windage Category
ATB, Bulk Carrier, Tanker (Chemical), Tanker (Crude), Tanker (Liquefied Gas), Tanker (Product), Towing Vessel (Oil), Towing Vessel (Oil) - Bunkering	Low
Container Ship, Cruise Ship, Ferry (Car), Fishing Vessel (Large), General/Other Cargo Ship (Large), Vehicle Carrier	High

Determining drift grounding

Vessel drift trajectories are simulated for 48-hour periods or until a drift grounding event occurs. The MDM identifies drift grounding events by performing a spatial intersection between the vessel drift trajectory and bathymetry depth contours equal to or less than the vessel design draft. The intersection of the drift trajectory with a bathymetry contour identifies the location and time of grounding. The MDM passes grounding events to the Vessel Rescue Analysis Module. Figure B-8 provides an illustration of the complete functionality of the MDM with the initial turn applied, drift trajectories with and without an initial turn, and drift groundings.

Oil Spill Risk Module

The Oil Spill Risk Module (OSRM) generates oil related risk metrics for each loss of propulsion incident for further analysis. The three risk metrics are drift grounding, oil volume at risk and oil outflow. The OSRM uses the hazard rate multiplier, described in *Calculated Hazard Probabilities for Simulated Vessels*, for the calculations of all three risk metrics.

Drift grounding

The model generates a drift grounding metric by dividing 1 by the hazard rate multiplier for the vessel type.

Oil Volume at Risk

Oil Volume at Risk is a second oil spill risk metric. It is designed to represent the catastrophic potential represented by the carriage of large quantities of oil. To calculate the Oil Volume at Risk for a given incident, the model uses maximum volume of oil carried by a vessel as fuel and cargo. The volume is generated from simulated vessel fuel and cargo capacity. The model calculates the final oil volume at risk metric by dividing the simulated volume by the hazard rate multiplier.

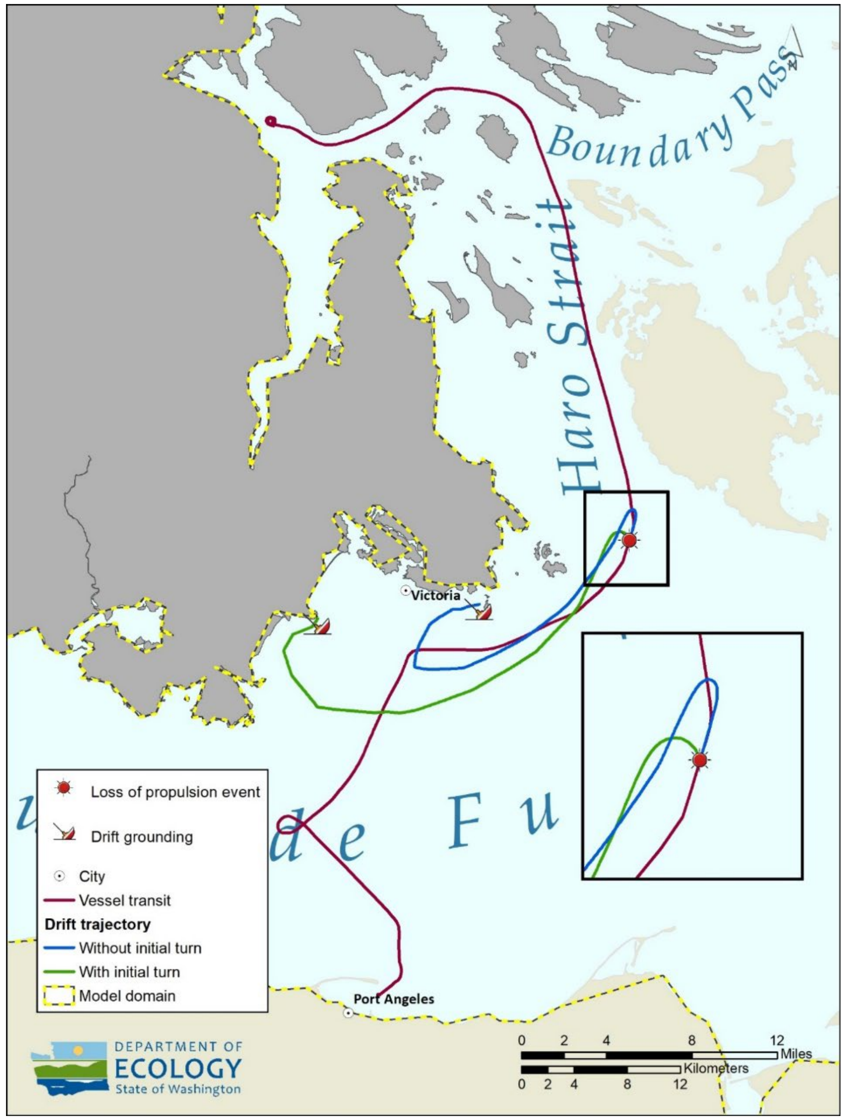

Figure B-8: Map of drift trajectory examples.

