Summary of Tug Escort Analysis Results

Report to the Legislature pursuant to RCW 88.16.260

Spill Prevention, Preparedness, and Response Program

Washington State Department of Ecology
Olympia, Washington

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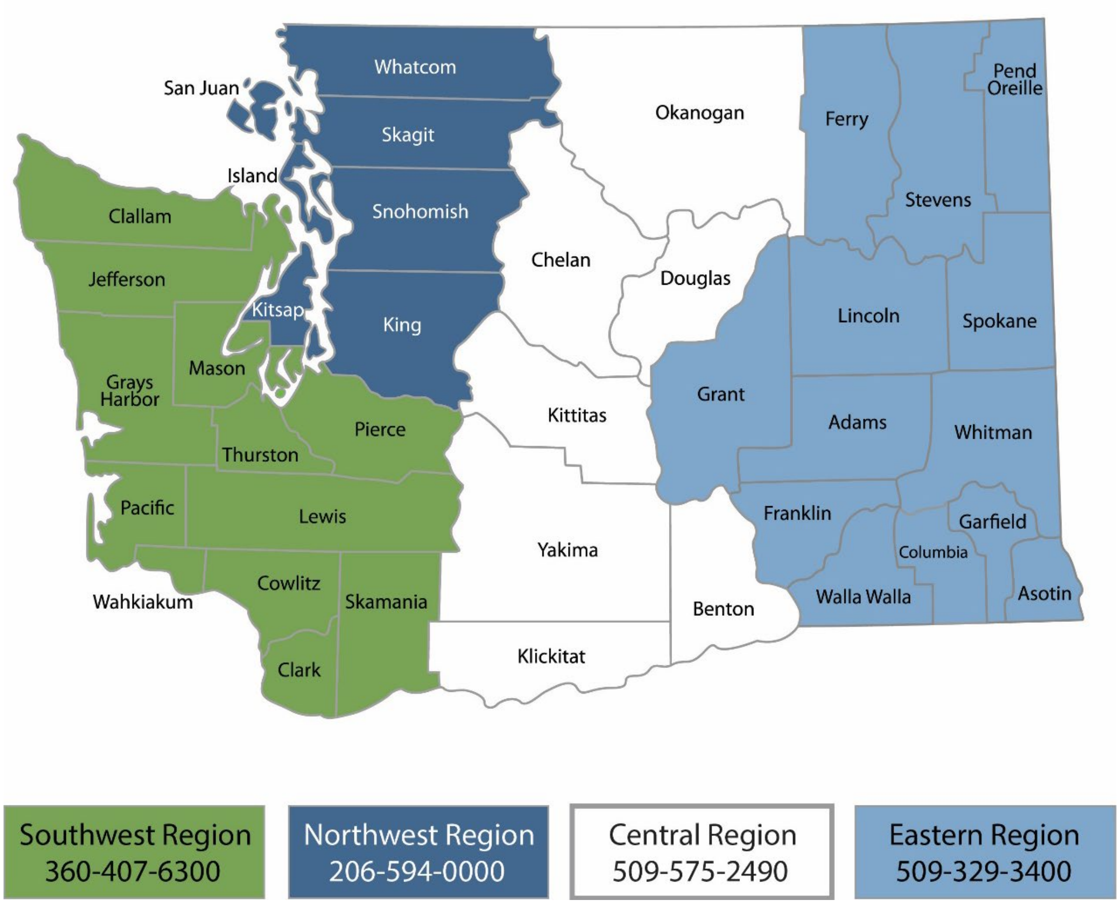

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Analysis of Tug Escorts for Tank Vessels

Report to the Legislature
Pursuant to RCW 88.16.260

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Washington State Department of Ecology

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DEPARTMENT OF
ECOLOGY
State of Washington

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Executive Summary

Tug escorts for tank ships have been an important part of the marine safety system in Washington state since 1975. This report summarizes the results of an analysis of expanding tug escorts to additional types and sizes of tank vessels on Washington waters.

In 2019 the Washington Legislature directed the Washington State Board of Pilotage Commissioners (BPC) to complete an analysis of tug escorts using an oil spill risk model that the Legislature directed the Washington State Department of Ecology (Ecology) to develop.

The analysis focused on how tug escorts can prevent tank vessels from drifting aground after losing propulsion and how they can limit oil spill risk from loss of steering events. We focused on these specific topics because escort tugs are generally considered best suited to intervening in these events.

The analysis also covered additional topics:

- potential benefits of tethering
- how model assumptions may affect model outputs
- how the projected Trans Mountain Expansion Project may affect any potential benefit from tug escort requirements
- how more tug escort traffic could increase tug related accidents
- how escort tug design characteristics affect oil spill risk

Most of the analysis was completed using the model that Ecology developed, with support from the BPC, to simulate vessel traffic patterns. We relied on outreach and consultation with potentially affected federally recognized Tribes, the U.S. Coast Guard (USCG), and stakeholders to learn about their priorities for model development. We also examined the relative impact of drift groundings as a contributor to oil spill risk by reviewing actual vessel incidents.

The model includes a loss of propulsion frequency and a physics-based drift model to plot the drift paths of vessels that have lost propulsion. It includes self-repair, anchoring, and potential rescue by an emergency response towing vessel (ERTV) and tugs of opportunity. Our analysis evaluated changes in oil spill risk metrics from changing simulated tug escort requirements.

We evaluated oil spill risk from drift groundings for three different tug escort scenarios. Tank vessels in Scenario 1 were simulated using the tug escort requirements in place prior to 2020. Tank vessels in Scenario 2 were simulated using the tug escort requirements established in 2020 (see RCW 88.16.190). Under these requirements, in addition to the tug escort requirements in place in Scenario 1, tug escorts were also required for laden articulated tug and barges (ATBs), tank barges, and tank ships between 5,000 and 40,000 deadweight tons (DWT) in Rosario Strait and connected waters east. Tank vessels in Scenario 3 were simulated using a theoretical expansion of tug escort requirements to the entire study area, which includes the inland Washington waters of the Salish Sea shown in Figure 1.

Based on our review of actual vessel incidents, we identified four drift groundings in the study area between 2002 and 2019. They account for about two percent of selected marine incidents involving large commercial vessels. None of these resulted in an oil spill. When we expanded our review to a much larger area, we found 190 drift groundings. Only 2.6 percent of these incidents were associated with oil spills.

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 reductions in drift groundings from additional tug escort requirements. We found a 2.3 percent reduction (0.0047 drift groundings per year) from Scenario 1 to Scenario 2, and a 1.8 percent reduction (0.0035 drift groundings per year) from Scenario 2 to Scenario 3.

Model results also indicated reductions in oil volume at risk and oil outflow metrics. Oil volume at risk declined 3.1 percent (22,430.1 gallons per year) and oil outflow declined 2.6 percent (1.5 gallons per year) from Scenario 1 to Scenario 2. The change from Scenario 2 to Scenario 3 was less than 1 percent for both oil volume at risk and oil outflow.

When looking at model results by vessel type, we found that escorts have a preventative effect on drift groundings of tank vessels. When comparing Scenario 1 against Scenario 2, ATBs saw a 13 percent reduction in risk, towed oil barges saw a 9 percent reduction in oil spill risk, and chemical tankers saw a 6-7 percent reduction in risk. The new escort regulations under Scenario 2 would potentially prevent about 1 in 8 ATB drift groundings, 1 in 12 towed oil barge drift groundings, 1 in 14 chemical tanker drift groundings.

When comparing Scenario 2 against Scenario 3 towed oil barges saw a 37 percent reduction in risk, and ATBs saw a 14 percent reduction in risk. The new escort regulations under Scenario 3 would potentially be able to prevent, on average, about 1 in 7 ATB drift groundings, and 1 in 3 towed oil barges drift groundings.

These reductions should be understood in the context of risk contribution to the system. ATBs only make up 1-2 percent of the overall risk in the system, towed oil barges make up 8-12 percent of the risk, and chemical tankers make up 5-9 percent of the risk.

On a zone-by-zone basis we found small reductions in risk when comparing Scenario 1 against Scenario 2 for the zones where escorts were newly required – Bellingham Channel, Sinclair Island and Waters East, Guemes Channel and Saddlebags, and Rosario Strait. When comparing Scenario 2 against Scenario 3, the zones with the most meaningful reductions in risk were Admiralty Inlet and Haro Strait and Boundary Pass.

Tank vessels make up only a portion of drift grounding risk, and that makes up only a small part of overall maritime oil spill risk. Our analysis shows tug escort requirements provide a level of protection against drift groundings, but not a big reduction overall. When in place, they form part of a larger web of protections against drift groundings, like the ability of the ship to self-repair, the potential for emergency anchoring, and potential rescue by an ERTV or a tug of opportunity.

Introduction

Tug escorts for tank ships have been an important part of the marine safety system in Washington state since 1975. This report summarizes the results of an analysis of expanding tug escorts to additional types and sizes of tank vessels on Washington waters.

What is the tug escort analysis?

In 2019 the legislature directed the Washington State Board of Pilotage Commissioners (BPC) to complete an analysis of tug escorts using an oil spill risk model that the Legislature directed the Washington State Department of Ecology (Ecology) to develop.[2]

RCW 88.16.260(d) states:

> “To inform rule making, the Board of Pilotage Commissioners must conduct an analysis of tug escorts using the model developed by the Department of Ecology under RCW 88.46.250. The Board of Pilotage Commissioners may: (a) Develop scenarios and subsets of oil tankers, articulated tug barges, and towed waterborne vessels or barges that could preclude requirements from being imposed under the rule making for a given zone or vessel; (b) Consider the benefits of vessel safety measures that are newly in effect on or after July 1, 2019, and prior to the adoption of rules under this section; and (c) Enter into an interagency agreement with the department of ecology to assist with conducting the analysis and developing the rules, subject to each of the requirements of this section.”

The statute also directed Ecology to produce a report: “By September 1, 2023, the department of ecology must submit a summary of the results of the analysis required under subsection (5) of this section to the legislature consistent with RCW 43.01.036” (RCW 88.16.260(5)).

The analysis of tug escorts evaluated the potential change in oil spill risk from covered vessels[3] resulting from the use of tug escorts by specific types and sizes of tank vessels[4] in Washington waters east of a line connecting New Dungeness Light with Discovery Island Light (Figure 1). The analysis centered on how escorts can prevent vessels from drifting aground after unexpectedly losing propulsion and how escorts can limit oil spill risk from loss of steering

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[2] See Engrossed Substitute House Bill 1578: Reducing Threats to Southern Resident Killer Whales by Improving the Oil Transportation Safety Act. The act amended RCW 88.16, 88.46, and 90.56.

[3] Covered vessels are defined in Wash. Rev. Code § 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.

[4] Specified tank vessels include articulated tug and barges (ATBs), towed oil barges, and tank ships over 5,000 deadweight tons (DWT).

events. We focused on loss of propulsion and loss of steering events because escort tugs are generally considered best suited to intervening in those events (ASTM, 2021; Allan, 2000). The analysis considered a tug's ability to respond to the ship it is escorting, as well as to other non-escorted ships as a 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.

Ships can avoid grounding after losing propulsion without the aid of an escort tug. To account for this, the model included the potential for vessels to self-repair or anchor, and the potential for tugs of opportunity or the Neah Bay Emergency Response Towing Vessel (ERTV) to respond to disabled vessels.

The analysis also evaluated the potential benefits of tethering, the effects of model assumptions on model outputs, how the Trans Mountain Expansion Project (TMEP) may affect any potential benefit from tug escort requirements, and the effect of tug escort traffic on tug related accidents (Trans Mountain, 2013). The report also includes a discussion of how escort tug design characteristics affect oil spill risk.

What is the model?

Ecology developed a model to simulate vessel traffic patterns. We created analysis results by evaluating changes in oil spill metrics produced by altering tug escort requirements.

This simulation modeling was used to answer most of the research questions. Simulation modeling is suitable for circumstances where insufficient data is available to otherwise characterize a system.

Simulation models are designed to represent key mechanisms and important processes of a system. Models can produce informative results even in the absence of extensive underlying data.

The model relies on simulating vessel traffic patterns and applying tug escorts for specific vessel types while they are laden with oil. We use loss of propulsion frequency, and a physics-

Figure 1: Study Area.

based drift model that plots the drift paths of vessels that have lost propulsion. Self-repair, anchoring, tug escorts, an ERTV, and tugs of opportunity are all included. The model study area is shown in Figure 1.

Many of the assumptions and parameters that we use 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 parameters, and on model structure are in Appendix B.

Scope of work

This analysis was guided by a scope of work developed by Ecology and Board of Pilotage Commissioners staff and formally approved by the Board of Pilotage Commissioners. 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 and how does the use of tug escorts change that distribution? How is oil spill risk distributed across covered vessel types and how does the use of tug escorts change that distribution?

How does the 2020 expansion of tug escorts in Rosario Strait and connected waters to the east change oil spill risk from covered vessels? How does tethering affect oil spill risk and how do key design characteristics for escort tugs affect oil spill risk?

Are there new safety measures adopted since July 1, 2019? If so, what are the benefits of these measures?

Out of scope topics

This analysis focuses on the effects on oil spill risks resulting from the use of tug escorts for specified tank vessels. Based on legislative direction, including that provided in RCW 88.16.260, the scope of work identified several topics as out of scope including:

- Consideration of underwater noise
- Vessel traffic impacts to established treaty fishing areas
- Estimates of expected costs and benefits of draft rules
- Consideration of air emissions from tug escorts
- Analysis of the potential fate and effects of oil spill scenarios generated by the model
- Tug escorts for unladen tank vessels, towed general cargo deck barges and vessels providing bunkering or refueling services

Outreach and consultation

From the outset of model development, we prioritized robust outreach and consultation. Our outreach process was used to gather information about what potentially affected federally recognized Tribes, the USCG, 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 modeling effort. The outreach and consultation that we completed during that time helped determine the structure of the tug escort analysis. Ecology held public events that were open to all interested parties and were designed to be a venue for open dialogue and knowledge sharing. We documented and considered feedback received during that process.

Between developing the model and the tug escort 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.

Ecology and the BPC worked together on the development of the model and the analysis. Both agencies were involved with the development of the oil spill risk model, the tug escort analysis, and the writing of the final report. The specific details of our coordination are available in Appendix D.

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 detail on our methods.

Appendix B describes the structure of the model and provides a reference for how we determined model assumptions and parameters.

Appendices C through E provide additional background on model development and the analysis.

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 between 2002 and 2019.
2. To analyze tug escorts, we used model simulation outputs.
3. For our discussion of escort tug design characteristics, we used a review of technical literature.

Understanding model simulation outputs

The analysis is primarily based on comparing different tug escort scenarios. We used different scenarios to represent past, present, and possible future tug escort requirements to compare their potential to influence oil spill risk.[5] A variety of risk metrics to quantify changes in risk between those scenarios were used. Each metric tells us something different about oil spill risk.

Tug escort scenarios

We evaluated oil spill risk from drift groundings for three different tug escort scenarios in the study area.

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). Under these requirements, in addition to the tug escort requirements in place in Scenario 1, tug escort were required for laden ATBs, tank barges, and tank ships between 5,000 and 40,000 DWT in Rosario Strait and connected waters east. Including this scenario allows us to evaluate the change in oil spill risk from this recent expansion in tug escort requirements.

Tank vessels in Scenario 3 were 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 were required to take an escort in all other portions of the study area where not previously required.

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[5] Table 34 in the Appendix B provides a detailed look at where escorts are required, and for which vessel types, under each scenario.

Table 1: Escort requirements by vessel type and by scenario.

Simulated escorts	Scenario 1	Scenario 2	Scenario 3
Laden tank ships over 40,000 DWT	Escorts required	Escorts required	Escorts Required
Laden tank ships, ATBs, and tank barges between 5,000 and 40,000 DWT in Rosario Strait and connected waters east.		Escorts required	Escorts required
Laden tank ships, ATBs, and tank barges between 5,000 and 40,000 DWT throughout the study area.			Escorts required

Evaluating differences between scenarios

We compared the results of Scenario 1 against Scenario 2 to show the change in oil spill risk from the RCW 88.16.190(2)(a)(ii) expansion of tug escort requirements to laden ATBs, tank barges, and tank ships between 5,000 and 40,000 DWT for Rosario Strait and connected waters east.

We compared the results from Scenario 2 against Scenario 3 to show the change in oil spill risk from the expansion of tug escort requirements for laden ATBs, tank barges, and tank ships between 5,000 and 40,000 DWT beyond Rosario Strait and connected waters to the rest of the study area.

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) 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

This 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 these events, 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 risk of an average potential spill is represented by the oil outflow metric. This metric 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 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.

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.

Risk is primarily evaluated using percentage values, but absolute values were included where appropriate to 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 the 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.

Study area and geographic zones

The study area included all Washington waters of the Salish Sea where the BPC might consider new tug escort rules. It consisted of all connected marine waters east of a line from Discovery Island light to New Dungeness light in the Strait of Juan de Fuca and south of the 49th Parallel in the Strait of Georgia (Figure 1).

We used a specific set of zones anytime we provided results in a geographic context. The development and use of a set of zones was required by RCW 88.16.260. The zones were developed by the BPC in conjunction with their Oil Transportation Safety Committee. The following zones were developed by the BPC:

1. Strait of Georgia
2. Strait of Georgia South
3. Haro Strait and Boundary Pass
4. Rosario Strait
5. Bellingham Channel, Sinclair Island, and waters to the East
6. Guemes Channel and Saddlebags
7. Eastern Strait of Juan de Fuca
8. Admiralty Inlet
9. Puget Sound
10. Possession Sound and Saratoga Passage
11. Rich Passage & Sinclair Inlet
12. Colvos Passage
13. South Sound to Olympia

[A detailed description of the zones](#) is available on the BPC webpage, and in Appendix E.[6]

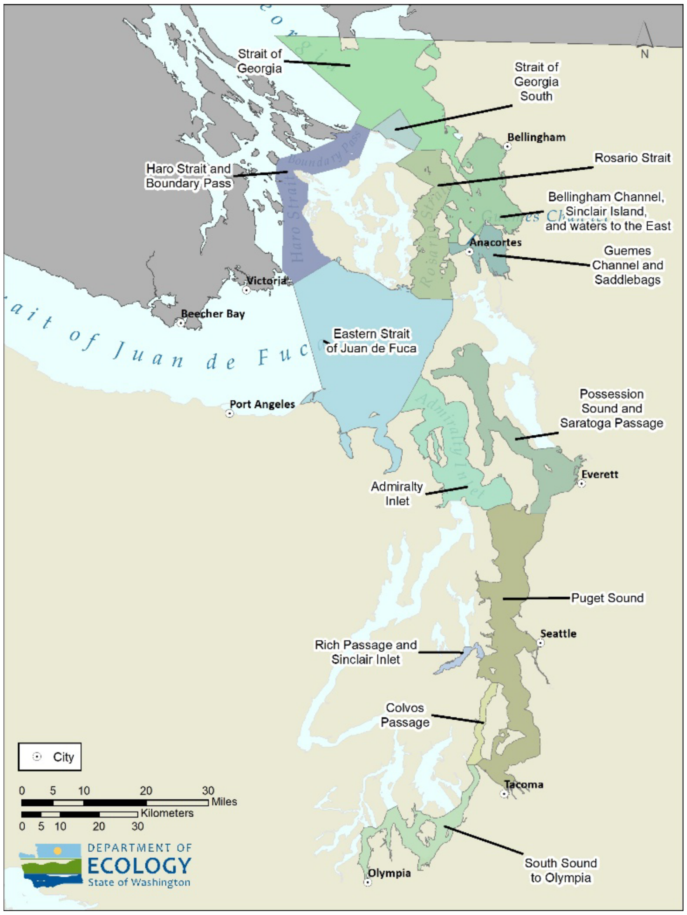

Figure 2: BPC Zones

Important reminders

The discussion of oil spill risk is limited to risk from drift groundings resulting from loss of propulsion events. Analysis results do not include oil spill risk from collisions, allisions, sinkings, other types of incidents, or risk from the smaller, non-covered vessels that operate in the study area.

This research does not consider or evaluate underwater noise, potential traffic impacts to treaty fishing areas, or estimations of cost and benefits.

Consideration of air emissions from tug escorts, analysis of the potential fate and effects of oil spill scenarios generated by the model, or potential benefit of tug escorts for vessels engaged in bunkering were not included. Tug escorts for vessels engaged in bunkering are specifically excluded from the analysis by the Legislature (RCW 88.16.260).

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[6] https://nebula.wsimg.com/a0c4bc354f3ca9d89232d290d537fcf8?AccessKeyId=F86D0A1E7A0091C2061F&disposition=0

Results

How drift groundings contribute to oil spill risk

Incident data suggests that drift groundings are rare events in the Model Domain (Figure 3) and the Bi-National Area.[7] Our analysis also suggests that they are a relatively small contributor to the overall number of marine incidents and oil spills. Based on our review of historical incidents in the Model Domain, we identified 4 drift groundings between 2002 and 2019 (an average of 0.2105 per year). None of these resulted in an oil spill. They account for about 2 percent of selected marine incidents involving large commercial vessels.

When we expanded our review to the Bi-National Area (which covers an area 84 times larger than the Model Domain) we found 190 drift groundings (an average of 10.5556 per year), of which only 2.6 percent were associated with oil spills.

Figure 3: Model Domain.

Our review of historical incidents found that both drift groundings and spills from those events are infrequent. 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.[8] For the incidents we identified in incident

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[7] 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.

[8] 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 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).

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 use a summarized selection of model results that do not include oil spill risk from car ferries, and only evaluates risk changes in BPC zones. 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 non-BPC zones and oil spill risk from car ferries.

This section discusses the distribution of oil spill risk for Scenario 2.[9] Model results indicated an average of 0.2011 drift groundings, an average oil volume at risk of 711,639.5 gallons, and an average oil outflow of 55.7 gallons per simulation.[10] Figure 4 and Figure 5 show how oil spill risk was distributed by vessel type and zones, respectively.

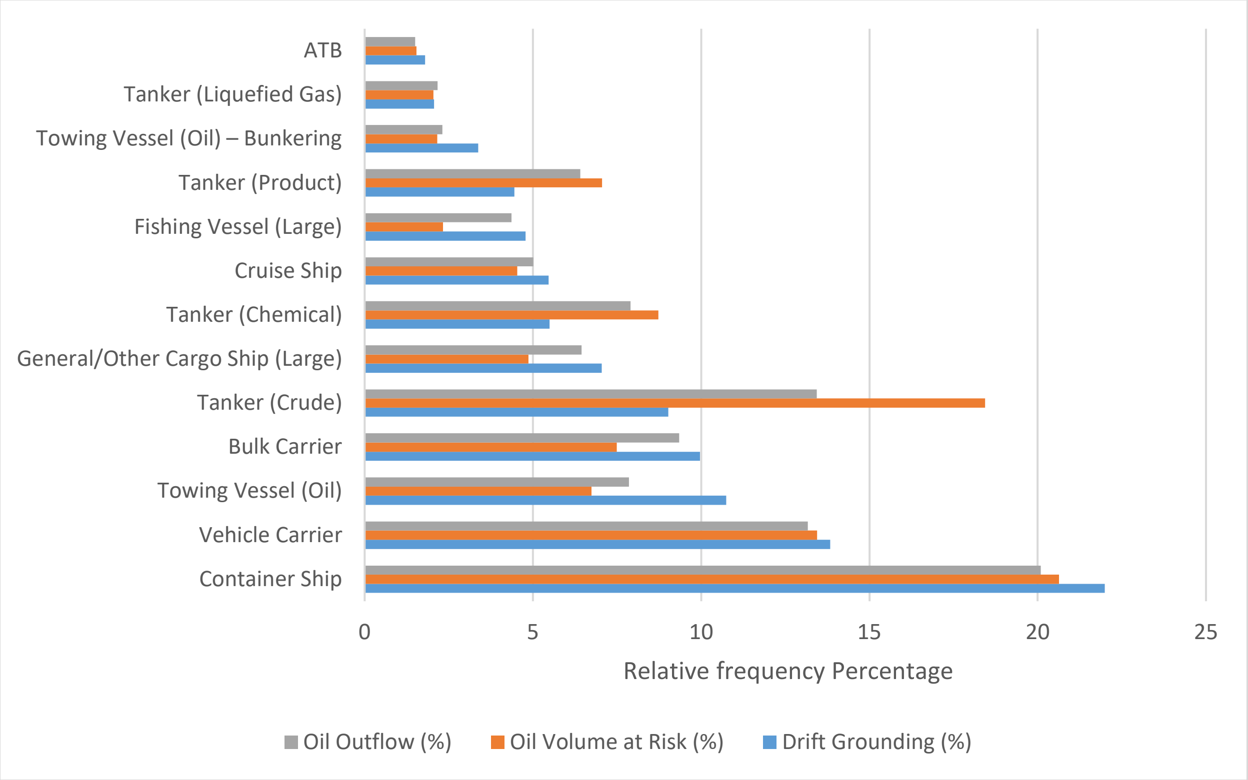

Figure 4: Relative frequency of oil spill risk metrics by vessel type.[11]

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[9] In Scenario 2 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, and for laden tank ships over 40,000 DWT in the rest of the study area.

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

[11] These values are from Appendix A, Table 21.

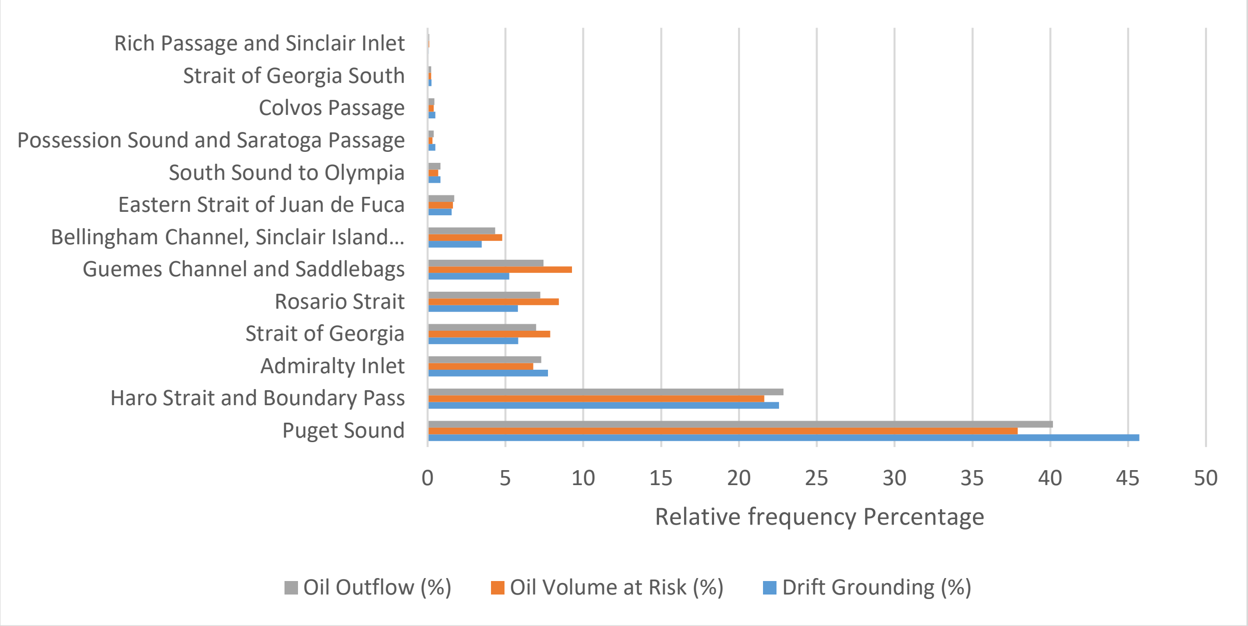

Figure 5: Relative frequency of oil spill risk metrics by zone.[12]

Discussion

We compared the distribution of risk by vessel type and zone against the operational minutes to help us determine which vessel types and zones represent more risk than would be expected from looking at the time they spent underway.[13]

The distribution of risk by vessel type does not match the operational minutes by vessel type. Some vessel types account for less risk than one would expect given their share of overall operational minutes. For example, ATBs make up 9 percent of the simulated traffic and account for only 2 percent of the oil spill risk.[14] Similarly, bulk carriers account for 20 percent of the simulated traffic, but only 7-10 percent of the risk. Other vessels account for more risk than one would expect given their share of overall operational minutes. Vehicle carriers make up 6 percent of the total simulated traffic but account for 14 percent of the oil spill risk. Of note, towed oil barges make up 24 percent of the traffic and 7-11 percent of the oil spill risk.

The distribution of risk by zone more closely matches the operational minutes by zone. Just over half of the zones see a relative frequency of operational minutes that approximates their relative frequency of oil spill risk. Three zones account for less risk that 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

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[12] These values are from Appendix A, Table 13.
[13] Tables showing the distribution of simulated operational minutes by zone and by vessel type are Appendix A Table 5 and Table 6 respectively.
[14] Risk values shown as ranges are based off highest and lowest values between drift grounding metric, oil volume at risk, and oil outflow.