Oil outflow

To calculate the oil outflow metric, the model first divides the average observed oil spill volume for that vessel type by the hazard rate multiplier. The model then multiplies that result by the observed oil spill probability. Oil spill probabilities and volumes are based on observed occurrences in the MISLE and MARSIS databases. See *Oil Spill Probabilities* for more details. If the average oil spill volume for a vessel type is greater than the simulated maximum volume of oil carried by the vessel, then the maximum oil volume is used instead of the average oil spill volume.

Fuel capacity value

For calculation of Oil Volume at Risk, the OSRM uses the fuel capacity value from the vessel attributes table.

Cargo capacity value

For calculation of Oil Volume at Risk, the model uses the 98 percent of the cargo capacity value from the vessel attributes table. This follows 46 CFR § 154.1844, which limits the maximum amount for filling liquid cargo tanks to 98 percent to allow for thermal expansion and to avoid overfilling during loading. When tank ships are not laden, the oil volume at risk only includes fuel capacity, not oil cargo capacity.

Vessel Rescue Analysis Module

The Momentum and Drift Model calculates a path when a vessel loses power until it grounds. Few loss of propulsion incidents actually result in drift groundings, so the model evaluates a series of ship actions for self-rescue to estimate a realistic likelihood of a drift grounding, absent outside intervention. The model incorporates some of these ship actions into other modules. These are:

- **Initial turn using residual momentum –** The ability of a ship to adjust its heading immediately following the loss of propulsion (Momentum and Drift Module)
- **Self-repair –** The time that it takes a ship to recover propulsion after losing it (Vessel Accident Module)

The Vessel Rescue Analysis Module (VRAM) includes one ship action:

- **Emergency anchoring –** The ability of a ship to arrest its drift by dropping anchor

The model also evaluates the ability of rescue tugs to intervene and prevent drift grounding when a ship loses propulsion. This is the core of our analyses and allows us to test the relative benefits of tug escorts, tugs of opportunity, and ERTVs.

For each drifting ship, the total time required for a tug to perform a rescue will be calculated. This "time to save" is calculated based on the travel and control time of the nearest escort tug, tug of opportunity, or ERTV. This time is compared to the drift duration to determine if the tug could have prevented that drift grounding.

Emergency anchoring function

A modeled vessel that is adrift following a loss of propulsion will attempt to anchor. At every one-minute interval along the drift trajectory, the model checks if the drift speed is 3 knots or less. If it is, the model checks water depth and distance to grounding depth to determine if emergency anchoring is available. Grounding depth is defined as the point along the drift trajectory where the ship's design draft equals the water depth.

If the following conditions are met, the drifting vessel can anchor:

- Speed is 3 knots or less
- Water depth is 60m or less
- Distance to grounding contour must be greater than ship length plus 500m
    - 100m for anchor to hold

- 300m anchor rode
- 100m safety margin

This emergency anchoring function is adapted from (Fowler and Sorgard 2000).

Tug of opportunity identification

When a simulated ship loses propulsion, the model will capture the location of all escort and assist tugs in the system at the time of the LOP. This excludes assist tugs engaged in maneuvering a ship. The model considers each of these potentially capable of responding to a disabled vessel. No other tugs, for instance, those engaged in towing barges, will be considered by the model as potential tugs of opportunity.

Transit route and time calculation

After the model identifies the location of all assist and escort tugs at the time of the LOP, it calculates a transit time dataset for each potential tug of opportunity and ERTV. The transit time dataset is generated using a custom Python script and ESRI ArcGIS spatial analysis tools. The tug is assumed to travel at an average speed of 10 knots and will take the shortest feasible route from the tug's location to where the interception point with the drifting ship is plotted.

Interception of drifting vessel

The interception point is determined by comparing the disabled vessel's drift trajectory to the tug's transit time dataset. The model identifies the tug transit time to all points along the disabled vessel's drift trajectory. Since the tug must arrive such that there is sufficient time to connect and control before grounding, the model adds the tug's time to connect and time to control to its transit times. The earliest point on the drift trajectory where a tug could arrive in time is the save location.

The model uses the following assumptions for tug rescue:

- Tug time to connect: 15 minutes
- Tug time to control of disabled vessel: 15 minutes

Emergency Response Towing Vessel (ERTV)

An ERTV has a 20-minute mobilization time added to its transit from the stationing location to point of interception with the drifting ship. The 20-minute mobilization time is the planning standard for the existing ERTV in Neah Bay as defined in RCW 88.46.135 – 1(a). The VRAM evaluates ERTV rescue from the existing ERTV staging location at Neah Bay and 7 additional locations, including the 6 locations suggested in Nuka Research and Planning Group's 2021 study of vessel drift and response analysis (Robertson et al. 2021) (Figure B-9). The complete list of ERTV staging locations evaluated by the VRAM is below.

- Anacortes
- Delta Port
- Neah Bay

- Port Angeles
- Port Townsend
- Roche Harbor
- Sidney, BC
- Victoria, BC

Other than the mobilization time, ERTVs have the same response capabilities as tugs of opportunity described above.

Tethering

Modeled escort tugs can be tethered or untethered. Tethering refers to the practice of escorting a ship with a towline connected. If the escort is untethered, the time to save an escorted vessel is 30 minutes. That value is the sum of time to connect and time to control. If an escort is tethered the time to save is 15 minutes, as only the time to control applies.

Model output for loss of propulsion events

The result for every loss of propulsion event is a series of simulated and calculated values. For each loss of propulsion event, the following attributes were recorded:

Figure B-9: ERTV locations

- Laden status of vessel
- Fuel capacity of vessel
- Cargo capacity of vessel
- If the vessel is escorted in Scenario 1
- If the vessel is escorted in Scenario 2
- If the vessel is escorted in Scenario 3
- The outcome of the drift trajectory (grounding, left study area, or drifted for 48 hours)
- Duration of drift trajectory
- If a complete loss of propulsion occurred
- Time until self-repair
- Time until successful emergency anchoring
- Time until rescue from Neah Bay ERTV
- Time until rescue from additional ERTV locations (calculated separately for each location)
- Time until rescue from the closest tug of opportunity in Scenario 1

- Time until rescue from the closest tug of opportunity in Scenario 2
- Time until rescue from the closest tug of opportunity in Scenario 3
- Drift grounding risk value
- Oil volume at risk value
- Oil outflow risk value

Taking the example illustrated in Figure B-8, the model would produce the following output:

Table B-36: Model output examples.

Model Output	**Without initial turn**	**With Initial turn**
Laden status	No	No
Fuel capacity	855,094 gallons	855,094 gallons
Cargo capacity	0 gallons	0 gallons
Escorted in Scenario 1	No	No
Escorted in Scenario 2	No	No
Escorted in Scenario 3	No	No
Outcome of drift trajectory	Grounded	Grounded
Time to drift grounding	489 minutes	402 minutes
Time to rescue, escorted without tethering	30 minutes	30 minutes
Time to rescue, escorted with tethering	15 minutes	15 minutes
Time to rescue, ERTV (Anacortes)[26]	228 minutes	279 minutes
Time to rescue, ERTV (Deltaport)26	315 minutes	358 minutes
Time to rescue, ERTV (Neah Bay)26	351 minutes	322 minutes
Time to rescue, ERTV (Port Angeles)26	170 minutes	149 minutes
Time to rescue, ERTV (Port Townsend)26	178 minutes	201 minutes
Time to rescue, ERTV (Roche Harbor)26	125 minutes	159 minutes
Time to rescue, ERTV (Sidney)26	158 minutes	182 minutes
Time to rescue, ERTV (Victoria)26	102 minutes	93 minutes
Time to rescue, closest tug of opportunity[27]	152 minutes	130 minutes
Complete loss of propulsion	Yes	Yes
Self-repair time	37 minutes	37 minutes

[26] Rescue time for ERTV includes mobilization time, time to connect, and time to control.
[27] Rescue time for tug of opportunity includes time to connect and time to control. Hypothetical tug location is based on the location of the closest tug to the vessel when it experienced a hypothetical loss of propulsion event.