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 when escort requirements were expanded in Rosario Strait and connected waters

The expansion of tug escorts in Scenario 2 resulted in a decrease in risk.[15] In terms of absolute values, drift groundings declined 0.0047 per simulation, oil volume at risk declined 22,430.1 gallons, and oil outflow declined 1.5 gallons.[16] The reduction in drift groundings is equivalent to potentially being able to prevent about 1 in 44 drift groundings occurring across all BPC zones. On a percentage basis, the risk reduction amounts to a 2.3 percent reduction in drift groundings, a 3.1 percent reduction in oil volume at risk, and a 2.6 percent reduction in oil outflow. All the vessel types and zones newly escorted saw decreases in risk.

Among newly escorted vessels, ATBs and towed oil barges saw the highest percentage reductions. Crude, chemical and product tankers saw smaller percentage reductions.[17]

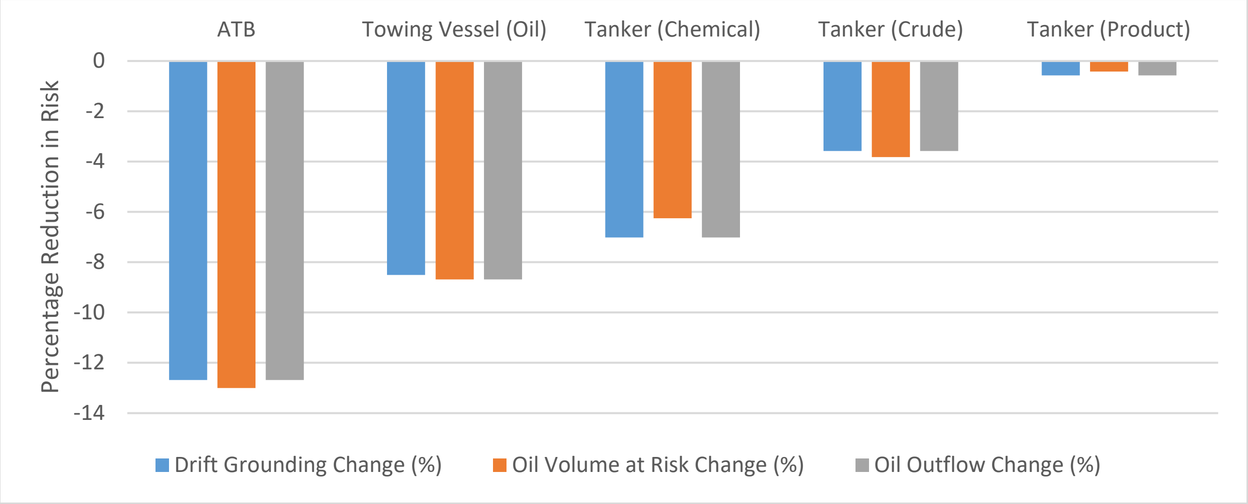

Figure 6: Oil spill risk metric changes between Scenario 1 and Scenario 2 by vessel type for vessels newly required to take escorts.[18]

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[15] In Scenario 2 escorts were required for laden ATBs, tank barges, and tank ships between 5,000 and 40,000 DWT in Rosario Strait and connected waters, and for laden tank ships over 40,000 DWT in the rest of the study area.

[16] These values are from Appendix A, Table 30.

[17] Escorts were only newly required for tank ships between 5,000 DWT and 40,000 DWT. About 40 percent of simulated chemical tankers are under 40,000 DWT, while only 1 percent of crude tankers and 12 percent of product tankers are. Chemical tankers probably see the largest risk reduction among tank ships because more of them are newly being escorted.

[18] These values are from Appendix A, Table 29.

We can also look at absolute reductions to understand how percentage reductions, which are relative to vessel type, contribute to overall reductions in risk. In terms of absolute values, chemical tankers saw the highest reduction in drift groundings (-0.0004) and oil outflow (-0.42), and crude tankers saw the highest reduction in oil volume at risk (-11,338.0). The larger percentage reductions for ATBs (-13 percent) and towed oil barges (-9 percent) correspond to low absolute reductions. ATBs saw a .0001 decline in drift groundings, 10.5 decline in oil volume at risk, and .01 decline in oil outflow, while towed oil barges saw a .0003 decline in drift groundings, 2.2 decline in oil volume at risk, and .02 decline in oil outflow.[19]

The new escort regulations under Scenario 2 would potentially prevent about 1 in 8 ATB drift groundings, 1 in 12 towed oil barge drift groundings, 1 in 14 chemical tanker drift groundings, 1 in 28 crude oil tanker drift groundings, and 1 in 176 product tanker drift groundings.

In Scenario 2, escorts were newly required in three zones: Bellingham Channel, Sinclair Island and Waters East, Guemes Channel and Saddlebags, and Rosario Strait. Each of these zones saw small percentage reductions in oil spill risk. See Figure 7.

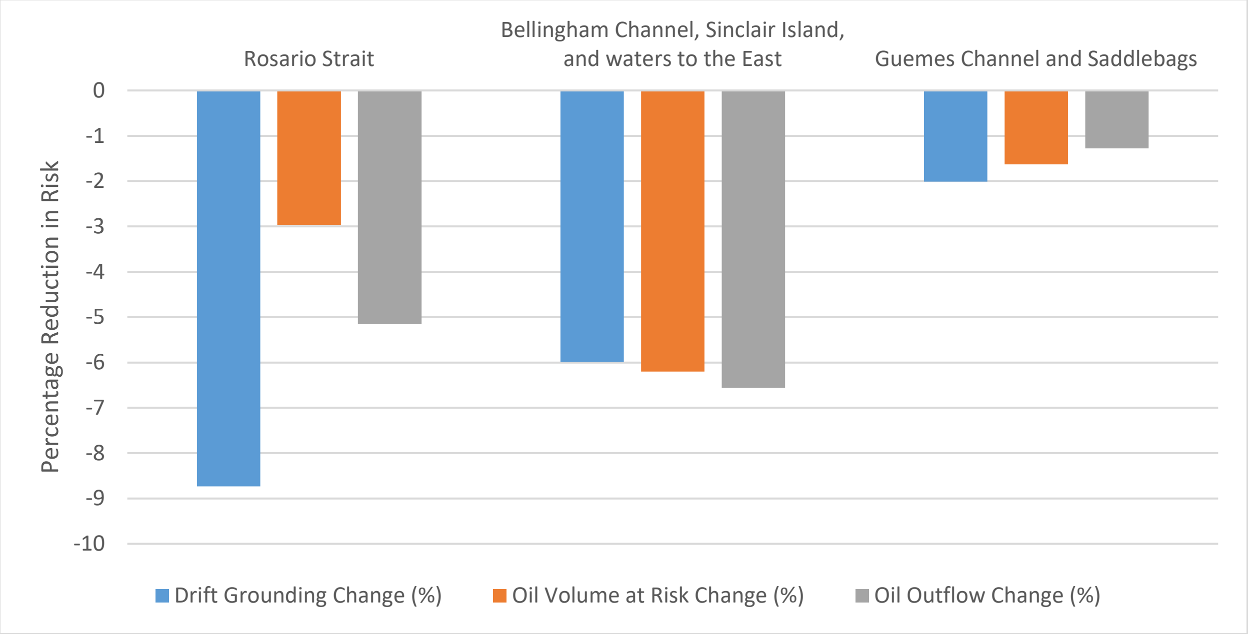

Figure 7: Oil spill risk metric changes between Scenario 1 and Scenario 2 by zone, for zones with new escort requirements.[20]

In terms of absolute values, Rosario Strait saw the highest reduction in drift groundings (-0.0004) and oil outflow (-0.20), and Bellingham Channel, Sinclair Island and waters to the East saw the highest reduction in oil volume at risk (-3,774.4).[21]

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[19] These values are from Appendix A, Table 30.

[20] These values are from Appendix A, Table 25.

[21] These values are from Appendix A, Table 26.

Indirect changes in risk when escort requirements are expanded in Rosario Strait and connected waters

Changing escort requirements altered the geographic distribution of tugs in the system, which then affected the location of potential tugs of opportunity. As a result, other zones, and other vessel types -- beyond those with new escort requirements -- saw changes in oil spill risk. For more information on how we simulated escort tugs, see Appendix A.

Of the vessels that were not newly required to take an escort under Scenario 2, bulk carriers and cargo ships saw the highest reduction in oil spill risk metrics. Both saw a reduction of about 4 percent. Towing vessels engaged in bunkering were the only vessel type not newly required to take an escort that saw a fairly large increase in risk (about 6 percent). Figure 8 shows the details. The only vessel types not included in Figure 8 are those newly required to take escorts, and cruise ships and vehicle carriers. Cruise ships and vehicle carries saw mixed results that functionally amount to little or no change.

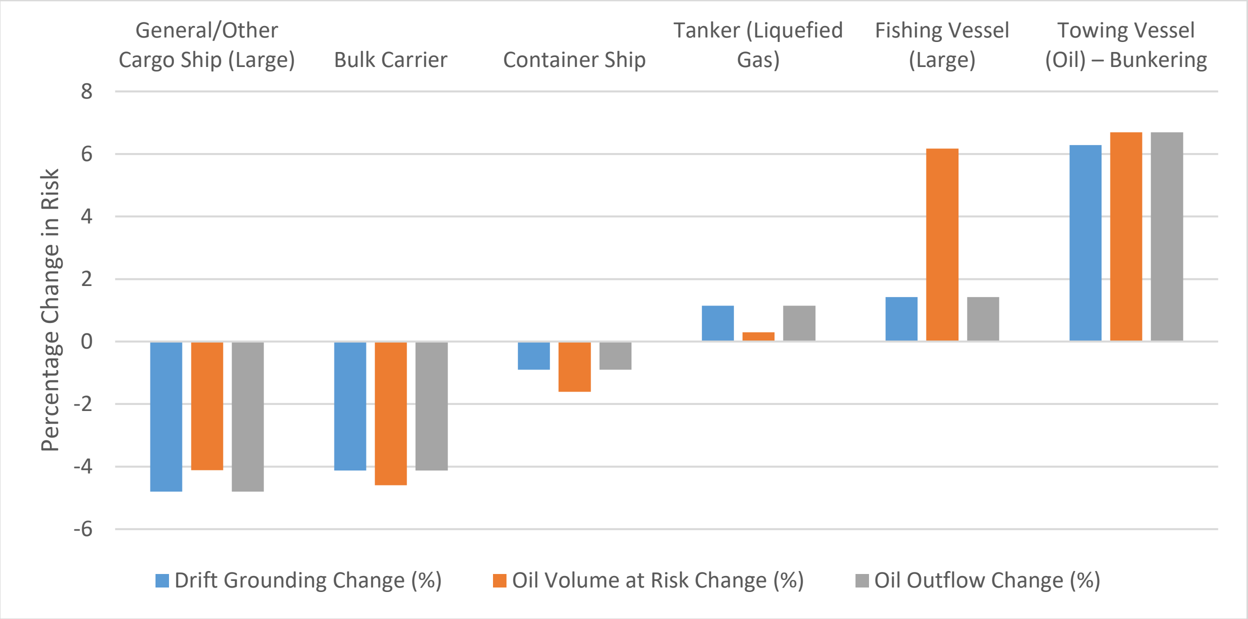

Figure 8: Oil spill risk metric changes between Scenario 1 and Scenario 2 by vessel type, for vessels not newly required to take an escort.[22]

Of the zones where no additional escort requirements were established, the majority (6 of 10) saw decreases in risk (Figure 9). Zones with the highest decreases, like Strait of Georgia South (-6-22 percent) and Eastern Strait of Juan de Fuca (-5-10 percent) are also zones that minimally contribute to overall risk (see Figure 5), so their decreases are not very meaningful to overall risk. The decreases in Admiralty Inlet and Puget Sound, zones responsible for 7-8 percent and 38-46 percent of the risk respectively, are more meaningful.

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[22] These values are from Appendix A, Table 29.

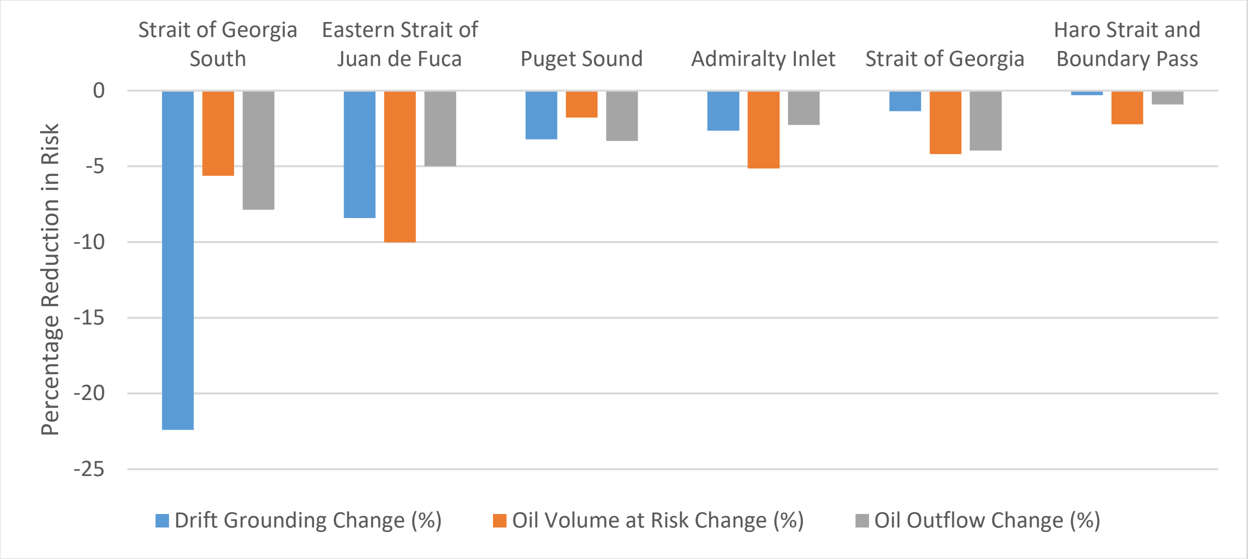

Figure 9: Oil spill risk metric changes between Scenario 1 and Scenario 2 by zone, for zones without new escort requirements.[23]

Colvos Passage was the only zone that saw an increase. Since Colvos Passage does not see a lot of traffic and is responsible for less than 1 percent of the overall risk, the increase is very small in absolute terms. Possession Sound and Saratoga Passage, Rich Passage and Sinclair Inlet, and South Sound to Olympia saw no change in risk.

Discussion

For vessels newly required to take escorts, the expanded escort requirements of Scenario 2 produced the largest relative change in oil spill risk metrics for ATBs. In terms of how the expanded escort requirements reduced overall risk in the study area, the new requirements for chemical tankers were arguably the most important. Adding escort requirements to chemical tankers under 40,000 DWT produced the largest absolute reduction in drift groundings and oil outflow. The new requirements for crude tankers (under 40,000 DWT) had the largest absolute reduction in oil volume at risk.

This mismatch between percentage reduction in risk and absolute reduction in risk can occur when a vessel type or zone has a small relative frequency of overall risk. For instance, the risk reduction for ATBs was around 13 percent, however, ATB contribution to study area risk was around 1-2 percent of the total. As a result, that 13 percent reduction for ATBs doesn’t amount to a large absolute reduction in risk.

For zones with newly expanded escort requirements, the expanded escort requirements of Scenario 2 were most beneficial for Rosario Strait. The percentage reduction for Rosario Strait was 3-9 percent and it also saw the highest absolute reductions in risk for drift groundings and oil outflow.

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[23] These values are from Appendix A, Table 25.

The zones and vessel types that show the highest benefit from Scenario 3 tug escort requirements

Under Scenario 3, we modeled an expansion of escort requirements for ATBs, towed oil barges, and tank ships between 5,000 and 40,000 DWT for all zones where they were not required in Scenario 2. This approach allowed us to evaluate which zones and vessel types showed the highest benefit from the addition of an escort tug requirement when compared to Scenario 2.

Modeling the expansion of tug escort rules from Scenario 2 to Scenario 3 resulted in a decrease in risk. In terms of absolute values, drift groundings declined 0.0035 per simulation, oil volume at risk declined 103.9 gallons, and oil outflow declined 0.4 gallons.[24] The reduction in drift groundings is equivalent to potentially being able to prevent about 1 in 57 drift groundings occurring across all BPC zones. On a percentage basis, that amounts to about a 1.8 percent reduction in drift groundings, less than 0.1 percent reduction in oil volume at risk, and a 0.8 percent reduction in oil outflow.[25] All the vessel types and zones newly required to take escorts saw decreases in risk.

Among newly escorted vessel types, towed oil barges and ATBs saw the highest percentage reductions. Crude, chemical and product tankers, of which only those under 40,000 DWT were newly required to take an escort, saw either no change or slight increases in risk. See Figure 10.

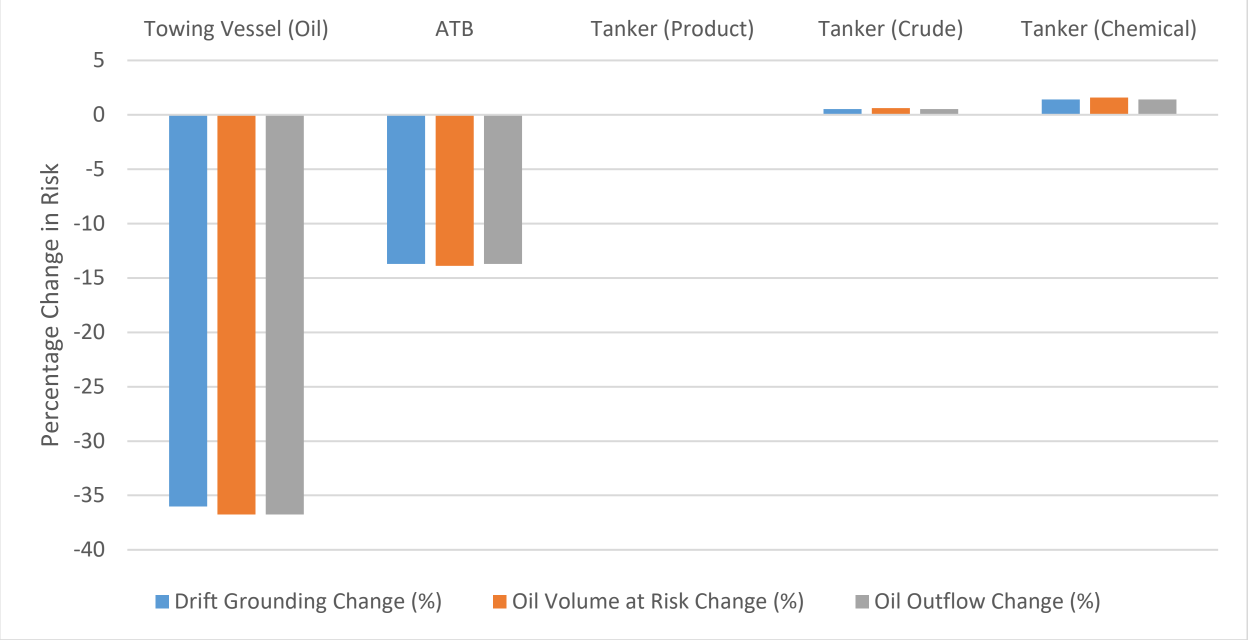

Figure 10: Oil spill risk metric changes between Scenario 2 and Scenario 3 by vessel type, for vessels newly required to take escorts.[26]

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[24] These values are from Appendix A, Table 38.

[25] These values are from Appendix A, Table 37.

[26] These values are from Appendix A, Table 37.

In absolute terms, towed oil barges showed higher reductions in risk than ATBs for drift groundings (-0.0012 vs -0.0001) and oil outflow (-0.06 vs -0.01). In terms of oil volume at risk, the reductions were about the same.

The new escort regulations under Scenario 3 would potentially be able to prevent, on average, about 1 in 3 towed oil barges drift groundings and 1 in 7 ATB drift groundings.

For the geographic zones where escorts were newly required, model results indicated percentage reductions in risk in Admiralty Inlet, Colvos Passage, Haro Strait and Boundary Pass, Puget Sound, South Sound to Olympia, Strait of Georgia, and Strait of Georgia South (Figure 11). Of those seven zones, Puget Sound, Haro Strait and Boundary Pass, Admiralty Inlet and the Strait of Georgia are meaningful contributors to overall system risk, at 38-46 percent, 22-23 percent, 7-8 percent, and 6-8 percent respectively (see Figure 5), so their percentage reductions correspond to meaningful absolute reductions.

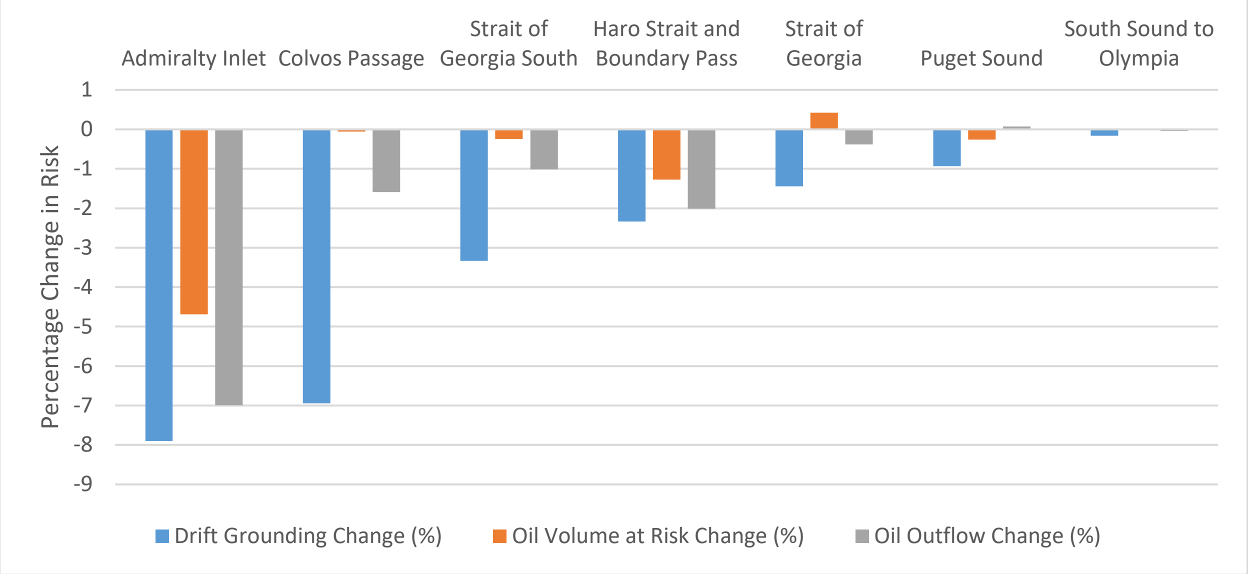

Figure 11: Oil spill risk metric changes between Scenario 2 and Scenario 3 by zone, for zones with new escort requirements.[27]

In absolute terms, Haro Strait and Boundary Pass saw the biggest reduction in risk across all risk metrics (-0.0015 in drift groundings, -1,790.3 in oil volume at risk, and -0.35 in oil outflow). Admiralty Inlet was a close second (-0.0015 in drift groundings, -1,736.7 in oil volume at risk, and -0.29 in oil outflow). Puget Sound and Strait of Georgia both saw mixed absolute outcomes – Puget Sound saw a slight increase in oil outflow, and Strait of Georgia saw a slight increase in oil volume at risk.

Discussion

Model results indicated that the expansion of tug escorts to ATBs, towed oil barges and tank ships between 5,000 and 40,000 DWT would be most beneficial for towed oil barges, and ATBs.

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[27] These values are from Appendix A, Table 33.

The zones that show the highest benefit from the addition of tug escort requirements are Admiralty Inlet and Haro Strait and Boundary Pass. All of the reductions in risk found by the model were small.

Among newly escorted vessel types, crude, chemical and product tankers saw either no change or slight increases in risk. The difference in the geographic distribution of simulated tugs for each scenario was likely a factor in this seemingly counterintuitive result.

How additional tug traffic produced by escort tug requirements affects risk

Model results provided estimates of how expanding tug escorts requirements increase escort tug movements. Based on historical incident rates for tugs, that increase in underway time implies an increase in risk. For Scenario 2, we estimated a 134 percent increase in underway escort tug time, which corresponded to an increase of 0.11 allisions/collisions per year, 0.03 groundings per year, 0.01 sinking/capsize per year and 0.50 other incidents per year. For Scenario 3, we estimated a 263 percent increase in underway escort tug time, which corresponded to an increase of 0.49 allisions/collisions per year, 0.15 groundings per year, 0.04 sinking/capsize per year and 2.32 other incidents per year. More information about how we simulated escort tug movements is available in Appendix B.

In terms of absolute numbers, the model produced around 345,000 minutes of escort and assist traffic per year in the study area under Scenario 1. The expansion of escort tugs under Scenario 2 saw that increase to just over 800,000 minutes per year. Under Scenario 3 the model simulated just over 2,930,000 minutes of escort and assist traffic per year.

To evaluate how these additional minutes might add to oil spill risk in the study area, we multiplied them against calculated incident rates (Table 2). The incident rates reflect recorded incidents involving tugs[28] in the model domain from 2002 to 2019. Our review found 52 allisions/collisions, 16 groundings, 4 sinking/capsize, and 244 other incidents. More information about the methodology behind this calculation can be found in Appendix B. Table 13 in Appendix B shows the calculations we used.

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[28] The vessel categories that we used to calculate hazards included tugs that aren’t specifically escort tugs. For the USCG MISLE database we included incidents associated with vessels classified as “towing vessels,” including “harbor/ship assist (tug)”, “pushing ahead (towboat)”, “pushing ahead/hauling alongside”, “ship/harbor assist”, “towing astern”, “towing behind (tug)”. For the Canadian MARSIS database we included incidents associated with vessels with length greater than 50 feet classified as “tug.”

Table 2: Escort tug hazard rates and estimated additional hazards per year.

Incident Type	**Incident Rate per operating minute**	**Number of additional incidents per year (Scenario 1 to Scenario 2)**	**Number of additional incidents per year (Scenario 2 to Scenario 3)**
Allisions/Collisions	2.31 x10^{-7}	0.1063	0.4917
Groundings	7.12 x10^{-8}	0.0328	0.1515
Sinking/Capsize	1.78 x10^{-8}	0.0082	0.0379
Other	1.09 x10^{-6}	0.5016	2.3201

How tethered escorts affect oil spill risk

When vessels required to be escorted under Scenario 2 are modeled as tethered the model shows an additional reduction in risk in the study area. In our model, the tethering of escort tugs reduces the time required for a tug to connect and control a disabled vessel from 30 minutes to 15 minutes.

Bellingham Channel, Sinclair Island, and waters to the east and Rosario Strait saw the greatest percentage reductions in drift groundings due to tethering, likely because they see large amounts of escorted traffic. These zones are also narrow, which could indicate that the 15-minute reduction in time to connect and control is more likely to affect the outcome of a loss of propulsion event. Figure 12 shows decreases in risk by zone and Figure 13 shows decreases in risk for vessels that take escorts.

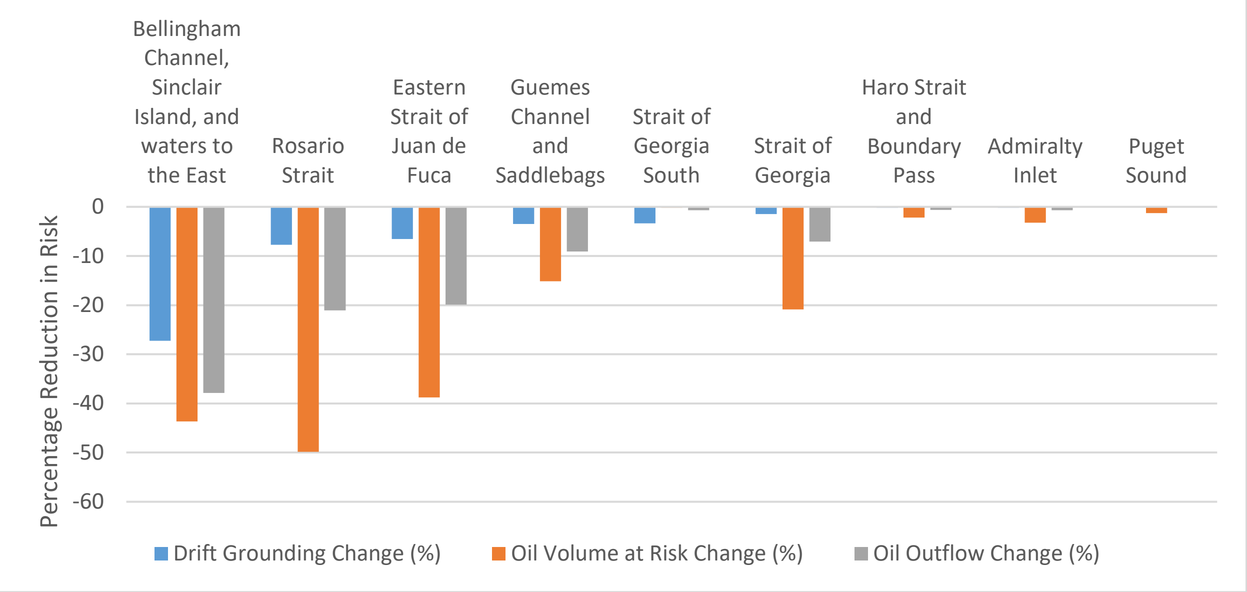

Figure 12: Change in oil spill risk from Scenario 2 without tethering to Scenario 2 with tethering for zones that showed a change in risk.[29]

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[29] These values are from Appendix A, Table 45.