Model Output	Without initial turn	With Initial turn
Emergency anchoring	Success (after 470 minutes adrift)	Success (after 347 minutes adrift)
Drift grounding risk value	0.04	0.04
Oil volume at risk value	3420.4	3420.4
Oil outflow value	0.8	0.8

Figure B-10 displays the location of tugs of opportunity in the example from Figure B-8. Figure B-11 illustrates the earliest points along the drift trajectories that the ERTVs and closest tug of opportunity would arrive.

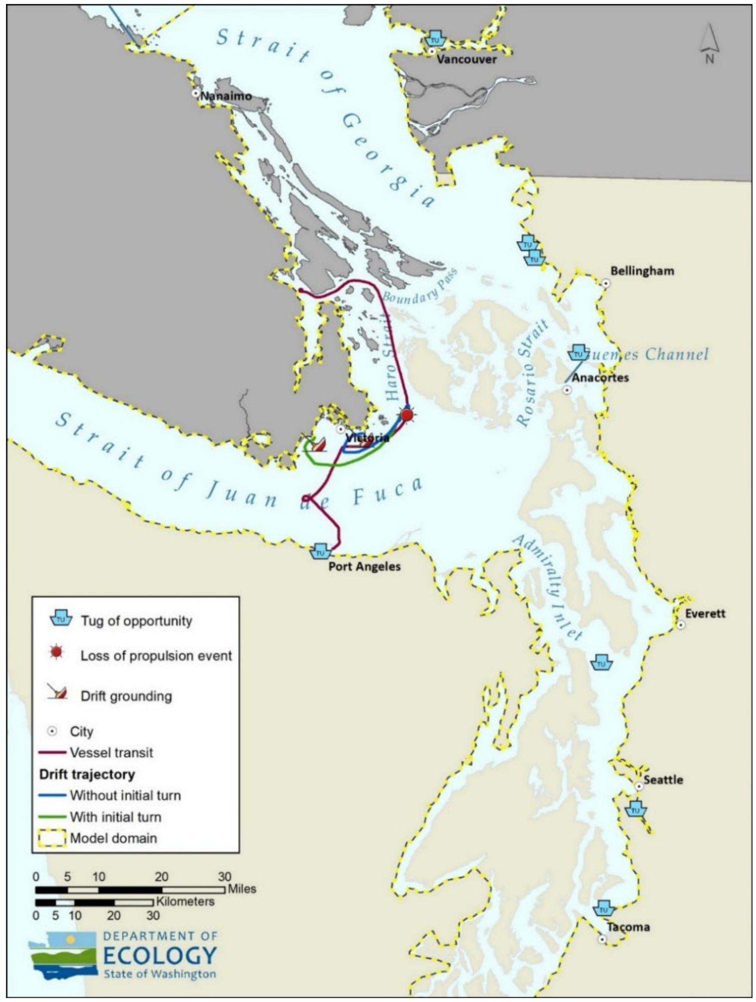

Figure B-10: Map showing tugs of opportunity when loss of propulsion occurs.

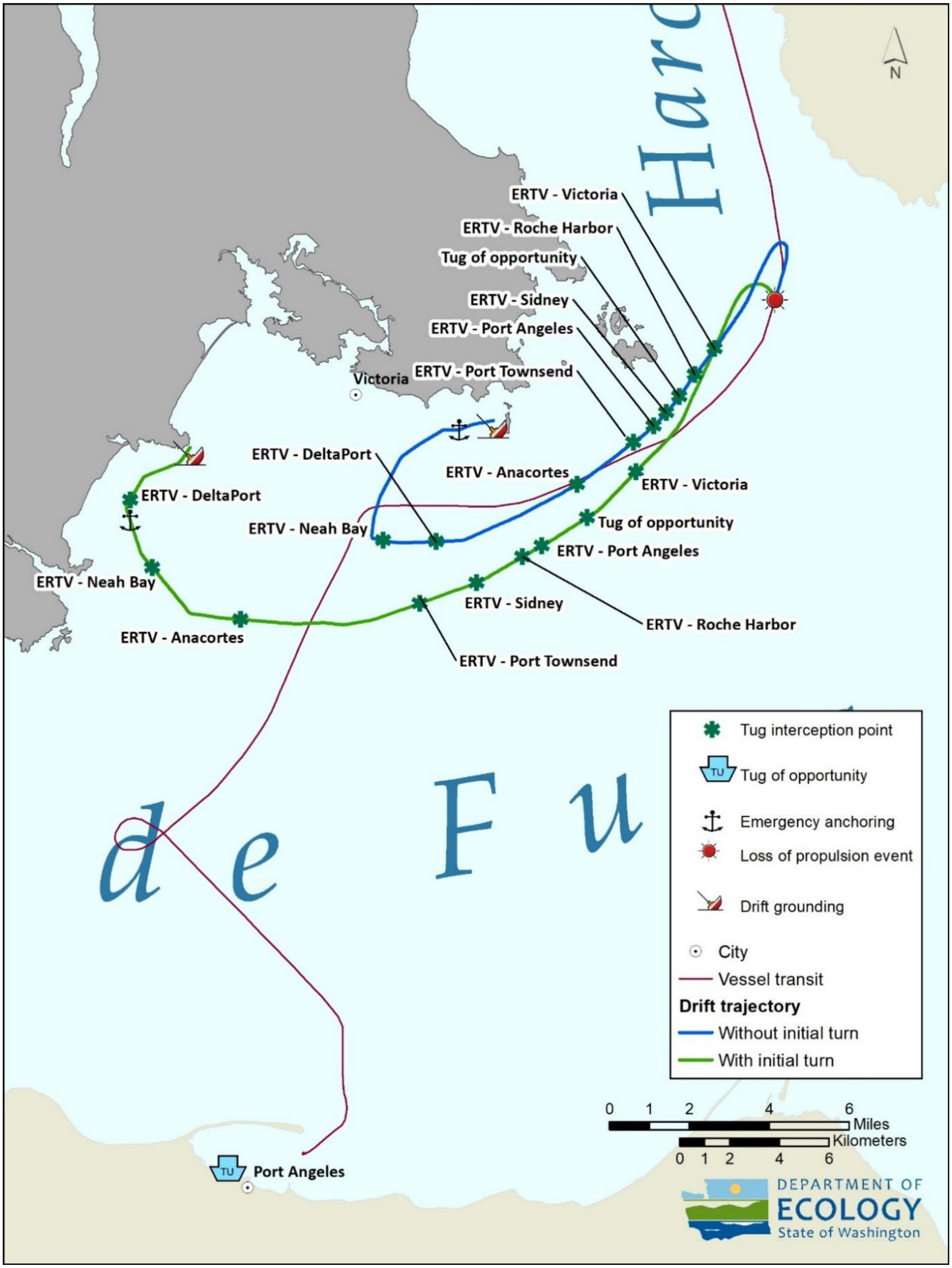

Figure B-11: Map showing rescue tug interception points along drift trajectories.

Model output for loss of steering events

For every loss of steering event, the model recorded the following attributes:

- Laden status of vessel
- Vessel is escorted in Scenario 1
- Vessel is escorted in Scenario 2
- Vessel is escorted in Scenario 3
- Time to reach location for the closest tug of opportunity in Scenario 1
- Time to reach location for the closest tug of opportunity in Scenario 2
- Time to reach location for the closest tug of opportunity in Scenario 3

Appendix C: Outreach and Consultation

Model development

Consultation outreach with potentially affected federally recognized Tribes

In late April 2020, Ecology sent consultation request letters to 33 potentially affected federally recognized Tribes. The letter offered consultation with Ecology on the development of the model.

We sent the letter to the following tribes:

- Confederated Tribes and Bands of the Yakama Nation
- Confederated Tribes of Grand Ronde Community of Oregon
- Confederated Tribes of the Chehalis Reservation
- Confederated Tribes of the Colville Reservation
- Confederated Tribes of the Umatilla Indian Reservation
- Confederated Tribes of the Warm Springs Reservation of Oregon
- Cowlitz Indian Tribe
- Hoh Indian Tribe
- Jamestown S'Klallam Tribe
- Kalispel Indian Community of the Kalispel Reservation
- Lower Elwha Tribal Community
- Lummi Tribe of the Lummi Reservation
- Makah Indian Tribe of the Makah Indian Reservation
- Muckleshoot Indian Tribe
- Nez Perce Tribe
- Nisqually Indian Tribe
- Nooksack Indian Tribe
- Port Gamble S'Klallam Tribe
- Puyallup Tribe of the Puyallup Reservation
- Quileute Tribe of the Quileute Reservation
- Quinault Indian Nation
- Samish Indian Nation
- Sauk-Suiattle Indian Tribe
- Shoalwater Bay Indian Tribe of the Shoalwater Bay Indian Reservation
- Skokomish Indian Tribe
- Snoqualmie Indian Tribe
- Spokane Tribe of the Spokane Reservation
- Squaxin Island Tribe of the Squaxin Island Reservation
- Stillaguamish Tribe of Indians of Washington
- Suquamish Indian Tribe of the Port Madison Reservation
- Swinomish Indian Tribal Community
- Tulalip Tribes of Washington