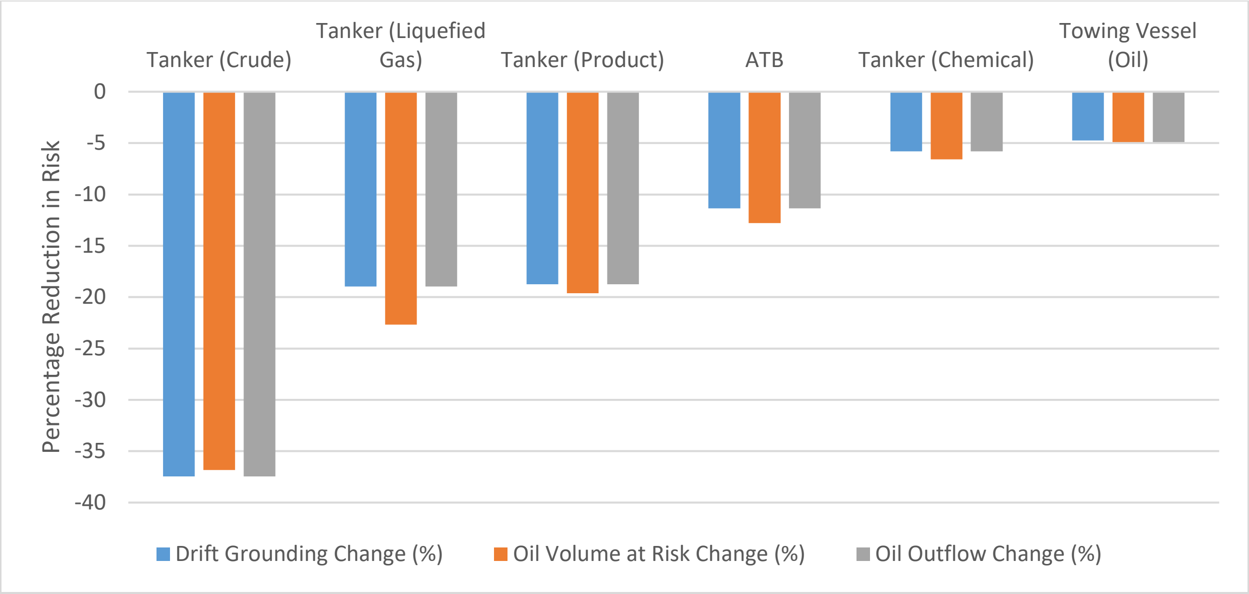

Figure 13: Change in oil spill risk from Scenario 2 without tethering to Scenario 2 with tethering for vessel types that take escorts.[30]

How escort traffic from the Trans Mountain Expansion Project (TMEP) affects escort tug expansions

The proposed TMEP will expand Trans Mountain's pipeline between Alberta and Burnaby, British Columbia. 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 laden portion of these transits will be escorted, so we looked at how this increase in escort traffic might affect the potential benefit of existing or additional escort requirements in Washington waters.

Escort transits were simulated to match the TMEP escort plan (TransMountain, 2021). The planned oil spill response vessel was also simulated at Beecher Bay as an ERTV. Simulated loss of propulsion event was not simulated for additional TMEP tanker transits, nor was any potential risk assessed that might be produce by those vessels.

Model results indicated that the additional escorts and the Beecher Bay response vessel associated with the TMEP did not substantively change the potential risk reduction benefit of expanding tug escort requirements in Washington waters.

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[30] These values are from Appendix A, Table 46.

How escort tugs may support vessels experiencing loss of steering events

Model results indicated that expanding escort requirements leads to additional protection against potential consequences of loss of steering. For loss of steering events, we assessed how frequently vessels are escorted when an event occurs, and we examined how close the nearest tug of opportunity was to the event. Since there is no clear connection between steering failures and drift groundings, drift trajectories were not modeled for these incidents, nor were any oil spill risk metrics calculated. However, tugs may be able to assist a ship experiencing steering problems. This provided an opportunity for the model to generate results that connect the frequency of this hazard with potential availability of tugs.

The expansion of escorts from Scenario 1 to Scenario 2 raised the percentage of loss of steering events that had an escort alongside a tank vessel from 7 percent to 11 percent. When considering only laden tank vessels, the numbers increased substantially. Scenario 1 saw an escort present at 38 percent of loss of steering events for laden tank vessels, while Scenario 2 saw that number increase to 62 percent. In Scenario 3, an escort was present at 99 percent of the loss of steering events on laden tank vessels.

Discussion

Model results indicated that on average the nearest tug of opportunity is over an hour away when a laden tank vessel loses steering. This suggests that it would be unlikely that a tug of opportunity would be a reliable option for preventing a grounding when vessels lose steering.

Tugs of opportunity could potentially assist in a loss of steering event. However, if we assume that a vessel is at greatest risk for a severe casualty in the first 15-30 minutes after losing steering, a tug of opportunity is unlikely to be close enough to prevent an accident. The proximity of an escort tugs makes them better suited for responding to this type of incident.

How escort tug design characteristics affect oil spill risk

Escort tugs reduce oil spill risk by reducing the chance that a sudden disabling of an underway vessel will result in a grounding, collision, or allision. Appropriate tug design is essential to the safe and effective operation of escort tugs, and their ability to reduce oil spill risk.

An escort tug’s hull shape, propulsion systems, deck equipment, and engine horsepower all contribute to a tug’s ability to control a disabled vessel effectively and safely. This section discusses how these design characteristics affect a tug’s ability to control disabled vessels.

Hull shape

Hull shape is a key design characteristic that allows escort tugs to control ships at higher speeds. Towing modes unique to escort tugs like “indirect towing” rely on hydrodynamic forces generated by the tug’s hull. The tug hull shape must be able to generate sufficient hydrodynamic lift and drag forces. These forces, combined with the force of the drive units, can be used to generate towline forces more than a tug’s rated bollard pull (Allan & Molyneux, 2004).

Because escorts tugs are engaged in supporting the safe transit of vessels at higher speeds, they must be able to apply emergency braking and steering forces using indirect towing modes. The hull forms that allow for this type of maneuver are a key escort tug characteristic. Typical ship handling tugs lack the stability and hull forms necessary to perform the maneuvers required for higher speed vessel escorting.

The required hull shape most commonly incudes an underwater fin called a skeg. The skeg is used to create the hydrodynamic forces necessary to develop the forces used in escorting (Allan & Molyneux, 2004).

Propulsion systems and horsepower

Escort tug hull forms work in conjunction with propulsion systems to generate the required forces to control escorted vessels. To this end, the propulsion systems of escort tugs usually have omni-directional thrust capabilities, meaning they can equally propel themselves in any direction. That type of propulsion is different from what is seen on “conventional” tugs. Conventional tugs are designed for efficient coastal or ocean towing and are primarily single-screw or twin-screw design with limited maneuvering capability compared to tugs designed for escort work.

There are a variety of different propulsion systems that provide the required omni-directional capabilities. A Voith-Schneider propeller is a vertical axis propeller system which has been widely adopted for escort tugs (Allan & Molyneux, 2004). An azimuth stern drive tug is another design used in escorting where the tug is fitted with two thrusters at the aft end of the ship. The thrusters can each independently rotate a full 360 degrees, giving the tug the ability to give equal thrust in all directions.

The more horsepower the tug is capable of producing, the higher bollard pull values available. However, as mentioned above, the unique relationship between propulsion, hull shape, and indirect towing capability means that escort tugs are designed to produce higher bollard pull forces than available by propulsion alone.

Though still a simplification, bollard pull is generally used as a proxy for a tug’s ability to control a ship (Oggel, 2019). A recent example of this is the Clear Seas report on availability of tugs of opportunity (Clear Seas, 2019). Regulations that establish escort tug suitability solely based on horsepower are not taking into consideration all aspects of a tug’s capability.

Deck equipment

In addition to unique, purpose-built hull and propulsion systems, escort tugs also use specialized deck equipment. An important component of the escort system is the tow line through which an escort tug transmits the forces it can develop to the escorted vessel. The line is controlled from the escort tug, using a dynamic winch. The use of a dynamic winch allows the towline to be automatically let out while under high loads. This helps prevent breaking of the towline and potential overturning of the escort tug. Winches used in escorting must also be able to recover tow lines quickly to prevent damage when the tow line goes slack during escort operations (Iglesias-Baniela, Vinagre-Ríos, & Pérez-Canosa, 2021).

Deck fittings aboard the escorted vessel present a potential weak point in the escort towing chain. Efforts have been made to address this, and the Puget Sound Harbor Safety Plan outlines industry standards for deck fitting safe working loads depending on the size of the escorted vessel (Puget Sound Harbor Safety Committee, 2023). An expansion of tug escorts to smaller vessels may require additional consideration of this topic. A 2014 report concluded that small tankers (less than 40,000 DWT) are generally not designed to have tethered escort tugs and they may be prone to connection point failure due to the force of a tethered tug pulling on the lines (Badger, 2014). Similar issues may exist for ATBs and towed oil barges.

Discussion

Additional information on escort tug design can also be found in classification society standards. ABS, Bureau Veritas, and others offer detailed requirements for escort tugs (American Bureau of Shipping, 2023; Bureau Veritas, 2022).

Consideration of recently adopted safety measures

The Legislative action that required this analysis also tasked Ecology with considering the benefits of vessel safety measures that were newly in effect on or after July 1, 2019. Ecology is not aware of any recently adopted vessel safety measures in the study area or elsewhere that have affected oil spill risk.

Conclusion

Drift groundings are rare events. Based on our review of historical incidents in the area modeled, we identified four 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 our review found that drift groundings and spills from drift groundings are infrequent, individual drift grounding events can still produce large spills. For the incidents reviewed (including collisions, allisions, non-drift groundings, and drift groundings), we found spills ranging in size from 1 to 420,000 gallons.

Tug escorts are a well-tested measure for protecting against groundings and other hazards that might occur after loss of propulsion and loss of steering events. They have been in place for many years for tank ships in Washington waters. Tug escorts are one level of protection against drift groundings. Our results show that when in place, they form part of a larger web of protections, including the ability of the ship to self-repair, the potential for emergency anchoring, and potential rescue by an ERTV or a tug of opportunity.

Model results indicated small potential reductions in drift groundings from additional tug escort requirements. We found a reduction of 0.0047 drift groundings per year from Scenario 1 to Scenario 2 and a reduction of 0.0035 drift groundings per year from Scenario 2 to Scenario 3. This is equivalent to the new escort regulations under Scenario 2 potentially being able to prevent about 1 in 44 drift groundings occurring in the BPC zones. The new escort regulations under Scenario 3 would potentially be able to prevent an additional 1 in 57 drift groundings occurring in the BPC zones, when compared to Scenario 2.

Reductions in average oil volume at risk and oil outflow metrics associated with tug escort expansions in Scenario 2 or Scenario 3 were also small. Average oil volume at risk declined 22,430.1 gallons per simulation and oil outflow declined 1.5 gallons per simulation from Scenario 1 to Scenario 2. The change from Scenario 2 to Scenario 3 was even smaller, with oil volume at risk dropping 103.9 gallons and oil outflow dropping 0.4 gallons. However, individual spill outcomes 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.

Escort tugs as a safety measure are targeted at a particular set of vessel types, and only required when those vessels are laden, so it makes sense that they might only reduce a portion of the drift groundings in a system.

Model results indicated that escorts have a more substantial, but still small overall preventative effect for drift groundings for tank vessels. When comparing Scenario 1 against Scenario 2, ATBs saw a 13 percent reduction in risk, towed oil barges saw a 9 percent reduction in oil spill risk, and chemical tankers saw a 6-7 percent reduction in risk. When comparing Scenario 2 against Scenario 3, towed oil barges saw a 37 percent reduction in risk, ATBs saw a 14 percent reduction in risk, and chemical tankers saw a slight increase in risk.

These reductions should be understood in the context of risk contribution to the system. For instance, when comparing Scenario 1 against Scenario 2, the risk reduction for ATBs (-13 percent) was higher than the risk reduction for towed oil barges (-6-7 percent). However, ATBs only make up 1-2 percent of the overall risk in the system, while towed oil barges make up 8-12 percent of the risk. A reduction of 13 percent on the 1-2 percent of the risk that ATBs represent, is a very small reduction in the larger context of overall risk in the system. The 6-7 percent reduction of risk for towed oil barges, which represent 8-12 percent of the risk in the system, is a more meaningful reduction.

The new escort regulations under Scenario 2 would potentially prevent about 1 in 8 ATB drift groundings, 1 in 12 towed oil barge drift groundings, 1 in 14 chemical tanker drift groundings, 1 in 28 crude tanker drift groundings, and 1 in 176 product tanker drift groundings. The new escort regulations under Scenario 3 would potentially be able to prevent, on average, about 1 in 7 ATB drift groundings, and 1 in 3 towed oil barges drift groundings.

When we looked at risk reduction from additional escorts on a zone-by-zone basis, we found that when comparing Scenario 1 against Scenario 2, the zones where escorts were newly required saw reductions in risk. Bellingham Channel, Sinclair Island and Waters East saw a 6-7 percent decrease, Guemes Channel and Saddlebags a 2 percent decrease, and Rosario Strait a 3-9 percent decrease. When comparing Scenario 2 against Scenario 3, the zones with the most meaningful reductions in risk were Admiralty Inlet (-5-8 percent) Haro Strait and Boundary Pass (-1-2 percent).

Our analysis also looked at several other topics. The conclusions of those analyses are summarized below:

- Model results provided estimates of how expanding tug escorts requirements increase escort tug movements. Based on historical incident rates for tugs, the increase underway time from additional escort requirements implies an increase in risk.
- When vessels required to be escorted under Scenario 2 are modeled as tethered the model shows a reduction in risk, particularly in zones that include narrow waterways where tank vessels often transit.
- The additional safety measures associated with the TMEP do not substantively change the potential risk reduction benefit of expanding tug escort requirements in Washington waters.
- Model results indicated that expanding escort requirements leads to additional protection against potential consequences of loss of steering events.
- Hull shape, propulsion systems, deck equipment, and engine horsepower, all contribute to an escort tug’s ability to control a disabled vessel effectively and safely.

- Ecology is not aware of any recently adopted safety measures in the study area or elsewhere that have affected oil spill risk.

Tank vessels make up only a portion of drift grounding risk, and drift grounding risk makes up only a small part of overall maritime oil spill risk. Our analysis shows tug escort requirements provide a level of protection against drift groundings, but not a big reduction overall. When in place, they form part of a larger web of protections like the ability of the ship to self-repair, the potential for emergency anchoring, and potential rescue by an ERTV or a tug of opportunity.

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.

Board of Pilotage Commissioners (BPC): Washington State Board of Pilotage Commissioners ensures against the loss of lives, loss of or damage to property and vessels, and protection of the marine environment by maintaining efficient and competent pilotage service on Washington State's inland waters. The BPC is also authorized to adopt rules regarding tug escorts in portions of Washington waters.

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

Bunkering: The practice of taking on ship's fuel oil.

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.

Covered vessel: Covered vessels are defined in Wash. Rev. Code § 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.

Oil Transportation Safety Committee (OTSC): A committee of the Board of Pilotage Commissioners (BPC) formed to conduct analysis and provide recommendations to the BPC concerning the responsibilities outlined in the 2019 legislation, The Reducing Threats to Southern Killer Whales by Improving the Transportation of Oil Act.

Skeg: A finlike projection on the bottom of an escort tug used to create large braking and steering forces.

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: All connected marine waters east of a line from Discovery Island light to New Dungeness light in the Strait of Juan de Fuca and south of the 49th Parallel in the Strait of Georgia

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

Acronyms and Abbreviations

ABS	American Bureau of Shipping
ASTM	ASTM International, formerly the American Society for Testing and Materials
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 rescue 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
TMEP	Trans Mountain Expansion Project
VEAT	Vessel Entries and Transits
VDS	Vessel Documentation Service
VMM	Vessel Movement Module
VRAM	Vessel Rescue Analysis Module

References

Allan, R. G. (2000). The evolution of escort tug technology, fulfilling a promise. *SNAME Transactions, Volume 108, pp. 99-122.*

Allan, R.G., Molyneux, D., & Birmingham, R.W. (2004). Escort tug design alternatives and a comparison of their hydrodynamic performance. *Transactions of the Society of Naval Architects and Marine Engineers, 112*, *191-205*. Retrieved from https://nrc-publications.canada.ca/eng/view/ft/?id=515af4f9-1f5e-4728-965b-3070df20cc6e

American Bureau of Shipping. (2023). *Rules for Building and Classing Marine Vessels, Part 5D: Offshore Support Vessels for Specialized Services.* Retrieved from https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/1-rules-building-classing-marine-vessels-2023/mvr-part-5d-jan23.pdf

ASTM Standard F1878-21. (2021). Standard Guide for Escort Vessel Evaluation and Selection. ASTM International West Conshohocken, PA, 2021, DOI: 10.1520/F1878-21, www.astm.org.

Badger, C. (2014). Report on the findings of the Pilotage Risk Management Methodology to assess the Use of Escort Tugs in Haro St and Boundary Pass for Liquid Bulk Vessels, In Product, less than 40,000 SDWT. Retrieved from https://docs2.cer-rec.gc.ca/ll-eng/llisapi.dll/fetch/2000/90464/90552/548311/956726/2392873/2449925/2450819/2786499/C135-8-4_-__Appendix_C_Haro_Straits_and_Boundary_Pass_PRMM_Final_Report_-_A4L9W8.pdf?nodeid=2786305&vernum=-2

Blendermann, W. (1994). Parameter identification of wind loads on ships. Journal of Wind Engineering and Industrial Aerodynamics 51:339–351.

Breivik, Ø. and A. A. Allen. (2008). An operational search and rescue model for the Norwegian Sea and the North Sea. Journal of Marine Systems 69:99–113.

Bureau Veritas. (2022). *Rules for the Classification of Steel Ships: Part E Service Notations for Offshore Service Vessels and Tugs.* Retrieved from https://erules.veristar.com/dy/data/bv/pdf/467-NR_PartE_2022-07.pdf

Clear Seas. (2019). Availability of Tugs of Opportunity in Canada's Pacific Region. Clear Seas. Retrieved from: https://clearseas.org/wp-content/uploads/2019/08/5520-ClearSeas-TugsOfOpportunity-Report-EN-vf-V2.pdf

Fowler, T. G., and E. Sorgard. (2000). Modeling Ship Transportation Risk. Risk Analysis 20:225–244.

House, D. J. (2010). Elements of modern ship construction. Brown, Son & Ferguson, Glasgow.

Iglesias-Baniela, S., Vinagre-Ríos, J., & Pérez-Canosa, J. M. (2021). Ship Handling in Unprotected Waters: A Review of New Technologies in Escort Tugs to Improve Safety. *Applied Mechanics*, *2*(1), 46–62. MDPI AG. Retrieved from http://dx.doi.org/10.3390/applmech2010004

Jurdzinski, M. (2020). Processes of a Freely Drifting Vessel. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation 14:687–693.

MacCready, P., R. M. McCabe, S. A. Siedlecki, M. Lorenz, S. N. Giddings, J. Bos, S. Albertson, N. S. Banas, and S. Garnier. (2021). Estuarine Circulation, Mixing, and Residence Times in the Salish Sea. Journal of Geophysical Research: Oceans 126.

Ni, Z., Z. Qiu, and T. C. Su. (2010). On predicting boat drift for search and rescue. Ocean Engineering 37:1169–1179.

Oil Companies International Marine Forum. (1994). *Prediction of wind loads and current loads on VLCCs* (2nd ed.). Witherby. Page 83.

Oggel, J. (2019). Global Shipping Trends and the Carrousel Rave Tug: Connecting the dots. Novatug. Retrieved from: https://novatug.nl/wp-content/uploads/2019/12/Novatug-WhitePaper-June-2019-1.pdf

Pacific Pilotage Authority. (2019). Notice to Industry: Escort tug rules for ships carrying liquids in bulk. Notice Number 07/2019. Retrieved from https://ppa.gc.ca/standard/pilotage/2019-11/Notice%20to%20Industry%2007-2019%20Rules%20for%20vessels%20carrying%20liquids%20in%20bulk.pdf

Puget Sound Harbor Safety Committee. (2023). Puget Sound Harbor Safety Plan. Retrieved from: https://pshsc.org/puget-sound-harbor-safety-plan

Robertson, T., B. Higman, S. Yun, and S. Fletcher. (2021). Vessel Drift and Response Analysis for the Strait of Juan de Fuca to the Southern Strait of Georgia. Nuka Research & Planning Group.

Trans Mountain. (2013). Trans Mountain Expansion Project Application to the National Energy Board. Kinder Morgan. Retrieved from: https://docs2.cer-rec.gc.ca/ll-eng/llisapi.dll/fetch/2000/90464/90552/548311/956726/2392873/956924/956916/A3H8S3_-_1._TMEP_Proj_Descip_-_TofC_to_Sec_2.pdf

Trans Mountain. (2021). Tug Fact Sheet. Trans Mountain. Retrieved from: https://www.kotugcanada.ca/application/files/8516/3835/4403/291121_KOTUG_TM_fact_sheet.pdf

Tveitnes, T. (2001). Application of Added Mass Theory in Planing. University of Glasgow.

Wash. Rev. Code § 88.16.190. (2019). Oil tankers—Restricted waters—Requirements. Revised Code of Washington. Retrieved from http://app.leg.wa.gov/RCW/default.aspx?cite=88.16.190

Wash. Rev. Code § 88.16.260. (2019). Board of pilotage commissioners authorized to adopt rules in consultation with other entities—Tug escorts. Retrieved from https://app.leg.wa.gov/rcw/default.aspx?cite=88.16.260

Zhang, S., P. T. Pedersen, and R. Villavicencio. (2019). Probability and Mechanics of Ship Collision and Grounding. Elsevier.

Appendix A: Methods, Results, and Discussion

Methods

This section describes the study area and the methods we used to evaluate incident data, traffic data, and simulation output.

Study area

The study area includes all marine waters of the Salish Sea east of a line running from Discovery Island Light to New Dungeness Light in the Strait of Juan de Fuca and south of the 49th Parallel in the Strait of Georgia (Figure A-1).

The study area encompasses the U.S. waters where the Washington State Board of Pilotage Commissioners (BPC) is required to establish tug escort rules under RCW 88.16.260. Adjacent Canadian waters are included in the study area boundaries.

Geographic zones

The study area is divided into geographic zones (Figure A-1). The zones help us communicate the spatial distribution of oil spill risk. The development and use of geographic zones is also mandated by RCW 88.16.260. The zones were developed by the BPC, in conjunction with their Oil Transportation Safety Committee. Appendix E has more information on the details of the BPC zones. The BPC zones include the areas within the study area where large commercial traffic is present, but they do not cover the entire study area. To address this, we also established additional non-BPC zones to allow us to fully represent the geographic distribution of results across the entire study area.

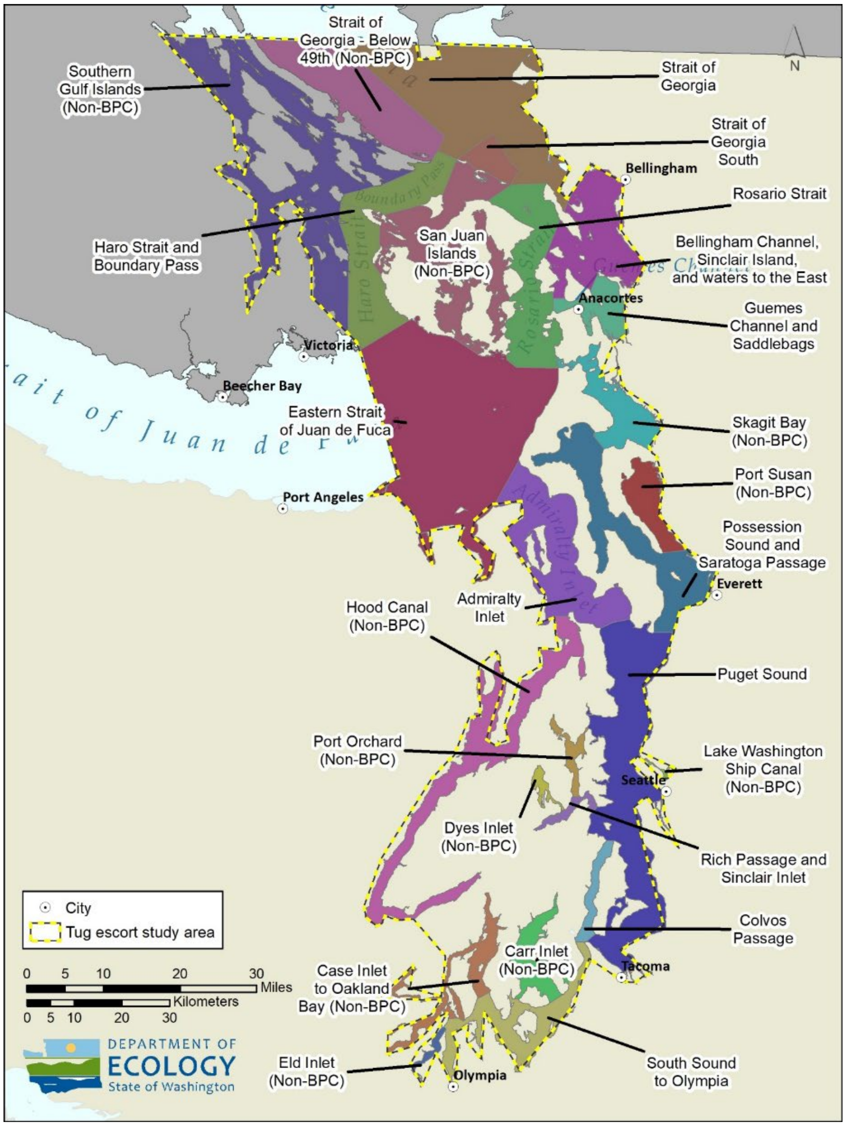

Figure A-1: Tug escort study area and geographic zones.

The BPC zones are:

- Admiralty Inlet
- Bellingham Channel, Sinclair Island, and waters to the East
- Colvos Passage
- Eastern Strait of Juan de Fuca
- Guemes Channel and Saddlebags
- Haro Strait and Boundary Pass
- Possession Sound and Saratoga Passage
- Puget Sound
- Rich Passage and Sinclair Inlet
- Rosario Strait
- South Sound to Olympia
- Strait of Georgia
- Strait of Georgia South

The non-BPC zones are:

- Carr Inlet
- Case Inlet to Oakland Bay
- Dyes Inlet
- Eld Inlet
- Hood Canal
- Lake Washington Ship Canal
- Port Orchard
- Port Susan
- San Juan Islands
- Skagit Bay
- Southern Gulf Islands
- Strait of Georgia - Below 49th

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. This provided perspective on how common drift groundings are compared to other incidents.

We evaluated the incident data in three ways. First, we calculated the relative frequency of incident types compared to the totals for all five types. Second, we calculated the relative frequency of each incident with oil spills to the total count of all five incidents with oil spills. Third, we calculated the rate of an oil spill occurring for each of the five incident types.

We reviewed incidents that occurred in two different geographic extents. First, a regional area that encompasses the Salish Sea, except for the northern portion of the Strait of Georgia. We refer to this area as the Model Domain (Figure A-2).

The second area encompasses the continental waters of the U.S. and Canada. We refer to this as the Bi-National Area (Figure A-3). The area includes waters up to 20 miles offshore and continuing inland only 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. This coverage excludes most inland rivers and lakes, apart from the portions of those that receive significant deep draft traffic. This area includes the following inland waters:

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

Figure A-2: Model domain.

We relied on incident data available in the U.S. Coast Guard Marine Information for Safety and Law Enforcement (MISLE) database and the Canadian Marine Safety Information System (MARSIS) database. We reviewed incidents that occurred between 2002 and 2019.