- Upper Skagit Indian Tribe

During the model development process, representatives or staff from the following Tribes either registered for an event, or reached out to learn more:

- Confederated Tribes of the Colville Reservation
- Cowlitz Indian Tribe
- Hoh Indian Tribe
- Jamestown S'Klallam Tribe
- Makah Indian Tribe of the Makah Indian Reservation
- Nez Perce Tribe
- Port Gamble S'Klallam
- Puyallup Tribe of the Puyallup Reservation
- Quileute Tribe of the Quileute Reservation
- Samish Indian Nation
- Shoalwater Bay Indian Tribe of the Shoalwater Bay Indian Reservation
- Stillaguamish Tribe of Indians of Washington
- Suquamish Indian Tribe of the Port Madison Reservation
- Swinomish Indian Tribal Community

Model development outreach events

Summer 2020

- Introductory Webinar for Model Development, Salish Sea Focus - 69 attendees.
- Introductory Webinar for Model Development Columbia and Snake Rivers Focus - 35 attendees.
- Introductory Webinar for Model Development Grays Harbor Focus - 17 attendees.
- The Science of Risk Modeling and Modeling Approaches - 115 attendees.

Fall 2020

- Presentation of Vessel Movement Module - 91 attendees.
- Vessel Movement Module: Factors associated with track selection - 23 attendees.
- Vessel Movement Module: Rules that may affect vessel movements in the Salish Sea - 24 attendees.
- Vessel Movement Module: Movements associated with the movements of other vessels - 20 attendees.
- Vessel Movement Module: Modeling vessels that do not transmit AIS data - 20 attendees.
- Updates and Follow Up on the Vessel Movement Module - 36 attendees.

Winter 2020-2021

- Presentation of Vessel Encounter Module - 45 attendees.

Spring 2021

- Vessel Encounter Module: Comparing Ship Domains - 23 attendees.
- Updates and Follow Up on Vessel Encounter Module - 30 attendees.

- Presentation on Vessel Accident Module - 48 attendees.

Summer 2021

- Model 101: A Review of the Model Structure - 28 attendees.
- Technical Discussion: Modeling Vessels and Anchorages - 19 attendees.
- Technical Discussion: Probability - 18 attendees.
- Vessel Accident Module Outstanding Topics and Follow Up - 26 attendees.

Fall 2021

- Oil Outflow Module Presentation - 23 attendees.

Model development informational presentations

Fall 2020

- Developing a Quantitative Oil Spill Risk Model. Salish Sea Forum Event.

Winter 2020-2021

- Oil Spill Risk Model Development. Washington State Board of Pilotage Commission event.

Spring 2022

- Ecology's Oil Spill Risk Model. Salish Sea Transboundary Working Group event.
- Oil Spill Risk Model Development and Analysis Planning Update. Oil Transportation Safety Committee. Board of Pilotage Commissioners event.
- A Collaborative Approach to Developing a Model for Oil Spill Policy Decision Support: Building a better model while learning together. Salish Sea Ecosystem Conference.

Model development comments received

Each event provided an opportunity for questions, comments, and discussion. We heard over 250 questions and provided real time and written responses to each of them. Key topics of discussion included data used for inputs, our approach to anchorages, and how to best represent severity of an oil spill.

Model development event attendees

There were 225 individual attendees at the events. The attendees were affiliated with the following 163 different entities:

- Alaska Department of Environmental Conservation
- Amber Carter Government Relations
- American Waterways Operators
- Americana Health and Rehabilitation Center
- Ammonia Safety and Training Institute
- Arcadis
- Auburn University
- Bainbridge Island Police Department

- British Columbia Chamber of Shipping
- British Columbia Coast Pilots Ltd
- British Columbia Government Environmental Emergency Program
- British Columbia Ministry of Environment and Climate Change Strategy
- Brusco Tug and Barge
- California Office of Spill Prevention and Response
- Canada Energy Regulator
- Canadian Coast Guard
- Centerline Logistics
- City of Bellingham
- City of Hoquiam
- City of Port Angeles
- Clallam County Marine Resource Committee
- Clean Harbors Environmental Services
- Clear Seas Centre for Responsible Marine Shipping
- Coastal & Ocean Resources
- Columbia River Pilots
- Columbia River Steamship Operators' Association
- Colville Confederated Tribes Environmental Trust Department
- Colville Tribes
- Communico
- Confederated Tribes of Umatilla Indian Reservation
- Cook Inlet Regional Citizen Advisory Committee
- Council of Marine Carriers
- Council of the Haida Nation
- Cowlitz 2 Fire and Rescue
- Cowlitz Indian Tribe
- Cowlitz Public Utility District
- Crowley Alaska Tankers LLC
- Crowley Maritime
- Disaster Medicine Project
- Environment and Climate Change Canada
- Evergreen Islands
- Faucett Lund
- Focus Wildlife
- Friends of Grays Harbor
- Friends of the San Juans
- Gitxaala Nation
- Global Diving and Salvage
- GMP Consulting
- Grant County Local Emergency Planning Committee

- Green Marine
- HASA Inc.
- Hoh Indian Tribe
- International Ship-Owners Alliance of Canada
- Island’s Oil Spill Association
- Jamestown S'Klallam Tribe
- Jefferson County
- King County Office of Emergency Management
- Kitasoo Xai'xais Nation
- Le Moyne College Rensselaer Polytechnic Institute
- Libby Environmental
- Lund Faucett
- Mac McCarthy, Inc.
- Makah Tribe
- Marathon Petroleum Company
- Marine Exchange of Puget Sound
- Marine Spill Response Corporation
- Maritime Fire and Safety Association
- Merchants Exchange of Portland
- Millennium Bulk Terminals Longview-LLC
- Monterey Environmental Services
- National Weather Service
- Natural Resources Canada
- Navy Region Northwest
- Nez Perce Tribe
- NJ Resources Inc.
- NOAA Office of Response and Restoration
- NOAA Olympic Coast National Marine Sanctuary
- Nuka Research and Planning Group
- NuStar Energy
- Oil Spill Recovery Institute
- Orca Conservancy
- Oregon Department of Environmental Quality
- Pacheedaht First Nation
- Pacific Merchant Shipping Association
- Pacific Northwest Waterways Association
- Phillips 66 Company -- Ferndale Refinery
- Polar Tankers / Conoco Phillips
- POLARIS Applied Sciences
- Port Gamble S’Klallam Tribe
- Port of Columbia County

- Port of Grays Harbor
- Port of Longview
- Port of Portland
- Port of Vancouver USA
- Prince William Sound Regional Citizens' Advisory Council
- Puget Sound Partnership
- Puget Sound Pilots
- Puget SoundKeeper Alliance
- Ramboll
- Renewable Energy Group
- Samish Indian Nation
- San Francisco Bay Conservation and Development Commission
- San Juan County Council
- Sause Bros
- Schwabe Williamson & Wyatt
- Seaspan Marine
- Seaspan ULC
- Security Minister of Quebec
- Senate Environment Energy & Technology Committee
- Shaver Transportation Company
- Shell Trading NA
- Shoalwater Bay Tribe
- Skagit Department of Emergency Management
- SLR International Corporation
- Snohomish County
- Snohomish County Marine Resource Committee
- Snohomish County Surface Water Management
- Snohomish Marine Resources Committee
- Stillaguamish Tribe Natural Resources
- SWAT Consulting Inc
- Swinomish Indian Tribal Community
- The American Waterways Operators
- The BC Coast Pilots Ltd
- The Whale Museum
- Tidewater Transportation & Terminals
- Tombolo Mapping Lab
- TransMountain
- Transport Canada
- Trident Seafoods
- Tsawout First Nation
- U.S. Army Corps of Engineers

- U.S. Coast Guard, Sector Columbia River
- U.S. Coast Guard, Sector Puget Sound
- U.S. Coast Guard, Waterways Management
- U.S. Department of Fish and Wildlife
- U.S. Environmental Protection Agency
- U.S. Navy, Manchester Fuel Department
- U.S. Navy, Northwest Region
- Umatilla County Local Emergency Planning Committee
- University of British Columbia
- University of New Hampshire
- University of Victoria
- Vane Brothers
- Walla Walla County Fire District 5
- Washington Environmental Council
- Washington State Board of Pilotage Commissioners
- Washington State Department of Archaeology and Historic Preservation
- Washington State Department of Fish and Wildlife
- Washington State Department of Health
- Washington State Department of Natural Resources
- Washington State Maritime Cooperative
- Washington State Military Department
- Washington State Senate
- Washington State Utilities and Transportation Commission
- Wave Consulting
- Western Canada Marine Response Corporation
- Western States Petroleum Association
- Western Towboat Co.
- Whatcom County
- Whitman County Emergency Management
- Witt O'Brien's Response Management
- Wuikinuxv Nation

ERTV analysis

Consultation outreach with potentially affected federally recognized Tribes

In December 2021, Ecology sent consultation request letters to the same 33 potentially affected federally recognized Tribes listed above in the section of model development. The letter offered consultation with Ecology on the ERTV analysis.