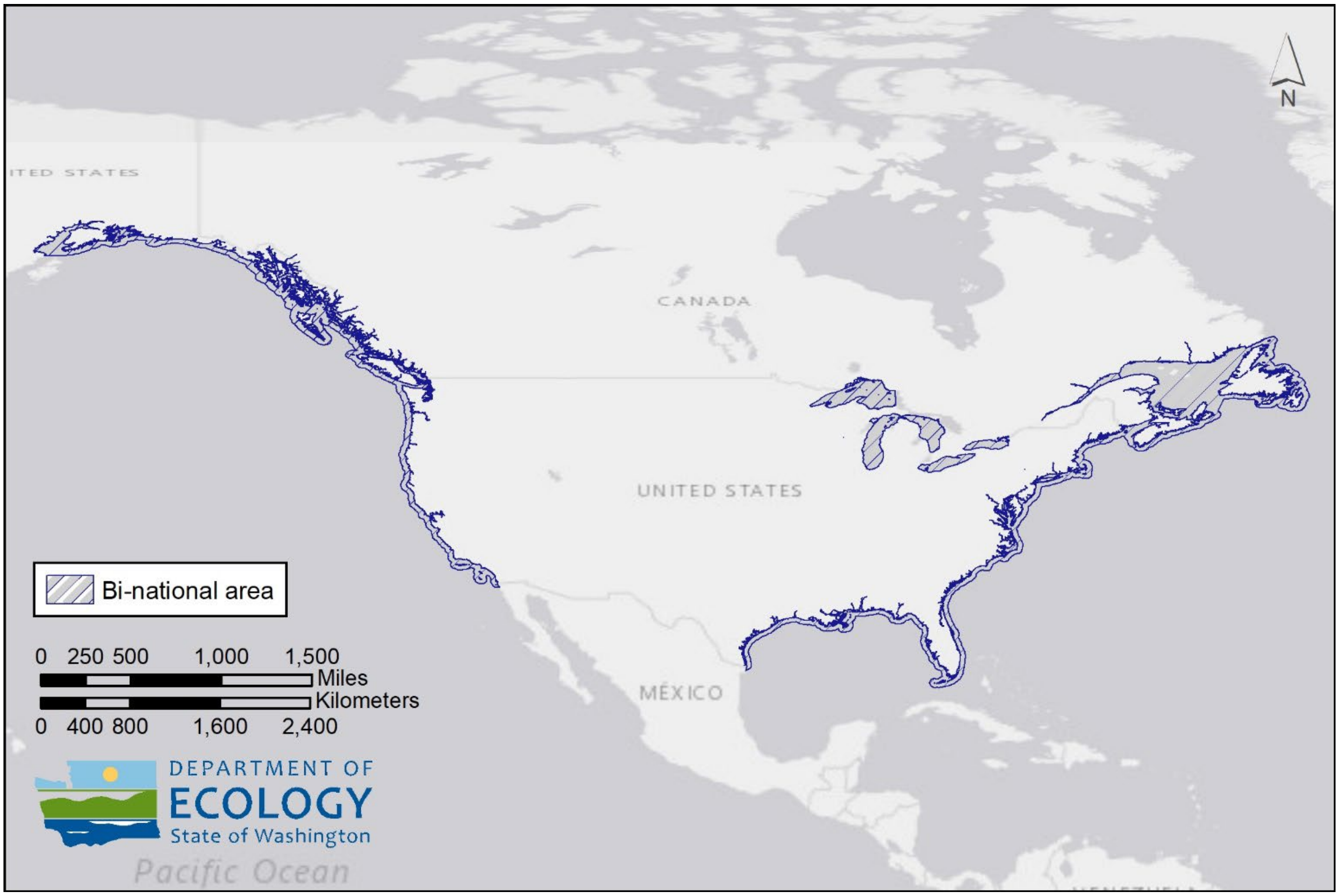

Figure A-3: Bi-National Area encompassing selected waters of U.S. and Canada.

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 changes in tug escort scenarios 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, several 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 and loss of steering events and evaluated how patterns of drift groundings and subsequent oil spills varied by tug escort scenarios. 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 Emergency Response Towing Vessel (ERTV). The simulation modeling was not designed to predict future oil outflow volumes or quantify any costs associated with adding escort tugs to the system.

Fourteen vessel types are included in the model. The complete list, with definitions, is included in Appendix B. Here are definitions for the subset of vessels that are most important to our analysis:

- **ATB:** a tug that almost exclusively travels with a mechanically linked tank barge.
- **Tanker (Chemical):** a tank ship that carries oil as cargo and could also carry non-oil liquid cargo.
- **Tanker (Crude):** a crude tanker is designed to carry unrefined oil.
- **Tanker (Product):** a tank ship that carries refined oil in bulk.
- **Towing Vessel (Oil):** a tug that generally operates with a tow (ahead or astern) that contains oil as cargo. We use the term "towed oil barges" in this report to refer to this vessel type.
- **Tug (Assist & Escort):** a tug that generally does not operate with a tow. These escort tugs and assist tugs run light and assist or escort other vessels. Generally, they are over 50 feet long.

The vessel types 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 and loss of steering events were generated for each simulation using different rates for each 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.[31]
- 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.

Tug escort scenarios

Three different escort tug scenarios were examined to assess how past, present, and theoretical future tug escort rules may prevent drift groundings. For each simulated loss of propulsion and loss of steering event, all three tug escort scenarios were simulated to evaluate intervention potential across scenarios. In all scenarios, no escorts are required for vessels providing bunkering or refueling services.[32]

Scenario 1: pre-2020 requirements

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.

Scenario 2: current requirements

In Scenario 2, tank vessels 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.

Scenario 3: escorts required throughout study area

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.

Comparing the scenarios

Comparison of results from Scenario 2 to Scenario 1 allows us to evaluate the potential oil spill risk reduction of the recently established expansion of tug escort requirements to laden ATBs, tank barges, and tank ships between 5,000 and 40,000 DWT in Rosario Strait and connected waters east.

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[31] 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.

[32] The exclusion of bunkering vessels from escorting requirements conforms to language in RCW 88.16.260, which states that the section does not apply to "A vessel providing bunkering or refueling services."

Comparison of results from Scenario 3 to Scenario 2 allows us to evaluate the potential oil spill risk reduction of expanding tug escort requirements beyond those currently in place.

How we simulated escort and assist tugs

The model treats escort and assist tugs as dependent vessels because 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 escort and assist tug traffic in the system.

For each simulation run, the model produced 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 expansion of tug escort requirements in Scenarios 2 and 3 increased dependent escort tug traffic for those scenarios. To simulate the same number of tug tracks for each scenario, the number of background tracks was 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.

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's 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 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 slower 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.

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.

Tug rescues

The model allowed drifting vessels to be rescued by tugs of opportunity or the Neah Bay ERTV. The Neah Bay ERTV is modeled with a 20-minute mobilization time, which is based on standards required under Washington state statute (RCW 88.46.135). 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 the ERTV 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 disabled vessel intersect. If a tug reaches a drifting vessel with sufficient time before grounding to connect and control, 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.

Spatial distribution of risk

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

Since this analysis focused on intervening in the accident chain at the moment of loss of propulsion, we elected to assign incident location based on the coordinates of the loss of propulsion events.

Evaluating changes between scenarios

To evaluate the oil spill risk reduction benefit of tug escort, we calculated the relative changes in oil spill risk metrics for vessel types and geographic zones between scenarios.

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 scenarios. Then, we calculated the averages across all simulations for each of those quantities. Finally, the overall percent change from one scenario to another was calculated by dividing the average difference between scenarios by the average total of the base scenario. The changes in drift groundings rates were calculated by taking the average per simulation of the difference in the drift grounding rates between scenarios. These were calculated for each vessel type and for each geographic zone.

Evaluation of vessel traffic data

We calculated the percentage of total simulated underway minutes by vessel type, and by area. This allows us to see how underway time was distributed across vessel types and across geographic zones.

We calculated relative contribution by dividing the annual average total time underway for each vessel type by the annual average total time underway in the system for all vessel types. We calculated relation contribution geographically by dividing the annual average total time underway within each zone by the annual average total time underway in the system for all zones.

We repeated these steps with the results from car ferries excluded.

Current oil spill risk profile

We characterized the current oil spill risk profile by calculating the relative frequency of oil spill risk metrics for each vessel type and for each geographical zone. We used data from Scenario 2 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 repeated these steps with the results from car ferries excluded.

Risk from escort tug traffic

We multiplied calculated incident rates against simulated underway minutes to estimate potential increases in incidents from increasing escort tug traffic. This allowed us to evaluate how the addition of more escort tug underway time to the system might increase risk.

Incident rates are based off incidents involving tugs that took place in the model domain (Figure 2) between 2002 and 2019. A full description of the methodology we used to estimate incident rates, including vessel type and hazard type mapping, is available in Appendix B.

Tethering effects

Tug escorts can be performed while tethered or untethered. During a tethered escort, the tug is physically tethered to a strong point on the escorted vessel and follows at a short distance. If the escorted vessel needs assistance, the tug is ready to provide nearly immediate response. During an untethered escort, the tug remains underway near the escorted vessel but without any physical connection. If the escorted vessel needs assistance, it must first establish a connection before it is able to provide a response.

In the model, the tethering of tugs reduced the time required for a tug to connect and control a disabled vessel from 30 minutes to 15 minutes.

Sensitivity analyses

We completed sensitivity analyses on model variables to understand how basic model assumptions influenced model results. These sensitivity analyses were all related to drifting vessels and their potential rescue. All sensitivity analyses were conducted independently (i.e., one variable at a time):

- To test the influence of self-repair assumptions, we removed self-repair as an option for disabled vessels.
- To test the influence of emergency anchoring assumptions, we removed emergency anchoring as an option for disabled vessels.
- To test the influence of time to connect and control on tug of opportunity and ERTV rescues, we reran the analysis with time to connect and control decreased by 50 percent (to 15 minutes) and increase by 50 percent (to 45 minutes).
- To test the influence of tug speed on tug of opportunity and ERTV rescues, we reran the analysis with tug speed decreased by 25 percent (to 7.5 knots) and increased by 25 percent (to 12.5 knots).
- To test the influence tug rescue success rate on tug of opportunity and ERTV rescues, we reran the analysis with tug success rate decreased from 100 percent to 90 percent or 50 percent.

The effects of changes to these assumptions on rescue by tugs of opportunity or by the Neah Bay ERTV were separately examined.

Each sensitivity analysis followed a similar approach to how changes between scenarios were evaluated. The results for each change of a model variable using Scenario 2 were compared to original results for Scenario 2. For the tugs of opportunity sensitivity analysis, the number of minutes for the nearest tug of opportunity to reach a drifting vessel was also calculated.

Trans Mountain Expansion Project

An analysis was performed to evaluate the effects of the additional tug traffic associated with Trans Mountain Expansion Project (TMEP) on drift grounding risk. This analysis required adding additional simulated transits to the traffic simulation produced for Scenario 2. The tug escorts are modeled to be consistent with the TMEP proposal (Trans Mountain, 2021), 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). 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 providing 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 ERTV.

Relative changes in oil spill risk metrics overall and among vessel types and geographic regions were calculated to compare oil spill metrics following additional tug of opportunity traffic resulting from the TMEP escort requirements. We did not simulate loss of propulsion events for the additional TMEP tanker transits, nor did we assess any potential risk that might be produced by those vessels. Calculation steps were similar to those described for evaluating changes between scenarios.

Loss of steering

For loss of steering events, we assessed how frequently the vessels are escorted when an event occurs, and we examined how close the nearest tug of opportunity was to the event. Since there is no clear connection between steering failures and drift groundings, drift trajectories were not modeled for these incidents, nor were any oil spill risk metrics calculated. However, tugs may be able to assist a ship experiencing steering problems, providing an opportunity for the model to generate results informing on the frequency of this hazard and the availability of tugs when it occurs.

We assessed escorting frequency by calculating the percentage of escorted vessels for each vessel category when a loss of steering incident happens. The vessel categories were created from the oil cargo carrying vessel types (Table A-1). Next, we calculated the average escorted frequency for all simulations for each vessel category. This was repeated for each scenario. For the nearest tug of opportunity portion of this analysis, we calculated the average travel time for the closest tug of opportunity for every incident under each scenario within a single simulation. We then calculated the average of that value across all simulations.

Table A-1: Loss of steering vessel categories and corresponding vessel types.

Loss of steering vessel category	Vessel type
Tank vessels	ATB, Tanker (Chemical), Tanker (Crude), Tanker (Product), Towing Vessel (Oil)
Tankers	Tanker (Chemical), Tanker (Crude), Tanker (Product)
ATBs	ATB
Towed oil barges	Towing Vessel (Oil)

Results

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

Our analysis of incident data

Twenty-seven covered vessel groundings and four covered vessel drift groundings[33] between 2002 and 2019 were identified within the Model Domain (Figure A-2) and none 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. One-hundred-ninety covered vessel drift groundings were 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-2: Relative frequency of vessel casualty types in the Model Domain and the Bi-National Area.

Casualty Type	Model Domain (Count)	Model Domain (%)	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
All Incident Types	194	100.00	11371	100.00

Table A-3: Relative frequency of incident type with an oil spill in the Model Domain and the Bi-National Area.

Incident Type	Model Domain	Count	%
Allision (with spill)	No reported spills	80	38.28
Collision (with spill)	No reported spills	55	26.32

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[33] The four records we identified as potential covered vessel drift groundings in the Model Domain 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	Model Domain	Count	%
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 groundings, 2.63 percent result in oil spills. Drift groundings have the third highest oil spill rate per incident, after sinking and collision.

Table A-4: Frequency of an oil spill per incident, by incident type, in the Model Domain and the Bi-National Area.

Incident Type	Model Domain Spills Per Incident (%)	Bi-National Area 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 data

Our analysis of simulated vessel traffic data[34]

Vessel traffic within the study area was unequally distributed across geographic zones and vessel types. These non-uniform distributions were seen in the observed historical vessel traffic and in the simulated vessel traffic. Observed vessel traffic distributions were reflected in the simulated results with the simulated results deviating less than 1 percent from expected for most zones and vessel types.

Car ferries alone made up over 60 percent of the vessel traffic. Their presence accounts for the high traffic values that we see in Southern Gulf Islands. A few other zones also see substantial ferry traffic, including San Juan Islands, Guemes Channel and Saddlebags, Rich Passage and Sinclair Inlet, and Possession Sound and Saratoga Passage.

When excluding car ferry traffic and focusing just on the areas included in BPC zones, Puget Sound accounts the highest proportion of the traffic, at around 35 percent. A handful of other zones combined make up an additional 50 percent of the traffic. They are Haro Strait and Boundary Pass, Admiralty Inlet, Strait of Georgia, and the Eastern Strait of Juan de Fuca.

Towed oil barges, bulk carriers, and container ships constitute over 60 percent of the simulated traffic, when car ferries are excluded. The relative contributions for zones and vessel types change minimally

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[34] In the context of this report, vessel traffic refers to “minutes of underway time.”

when excluding traffic in non-BPC zones. Table A-5 and Table A-6 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-5: Relative contributions of simulated vessel traffic (in underway minutes) by geographic zone

Geographic Zone	**Relative Contribution (%)**	**Relative Contribution Excluding Ferries (%)**	**Relative Contribution Excluding Ferries, BPC Zones Only (%)**
Admiralty Inlet	6.18	11.26	12.35
Bellingham Channel, Sinclair Island, and waters to the East	0.68	1.68	1.84
Carr Inlet (Non-BPC)	0.00	0.00	N/A
Case Inlet to Oakland Bay (Non-BPC)	0.69	0.00	N/A
Colvos Passage	0.14	0.37	0.40
Dyes Inlet (Non-BPC)	0.00	0.00	N/A
Eastern Strait of Juan de Fuca	3.86	10.70	11.74
Eld Inlet (Non-BPC)	0.00	0.00	N/A
Guemes Channel and Saddlebags	2.17	1.60	1.75
Haro Strait and Boundary Pass	5.58	15.24	16.73
Hood Canal (Non-BPC)	0.00	0.01	N/A
Lake Washington Ship Canal (Non-BPC)	0.20	0.55	N/A
Port Orchard (Non-BPC)	0.00	0.00	N/A
Port Susan (Non-BPC)	0.00	0.00	N/A
Possession Sound and Saratoga Passage	3.27	0.45	0.49
Puget Sound	29.88	32.34	35.48
Rich Passage and Sinclair Inlet	2.23	0.01	0.01
Rosario Strait	3.98	5.40	5.92
San Juan Islands (Non-BPC)	6.74	0.04	N/A
Skagit Bay (Non-BPC)	0.00	0.01	N/A
South Sound to Olympia	2.05	0.42	0.46
Southern Gulf Islands (Non-BPC)	19.60	4.90	N/A
Strait of Georgia	8.10	11.21	12.30
Strait of Georgia - Below 49th (Non-BPC)	4.61	3.36	N/A
Strait of Georgia South	0.19	0.47	0.51
All Zones	100.00	100.00	100.00

Table A-6: Relative contributions of simulated vessel traffic (in underway minutes) by vessel type.

Vessel Type	Relative Contribution (%)	Relative Contribution Excluding Ferries (%)	Relative Contribution Excluding Ferries, BPC Zones Only (%)
ATB	3.18	8.88	9.07
Bulk Carrier	7.33	20.47	19.51
Container Ship	5.91	16.51	17.60
Cruise Ship	1.00	2.79	2.98
Ferry (Car)	64.17	N/A	N/A
Fishing Vessel (Large)	1.52	4.25	3.89
General/Other Cargo Ship (Large)	1.57	4.37	4.43
Tanker (Chemical)	0.96	2.69	2.75
Tanker (Crude)	0.85	2.38	2.59
Tanker (Liquefied Gas)	0.09	0.26	0.28
Tanker (Product)	0.76	2.12	2.26
Towing Vessel (Oil)	8.73	24.33	23.62
Towing Vessel (Oil) – Bunkering	2.04	5.70	5.48
Vehicle Carrier	1.88	5.25	5.55
All Vessel Types	100.00	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-7). Almost 64 percent of total drift grounding risk occurred in only three geographic zones: Puget Sound (33.22 percent), Southern Gulf Islands (19.65 percent), and Haro Strait and Boundary Pass (10.98 percent) The top three zones for the oil volume at risk represented about 58 percent of the total volume: Puget Sound (30.83 percent), Southern Gulf Islands (19.65 percent) and Haro Strait and Boundary Pass (16.48 percent). The top three zones for oil outflow represented about 61 percent of total oil outflow: Puget Sound (30.65 percent), Southern Gulf Islands (18.63 percent), and Haro Strait and Boundary Pass (11.69 percent).

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

Drift grounding rates

The zones with the three highest grounding rates were Skagit Bay (33.33 percent), Lake Washington Ship Canal (20.18 percent), and Rich Passage and Sinclair Inlet (12.34) (Table A-7).

Zones with grounding rates of less than 0.1 percent were Case Inlet to Oakland Bay (0.0 percent) and Hood Canal (0.0 percent).

Table A-7: Relative contribution of oil spill risk metrics by geographic zone, study area.

Geographic Zone	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
Admiralty Inlet	4.89	5.36	4.74	2.31
Bellingham Channel, Sinclair Island, and waters to the East	1.62	4.01	2.30	4.38
Carr Inlet (Non-BPC)	0.00	0.00	0.00	N/A
Case Inlet to Oakland Bay (Non-BPC)	0.00	0.00	0.00	0.00
Colvos Passage	0.12	0.06	0.10	9.20
Dyes Inlet (Non-BPC)	0.00	0.00	0.00	N/A
Eastern Strait of Juan de Fuca	0.85	1.33	0.98	0.38
Eld Inlet (Non-BPC)	0.00	0.00	0.00	N/A
Guemes Channel and Saddlebags	2.39	7.82	3.66	8.97
Haro Strait and Boundary Pass	10.98	16.48	11.69	4.66
Hood Canal (Non-BPC)	0.00	0.00	0.00	0.00
Lake Washington Ship Canal (Non-BPC)	0.45	0.21	0.34	20.18
Port Orchard (Non-BPC)	0.00	0.00	0.00	N/A
Port Susan (Non-BPC)	0.00	0.00	0.00	N/A
Possession Sound and Saratoga Passage	3.85	1.89	3.70	8.80
Puget Sound	33.22	30.83	30.65	5.92
Rich Passage and Sinclair Inlet	2.62	1.41	2.57	12.34
Rosario Strait	4.01	7.50	5.12	2.58
San Juan Islands (Non-BPC)	6.58	2.53	6.38	11.60
Skagit Bay (Non-BPC)	0.00	0.00	0.00	33.33
South Sound to Olympia	1.12	0.71	1.09	6.59
Southern Gulf Islands (Non-BPC)	19.65	10.80	18.63	10.07
Strait of Georgia	4.54	6.75	4.92	1.86
Strait of Georgia - Below 49th (Non-BPC)	3.11	2.30	3.10	2.39
Strait of Georgia South	0.02	0.02	0.01	1.54
All Zones	100.00	100.00	100.00	4.19

Table A-8: Average oil spill risk metrics per simulation by geographic zone, in study area.

Geographic Zone	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Admiralty Inlet	0.0433	37,628.5252	9.4071
Carr Inlet (Non-BPC)	0.0033	57,134.1989	2.2101
Case Inlet to Oakland Bay (Non-BPC)	0.0000	0.0000	0.0000
Colvos Passage	0.0000	0.0000	0.0000
Dyes Inlet (Non-BPC)	0.0007	495.0561	0.1436
Eastern Strait of Juan de Fuca	0.0000	0.0000	0.0000
Eld Inlet (Non-BPC)	0.0028	15,855.7709	0.9039
Guemes Channel and Saddlebags	0.0000	0.0000	0.0000
Haro Strait and Boundary Pass	0.0168	114,160.9143	5.9978
Hood Canal (Non-BPC)	0.0657	141,366.1375	17.3873
Lake Washington Ship Canal (Non-BPC)	0.0000	0.0000	0.0000
Port Orchard (Non-BPC)	0.0022	276.0552	0.4598
Port Susan (Non-BPC)	0.0000	0.0000	0.0000
Possession Sound and Saratoga Passage	0.0000	0.0000	0.0000
Puget Sound	0.0607	7,713.2775	12.9697
Rich Passage and Sinclair Inlet	0.2986	169,069.7538	63.6703
Rosario Strait	0.0425	4,393.6400	9.1377
San Juan Islands (Non-BPC)	0.0223	103,849.1440	7.4061
Skagit Bay (Non-BPC)	0.1148	6,286.5543	24.5575
South Sound to Olympia	0.0000	0.0317	0.0002
Southern Gulf Islands (Non-BPC)	0.0135	1,532.1913	2.8773
Strait of Georgia	0.3017	30,858.2893	62.8830
Strait of Georgia - Below 49th (Non-BPC)	0.0415	94,575.7994	8.2412
Strait of Georgia South	0.0598	12,608.1303	12.8243
Bellingham Channel, Sinclair Island, and waters to the East	0.0001	13.4424	0.0229
All Zones	1.0903	797,816.9121	241.0998

Geographic distribution: study area excluding car ferries

Primary risk metrics

Excluding car ferries, the top three zones for drift grounding risk in the study area were Puget Sound (42.46 percent), Haro Strait and Boundary Pass (21.15 percent), and Admiralty Inlet (7.29 percent) (Table A-9). The top three zones for oil volume at risk were Puget Sound (35.49 percent), Haro Strait and Boundary Pass (20.74 percent), and Rosario Strait (8.15 percent). The top three zones for oil outflow were Puget Sound (37.47 percent), Haro Strait and Boundary Pass (21.55 percent), and Admiralty Inlet (6.99 percent).

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

Drift grounding rates

The top three zones for drift grounding rates were Skagit Bay (33.33 percent) and Lake Washington Ship Canal (20.18 percent), and Rich Passage and Sinclair Inlet (14.29 percent).

Table A-9: Relative contribution of oil spill risk metrics by geographic zone excluding ferries, in study area excluding ferries.

Geographic Zone	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
Admiralty Inlet	7.29	6.57	6.99	2.15
Bellingham Channel, Sinclair Island, and waters to the East	3.20	4.70	4.17	4.39
Carr Inlet (Non-BPC)	0.00	0.00	0.00	NA
Case Inlet to Oakland Bay (Non-BPC)	0.00	0.00	0.00	NA
Colvos Passage	0.46	0.38	0.43	9.20
Dyes Inlet (Non-BPC)	0.00	0.00	0.00	NA
Eastern Strait of Juan de Fuca	1.45	1.58	1.64	0.38
Eld Inlet (Non-BPC)	0.00	0.00	0.00	NA
Guemes Channel and Saddlebags	4.72	8.95	6.99	9.35
Haro Strait and Boundary Pass	21.15	20.74	21.55	4.66
Hood Canal (Non-BPC)	0.00	0.00	0.00	0.00
Lake Washington Ship Canal (Non-BPC)	1.28	0.69	1.09	20.18
Port Orchard (Non-BPC)	0.00	0.00	0.00	NA
Port Susan (Non-BPC)	0.00	0.00	0.00	NA
Possession Sound and Saratoga Passage	0.49	0.30	0.38	5.50
Puget Sound	42.46	35.49	37.47	5.74
Rich Passage and Sinclair Inlet	0.06	0.11	0.10	14.29
Rosario Strait	5.39	8.15	6.94	2.44
San Juan Islands (Non-BPC)	0.00	0.00	0.00	0.00
Skagit Bay (Non-BPC)	0.00	0.00	0.00	33.33
South Sound to Olympia	0.79	0.59	0.75	16.95
Southern Gulf Islands (Non-BPC)	4.67	3.27	3.79	8.74
Strait of Georgia	5.45	7.61	6.65	1.72
Strait of Georgia - Below 49th (Non-BPC)	0.90	0.66	0.84	0.80
Strait of Georgia South	0.23	0.21	0.22	1.55
All Zones	100.00	100.00	100.00	3.63

Table A-10: Average oil spill risk metrics per simulation by geographic zone, study area excluding ferries.

Geographic Zone	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Admiralty Inlet	0.0186	37,030.3172	4.1321
Bellingham Channel, Sinclair Island, and waters to the East	0.0033	57,134.1989	2.2101
Carr Inlet (Non-BPC)	0.0000	0.0000	0.0000
Case Inlet to Oakland Bay (Non-BPC)	0.0000	0.0000	0.0000
Colvos Passage	0.0007	495.0561	0.1436
Dyes Inlet (Non-BPC)	0.0000	0.0000	0.0000
Eastern Strait of Juan de Fuca	0.0028	15,855.7709	0.9039
Eld Inlet (Non-BPC)	0.0000	0.0000	0.0000
Guemes Channel and Saddlebags	0.0049	113,597.3943	4.2156
Haro Strait and Boundary Pass	0.0652	141,268.6465	17.2803
Hood Canal (Non-BPC)	0.0000	0.0000	0.0000
Lake Washington Ship Canal (Non-BPC)	0.0022	276.0552	0.4598
Port Orchard (Non-BPC)	0.0000	0.0000	0.0000
Port Susan (Non-BPC)	0.0000	0.0000	0.0000
Possession Sound and Saratoga Passage	0.0018	2,164.1928	0.3880
Puget Sound	0.0837	147,177.3048	17.7275
Rich Passage and Sinclair Inlet	0.0000	1,110.1453	0.0490
Rosario Strait	0.0045	102,383.2483	3.5924
San Juan Islands (Non-BPC)	0.0000	0.0000	0.0000
Skagit Bay (Non-BPC)	0.0000	0.0317	0.0002
South Sound to Olympia	0.0025	1,275.4953	0.5250
Southern Gulf Islands (Non-BPC)	0.0087	5,064.4017	1.7002
Strait of Georgia	0.0130	92,134.2926	4.5346
Strait of Georgia - Below 49th (Non-BPC)	0.0026	4,765.5706	0.5990
Strait of Georgia South	0.0001	13.4424	0.0229
All Zones	0.2146	721745.5646	58.4842

Geographic distribution: BPC zones

Primary risk metrics

For BPC-defined zones, the top three zones for drift grounding risk were Puget Sound (47.75 percent), Haro Strait and Boundary Pass (15.80 percent), and Admiralty Inlet (7.00 percent) (Table A-11). The top three zones for oil volume at risk were Puget Sound (38.92 percent), Haro Strait and Boundary Pass (18.72 percent), and Guemes Channel and Saddlebags (8.74 percent). The top three zones for oil outflow were Puget Sound (43.50 percent), Haro Strait and Boundary Pass (16.36 percent), and Rosario Strait (6.92 percent).

Colvos Passage and Strait of Georgia South had the lowest values for all three primary risk metrics.

Drift grounding rates

The top three zones for drift grounding rates were Rich Passage and Sinclair Inlet (12.34 percent), Colvos Passage (9.20 percent), and Possession Sound and Saratoga Passage (8.80 percent) (Table A-11).

Table A-11: Relative contribution of oil spill risk metrics by geographic zone, BPC zones.

Geographic Zone	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
Admiralty Inlet	7.00	6.34	6.71	2.31
Bellingham Channel, Sinclair Island, and waters to the East	2.59	4.52	3.36	4.38
Colvos Passage	0.17	0.07	0.11	9.20
Eastern Strait of Juan de Fuca	0.96	1.40	1.09	0.38
Guemes Channel and Saddlebags	4.20	8.74	5.83	8.97
Haro Strait and Boundary Pass	15.80	18.72	16.36	4.66
Possession Sound and Saratoga Passage	4.63	2.15	4.39	8.80
Puget Sound	47.75	38.92	43.50	5.92
Rich Passage and Sinclair Inlet	3.24	1.75	3.18	12.34
Rosario Strait	5.64	8.46	6.92	2.58
South Sound to Olympia	1.51	0.96	1.52	6.59
Strait of Georgia	6.27	7.76	6.80	1.86
Strait of Georgia South	0.23	0.21	0.21	1.54
All BPC Zones	100.00	100.00	100.00	3.76

Table A-12: Average oil spill risk metrics per simulation by geographic zone, BPC zones.

Geographic Zone	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Admiralty Inlet	0.0433	37,628.5252	9.4071
Bellingham Channel, Sinclair Island, and waters to the East	0.0033	57,134.1989	2.2101
Colvos Passage	0.0007	495.0561	0.1436
Eastern Strait of Juan de Fuca	0.0028	15,855.7709	0.9039
Guemes Channel and Saddlebags	0.0168	114,160.9143	5.9978
Haro Strait and Boundary Pass	0.0657	141,366.1375	17.3873
Possession Sound and Saratoga Passage	0.0607	7,713.2775	12.9697
Puget Sound	0.2986	169,069.7538	63.6703

Geographic Zone	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Rich Passage and Sinclair Inlet	0.0425	4,393.6400	9.1377
Rosario Strait	0.0223	103,849.1440	7.4061
South Sound to Olympia	0.0135	1,532.1913	2.8773
Strait of Georgia	0.0415	94,575.7994	8.2412
Strait of Georgia South	0.0001	13.4424	0.0229
All zones	0.6118	747,787.8513	140.3750

Geographic Distribution: BPC zones excluding car ferries

Primary risk metrics

The top three BPC zones for drift groundings excluding car ferries were Puget Sound (45.71 percent), Haro Strait and Boundary Pass (22.58 percent), and Admiralty Inlet (7.73 percent) (Table A-13). The top three zones for oil volume at risk were Puget Sound (37.90 percent), Haro Strait and Boundary Pass (21.63 percent), and Guemes Channel and Saddlebags (9.28 percent). The top three zones for oil outflow were Puget Sound (40.17 percent), Haro Strait and Boundary Pass (22.85 percent), and Guemes Channel and Saddlebags (7.45 percent).

Colvos Passage, Rich Passage and Sinclair Inlet, and Strait of Georgia South had the lowest values for all three primary risk metrics.

Drift grounding rates

The top three zones for drift grounding rates were South Sound to Olympia (16.95 percent), Rich Passage and Sinclair Inlet (14.29 percent), and Guemes Channel and Saddlebags (9.35 percent) (Table A-13).

Table A-13: Relative contribution of oil spill risk metrics by geographic zone, BPC zones excluding ferries.

Geographic Zone	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
Admiralty Inlet	7.73	6.78	7.30	2.15
Bellingham Channel, Sinclair Island, and waters to the East	3.47	4.80	4.33	4.39
Colvos Passage	0.49	0.39	0.44	9.20
Eastern Strait of Juan de Fuca	1.54	1.62	1.71	0.38
Guemes Channel and Saddlebags	5.25	9.28	7.45	9.35
Haro Strait and Boundary Pass	22.58	21.63	22.85	4.66
Possession Sound and Saratoga Passage	0.50	0.31	0.39	5.50
Puget Sound	45.71	37.90	40.17	5.74
Rich Passage and Sinclair Inlet	0.06	0.11	0.10	14.29
Rosario Strait	5.79	8.42	7.24	2.44
South Sound to Olympia	0.83	0.67	0.82	16.95
Strait of Georgia	5.81	7.88	6.97	1.72

Geographic Zone	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
Strait of Georgia South	0.24	0.22	0.22	1.55
All BPC Zones excluding ferries	100.00	100.00	100.00	3.50

Table A-14: Average oil spill risk metrics per simulation by geographic zone, BPC zones excluding ferries.

Geographic Zone	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Admiralty Inlet	0.0186	37,030.3172	4.1321
Bellingham Channel, Sinclair Island, and waters to the East	0.0033	57,134.1989	2.2101
Colvos Passage	0.0007	495.0561	0.1436
Eastern Strait of Juan de Fuca	0.0028	15,855.7709	0.9039
Guemes Channel and Saddlebags	0.0049	113,597.3943	4.2156
Haro Strait and Boundary Pass	0.0652	141,268.6465	17.2803
Possession Sound and Saratoga Passage	0.0018	2,164.1928	0.3880
Puget Sound	0.0837	147,177.3048	17.7275
Rich Passage and Sinclair Inlet	0.0000	1,110.1453	0.0490
Rosario Strait	0.0045	102,383.2483	3.5924
South Sound to Olympia	0.0025	1,275.4953	0.5250
Strait of Georgia	0.0130	92,134.2926	4.5346
Strait of Georgia South	0.0001	13.4424	0.0229
All zones	0.2011	711,639.5054	55.7250

Vessel type distribution: study area

Primary risk metrics

The top three vessel types for drift grounding risk were car ferries (51.08 percent of all drift groundings), container ships (12.75 percent), and bulk carriers (6.38 percent) (Table A-15). The top three vessel types for oil volume at risk were car ferries (25.68 percent), container ships (18.08 percent), and crude tankers (16.22 percent). The top three vessel types for oil outflow risk were car ferries (49.18 percent), container ships (11.83 percent) and bulk carriers (6.11 percent).

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

Drift grounding rates

The three vessel types with the highest drift grounding rates were car ferries (8.71 percent), container ships (5.30 percent), and bunkering barges (4.92 percent) (Table A-15).

Vessel type distribution: study area excluding car ferries

Primary risk metrics

The top three vessel types for drift grounding risk in the study area excluding car ferries were container ships (21.54 percent), vehicle ships (12.99 percent), and towed oil barges (12.08 percent) (Table A-17).

The top three for oil volume at risk were container ships (20.38 percent), crude tankers (17.91 percent), and vehicle ships (12.82 percent). The top three for oil outflow were container ships (19.70 percent), crude tankers (12.72 percent), and vehicle ships (12.51 percent).

ATBs and liquified gas tankers had the lowest values for the primary oil spill risk metrics across vessel types.

Drift grounding rates

The top three vessel types for drift grounding rates were container ships (5.30 percent), towed oil barges (5.21 percent), and bunkering barges (4.92 percent) (Table A-17).

Table A-15: Relative contribution of oil spill risk metrics by vessel type in study area.

Vessel Type	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
ATB	0.60	0.46	0.44	1.66
Bulk Carrier	6.38	6.67	6.11	3.63
Container Ship	12.75	18.08	11.83	5.30
Cruise Ship	2.32	2.61	2.21	2.59
Ferry Car	51.08	25.68	49.18	8.71
Fishing Vessel (Large)	2.33	1.11	2.06	2.39
General/Other Cargo Ship (Large)	3.13	2.50	2.75	3.54
Tanker (Chemical)	2.74	7.43	4.47	2.33
Tanker (Crude)	3.46	16.22	6.17	3.96
Tanker (Liquefied Gas)	0.89	0.83	0.90	1.90
Tanker (Product)	1.92	6.22	3.46	2.64
Towing Vessel (Oil)	5.13	3.23	3.70	5.21
Towing Vessel (Oil) – Bunkering	1.07	0.50	0.59	4.92
Vehicle Carrier	6.21	8.47	6.14	4.22
All Vessel Types	100.00	100.00	100.00	4.19

Table A-16: Average oil spill risk metrics per simulation by vessel type in study area.

Vessel Type	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
ATB	0.0005	75.3379	0.0576
Bulk Carrier	0.0607	41,736.0238	12.9864
Container Ship	0.0890	207,193.3305	19.0329
Cruise Ship	0.0049	3,416.0154	1.0379
Ferry Car	0.8755	76,071.3475	182.6155
Fishing Vessel (Large)	0.0099	1,540.6336	2.1171
General/Other Cargo Ship (Large)	0.0107	5,187.6707	2.2788
Tanker (Chemical)	0.0057	82,012.4860	5.6145
Tanker (Crude)	0.0075	285,204.8457	7.3903

Vessel Type	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Tanker (Liquefied Gas)	0.0004	138.6168	0.0937
Tanker (Product)	0.0044	80,640.9128	4.3088
Towing Vessel (Oil)	0.0044	29.7105	0.2166
Towing Vessel (Oil) – Bunkering	0.0010	4.3672	0.0318
Vehicle Carrier	0.0155	14,565.6136	3.3175
All vessel types	1.0901	797,816.9120	241.0994

Table A-17: Relative contribution of oil spill risk metrics by vessel type in study area, excluding ferries.

Vessel Type	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
ATB	1.59	1.39	1.32	1.66
Bulk Carrier	10.81	8.32	10.21	3.63
Container Ship	21.54	20.38	19.70	5.30
Cruise Ship	5.20	4.51	4.88	2.59
Fishing Vessel (Large)	6.23	3.12	5.61	2.39
General/Other Cargo Ship (Large)	7.10	4.82	6.47	3.54
Tanker (Chemical)	5.24	8.61	7.69	2.33
Tanker (Crude)	8.16	17.91	12.72	3.96
Tanker (Liquefied Gas)	1.89	1.96	2.07	1.90
Tanker (Product)	4.05	6.88	6.11	2.64
Towing Vessel (Oil)	12.08	7.55	8.77	5.21
Towing Vessel (Oil) – Bunkering	3.13	1.74	1.93	4.92
Vehicle Carrier	12.99	12.82	12.51	4.22
All Vessel Types	100.00	100.00	100.00	3.63

Table A-18: Average oil spill risk metrics per simulation by vessel type in study area, excluding ferries.

Vessel Type	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
ATB	0.0005	75.3379	0.0576
Bulk Carrier	0.0607	41,736.0238	12.9864
Container Ship	0.0890	207,193.3305	19.0329
Cruise Ship	0.0049	3,416.0154	1.0379
Fishing Vessel (Large)	0.0099	1,540.6336	2.1171
General/Other Cargo Ship (Large)	0.0107	5,187.6707	2.2788
Tanker (Chemical)	0.0057	82,012.4860	5.6145
Tanker (Crude)	0.0075	285,204.8457	7.3903
Tanker (Liquefied Gas)	0.0004	138.6168	0.0937
Tanker (Product)	0.0044	80,640.9128	4.3088
Towing Vessel (Oil)	0.0044	29.7105	0.2166

Vessel Type	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Towing Vessel (Oil) – Bunkering	0.0010	4.3672	0.0318
Vehicle Carrier	0.0155	14,565.6136	3.3175
All vessel types	0.2146	721,745.5645	58.4839

Vessel type distribution: BPC zones

Primary risk metrics

The vessel type results differed slightly when only considering BPC-defined zones (Table A-19). The top three for drift grounding risk were car ferries (30.02 percent), container ships (16.67 percent), and vehicle ships (10.02 percent). The top three for oil volume at risk were container ships (19.10 percent), crude tankers (17.35 percent), and car ferries (15.33 percent). The top three for oil outflow were car ferries (28.69 percent), container ships (15.23 percent), and vehicle ships (9.69 percent).

Similar to the results for the entire study area, ATBs, liquefied gas tankers, and bunkering barges had the lowest values for the primary risk metrics.

Drift grounding rates

The top three vessel type for grounding rates within BPC zones only were car ferries (7.27 percent), container ships (5.32 percent), and bunkering barges (4.78 percent) (Table A-19).

Vessel type distribution: BPC zones excluding car ferries

Primary risk metrics

The top three vessels for drift groundings in BPC zones excluding car ferries were container ships (21.99 percent), vehicle ships (13.83 percent), and towed oil barges (10.74 percent) (Table A-21). The top three for oil volume at risk were container ships (20.63 percent), crude tankers (18.44 percent), and vehicle ships (13.44 percent). The top three for oil outflow were container ships (20.09 percent), crude tankers (13.43 percent), and vehicle ships (13.17 percent).

Drift grounding rates

The top three vessel type for drift groundings in BPC zones excluding car ferries were container ships (5.30 percent), towed oil barges (5.21 percent), and bunkering barges (4.92 percent) (Table A-21).

Table A-19: Relative contribution of oil spill risk metrics by vessel type in BPC zones.

Vessel Type	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
ATB	1.13	0.91	0.90	1.71
Bulk Carrier	7.85	6.67	7.44	3.73
Container Ship	16.67	19.10	15.23	5.32
Cruise Ship	3.66	3.23	3.34	2.61
Ferry (Car)	30.02	15.33	28.69	7.27
Fishing Vessel (Large)	2.98	1.54	2.73	1.97
General/Other Cargo Ship (Large)	4.43	3.41	4.02	3.50

Vessel Type	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
Tanker (Chemical)	3.69	7.98	5.80	2.45
Tanker (Crude)	6.18	17.35	9.70	4.00
Tanker (Liquefied Gas)	1.55	1.38	1.52	1.90
Tanker (Product)	2.87	6.62	4.69	2.66
Towing Vessel (Oil)	6.89	4.17	4.86	4.47
Towing Vessel (Oil) – Bunkering	2.06	1.28	1.40	4.78
Vehicle Carrier	10.02	11.02	9.69	4.30
All Vessel Types	100.00	100.00	100.00	3.76

Table A-20: Average oil spill risk metrics per simulation by vessel type in BPC zones.

Vessel Type	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
ATB	0.0005	70.5236	0.0541
Bulk Carrier	0.0539	37,602.4306	11.5310
Container Ship	0.0877	203,852.4160	18.7549
Cruise Ship	0.0048	3,409.0138	1.0293
Ferry (Car)	0.4105	36,148.3458	84.6501
Fishing Vessel (Large)	0.0072	1,118.4340	1.5290
General/Other Cargo Ship (Large)	0.0097	4,670.5437	2.0701
Tanker (Chemical)	0.0057	80,959.9428	5.5362
Tanker (Crude)	0.0075	285,204.8457	7.3903
Tanker (Liquefied Gas)	0.0004	138.6168	0.0937
Tanker (Product)	0.0044	80,285.5613	4.2843
Towing Vessel (Oil)	0.0034	23.5177	0.1715
Towing Vessel (Oil) – Bunkering	0.0008	3.6391	0.0265
Vehicle Carrier	0.0152	14,300.0202	3.2539
All vessel types	0.6117	747,787.8511	140.3749

Table A-21: Relative contribution of oil spill risk metrics by vessel type in BPC zones, excluding ferries.

Vessel Type	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
ATB	1.80	1.54	1.50	1.71
Bulk Carrier	9.96	7.49	9.35	3.73
Container Ship	21.99	20.63	20.09	5.32
Cruise Ship	5.47	4.53	5.01	2.61
Fishing Vessel (Large)	4.78	2.33	4.36	1.97
General/Other Cargo Ship (Large)	7.04	4.87	6.45	3.50
Tanker (Chemical)	5.49	8.73	7.90	2.45
Tanker (Crude)	9.02	18.44	13.43	4.00
Tanker (Liquefied Gas)	2.06	2.04	2.17	1.90

Vessel Type	Drift Grounding (%)	Oil Volume at Risk (%)	Oil Outflow (%)	Grounding Rate (%)
Tanker (Product)	4.45	7.05	6.41	2.66
Towing Vessel (Oil)	10.74	6.74	7.85	4.47
Towing Vessel (Oil) – Bunkering	3.37	2.16	2.31	4.78
Vehicle Carrier	13.83	13.44	13.17	4.30
All Vessel Types (excluding ferries)	100.00	100.00	100.00	3.50

Table A-22: Average oil spill risk metrics per simulation by vessel type in BPC zones, excluding ferries.

Vessel Type	Drift Groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
ATB	0.0005	70.5236	0.0541
Bulk Carrier	0.0539	37,602.4306	11.5310
Container Ship	0.0877	203,852.4160	18.7549
Cruise Ship	0.0048	3,409.0138	1.0293
Fishing Vessel (Large)	0.0072	1,118.4340	1.5290
General/Other Cargo Ship (Large)	0.0097	4,670.5437	2.0701
Tanker (Chemical)	0.0057	80,959.9428	5.5362
Tanker (Crude)	0.0075	285,204.8457	7.3903
Tanker (Liquefied Gas)	0.0004	138.6168	0.0937
Tanker (Product)	0.0044	80,285.5613	4.2843
Towing Vessel (Oil)	0.0034	23.5177	0.1715
Towing Vessel (Oil) – Bunkering	0.0008	3.6391	0.0265
Vehicle Carrier	0.0152	14,300.0202	3.2539
All Vessel Types (excluding ferries)	0.2012	711,639.5053	55.7248

Comparing escort tug scenarios: Scenario 1 to Scenario 2

Geographic distribution: study area

Primary risk metrics

Value for the three primary risk metrics mostly decreased modestly or were similar across study area geographic zones between Scenario 1 and Scenario 2 (Table A-23). Some zones had large increases, and a few had modest increases.35 The three zones with the largest changes in drift groundings were Strait of Georgia South (-22.41 percent), Eastern Strait of Juan de Fuca (-8.42 percent), and Rich Passage and Sinclair Inlet (+8.04 percent). The three zones with the largest changes in oil volume at risk were Eastern Strait of Juan de Fuca (-10.02 percent), Bellingham Channel, Sinclair Island, and waters to the East (-6.20 percent), and Strait of Georgia South (-5.63 percent). The three zones with the largest

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[35] A decrease in risk moving from Scenario 1 to Scenario 2 is indicated by a negative number where as positive number represents an increase in oil risk metrics.

changes in oil outflow were Rich Passage and Sinclair Inlet (+8.00 percent), Strait of Georgia South (-7.86 percent), and Bellingham Channel, Sinclair Island, and waters to the East (-6.56 percent).

Drift grounding rates

The zones with the largest changes in drift grounding rates in the study area were Strait of Georgia South (-0.96 percent), Rich Passage and Sinclair Inlet (+0.85 percent), and Colvos Passage (+0.57 percent) (Table A-23).

Geographic distribution: study area excluding car ferries

Primary risk metrics

Results for the primary risk metrics in the study area with car ferries excluded were similar to results with the inclusion of car ferries (Table A-25). The three zones with the largest changes in the drift grounding risk metric were San Juan Islands (-100.00 percent), Strait of Georgia South (-22.41 percent), and Strait of Georgia - Below 49th (-18.55 percent). The three zones with the largest changes in oil volume at risk were, San Juan Islands (-100.00 percent), Strait of Georgia - Below 49th (-11.70 percent) and Eastern Strait of Juan de Fuca (-10.02 percent). The three zones with the largest changes in oil outflow were San Juan Islands (-100.00 percent), Strait of Georgia - Below 49th (-18.47 percent), and Strait of Georgia South (-7.86 percent).

Drift grounding rates

The three zones with the largest changes in drift grounding rates in the study area with car ferries excluded were San Juan Islands (-4.55 percent), Strait of Georgia South (-0.96 percent), and Colvos Passage (+0.57 percent) (Table A-25).

Table A-23: Oil spill risk metric relative changes between Scenario 1 and Scenario 2 by geographic zone, study area.

Geographic Zone	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
Admiralty Inlet	1.95	-4.98	2.06	2.42	-0.11
Bellingham Channel, Sinclair Island, and waters to the East	-5.99	-6.20	-6.56	4.74	-0.36
Carr Inlet (Non-BPC)	NA	NA	NA	NA	NA
Case Inlet to Oakland Bay (Non-BPC)	NA	NA	NA	0.00	0.00
Colvos Passage	1.81	0.02	0.41	8.62	0.57
Dyes Inlet (Non-BPC)	NA	NA	NA	NA	NA
Eastern Strait of Juan de Fuca	-8.42	-10.02	-5.00	0.45	-0.07
Eld Inlet (Non-BPC)	NA	NA	NA	NA	NA
Guemes Channel and Saddlebags	-0.60	-1.62	-0.90	9.33	-0.35
Haro Strait and Boundary Pass	-0.29	-2.23	-0.92	4.70	-0.03

Geographic Zone	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
Hood Canal (Non-BPC)	NA	NA	NA	0.00	0.00
Lake Washington Ship Canal (Non-BPC)	0.00	0.00	0.00	20.18	0.00
Port Orchard (Non-BPC)	NA	NA	NA	NA	NA
Port Susan (Non-BPC)	NA	NA	NA	NA	NA
Possession Sound and Saratoga Passage	0.00	0.00	0.00	8.80	0.00
Puget Sound	-0.81	-1.56	-0.84	5.87	0.04
Rich Passage and Sinclair Inlet	8.04	3.88	8.00	11.49	0.85
Rosario Strait	-1.88	-2.92	-2.57	2.94	-0.36
San Juan Islands (Non-BPC)	-0.01	0.00	0.00	11.68	-0.08
Skagit Bay (Non-BPC)	0.00	0.00	0.00	33.33	0.00
South Sound to Olympia	0.00	0.00	0.00	6.59	0.00
Southern Gulf Islands (Non-BPC)	-0.62	-0.09	-0.48	10.38	-0.31
Strait of Georgia	-3.52	-4.18	-5.42	1.95	-0.09
Strait of Georgia - Below 49th (Non-BPC)	-0.98	-4.77	-1.05	2.50	-0.11
Strait of Georgia South	-22.41	-5.63	-7.86	2.50	-0.96
All vessels - All zones	-0.33	-2.81	-0.50	4.29	-0.10

Table A-24: Average differences in oil spill risk metrics per simulation between Scenario 1 and Scenario 2 (Scenario 2 – Scenario 1) by geographic zone, study area.

Geographic Zone	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Admiralty Inlet	0.0008	-1,972.4075	0.1897
Bellingham Channel, Sinclair Island, and waters to the East	-0.0002	-3,774.3570	-0.1553
Carr Inlet (Non-BPC)	0.0000	0.0000	0.0000
Case Inlet to Oakland Bay (Non-BPC)	0.0000	0.0000	0.0000
Colvos Passage	0.0000	0.0810	0.0006
Dyes Inlet (Non-BPC)	0.0000	0.0000	0.0000
Eastern Strait of Juan de Fuca	-0.0003	-1,765.3649	-0.0476
Eld Inlet (Non-BPC)	0.0000	0.0000	0.0000
Guemes Channel and Saddlebags	-0.0001	-1,883.7956	-0.0546
Haro Strait and Boundary Pass	-0.0002	-3,217.9312	-0.1609
Hood Canal (Non-BPC)	0.0000	0.0000	0.0000
Lake Washington Ship Canal (Non-BPC)	0.0000	0.0000	0.0000
Port Orchard (Non-BPC)	0.0000	0.0000	0.0000

Geographic Zone	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Port Susan (Non-BPC)	0.0000	0.0000	0.0000
Possession Sound and Saratoga Passage	0.0000	0.0000	0.0000
Puget Sound	-0.0024	-2,671.3012	-0.5394
Rich Passage and Sinclair Inlet	0.0032	163.9637	0.6772
Rosario Strait	-0.0004	-3,121.1745	-0.1956
San Juan Islands (Non-BPC)	0.0000	-0.1057	-0.0008
Skagit Bay (Non-BPC)	0.0000	0.0000	0.0000
South Sound to Olympia	0.0000	0.0000	0.0000
Southern Gulf Islands (Non-BPC)	-0.0019	-28.5241	-0.3055
Strait of Georgia	-0.0015	-4,127.6180	-0.4719
Strait of Georgia - Below 49th (Non-BPC)	-0.0006	-631.7566	-0.1357
Strait of Georgia South	0[**]	-0.8017	-0.0020
All Zones	-0.0036	-23,031.0933	-1.2018

Table A-25: Oil spill risk metric relative changes between Scenario 1 and Scenario 2 by geographic zone, study area, excluding ferries.

Geographic Zone	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
Admiralty Inlet	-2.65	-5.13	-2.26	2.28	-0.13
Bellingham Channel, Sinclair Island, and waters to the East	-5.99	-6.20	-6.56	4.75	-0.36
Carr Inlet (Non-BPC)	NA	NA	NA	NA	NA
Case Inlet to Oakland Bay (Non-BPC)	NA	NA	NA	NA	NA
Colvos Passage	1.81	0.02	0.41	8.62	0.57
Dyes Inlet (Non-BPC)	NA	NA	NA	NA	NA
Eastern Strait of Juan de Fuca	-8.42	-10.02	-5.00	0.46	-0.07
Eld Inlet (Non-BPC)	NA	NA	NA	NA	NA
Guemes Channel and Saddlebags	-2.01	-1.63	-1.28	9.83	-0.48
Haro Strait and Boundary Pass	-0.29	-2.23	-0.92	4.70	-0.03
Hood Canal (Non-BPC)	NA	NA	NA	0.00	0.00
Lake Washington Ship Canal (Non-BPC)	0.00	0.00	0.00	20.18	0.00
Port Orchard (Non-BPC)	NA	NA	NA	NA	NA
Port Susan (Non-BPC)	NA	NA	NA	NA	NA

[**] Value between 0 and -0.0001.

Geographic Zone	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
Possession Sound and Saratoga Passage	0.00	0.00	0.00	5.50	0.00
Puget Sound	-3.21	-1.77	-3.33	5.69	0.05
Rich Passage and Sinclair Inlet	0.00	0.00	0.00	14.29	0.00
Rosario Strait	-8.73	-2.96	-5.16	2.81	-0.37
San Juan Islands (Non-BPC)	-100.00	-100.00	-100.00	4.55	-4.55
Skagit Bay (Non-BPC)	0.00	0.00	0.00	33.33	0.00
South Sound to Olympia	0.00	0.00	0.00	16.95	0.00
Southern Gulf Islands (Non-BPC)	-0.64	-0.07	-0.27	9.28	-0.54
Strait of Georgia	-1.36	-4.18	-3.95	1.81	-0.09
Strait of Georgia - Below 49th (Non-BPC)	-18.55	-11.70	-18.47	0.94	-0.14
Strait of Georgia South	-22.41	-5.63	-7.86	2.52	-0.96
All zones	-2.42	-3.10	-2.74	3.75	-0.11

Table A-26: Average differences in oil spill risk metrics per simulation between Scenario 1 and Scenario 2 (Scenario 2 - Scenario 1) by geographic zone, study area, excluding ferries.

Geographic Zone	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Admiralty Inlet	-0.0005	-2,003.5222	-0.0955
Bellingham Channel, Sinclair Island, and waters to the East	-0.0002	-3,774.3570	-0.1553
Carr Inlet (Non-BPC)	0.0000	0.0000	0.0000
Case Inlet to Oakland Bay (Non-BPC)	0.0000	0.0000	0.0000
Colvos Passage	0.0000	0.0810	0.0006
Dyes Inlet (Non-BPC)	0.0000	0.0000	0.0000
Eastern Strait of Juan de Fuca	-0.0003	-1,765.3649	-0.0476
Eld Inlet (Non-BPC)	0.0000	0.0000	0.0000
Guemes Channel and Saddlebags	-0.0001	-1,883.7956	-0.0546
Haro Strait and Boundary Pass	-0.0002	-3,217.9312	-0.1609
Hood Canal (Non-BPC)	0.0000	0.0000	0.0000
Lake Washington Ship Canal (Non-BPC)	0.0000	0.0000	0.0000
Port Orchard (Non-BPC)	0.0000	0.0000	0.0000
Port Susan (Non-BPC)	0.0000	0.0000	0.0000
Possession Sound and Saratoga Passage	0.0000	0.0000	0.0000
Puget Sound	-0.0028	-2,647.1733	-0.6106
Rich Passage and Sinclair Inlet	0.0000	0.0000	0.0000
Rosario Strait	-0.0004	-3,121.1745	-0.1956
San Juan Islands (Non-BPC)	0.0000	-0.1057	-0.0008

Geographic Zone	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Skagit Bay (Non-BPC)	0.0000	0.0000	0.0000
South Sound to Olympia	0.0000	0.0000	0.0000
Southern Gulf Islands (Non-BPC)	-0.0001	-3.7741	-0.0046
Strait of Georgia	-0.0002	-4,016.0513	-0.1867
Strait of Georgia - Below 49th (Non-BPC)	-0.0006	-631.7566	-0.1357
Strait of Georgia South	0[**]	-0.8017	-0.0020
All Zones	-0.0054	-23,065.7271	-1.6493

Vessel type distribution: study area

Primary risk metrics

Values for primary oil spill risk metrics mostly decreased though some modestly increased (Table A-27). The mean change in drift grounding risk was -0.33 percent and the vessel types with the largest changes in drift groundings were ATBs (-15.38 percent), towed oil barges (-7.79 percent), and chemical tankers (-7.13 percent). The mean change in oil volume at risk was -2.81 percent and the largest changes in oil volume at risk were for ATBs (-16.29 percent), towed oil barges (-8.24 percent), and chemical tankers (-6.38 percent). The mean change in oil outflow was -0.10 percent and the largest changes in oil outflow were for ATBs (-15.38 percent), towed oil barges (-8.24 percent), and chemical tankers (-7.13 percent).