During the tug escort analysis process, representatives or staff from the following Tribes either registered for an event, or reached out to learn more:

- Jamestown S'Klallam Tribe

- Lummi Tribe of the Lummi Reservation
- Makah Indian Tribe of the Makah Indian Reservation
- Nez Perce Tribe
- Port Gamble S'Klallam Tribe
- Samish Indian Nation
- Swinomish Indian Tribal Community

Review and approval of the scope of work for ERTV analysis

In summer 2021, Ecology developed a draft scope of work for the ERTV analysis. In late August 2021, we publicized the draft and solicited input from the public, and local and tribal governments.

We received 8 formal comments. We provided written responses and adjusted the scope of work as appropriate. Ecology formally approved the scope of work in February 2022.

ERTV analysis outreach events

Summer 2022

- Tug Escort and ERTV Analysis Projects - Introductory Webinar - 77 attendees.
- Final Model Analysis Plan - 48 attendees.

Spring 2023

- Preliminary Review of Analysis Results – 63 attendees.

ERTV analysis informational presentations

Summer 2022

- Rescue Towing Analysis Model: Tug Escort and ERTV Analyses. Puget Sound Coastal Area Committee Meeting.

Winter 2023

- Presentation at Affiliated Tribes of Northwest Indians Winter Convention.

ERTV analysis comments received

Each event provided an opportunity for questions, comments, and discussion. We provided real time and written responses to over 85 questions.

ERTV analysis event attendees

There were more than 100 individual attendees at the events. The attendees were affiliated with the following 76 different entities:

- Alaska Department of Environmental Conservation
- Alaska Tanker Company, LLC
- Amber Carter Government Relations
- American Waterways Operators
- Auburn University

- BC Pacific States Task Force
- BC Chamber of Shipping
- BP Cherry Point Refinery
- Canadian Coast Guard
- Centerline Logistics
- Clear Seas Centre for Responsible Marine Shipping
- City of Port Angeles
- Columbia River Pilots
- ConocoPhillips / Polar Tankers Inc.
- Cook Inlet Regional Citizens Advisory Council
- Council of the Haida Nation
- Council of Marine Carriers
- Crowley Maritime
- Dalhousie University
- Delphi Maritime, LLC
- Dept of Fisheries and Oceans Canada
- DTOM Maritime, LLC
- Dunlap Towing Company
- Environment and Climate Change Canada
- Evergreen Islands
- Fourem Konform Maritime Systems, Inc
- Friends of the Earth U.S.
- Friends of the San Juans
- Gallagher Marine Systems, LLC
- Global Diving & Salvage
- HF Sinclair
- Jamestown S'Klallam Tribe
- Kirby Offshore Marine
- Le Moyne College, Rensselaer Polytechnic Institute
- Lund Faucett
- Mac McCarthy, Inc.
- Makah Tribe
- Marathon Petroleum
- Marine Exchange of Puget Sound
- Maritime Blue/Quiet Sound
- Maritime Fire and Safety Association
- Moss Landing Marine Labs Center for Habitat Studies
- National Oceanic and Atmospheric Administration
- Nuka Research
- Pacific Merchant Shipping Association
- Pearson Consulting

- Polar Tankers
- Port Gamble S'Klallam Tribe
- Prince William Sound Citizens Advisory Council
- Puget Sound Partnership
- Puget Sound Pilots
- REG Grays Harbor
- San Juan County
- San Juan County Department of Emergency Management
- San Juan County Marine Resources Committee
- Sause Bros.
- Shaver Transportation
- Strait Ecosystem Recovery Network
- Tidewater
- Tombolo Mapping Lab
- Transport Canada
- Tsawout First Nation
- US Coast Guard
- US Coast Guard Sector Puget Sound
- US Fish and Wildlife Service
- US Senate Committee on Commerce, Science, and Transportation
- Vane Line Bunkering
- Washington Conservation Action
- Washington Environmental Council
- Washington State Board of Pilotage Commissioners
- Washington State Department of Natural Resources
- Washington State House of Representatives
- Washington State Senate
- Wave Consulting
- Western Canada Marine Response Corporation
- Western States Petroleum Association