Drift grounding rates

The largest changes in drift grounding rates were for towed oil barges (-0.55 percent), bunkering barges (+0.33 percent), and ATBs (-0.29 percent).

Table A-27: Oil spill risk metric relative changes between Scenario 1 and Scenario 2 by vessel type in study area.

Vessel Type	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
ATB	-15.38	-16.29	-15.38	1.95	-0.29
Bulk Carrier	-4.55	-5.11	-4.55	3.78	-0.15
Container Ship	-0.89	-1.59	-0.89	5.34	-0.04
Cruise Ship	-0.27	0.11	-0.27	2.56	0.03
Ferry (Car)	0.19	0.05	0.25	8.71	0.01
Fishing Vessel (Large)	1.02	4.41	1.02	2.33	0.06
General/Other Cargo Ship (Large)	-4.38	-3.87	-4.38	3.69	-0.14
Tanker (Chemical)	-7.13	-6.38	-7.13	2.51	-0.18
Tanker (Crude)	-3.58	-3.82	-3.58	4.10	-0.14
Tanker (Liquefied Gas)	1.15	0.30	1.15	1.88	0.02

[**] Value between 0 and -0.0001.

Vessel Type	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
Tanker (Product)	-0.56	-0.42	-0.56	2.68	-0.04
Towing Vessel (Oil)	-7.79	-8.24	-8.24	5.76	-0.55
Towing Vessel (Oil) – Bunkering	5.17	5.51	5.51	4.59	0.33
Vehicle Carrier	-0.48	-0.33	-0.48	4.14	0.08
All types	-0.33	-2.81	-0.50	4.29	-0.10

Table A-28: Average differences in oil spill risk metrics per simulation between Scenario 1 and Scenario 2 (Scenario 2 - Scenario 1) by vessel type in study area.

Vessel Type	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
ATB	-0.0001	-14.6596	-0.0105
Bulk Carrier	-0.0029	-2,246.4017	-0.6196
Container Ship	-0.0008	-3,345.6582	-0.1711
Cruise Ship	0.0000	3.6639	-0.0029
Ferry (Car)	0.0017	34.6338	0.4475
Fishing Vessel (Large)	0.0001	65.0127	0.0214
General/Other Cargo Ship (Large)	-0.0005	-209.0764	-0.1044
Tanker (Chemical)	-0.0004	-5,590.8290	-0.4309
Tanker (Crude)	-0.0003	-11,337.9820	-0.2742
Tanker (Liquefied Gas)	0[*]	0.4127	0.0011
Tanker (Product)	0.0000	-339.5780	-0.0245
Towing Vessel (Oil)	-0.0004	-2.6692	-0.0195
Towing Vessel (Oil) – Bunkering	0[*]	0.2282	0.0017
Vehicle Carrier	-0.0001	-48.1906	-0.0159
All vessel types	-0.0037	-23,031.0934	-1.2018

Vessel type distribution: BPC zones

Primary risk metrics

Values for primary oil spill risk metrics mostly decreased though some modestly increased (Table A-29). The mean change in drift groundings was -0.19 percent and the vessel types with the largest changes in drift groundings were ATBs (-12.68 percent), towed oil barges (-8.50 percent), and chemical tankers (-7.02 percent). The mean change in oil volume at risk was -2.21 percent and the largest changes in oil volume at risk were for ATBs (-13.00 percent), towed oil barges (-8.68 percent), and chemical tankers (-6.25 percent).

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[*] Value between 0 and 0.0001

Drift grounding rates

The largest changes in drift grounding rates were for towed oil barges (-0.51 percent), bunkering barges (+0.43 percent), and ATBs (-0.22 percent) (Table A-29).

Table A-29: Oil spill risk metric relative changes between Scenario 1 and Scenario 2 (Scenario 2 - Scenario 1) by vessel type in BPC zones.

Vessel Type	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding rate	Grounding Rate Change
ATB	-12.68	-13.00	-12.68	1.94	-0.22
Bulk Carrier	-4.13	-4.60	-4.13	3.90	-0.17
Container Ship	-0.90	-1.61	-0.90	5.38	-0.06
Cruise Ship	-0.28	0.11	-0.28	2.58	0.02
Ferry (Car)	0.86	0.16	0.89	7.21	0.06
Fishing Vessel (Large)	1.42	6.17	1.42	1.91	0.05
General/Other Cargo Ship (Large)	-4.80	-4.11	-4.80	3.67	-0.17
Tanker (Chemical)	-7.02	-6.25	-7.02	2.61	-0.16
Tanker (Crude)	-3.58	-3.82	-3.58	4.14	-0.14
Tanker (Liquefied Gas)	1.15	0.30	1.15	1.88	0.02
Tanker (Product)	-0.57	-0.42	-0.57	2.70	-0.04
Towing Vessel (Oil)	-8.50	-8.68	-8.68	4.97	-0.51
Towing Vessel (Oil) – Bunkering	6.28	6.69	6.69	4.35	0.43
Vehicle Carrier	-0.49	-0.34	-0.49	4.21	0.09
All types	-0.19	-2.90	-0.54	3.84	-0.09
Total (excluding ferries)	-2.27	-3.06	-2.64	3.60	-0.10

Table A-30: Average differences in oil spill risk metrics per simulation between Scenario 1 and Scenario 2 (Scenario 2 - Scenario 1) by vessel type in BPC zones.

Vessel Type	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
ATB	-0.0001	-10.5382	-0.0079
Bulk Carrier	-0.0023	-1,813.2017	-0.4974
Container Ship	-0.0008	-3,345.6582	-0.1711
Cruise Ship	0.0000	3.6639	-0.0029
Ferry (Car)	0.0035	59.3838	0.7485
Fishing Vessel (Large)	0.0001	65.0127	0.0214
General/Other Cargo Ship (Large)	-0.0005	-200.3354	-0.1044
Tanker (Chemical)	-0.0004	-5,401.6879	-0.4178
Tanker (Crude)	-0.0003	-11,337.9820	-0.2742

Vessel Type	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Tanker (Liquefied Gas)	0*	0.4127	0.0011
Tanker (Product)	0**	-339.5780	-0.0245
Towing Vessel (Oil)	-0.0003	-2.2363	-0.0163
Towing Vessel (Oil) – Bunkering	0*	0.2282	0.0017
Vehicle Carrier	-0.0001	-48.1906	-0.0159
All vessel types	-0.0012	-22,370.7070	-0.7597
Total (excluding ferries)	-0.0047	-22,430.0907	-1.5081

Comparing escort tug scenarios: Scenario 2 to Scenario 3

Geographic distribution: study area

Primary risk metrics

Modest increases and decreases occurred in values of the primary risk metrics across the study area from Scenario 2 to Scenario 3 (Table A-31).[36] The mean change in drift grounding rate across geographic zones in the study area was -0.43 percent and the largest changes for this metric were in Eastern Strait of Juan de Fuca (+7.21 percent), Colvos Passage (-6.94 percent), and Rich Passage and Sinclair Inlet (-4.31 percent). The mean change in oil volume at risk was -0.17 percent and the largest changes for this metric were in Strait of Georgia - Below 49th (-9.52 percent), Admiralty Inlet (-4.62 percent), and Rich Passage and Sinclair Inlet (-2.16 percent).The mean change in oil outflow was -0.30 percent and the largest changes for this metric were in Eastern Strait of Juan de Fuca (+5.43 percent), Rich Passage and Sinclair Inlet (-4.29 percent), and South Sound to Olympia (+3.71 percent).

Drift grounding rates

The larges changes in drift grounding rates were in Colvos Passage (-2.59 percent), Puget Sound (-0.60 percent), and Rich Passage and Sinclair Inlet (-0.51 percent) (Table A-31).

Table A-31: Oil spill risk metric relative changes between Scenario 2 and Scenario 3 by geographic zone, study area.

Geographic Zone	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Grounding Rate	Grounding Rate Change
Admiralty Inlet	-3.40	-4.62	-3.07	2.31	-0.48
Bellingham Channel, Sinclair Island, and waters to the East	0.00	0.00	0.00	4.38	0.00
Carr Inlet (Non-BPC)	NA	NA	NA	NA	NA
Case Inlet to Oakland Bay (Non-BPC)	NA	NA	NA	0.00	0.00

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* Value between 0 and 0.0001

** Value between 0 and -0.0001

[36] A decrease in risk moving from Scenario 2 to Scenario 3 is indicted by a negative number where as positive number represents an increase in oil risk metrics.

Geographic Zone	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Grounding Rate	Grounding Rate Change
Colvos Passage	-6.94	-0.06	-1.59	9.20	-2.59
Dyes Inlet (Non-BPC)	NA	NA	NA	NA	NA
Eastern Strait of Juan de Fuca	7.21	1.56	5.43	0.38	-0.02
Eld Inlet (Non-BPC)	NA	NA	NA	NA	NA
Guemes Channel and Saddlebags	0.26	1.53	0.66	8.97	0.15
Haro Strait and Boundary Pass	-2.32	-1.27	-2.00	4.66	-0.20
Hood Canal (Non-BPC)	NA	NA	NA	0.00	0.00
Lake Washington Ship Canal (Non-BPC)	0.00	0.00	0.00	20.18	0.00
Port Orchard (Non-BPC)	NA	NA	NA	NA	NA
Port Susan (Non-BPC)	NA	NA	NA	NA	NA
Possession Sound and Saratoga Passage	0.00	-0.08	0.00	8.80	-0.13
Puget Sound	1.25	0.16	1.53	5.92	-0.60
Rich Passage and Sinclair Inlet	-4.31	-2.16	-4.29	12.34	-0.51
Rosario Strait	1.16	1.37	1.52	2.58	0.04
San Juan Islands (Non-BPC)	0.00	0.00	0.00	11.60	0.00
Skagit Bay (Non-BPC)	0.00	0.00	0.00	33.33	0.00
South Sound to Olympia	3.69	0.76	3.71	6.59	0.16
Southern Gulf Islands (Non-BPC)	-1.01	-1.56	-1.00	10.07	-0.43
Strait of Georgia	-1.66	0.31	-1.51	1.86	-0.07
Strait of Georgia - Below 49th (Non-BPC)	-1.33	-9.52	-1.73	2.39	-0.14
Strait of Georgia South	-3.33	-0.24	-1.01	1.54	-0.32
All zones	-0.43	-0.17	-0.30	4.19	-0.28

Table A-32: Average differences in oil spill risk metrics per simulation between Scenario 2 and Scenario 3 (Scenario 3 - Scenario 2) by geographic zone, study area.

Geographic Zone	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Admiralty Inlet	-0.0015	-1,736.7028	-0.2887
Bellingham Channel, Sinclair Island, and waters to the East	0.0000	0.0000	0.0000
Carr Inlet (Non-BPC)	0.0000	0.0000	0.0000
Case Inlet to Oakland Bay (Non-BPC)	0.0000	0.0000	0.0000
Colvos Passage	-0.0001	-0.3128	-0.0023
Dyes Inlet (Non-BPC)	0.0000	0.0000	0.0000

Geographic Zone	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Eastern Strait of Juan de Fuca	0.0002	246.7202	0.0490
Eld Inlet (Non-BPC)	0.0000	0.0000	0.0000
Guemes Channel and Saddlebags	0[*]	1,747.6392	0.0396
Haro Strait and Boundary Pass	-0.0015	-1,790.3221	-0.3480
Hood Canal (Non-BPC)	0.0000	0.0000	0.0000
Lake Washington Ship Canal (Non-BPC)	0.0000	0.0000	0.0000
Port Orchard (Non-BPC)	0.0000	0.0000	0.0000
Port Susan (Non-BPC)	0.0000	0.0000	0.0000
Possession Sound and Saratoga Passage	0.0000	-5.9880	0.0000
Puget Sound	0.0037	271.2436	0.9755
Rich Passage and Sinclair Inlet	-0.0018	-94.9263	-0.3921
Rosario Strait	0.0003	1,418.4221	0.1129
San Juan Islands (Non-BPC)	0.0000	0.0000	0.0000
Skagit Bay (Non-BPC)	0.0000	0.0000	0.0000
South Sound to Olympia	0.0005	11.6363	0.1067
Southern Gulf Islands (Non-BPC)	-0.0030	-481.9222	-0.6280
Strait of Georgia	-0.0007	291.7591	-0.1241
Strait of Georgia - Below 49th (Non-BPC)	-0.0008	-1,199.7949	-0.2213
Strait of Georgia South	0[**]	-0.0317	-0.0002
All Zones	-0.0047	-1,322.5803	-0.7210

Geographic distribution: study area excluding car ferries

Primary risk metrics

Modest increases and decreases occurred in values of the primary risk metrics across the study area from Scenario 2 to Scenario 3 with car ferries excluded (Table A-33). The mean change in drift grounding rate across geographic zones in the study area excluding car ferries was -2.11 percent and the largest changes were in Strait of Georgia - Below 49th (-11.37 percent), Southern Gulf Islands (-8.23 percent), and Admiralty Inlet (-7.90 percent). The mean change in oil volume at risk was -0.20 percent and the larges changes were in Strait of Georgia - Below 49th (-23.13 percent), Southern Gulf Islands (-5.30 percent), and Admiralty Inlet (-4.69 percent). The mean change in oil outflow was -1.17 percent and the largest changes were again in Strait of Georgia - Below 49th (-19.09 percent), Southern Gulf Islands (-7.59 percent), and Admiralty Inlet (-6.99 percent).

Drift grounding rates

Drift grounding rates excluding car ferries in the study area mostly decreased modestly. The largest changes were in Colvos Passage (-2.59 percent), South Sound to Olympia (-1.69 percent), and Southern Gulf Islands (-0.86 percent).

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[*] Value between 0 and 0.0001.
[**] Value between 0 and -0.0001.

Table A-33: Oil spill risk metric relative changes between Scenario 2 and Scenario 3 by geographic zone, study area, excluding ferries.

Geographic Zone	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
Admiralty Inlet	-7.90	-4.69	-6.99	2.15	-0.50
Bellingham Channel, Sinclair Island, and waters to the East	0.00	0.00	0.00	4.39	0.00
Carr Inlet (Non-BPC)	NA	NA	NA	NA	NA
Case Inlet to Oakland Bay (Non-BPC)	NA	NA	NA	NA	NA
Colvos Passage	-6.94	-0.06	-1.59	9.20	-2.59
Dyes Inlet (Non-BPC)	NA	NA	NA	NA	NA
Eastern Strait of Juan de Fuca	7.21	1.56	5.43	0.38	-0.02
Eld Inlet (Non-BPC)	NA	NA	NA	NA	NA
Guemes Channel and Saddlebags	0.89	1.54	0.94	9.35	0.16
Haro Strait and Boundary Pass	-2.34	-1.27	-2.01	4.66	-0.20
Hood Canal (Non-BPC)	NA	NA	NA	0.00	0.00
Lake Washington Ship Canal (Non-BPC)	0.00	0.00	0.00	20.18	0.00
Port Orchard (Non-BPC)	NA	NA	NA	NA	NA
Port Susan (Non-BPC)	NA	NA	NA	NA	NA
Possession Sound and Saratoga Passage	0.00	0.00	0.00	5.50	0.00
Puget Sound	-0.93	-0.26	0.07	5.74	-0.69
Rich Passage and Sinclair Inlet	0.00	0.00	0.00	14.29	0.00
Rosario Strait	5.79	1.39	3.14	2.44	0.04
San Juan Islands (Non-BPC)	NA	NA	NA	0.00	0.00
Skagit Bay (Non-BPC)	0.00	0.00	0.00	33.33	0.00
South Sound to Olympia	-0.16	0.00	-0.04	16.95	-1.69
Southern Gulf Islands (Non-BPC)	-8.23	-5.30	-7.59	8.74	-0.86
Strait of Georgia	-1.44	0.42	-0.38	1.72	-0.05
Strait of Georgia - Below 49th (Non-BPC)	-11.37	-23.13	-19.09	0.80	-0.19
Strait of Georgia South	-3.33	-0.24	-1.01	1.55	-0.32
All zones	-2.11	-0.20	-1.17	3.63	-0.31

Table A-34: Average differences in oil spill risk metrics per simulation between Scenario 2 and Scenario 3 (Scenario 3 - Scenario 2) by geographic zone, study area, excluding ferries.

Geographic Zone	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
Admiralty Inlet	-0.0015	-1,736.7028	-0.2887
Bellingham Channel, Sinclair Island, and waters to the East	0.0000	0.0000	0.0000
Carr Inlet (Non-BPC)	0.0000	0.0000	0.0000
Case Inlet to Oakland Bay (Non-BPC)	0.0000	0.0000	0.0000
Colvos Passage	-0.0001	-0.3128	-0.0023
Dyes Inlet (Non-BPC)	0.0000	0.0000	0.0000
Eastern Strait of Juan de Fuca	0.0002	246.7202	0.0490
Eld Inlet (Non-BPC)	0.0000	0.0000	0.0000
Guemes Channel and Saddlebags	0[*]	1,747.6392	0.0396
Haro Strait and Boundary Pass	-0.0015	-1,790.3221	-0.3480
Hood Canal (Non-BPC)	0.0000	0.0000	0.0000
Lake Washington Ship Canal (Non-BPC)	0.0000	0.0000	0.0000
Port Orchard (Non-BPC)	0.0000	0.0000	0.0000
Port Susan (Non-BPC)	0.0000	0.0000	0.0000
Possession Sound and Saratoga Passage	0.0000	0.0000	0.0000
Puget Sound	-0.0008	-378.5339	0.0132
Rich Passage and Sinclair Inlet	0.0000	0.0000	0.0000
Rosario Strait	0.0003	1,418.4221	0.1129
San Juan Islands (Non-BPC)	0.0000	0.0000	0.0000
Skagit Bay (Non-BPC)	0.0000	0.0000	0.0000
South Sound to Olympia	0[**]	-0.0317	-0.0002
Southern Gulf Islands (Non-BPC)	-0.0007	-268.2467	-0.1290
Strait of Georgia	-0.0002	389.2501	-0.0172
Strait of Georgia - Below 49th (Non-BPC)	-0.0003	-1,102.3039	-0.1143
Strait of Georgia South	0[**]	-0.0317	-0.0002
All Zones	-0.0046	-1,474.4540	-0.6852

Vessel type distribution: study area

Primary risk metrics

The primary risk metrics mostly decreased across vessel types from Scenario 2 to Scenario 3 (Table A-35). The mean change in drift groundings across vessel types in the study area was -0.43 percent and the largest changes were for towed oil barges (-31.72 percent), ATBs (-12.12 percent), and cruise ships (-7.69 percent). The mean change in oil volume at risk was -0.17 and the largest changes were for towed oil barges (-32.30 percent), ATBs (-12.10 percent), and cruise ships (-8.40 percent). The mean change in oil

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[*] Value between 0 and 0.0001.

[**] Value between 0 and -0.0001.

outflow as -0.30 percent and the largest changes were for towed oil barges (-32.30 percent), ATBs (-12.12 percent), and cruise ships (-7.69 percent).

Drift grounding rates

The mean change in drift grounding rates -0.28 percent and the largest changes were for towed oil barges (-1.63 percent), vehicle ships (-0.24 percent), and cruise ships (-0.19 percent) (Table A-35).

Table A-35: Oil spill risk metric relative changes between Scenario 2 and Scenario 3 by vessel type in study area.

Vessel Type	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
ATB	-12.12	-12.10	-12.12	1.66	-0.17
Bulk Carrier	-1.01	-0.15	-1.01	3.63	-0.01
Container Ship	-1.35	-1.13	-1.35	5.30	-0.09
Cruise Ship	-7.69	-8.40	-7.69	2.59	-0.19
Ferry (Car)	-0.02	0.20	-0.02	8.71	-0.02
Fishing Vessel (Large)	-0.51	-3.68	-0.51	2.39	-0.01
General/Other Cargo Ship (Large)	-0.68	-2.11	-0.68	3.54	-0.02
Tanker (Chemical)	0.23	0.44	0.23	2.33	-0.02
Tanker (Crude)	0.53	0.63	0.53	3.96	0.04
Tanker (Liquefied Gas)	-0.23	-0.06	-0.23	1.90	0.01
Tanker (Product)	0.00	-0.03	0.00	2.64	0.04
Towing Vessel (Oil)	-31.72	-32.30	-32.30	5.21	-1.63
Towing Vessel (Oil) – Bunkering	-4.51	-4.09	-4.09	4.92	-0.34
Vehicle Carrier	-4.99	-5.09	-4.99	4.22	-0.24
All types	-0.43	-0.17	-0.30	4.19	-0.28

Table A-36: Average differences in oil spill risk metrics per simulation between Scenario 2 and Scenario 3 (Scenario 3 - Scenario 2) by vessel type in study area.

Vessel Type	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
ATB	-0.0001	-9.1183	-0.0070
Bulk Carrier	-0.0006	-61.4122	-0.1308
Container Ship	-0.0012	-2,333.0310	-0.2566
Cruise Ship	-0.0004	-287.0113	-0.0798
Ferry (Car)	-0.0002	151.8737	-0.0356
Fishing Vessel (Large)	0[**]	-56.6912	-0.0107

[**] Value between 0 and -0.0001.

Vessel Type	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
General/Other Cargo Ship (Large)	-0.0001	-109.6671	-0.0154
Tanker (Chemical)	0[*]	358.0089	0.0131
Tanker (Crude)	0[*]	1,802.3340	0.0392
Tanker (Liquefied Gas)	0[**]	-0.0892	-0.0002
Tanker (Product)	0.0000	-26.8933	0.0000
Towing Vessel (Oil)	-0.0014	-9.5966	-0.0700
Towing Vessel (Oil) – Bunkering	0[**]	-0.1786	-0.0013
Vehicle Carrier	-0.0008	-741.1083	-0.1657
All vessel types	-0.0048	-1,322.5805	-0.7208

Vessel type distribution: BPC zones

Primary risk metrics

Values of the primary risk metrics mostly decreased modestly in the BPC zones (Table A-37). The mean change in drift groundings across vessel types in the BPC zones was -0.14 percent and the largest changes occurred for towed oil barges (-36.03 percent), ATBs (-13.71 percent), and cruise ships (-8.59 percent). The mean change in oil volume at risk was +0.05 percent and the largest changes were for towed oil barges (-36.76 percent), ATBs (-13.89 percent), and cruise ships (-8.62 percent). The mean change in oil outflow was +0.09 percent and the largest changes were for towed oil barges (-36.76 percent), ATBs (-13.71 percent), and cruise ships (-8.59 percent).

Drift grounding rates

The mean change in grounding rates across vessel types in the study area was -0.28 percent and the largest changes were for towed oil barges (-1.62 percent), bunkering barges (-0.40 percent), and ATBs (-0.22 percent) (Table A-37).

Table A-37: Oil spill risk metric relative changes between Scenario 2 and Scenario 3 by vessel type in BPC zones.

Vessel Type	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
ATB	-13.71	-13.89	-13.71	1.71	-0.22
Bulk Carrier	-0.07	0.55	-0.07	3.73	0.07
Container Ship	-1.37	-1.14	-1.37	5.32	-0.07
Cruise Ship	-8.59	-8.62	-8.59	2.61	-0.20
Ferry (Car)	0.65	1.28	0.67	7.27	0.00
Fishing Vessel (Large)	0.70	-3.29	0.70	1.97	-0.01
General/Other Cargo Ship (Large)	-0.74	-2.35	-0.74	3.50	0.00

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[*] Value between 0 and 0.0001.
[**] Value between 0 and -0.0001.

Vessel Type	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
Tanker (Chemical)	1.42	1.60	1.42	2.45	0.00
Tanker (Crude)	0.53	0.63	0.53	4.00	0.04
Tanker (Liquefied Gas)	-0.23	-0.06	-0.23	1.90	0.01
Tanker (Product)	0.00	-0.03	0.00	2.66	0.04
Towing Vessel (Oil)	-36.03	-36.76	-36.76	4.47	-1.62
Towing Vessel (Oil) – Bunkering	-5.91	-5.46	-5.46	4.78	-0.40
Vehicle Carrier	-3.97	-4.12	-3.97	4.30	-0.21
All Vessel Types	-0.14	0.05	0.09	3.76	-0.28
Total (excluding ferries)	-1.75	-0.01	-0.79	3.50	-0.30

Table A-38: Average differences in oil spill risk metrics per simulation between Scenario 2 and Scenario 3 (Scenario 3 - Scenario 2) by vessel type in BPC zones.

Vessel Type	Drift groundings	Oil Volume at Risk (gal.)	Oil Outflow (gal.)
ATB	-0.0001	-9.7928	-0.0074
Bulk Carrier	0[*]	205.9033	-0.0086
Container Ship	-0.0012	-2,333.0310	-0.2566
Cruise Ship	-0.0004	-293.8456	-0.0884
Ferry (Car)	<0.0027	463.0402	0.5703
Fishing Vessel (Large)	0[**]	-36.8519	0.0107
General/Other Cargo Ship (Large)	-0.0001	-109.6671	-0.0154
Tanker (Chemical)	0.0001	1,296.0926	0.0783
Tanker (Crude)	0[*]	1,802.3340	0.0392
Tanker (Liquefied Gas)	0[**]	-0.0892	-0.0002
Tanker (Product)	0[**]	-26.8933	0.0000
Towing Vessel (Oil)	-0.0012	-8.6452	-0.0630
Towing Vessel (Oil) – Bunkering	0[**]	-0.1987	-0.0014
Vehicle Carrier	-0.0006	-589.2185	-0.1290
All vessel types	-0.0008	359.1368	0.1285
Total (excluding ferries)	-0.0035	-103.9034	-0.4419

Risk from escort tug traffic

On average, the number of tug tracks simulated (78,884) per simulation was slightly less than the maximum observed (78,911 in 2018), but the simulated tug underway minutes was consistently greater for each escort scenario than the maximum observed in 2018. See Table A-40 and Table A-42 for more detailed results. While the number of tracks was held constant across each escort scenario,

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[*] Value between 0 and 0.0001.

[**] Value between 0 and -0.0001.

escort tracks tended to have longer durations than background tracks leading to the overall tug underway minutes increasing from Scenario 1 to Scenario 2 to Scenario 3.

There were noticeable spatial trends in the observed tug traffic. Puget Sound (40.69 percent) and Haro Strait and Boundary Pass (21.32 percent) accounted for over 60 percent of all observed assist and escort tug traffic. The next highest zone was Strait of Georgia at 7.41 percent (Table A-41). The simulated tug traffic spatial patten is appreciably different from the observed for all three scenarios. For the simulated tug traffic in all three scenarios, Puget Sound remained the highest zone but accounted for roughly 10-15 percent less of the traffic compared to the historical traffic. Simulated traffic in Haro Strait and Boundary Pass decreased over 15 percent for all three scenarios. As tug traffic decreased for these zones, the tug traffic for the following zones all increased 5 percent or more in all scenarios: Southern Gulf Islands (Non-BPC), Strait of Georgia, and Strait of Georgia-Below 49th (Non-BPC). Traffic for Strait of Georgia increased nearly 10 percent for all scenarios. It is also worth noting that tug traffic for Rosario Strait increased in all three scenarios. The highest increase was in Scenario 2 (+6.78 percent).

Table A-39: Observed underway vessel traffic for Tug (Assist & Escort) vessels for 2015 through 2019

Year	Observed underway tracks	Observed underway minutes
2015	65,149	3,830,386
2016	66,839	4,120,607
2017	72,397	4,239,865
2018	78,911	4,565,478
2019	76,532	4,410,443

Table A-40: Average per simulation of tug traffic for each tug track type and escort scenario.

Tug track type category	Scenario 1	Scenario 2	Scenario 3
Assist Tracks	41,756	41,307	38,056
Assist Minutes	2,750,841	2,724,481	2,516,826
Escort Tracks	5,299	11,532	40,320
Escort Minutes	345,321	805,520	2,934,014
Background Tracks	31,829	26,044	508
Background Minutes	1,872,040	1,531,790	179,219
Total Tracks	78,884	78,884	78,884
Total Minutes	4,968,202	5,061,791	5,630,060

Table A-41: Percentage of simulated Tug (Assist & Escort) traffic for each geographic zone per scenario.

Geographic Zone	Scenario 1 (%)	Scenario 2 (%)	Scenario 3 (%)
Admiralty Inlet	6.04	6.99	8.78
Bellingham Channel, Sinclair Island, and waters to the East	4.10	4.75	2.60

Geographic Zone	Scenario 1 (%)	Scenario 2 (%)	Scenario 3 (%)
Carr Inlet (Non-BPC)	0.01	0.00	0.00
Case Inlet to Oakland Bay (Non-BPC)	0.02	0.02	0.01
Colvos Passage	1.07	0.87	0.75
Dyes Inlet (Non-BPC)	0.01	0.01	0.00
Eastern Strait of Juan de Fuca	10.19	11.28	10.55
Eld Inlet (Non-BPC)	0.00	0.00	0.00
Guemes Channel and Saddlebags	7.44	8.17	4.51
Haro Strait and Boundary Pass	5.23	4.65	5.83
Hood Canal (Non-BPC)	0.69	0.54	0.13
Lake Washington Ship Canal (Non-BPC)	0.99	0.78	0.14
Port Orchard (Non-BPC)	0.25	0.19	0.06
Port Susan (Non-BPC)	0.00	0.00	0.00
Possession Sound and Saratoga Passage	3.47	3.05	2.72
Puget Sound	26.46	24.09	29.63
Rich Passage and Sinclair Inlet	0.77	0.61	0.23
Rosario Strait	8.51	11.41	6.10
San Juan Islands (Non-BPC)	0.08	0.07	0.13
Skagit Bay (Non-BPC)	0.09	0.08	0.07
South Sound to Olympia	1.44	1.22	0.95
Southern Gulf Islands (Non-BPC)	6.15	5.48	7.66
Strait of Georgia	15.99	14.85	16.82
Strait of Georgia - Below 49th (Non-BPC)	5.67	5.04	7.05
Strait of Georgia South	0.61	0.54	1.13
All Zones	100.00	100.00	100.00

Table A-42: Average percentage per simulation of tank vessel underway minutes that are escorted.

Vessel type	Scenario 1 (%)	Scenario 2 (%)	Scenario 3 (%)
Tank vessels, all	25.3	40.9	71.7
Tank vessels, laden	35.1	56.7	99.4
Tankers, all	53.1	57	59.8
Tankers, laden	88.7	95.2	99.9
ATBs, all	0	37.4	80.8
ATBs, laden	0	46.1	99.8
Towed oil barges, all	0	19.4	83.5
Towed oil barges, laden	0	22.9	98.8

Escort tug underway time includes time spent traveling to an escort job, time while escorting a tank vessel, and time spent traveling from an escort job. From Scenario 1 to Scenario 2, escort tug underway time increased a mean of 134.4 percent, equivalent to an additional 460,200 underway minutes. From Scenario 2 to Scenario 3, escort tug underway time increased a mean of 263.4 percent, equivalent to an additional 2,128,493 underway minutes. Calculated hazard rates due to these increases in underway minutes are in Table A-43. The additional increases in risk of the selected hazards were low.

Table A-43: Escort tug hazard rates and estimated additional hazards per year.

Hazard Type	Hazard Rate per operating minute	Number of additional hazards per year (Scenario 1 to Scenario 2)	Number of additional hazards per year (Scenario 2 to Scenario 3)
Allisions/Collisions	2.31×10^{-7}	0.1063	0.4917
Groundings	7.12×10^{-8}	0.0328	0.1515
Sinking/Capsize	1.78×10^{-8}	0.0082	0.0379
Other	1.09×10^{-6}	0.5016	2.3201

Tethering effects

Overall change in risk from tethering

When escorted vessels are tethered, oil spill risk decreases in the study area (Table A-44). The results are similar when limited to just BPC zones. Tethering effects were evaluated using data for Scenario 2.

Table A-44: Change in oil spill risk metrics due to tethering.

Geographic area	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate	Grounding Rate Change
Study area	-0.40	-15.83	-1.63	4.19	-0.20
BPC Zones	-0.70	-16.89	-2.80	3.76	-0.21

Geographic distribution: change in risk from tethering

Primary risk metrics

Most geographic zones had modest (less than -10.00 percent) reduction in values for the primary risk metrics (Table A-45). The three geographic zones with the largest reductions in drift grounding values were Bellingham Channel, Sinclair Island, and waters to the East (-27.24 percent), Rosario Strait (-7.70 percent), and Eastern Strait of Juan de Fuca (-6.57 percent). The top three zones for reductions in oil volume at risk were Rosario Strait (49.87 percent), Bellingham Channel, Sinclair Island, and waters to the East (-43.65 percent) and Eastern Strait of Juan de Fuca (-38.80 percent). The top three zones for reductions in oil outflow were Bellingham Channel, Sinclair Island, and waters to the East (-37.84 percent), Rosario Strait (-21.06 percent), and Eastern Strait of Juan de Fuca (-19.86 percent).

Drift grounding rates

Waters East (-1.56 percent), Guemes Channel and Saddlebags (-1.34 percent), and Rosario Strait (-0.87 percent) had the greatest reductions in grounding rate (Table A-45).

Table A-45: Change in oil spill risk metrics due to tethering by geographic zone.

Geographic Zone	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
Admiralty Inlet	-0.15	-3.25	-0.66	2.31	-0.02
Bellingham Channel, Sinclair Island, and waters to the East	-27.24	-43.65	-37.84	4.38	-1.56
Carr Inlet (Non-BPC)	N/A	N/A	N/A	N/A	N/A
Case Inlet to Oakland Bay (Non-BPC)	N/A	N/A	N/A	0.00	0.00
Colvos Passage	0.00	0.00	0.00	9.20	0.00
Dyes Inlet (Non-BPC)	N/A	N/A	N/A	N/A	N/A
Eastern Strait of Juan de Fuca	-6.57	-38.80	-19.86	0.38	-0.05
Eld Inlet (Non-BPC)	N/A	N/A	N/A	N/A	N/A
Guemes Channel and Saddlebags	-3.51	-15.13	-9.10	8.97	-1.34
Haro Strait and Boundary Pass	-0.20	-2.17	-0.61	4.66	-0.10
Hood Canal (Non-BPC)	N/A	N/A	N/A	0.00	0.00
Lake Washington Ship Canal (Non-BPC)	0.00	0.00	0.00	20.18	0.00
Port Orchard (Non-BPC)	N/A	N/A	N/A	N/A	N/A
Port Susan (Non-BPC)	N/A	N/A	N/A	N/A	N/A
Possession Sound and Saratoga Passage	0.00	0.00	0.00	8.80	0.00
Puget Sound	-0.02	-1.27	-0.10	5.92	-0.01
Rich Passage and Sinclair Inlet	0.00	0.00	0.00	12.34	0.00
Rosario Strait	-7.70	-49.87	-21.06	2.58	-0.87
San Juan Islands (Non-BPC)	0.00	0.00	0.00	11.60	0.00
Skagit Bay (Non-BPC)	0.00	0.00	0.00	33.33	0.00
South Sound to Olympia	0.00	0.00	0.00	6.59	0.00
Southern Gulf Islands (Non-BPC)	-0.03	-0.01	-0.01	10.07	-0.19
Strait of Georgia	-1.47	-20.86	-7.04	1.86	-0.27
Strait of Georgia - Below 49th (Non-BPC)	0.00	0.00	0.00	2.39	0.00
Strait of Georgia South	-3.33	-0.16	-0.67	1.54	-0.32

Vessel type distribution: change in risk from tethering

Primary risk metrics

All escorted vessel types had a reduction in values for the primary risk metrics with crude tankers having the largest decrease (Table A-46).

Drift grounding rates

All escorted vessel types had a reduction in drift ground rates. Crude tankers showed the largest decrease.

Table A-46: Change in oil spill risk metrics due to tethering by vessel type.

Vessel Type	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
ATB	-11.36	-12.79	-11.36	1.66	-0.20
Tanker (Chemical)	-5.81	-6.57	-5.81	2.33	-0.18
Tanker (Crude)	-37.46	-36.84	-37.46	3.96	-1.34
Tanker (Liquefied Gas)	-18.95	-22.67	-18.95	1.90	-0.34
Tanker (Product)	-18.75	-19.62	-18.75	2.64	-0.53
Towing Vessel (Oil)	-4.73	-4.90	-4.90	5.21	-0.26

Sensitivity analysis of model parameters

Self-repair

Removing self-repair resulted in large increases for the primary risk metrics and grounding rates and these large increases were consistent across geographic zones and vessel types (Table A-47). Results were similar between the entire study area and BPC zones. Comparisons were made using data from Scenario 2.

Table A-47: Change in oil spill risk metrics from removing self-repair for drifting vessels.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels - All Zones	44.50	53.98	44.80	4.19	2.62
All Vessels - BPC Zones	50.49	54.65	50.76	3.76	2.47

Emergency anchoring

Removing emergency anchoring resulted in large increases for the primary risk metrics and grounding rates and these large increases were consistent across geographic zones and vessel types (Table A-48). Results were similar between the entire study area and BPC zones. Comparisons were made using data from Scenario 2.

Table A-48: Change in oil spill risk metrics from removing emergency anchoring for drifting vessels.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels - All Zones	41.35	25.43	39.34	4.19	1.38
All Vessels - BPC Zones	43.42	24.94	40.62	3.76	1.27

Tugs of opportunity

Removing tug of opportunities increased oil spill risk but had less impact than self-repair and emergency anchoring. Results were similar between the entire study area and BPC zones (Table A-49). Comparisons were made using data from Scenario 2.

Table A-49: Change in oil spill risk metrics from disallowing tugs of opportunity rescuing drifting vessels.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels - All Zones	11.73	16.36	11.98	4.19	1.12
All Vessels - BPC Zones	17.14	16.39	17.13	3.76	1.16

The time for the nearest tug of opportunity to reach a drifting vessel decreased 10 to 20 minutes from Scenario 1 to Scenario 2, depending on the type of tank vessel (Table A-50). Overall, the average time for the nearest tug of opportunity to arrive ranged from 1 to 2 hours across escort scenarios and tank vessel categories.

Table A-50: Average minutes per simulation for the nearest tug of opportunity to tank vessels when loss of propulsion occurred.

Vessel type	Scenario 1 (minutes)	Scenario 2 (minutes)	Scenario 3 (minutes)
Tank vessels, all	113.9	102.6	108.3
Tank vessels, laden	113.1	97.5	109.9
Tankers, all	103.2	101.8	105.4
Tankers, laden	62.3	63.2	110.4
ATBs, all	113.1	95.9	110.9
ATBs, laden	112.8	91.9	106
Towed oil barges, all	122.3	107.5	117.3
Towed oil barges, laden	120.5	103.3	111.2

Neah Bay ERTV

Removing the Neah Bay ERTV as a tug rescue option had no measurable impact on the oil spill risk in the study area (Table A-51). Comparisons were made using data from Scenario 2.

Table A-51: Change in oil spill risk metrics from disallowing Neah Bay ERTV rescuing drifting vessels.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels – All Zones	0.00	0.00	0.00	4.19	0.00
All Vessels – BPC Zones	0.00	0.00	0.00	3.76	0.00

Evaluation of rescue towing assumptions: time to connect and control

50 percent increase

Increasing the time to connect and control from 30 minutes to 45 minutes increased the overall primary risk metric values and grounding rates (Table A-52). Results were similar between the entire study area and BPC zones. Comparisons were made using data from Scenario 2.

Table A-52: Changes in oil spill risk metrics from increasing time to connect and control for rescue tugs.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels - All Zones	2.51	10.03	3.13	4.19	0.28
All Vessels - BPC Zones	3.83	10.57	4.78	3.76	0.29

50 percent decrease

Decreasing the time to connect and control to 15 minutes from 30 minutes decreased overall oil spill risk (Table A-53). The larger decreases in oil volume at risk was due to the larger decreases in this metric from tank vessels. Results were similar between the entire study area and BPC zones. Comparisons were made using data from Scenario 2.

Table A-53: Changes in oil spill risk metrics from decreasing time to connect and control for rescue tugs.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels – All Zones	-3.58	-21.19	-4.90	4.19	-0.45
All Vessels – BPC Zones	-5.19	-22.29	-7.33	3.76	-0.47

Evaluation of rescue towing assumptions: tug transit speed

25 percent increase

Increasing the rescue tug speed from 10 to 12.5 knots modestly decreased oil spill risk. Results were similar between the entire study area and BPC zones (Table A-54). Comparisons were made using data from Scenario 2.

Table A-54: Changes in oil spill risk metrics from increasing rescue tug transit speed.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels - All Zones	-3.26	-3.03	-3.28	4.19	-0.09
All Vessels - BPC Zones	-3.39	-2.84	-3.40	3.76	-0.09

25 percent decrease

Decreasing the rescue tug speed from 10 to 7.5 knots modestly increased oil spill risk. Results were similar between the entire study area and BPC zones (Table A-55). Comparisons were made using data from Scenario 2.

Table A-55: Changes in oil spill risk metrics from decreasing rescue tug transit speed.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels – All Zones	1.67	1.35	1.60	4.19	0.18
All Vessels – BPC Zones	2.55	1.45	2.36	3.76	0.18

Evaluation of rescue towing assumptions: tug rescue success rate

50 percent success rate

Decreasing tug rescue success rate from 100 percent to 50 percent resulted in a moderate increase in oil spill risk. Results were similar between the entire study area and BPC zones (Table A-56). Comparisons were made using data from Scenario 2.

Table A-56: Changes in oil spill risk metrics from rescue tug success rate of 50%.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels – All Zones	6.11	17.53	7.04	4.19	0.78
All Vessels – BPC Zones	9.78	17.97	10.95	3.76	0.80

90 percent success rate

Decreasing tug rescue success rate from 100 percent to 90 percent resulted in a moderate increase in oil spill risk (Table A-57). Results were similar between the entire study area and BPC zones. Comparisons were made using data from Scenario 2.

Table A-57: Changes in oil spill risk metrics from rescue tug success rate of 90%.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels - All Zones	1.29	3.76	1.50	4.19	0.17

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels - BPC Zones	1.96	3.60	2.21	3.76	0.17

Trans Mountain Expansion Project traffic

Escort tug traffic and Beecher Bay OSRV associated with Trans Mountain Expansion Project resulted in a minor decrease in oil spill risk. Results were similar between the entire study area and BPC zones (Table A-58). Comparisons were made using data from Scenario 2.

Table A-58: Changes in oil spill risk metrics from Trans Mountain Expansion Project traffic.

Category	Drift Grounding Change (%)	Oil Volume at Risk Change (%)	Oil Outflow Change (%)	Original Grounding Rate S2	Grounding Rate Change
All Vessels - All Zones	-0.71	-0.61	-0.72	4.19	-0.05
All Vessels - BPC Zones	-0.73	-0.60	-0.77	3.76	-0.04

Loss of steering

Across all tank vessels, the percent of loss of steering events that occurred while a tank vessel was escorted increased from Scenario 1 to Scenario 2 and from Scenario 2 to Scenario 3 (Table A-59). The time for a tug-of-opportunity to reach a drifting tank vessel was generally lowest for Scenario 2 and Scenario 3 but differences were generally not large between these scenarios.

Table A-59: The percentage of loss of steering events that occurred while a tank vessel was escorted with tug transit time in minutes for closest tug of opportunity at the time of loss of steering event.

Vessel type	Scenario 1, % Escorted	Scenario 2, % Escorted	Scenario 3, % Escorted	Scenario 1, Transit time (mins.)	Scenario 2, Transit time (mins.)	Scenario 3, Transit time (mins.)
Tank vessels	7.1	11.3	18.1	90.8	81.2	82.6
Tank vessels, laden	38.4	61.7	99.3	89.6	75.9	88.6
Tankers	50.0	53.8	56.8	79.2	79.9	81.5
Tankers, laden	87.3	94.4	99.9	22.3	24.8	52.8
ATBs	0.0	39.0	79.9	89.0	72.0	80.3
ATBs, laden	0.0	48.2	99.5	86.9	68.7	105.9
Towed oil barges	0.0	19.4	81.1	108.0	94.4	101.0
Towed oil barges, laden	0.0	23.6	98.3	105.9	89.6	90.7

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 just over 80 percent of the traffic is in Puget Sound, Haro Strait and Boundary Pass, Admiralty Inlet, Strait of Georgia, and Eastern 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 over 60 percent of underway minutes. ATBs and towed oil barges account for over 30 percent of all traffic and oil tankers a bit less than 10 percent. Altogether, vessels that transport oil as cargo make up a little over 40 percent of all simulated traffic.

Current oil spill risk profile

Model results provided insight on how oil spill risk due to loss of propulsion events and subsequent drift groundings varies across geographic zones, vessel types, and escort tug scenarios. For a given vessel type, area, and time period, loss of propulsion event frequency is a function of vessel traffic intensity and probabilities of loss of propulsion events.

For the most part, the spatial distribution of the oil spill risk metrics reflects traffic patterns. While there are several contributing factors in a loss of propulsion resulting in a drift grounding (wind and current conditions, vessel characteristics, proximity to shoreline, shoreline characteristics, etc.), the results for the geographic distribution of oil spill risk support a common-sense insight: high traffic regions have the highest oil spill risk. For example, Puget Sound accounted for about 35 percent of the traffic and accounted for about 39-48 percent of oil spill risk metric contributions.

There are some differences in grounding rates that seem to be the result of waterway characteristics. For example, some lower traffic zones such as South Sound to Olympia and Rich Passage and Sinclair Inlet have relatively high grounding rates. This is likely because they are narrow waterways where vessels routing brings them closer to shorelines. If a loss of propulsion takes place there, a vessel has little opportunity for rescue. Although the grounding rates for these zones were very high, the relative contribution of these zones to oil risk metrics in the study area was very low compared with other zones (up to 2 percent). This can be attributed to comparably low traffic volumes (less than 0.5 percent of the total). In addition to the proximity of the shoreline, the scarcity of tugs of opportunity in these lower traffic areas may also contribute to the higher groundings rates.

The distribution of oil spill risk by vessel type reflects traffic patterns like the zones do. Bulk carriers account for around 20 percent of the simulated traffic, but only 8-10 percent of the risk. Vehicle carriers on the other hand make up 5 percent of the total simulation traffic but account for 13 percent of the oil spill risk. Of note, ATBs make up 9 percent of the simulated traffic and account for only 1 percent of the oil spill risk while towed oil barges make up 24 percent of the traffic and 7-9 percent of the risk.

Container ships and vehicle carriers both represent more risk than their traffic levels would suggest. This may be related to their representation as “high-windage” vessels in our drift model. A “high-windage” vessel would have been more susceptible to the influence of wind while drifting, perhaps leading to more simulated groundings, as suggested by their relatively high grounding rate (5.30 percent). While tank vessels, such as crude tankers, might be thought to have higher oil spill risk due to carrying a large oil cargo, such vessels have substantially lower underway time in the study area relative to container ships. The results suggest that the cumulative amount of traffic by container ships and the cumulative amount of bunker fuel associated with this traffic produces higher oil spill risk than tank ships.

Looking at the grounding rates, towed oil barges and bunkering barges have the second and the third highest values after container ships: 5.21 percent and 4.92 percent, respectively. A possible explanation for this result is that these vessels operate on routes closer to the edges of the shipping lanes compared to deep draft vessels. When a loss of propulsion occurs, the time to a drift grounding is short, limiting the potential for effective interventions.

Changes between scenarios

Comparing escort scenarios found that increased tug escort coverage for tank vessels resulted in mostly modest decreases in oil spill risk. Towed oil barges and ATBs had the largest consistent decreases in oil spill risk metrics as escort coverage increased for these vessels across scenarios.

A seemingly counterintuitive finding is that oil spill risk increased for some geographic zones as escort coverage increased from Scenario 1 to 2 and from Scenario 2 to 3. Specifically, Eastern Strait of Juan de Fuca and Rosario Strait saw an increase from Scenarios 2 to 3 after seeing decreases in oil spill risk from Scenarios 1 to 2. The difference in the geographic distribution of simulated tugs for each scenario was likely a factor in this result. As escort and assist tugs underway time was assumed constant, the number of background tugs decreased as escort coverage increased across scenarios and the number of escort tugs in high traffic areas increased.

For example, there were less tugs of opportunity simulated in Eastern Strait of Juan de Fuca and Rosario Strait in Scenario 3 compared to Scenario 2. This change in spatial distribution of tugs in the model might have led to higher drift groundings in some regions as fewer tugs of opportunity were available where a loss of propulsion occurred. The opposite of that was true for other zones. For Puget

Sound, the percentage of simulated tug traffic went up from Scenario 2 to Scenario 3, and, as expected, the drift grounding rate and oil spill risk metrics went down.

The analysis provided clear indications of the beneficial effects of tug escorts for laden tank vessels. The number of routes where vessels are escorted increases from Scenario 1 to Scenario 2 and from Scenario 2 to Scenario 2, and as a result the oil volume at risk metrics decreased for tank vessels. For these vessels, tug escorts effectively prevented drift groundings.

The changes in the oil spill metrics for other vessel types not newly escorted were mixed: for some they went up, for others they went down. The changes in the zones follow a similar trend as for other vessel types. This could be due to the difference in the spatial distribution of tugs for each escort scenario. These trends suggest that if escort requirements are expanded, oil spill risk could increase for some geographic zones and vessel types if the number of the tugs operating in the system is not also increased.

Risk from escort tug traffic

When escort requirements were added to Rosario Strait and connected waters (Scenario 2), escort tug underway time increased. On average, the increase was around 460,000 minutes per simulated year. That’s a mean increase of 134 percent over Scenario 1. In terms of absolute numbers, we estimate around 345,000 minutes of escort and assist traffic a year in the study area under Scenario 1, and the expansion of escort tugs under Scenario 2 saw that increase to just over 800,000 minutes per year.

When escort requirements were added to the remaining zones in the study area (Scenario 3), escort tug underway time saw substantial increases. On average, the increase was around 2,130,000 minutes per year. That’s a mean increase of 263 percent over Scenario 2. In terms of absolute numbers, we estimate around 800,000 minutes of escort and assist traffic a year in the study area under Scenario 2, and the expansion of escort tugs under Scenario 3 saw that increase to just over 2,930,000 minutes per year.

Overall, tug incident rates are fairly low. Even a two- to three-fold increase in underway time, while a dramatic relative increase, does not produce many projected incidents per year.

Tethering effects

Tethering of escort tugs reduced the time required for a tug to connect and control a disabled vessel. Bellingham Channel, Sinclair Island, and waters to the east, as well as Guemes Channel and Saddlebags, and Rosario Strait all saw the greatest reductions in drift grounding rates. This is likely due to the presence of escorts for all tank vessels over 5,000 DWT in those zones since this analysis was run against Scenario 2. Those additional escorts mean more opportunity for drift grounding reduction. These zones are also fairly narrow, which could indicate that the 15-minute reduction in time to connect may more frequently have been enough to change the outcome of a loss of propulsion event.

Sensitivity analysis

The sensitivity analysis provided an opportunity to assess to what degree different vessel actions or tug interventions contribute to potential tug rescue. Vessel self-repair and emergency anchoring were the biggest determiners for whether a drifting vessel would ground. A combination of waterway characteristics and scarcity of tugs of opportunity make some vessel types and zones more susceptible to drift groundings when the potential to self-repair and emergency anchor is removed.

Self-repair

Removing self-repair as a potential option increased oil spill risk over 50 percent within BPC zones. Towed oil barges and bulk carriers benefited the most from the potential to self-repair, compared to other vessel types. This indicated that the self-repair option was the greatest factor in determining if a vessel experienced a drift grounding or not.

Emergency anchoring

Removing the potential to emergency anchor increased oil spill risk more than 40 percent for 2 of 3 oil spill risk metrics. While not quite as high as with self-repair, the option for a vessel to successfully execute emergency anchoring was nearly as important in preventing drift groundings.

Tugs of opportunity

Removing tugs of opportunity as a potential intervention produced a less dramatic increase in risk (17 percent). Towed oil barges, and bunkering vessels benefit the most from the potential for rescue by tugs of opportunity. This suggests that tugs of opportunity may be a key factor in reducing oil spill risk from drift groundings.

Neah Bay ERTV

Model results are not an evaluation of the Neah Bay ERTV, since the study area is outside the primary operating range of that vessel. The results only indicate that the Neah Bay ERTV does not meaningfully reduce oil spill risk in study area waters. Its location on the western edge of the Strait of Juan de Fuca means that it is much better positioned to serve waters outside the study area.

Time to connect and control

As one would expect, the increase of time to connect and control to 45 minutes produced an increase in oil spill risk. The decrease of time to control to 15 minutes produced the same results as discussed under our review of tethering. However, the relationship between time to connect and control and oil spill metrics does not seem linear since a 50 percent decrease in the time to connect and control, resulted in a higher absolute decrease in oil spill metrics than a 50 percent decrease.

Tug speed

An increase in tug speed to 12.5 knots only moderately decreased oil spill risk. The percentage reduction was higher than the percentage increase in risk that we found from decreasing tug speed to 7.5 knots. However, the relationship between tug speed and oil spill metrics does not seem linear since a 25 percent increase in the time to connect and control, resulted in a higher absolute decrease in oil spill metrics than a 25 percent increase.

The decrease in tug speed by 25 percent and time to connect and control of 50 percent lead to somewhat similar reductions in drift grounding rates. This suggest that it is possible that tug speed may have a higher relative impact on the oil spill risk than time to connect and control.

Tug success rate

Restricting tugs to a 50 percent rescue success rate produced about the same increase in oil spill risk as removing potential for a tug of opportunity rescue. Restricting tugs to a 90 percent rescue success rate produced about the same increase in oil spill risk as reducing tug speed to 7.5 knots.

Trans Mountain Expansion Project (TMEP)

In general, the model results indicated a slight decrease in overall oil spill risk due to the additional tug rescue options associated with the TMEP. The additional safety measures associated with the TMEP did not substantively change the potential risk reduction benefit of expanding tug escort requirements in Washington waters.

Loss of steering

Since the focus of the model and the tug escort analysis was on loss of propulsion and drift groundings, the investigation into loss of steering events was minimal. The model did present the chance to evaluate the presence of an escort tug and the availability of tugs of opportunity when such an event occurs. If one assumes that a vessel is at greatest risk for a severe casualty in the first 15-30 minutes after losing steering, then a tug escorting that vessel or a nearby tug of opportunity could prevent an accident. The simulated results indicate that increasing escort requirements logically leads to a higher percentage of laden vessels being escorted. The results indicate that on average the nearest tug of opportunity is over an hour away when laden tank vessel loses steering. This suggests that it would be unlikely that a tug of opportunity would be reliable option for preventing vessels losing steering.

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, these estimates had substantial uncertainty. A potential source of uncertainty is the relationship between a report of a loss of propulsion – which is required for any reduction in propulsion, and the type of complete loss of power that would lead to a drifting vessel.

We developed a likelihood that a given loss of propulsion report was a complete loss (see Appendix B, Self-Repair Analysis for details) but that likelihood was based primarily on reporting by deep draft vessels. That calculated likelihood may not be suitable for all vessel types. For example, car ferries are more likely to have redundant propulsion systems and are likely to experience complete losses of propulsion at rates lower than were simulated.

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, geographic zones, and escort scenarios. Focusing on relative differences in oil spill risk also reduces the importance of the overall accuracy of the estimated probabilities.

Another source of uncertainty is the drift and momentum module, which 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. The model relied upon many general assumptions, so simulated trajectories should be considered coarse representations of actual drift trajectories.

As we mentioned in the results section, 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. We added simulated tugs to Scenarios 1 and 2 to keep overall tug traffic levels the same between the three 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.

There were some clear differences in the geographic distribution between observed and simulated tug traffic. Puget Sound and Haro Strait and Boundary Pass saw dramatic decreases in escort and assist traffic while Eastern Strait of Juan de Fuca and Strait of Georgia had modest increases. These are clear indicators that our simulation approach spatially distributed tug traffic differently that what was observed from 2015 to 2019. These differences were even apparent in Scenario 1, a scenario intended to reflect tug escort rule prior to 2020.

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 on which routes and how often such vessels are 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 highlights the potential value of re-visiting these model assumptions in the future.

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, see Figure A-3) 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), we found spills ranging in size from 1 to 420,000 gallons. 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.[37]

On average, our analysis found small potential reductions in drift groundings: -0.0047 drift groundings per year from Scenario 1 to Scenario 2 and -0.0035 drift groundings per year from Scenario 2 to Scenario 3.[38] This is equivalent to the new escort regulations under Scenario 2 potentially being able to prevent about 1 in 44 drift groundings occurring in the BPC zones, on average. The new escort regulations under Scenario 3 would then potentially be able to prevent an additional 1 in 57 drift groundings occurring in the BPC zones, on average, when compared to Scenario 2.

The potential average reductions were even greater for newly escorted vessel types. The new escort regulations under Scenario 2 would potentially prevent about 1 in 8 ATB drift groundings, 1 in 12 towed oil barge drift groundings, 1 in 14 chemical tanker drift groundings, 1 in 28 crude tanker drift groundings, and 1 in 176 product tanker drift groundings. The new escort regulations under Scenario 3 would potentially be able to prevent, on average, about 1 in 7 ATB drift groundings, and 1 in 3 towed oil barges drift groundings. Some of these numbers might seem surprisingly low, but it is important to remember that escorts are only assigned to laden vessels, so not all transits in the newly required zones are directly supported by the addition of escorts. Those vessel types also have very low average counts of simulated drift groundings per year. ATBs had 0.0005, towed oil barges had 0.0035, chemical tankers had 0.0001, crude tankers had 0.0075, and product tankers had 0.0044.

When looking at the top four traffic zones (about 77 percent of vessel traffic), the new escort regulations under Scenario 2 would potentially prevent about 1 in 31 drift groundings in Puget Sound, 1 in 346 drift groundings in Haro Strait and Boundary Pass, 1 in 38 drift groundings in Admiralty Inlet, and 1 in 73 in Strait of Georgia. The new escort regulations under Scenario 3 would potentially be able to prevent, on average, 1 in 108 drift groundings in Puget Sound, 1 in 43 drifting groundings in Haro Strait and Boundary Pass, 1 in 13 drift groundings in Admiralty Inlet, and 1 in 69 drift groundings in Strait of Georgia. These reductions do not necessarily translate to an appreciable decrease in drift groundings. Those zones have very low average counts of simulated drift groundings per year. Puget Sound had 0.0865, Haro Strait and Boundary Pass had 0.0654, Admiralty Inlet had 0.0191, and Strait of Georgia had 0.0132.

The potential average reduction in oil volume at risk and oil outflows associated with these reductions is small. Yet, the risk metrics do not speak to whether the specific drift groundings prevented by the new tug escort requirements 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, a small number are associated with large spills. It follows that while our

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

[38] The values in this summary are for BPC zones only, and exclude oil spill risk from ferries.

risk metrics show small average reductions in risk, the prevention of an individual drift grounding could potentially be preventing a large spill.

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.

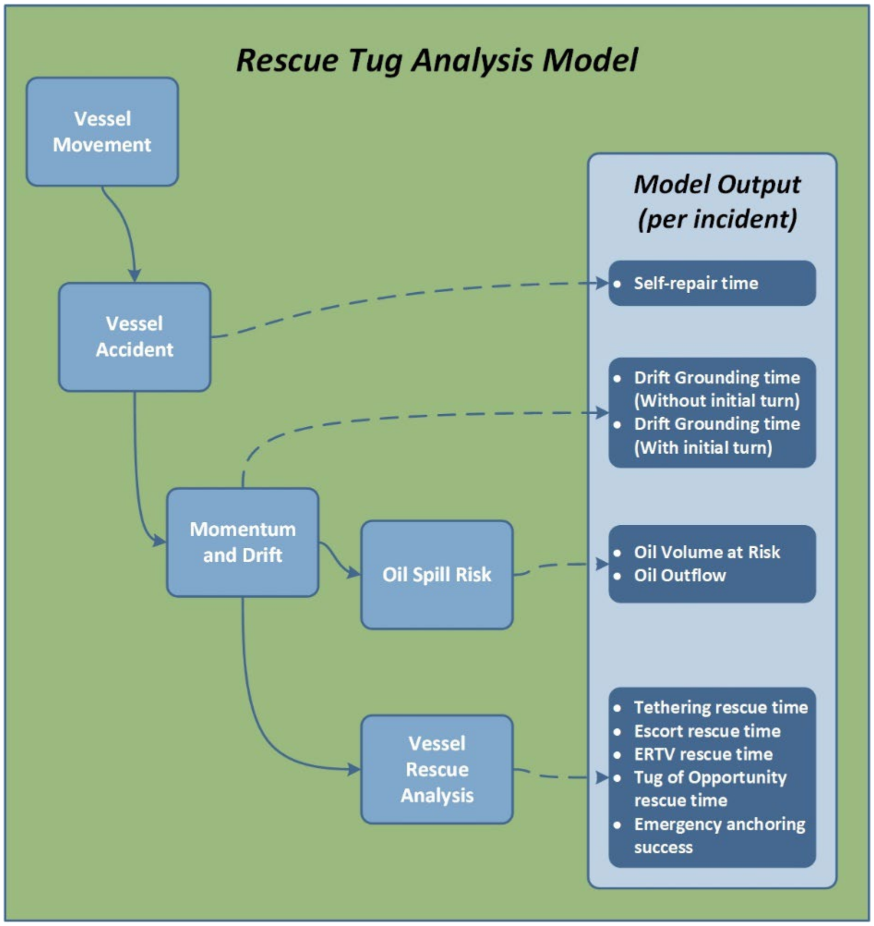

Figure B-1: Rescue Tug Analysis Model.

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.

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).

Figure B-2: Model domain.

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 a number of 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[39]
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

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[39] 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.

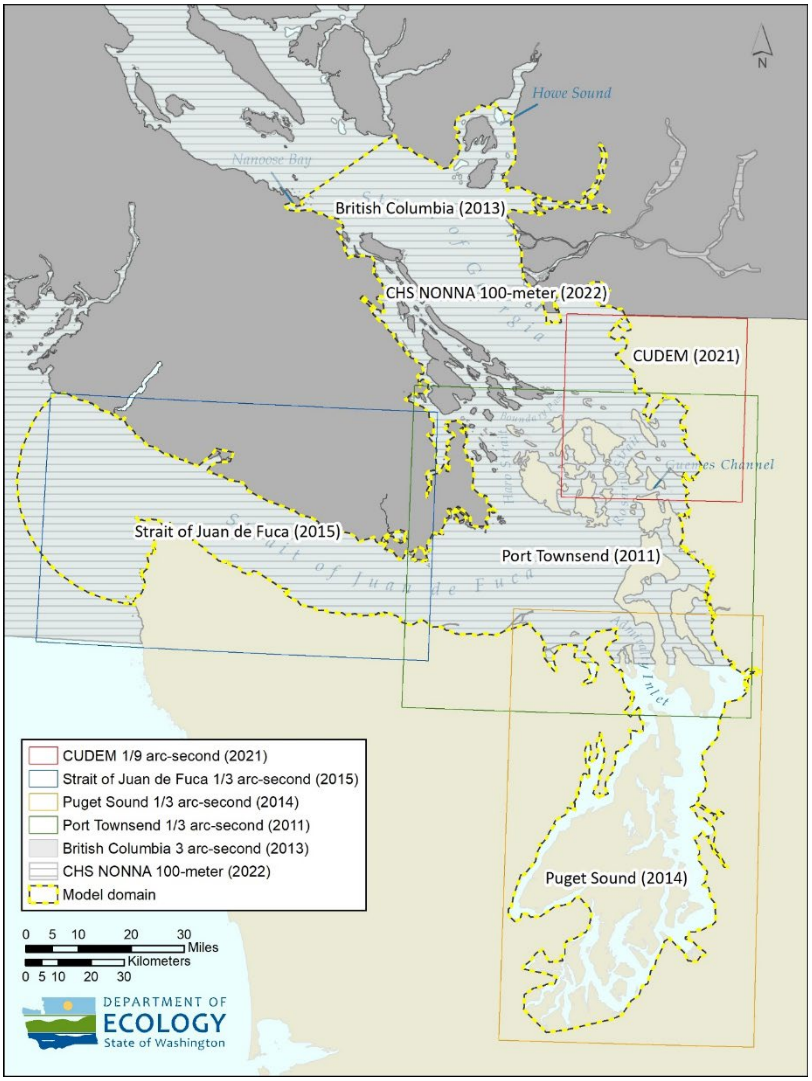

Figure B-3: Bathymetry sources.

Wind and current data

The model uses wind and current data to determine vessel drift trajectories. The model uses wind and current hindcast data from LiveOcean. 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.

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 also 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.
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)
Vehicles Carrier	Vehicle Carrier
Crude/Oil Products Tanker Products Tanker	Tanker (Product)

IHS-Markit Vessel Category	Model Vessel Type
Replenishment Tanker	
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] General Cargo with Container Capacity [Marine Exchange] Container Ship (Fully Cellular) [Marine Exchange] Container Ship [TSB]	Container Ship

Vessel Category [Source]	Model Vessel Type
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, we assigned default values.

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

Model Vessel Type	Length	Width	Draft	Fuel Capacity	Cargo Capacity	Tons (DWT)	Tons (displacement)
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 the model primarily used known values. When known values were not available, the model 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;
- $\beta_1$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	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$
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	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$
ATB	-5.65	0.48

Model Vessel Type	β_1	β_2
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 are laden or unladen. 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 is 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

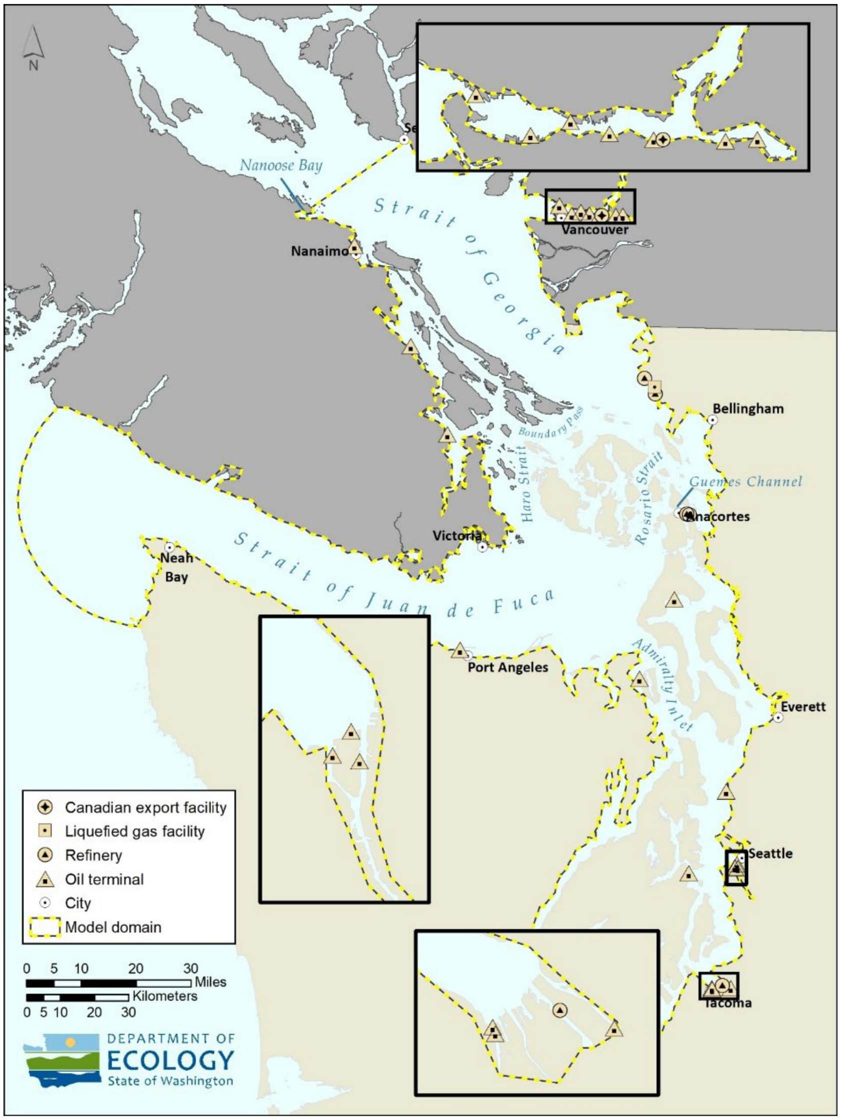

Figure B-4: Oil handling facilities.

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

Vessel Type	Refinery	Canadian Export Facility	LG Facility	Other (including Oil Terminal)
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 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 because the incident databases did not differentiate them sufficiently to allow for separate hazard counts. We consolidated general cargo and vehicle carrier vessel types for the same reason. 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
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. We looked at incidents that occurred between 2002 and 2019 in the model domain (Figure B-2). We used the hazard mapping methods described in *Methods and Hazard Mapping* to identify loss of propulsion events and loss of steering events.

Using this method, we identified incidents that we were able to categorize as loss of propulsion and incidents that we were able to categorize as loss of steering. We also found incidents where we were unable to make a determination 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
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

MISLE Initial Event Type	Additional Criteria	Model Hazard Type
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 Flooding - Initial Flooding - Progressive Fouling Implosion	See keyword search criteria for Loss of Steering	Loss of Steering

MISLE Initial Event Type	Additional Criteria	Model Hazard Type
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 Fire - Reflash Flooding - Initial Flooding - Progressive Fouling Implosion	See keyword search criteria for Collision	Collision

MISLE Initial Event Type	Additional Criteria	Model Hazard Type
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 Fire - Initial Fire - Reflash Flooding - Initial Flooding - Progressive Fouling Implosion	See keyword search criteria for Capsize/Sinking	Capsize/Sinking

MISLE Initial Event Type	**Additional Criteria**	**Model Hazard Type**
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*
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*

Model Hazard Type	Keyword Search Criteria
	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
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	Grounding

MARSIS Hazard Type	Additional Criteria	Model Hazard Type
	Propulsion or Loss of Steering	
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 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 Propulsion	Loss of Propulsion

MARSIS Hazard Type	Additional Criteria	Model Hazard Type
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. TOTAL FAILURE OF ANY MACHINERY OR TECHNICAL SYSTEM	Does not meet keyword search criteria for Loss of Propulsion or Loss of Steering	Other

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* *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*

Model Hazard Type	Keyword Search Criteria
	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.[40] 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.

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

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[40] 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.

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 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
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 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
	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 covers a number of different aspects of vessel movements. It starts with a list of the components of a vessel movement. Then it describes the process for the creation of tracks out of raw AIS data. The process for identification and assignment of vessel attributes is also described in this section.

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

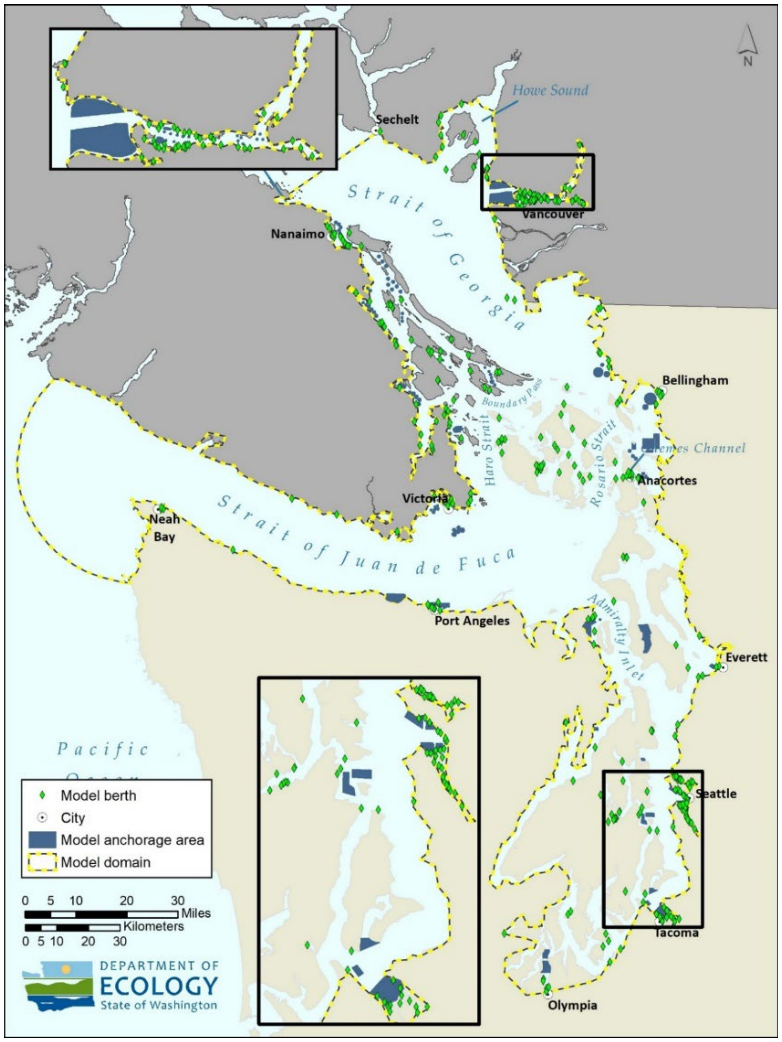

Figure B-5: Model berths and anchorages

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.

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.

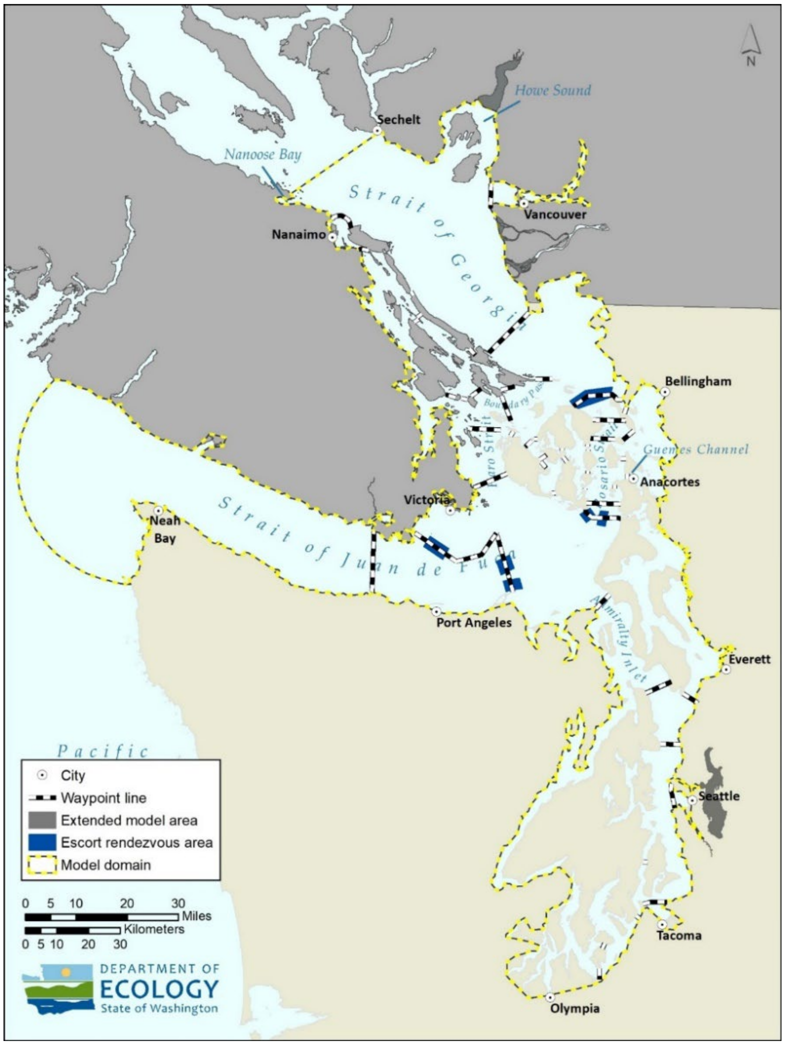

Figure B-6: Model waypoints, escort rendezvous areas, and extended model areas

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. 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.

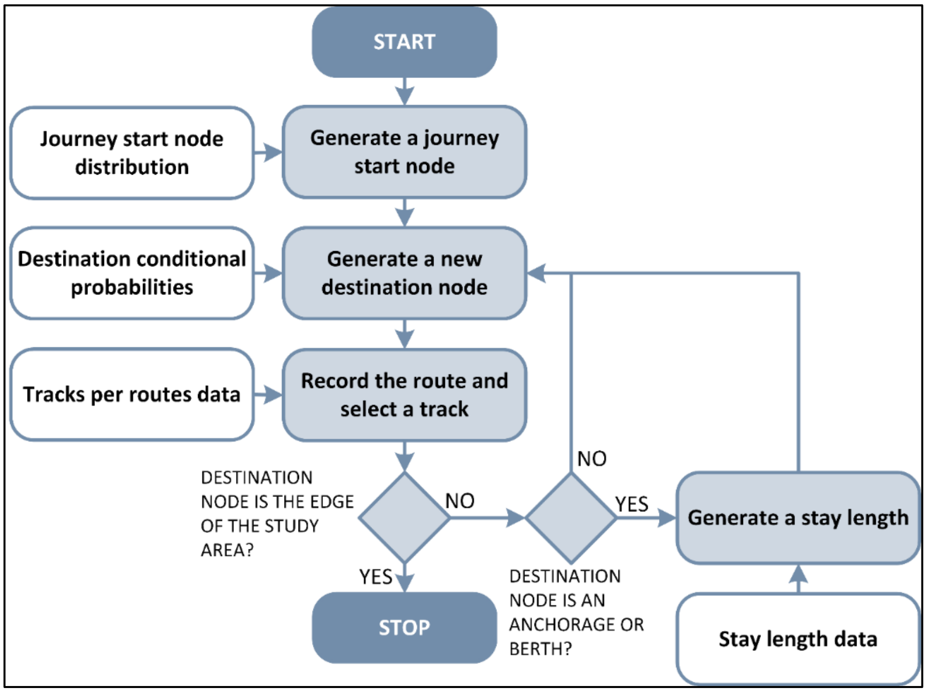

Figure B-7: Route generation process (simplified)

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.

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 the escort job 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 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 – 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 in model

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 time period 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. They include both theoretical and experimental methods. There are 36 components of the added mass corresponding 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, which is the longitudinal motion along the x-axis. We are only interested in surge since 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 1/5th 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.

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

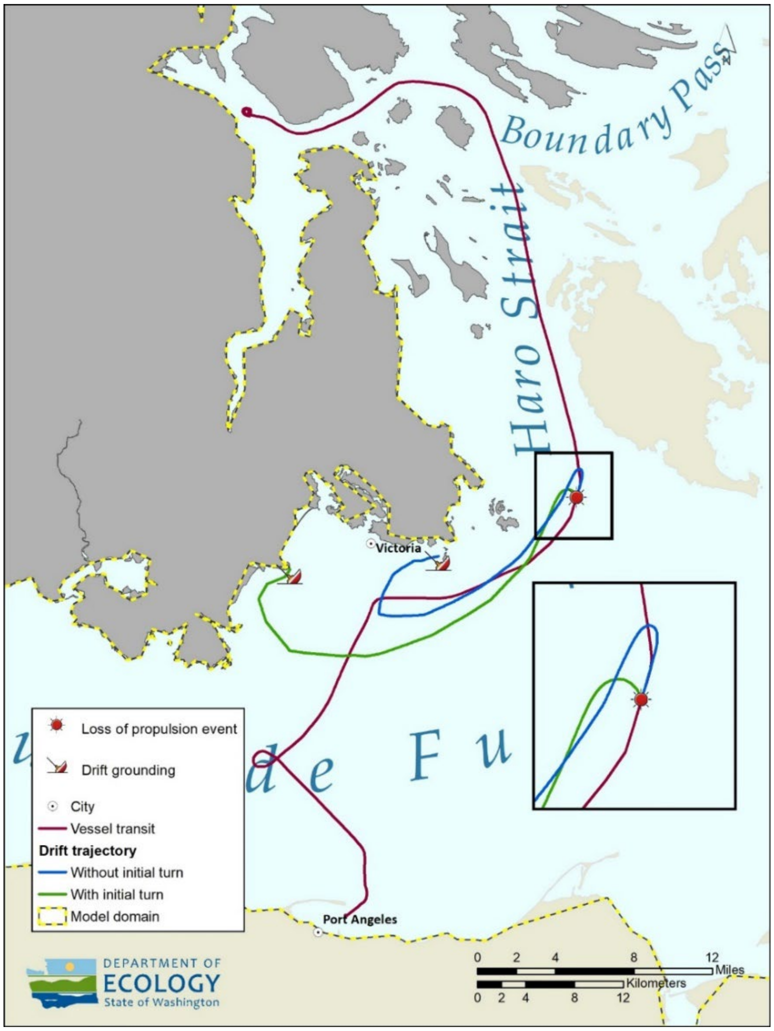

Figure B-8: Map of drift trajectory examples multiplies that result by the observed oil spill probability. Oil spill probabilities and volumes are based on observed occurrences in the MISLE and MARSIS databases. See *Oil Spill Probabilities* for more details. If the average oil spill volume for a vessel 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. The model defines the grounding depth 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, the model calculates a transit time dataset for each potential tug of opportunity and ERTV. The model generates the transit time dataset using a custom Python script and ESRI ArcGIS spatial analysis tools. The model assumes the tug travels 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 ship

The model determines the interception point 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 model identifies the earliest point on the drift trajectory where a tug could arrive in time for a save.

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.

Figure B-9: ERTV locations

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 end 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:

- 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)[41]	228 minutes	279 minutes
Time to rescue, ERTV (Deltaport)41	315 minutes	358 minutes
Time to rescue, ERTV (Neah Bay)41	351 minutes	322 minutes
Time to rescue, ERTV (Port Angeles)41	170 minutes	149 minutes
Time to rescue, ERTV (Port Townsend) 41	178 minutes	201 minutes

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[41] Rescue time for ERTV includes mobilization time, time to connect, and time to control.

Model Output	**Without initial turn**	**With Initial turn**
Time to rescue, ERTV (Roche Harbor)41	125 minutes	159 minutes
Time to rescue, ERTV (Sidney)41	158 minutes	182 minutes
Time to rescue, ERTV (Victoria)41	102 minutes	93 minutes
Time to rescue, closest tug of opportunity[42]	152 minutes	130 minutes
Complete loss of propulsion	Yes	Yes
Self-repair time	37 minutes	37 minutes
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.

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[42] 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.

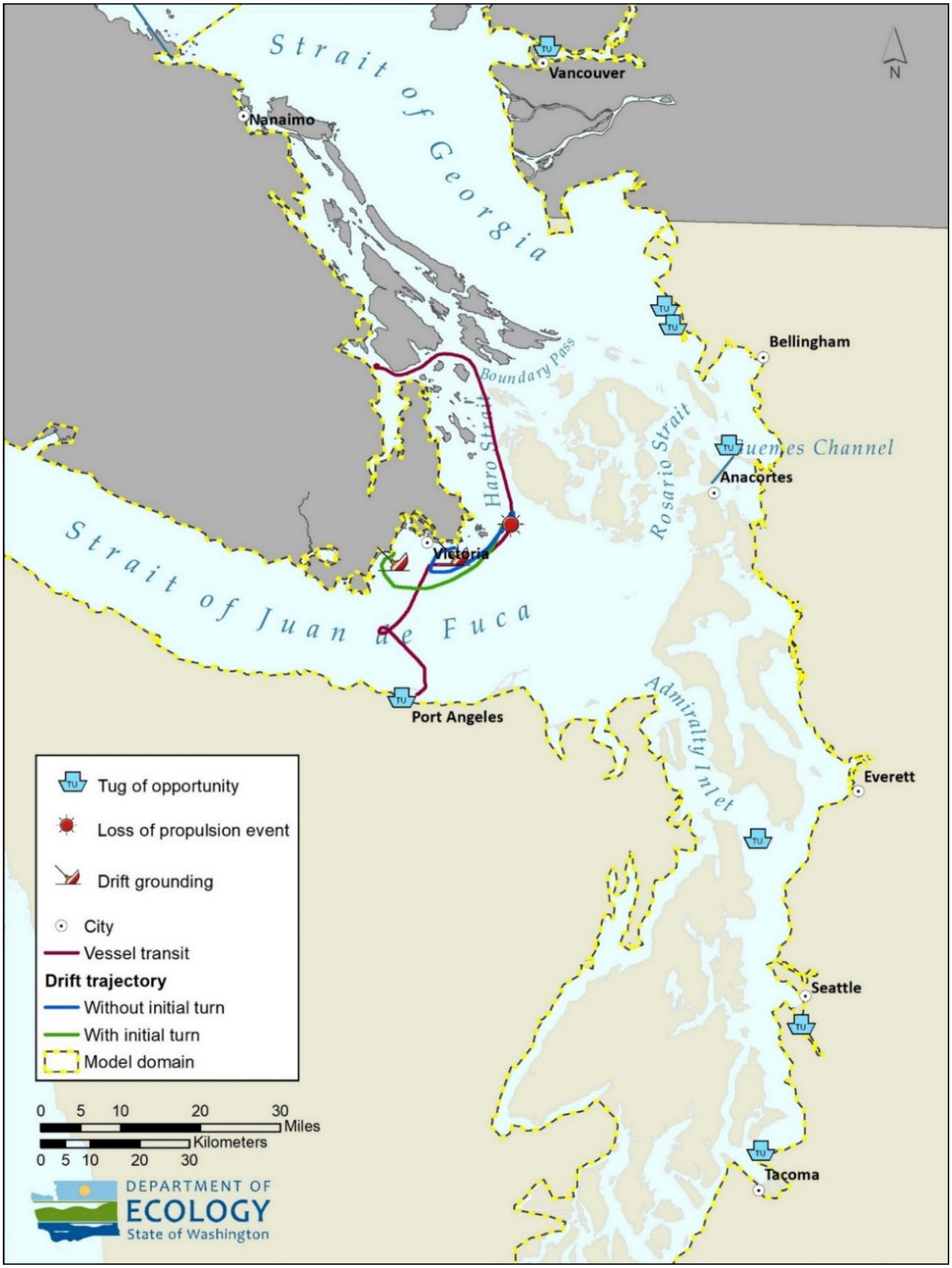


Figure B-10: Map showing tugs of opportunity when loss of propulsion occurs.

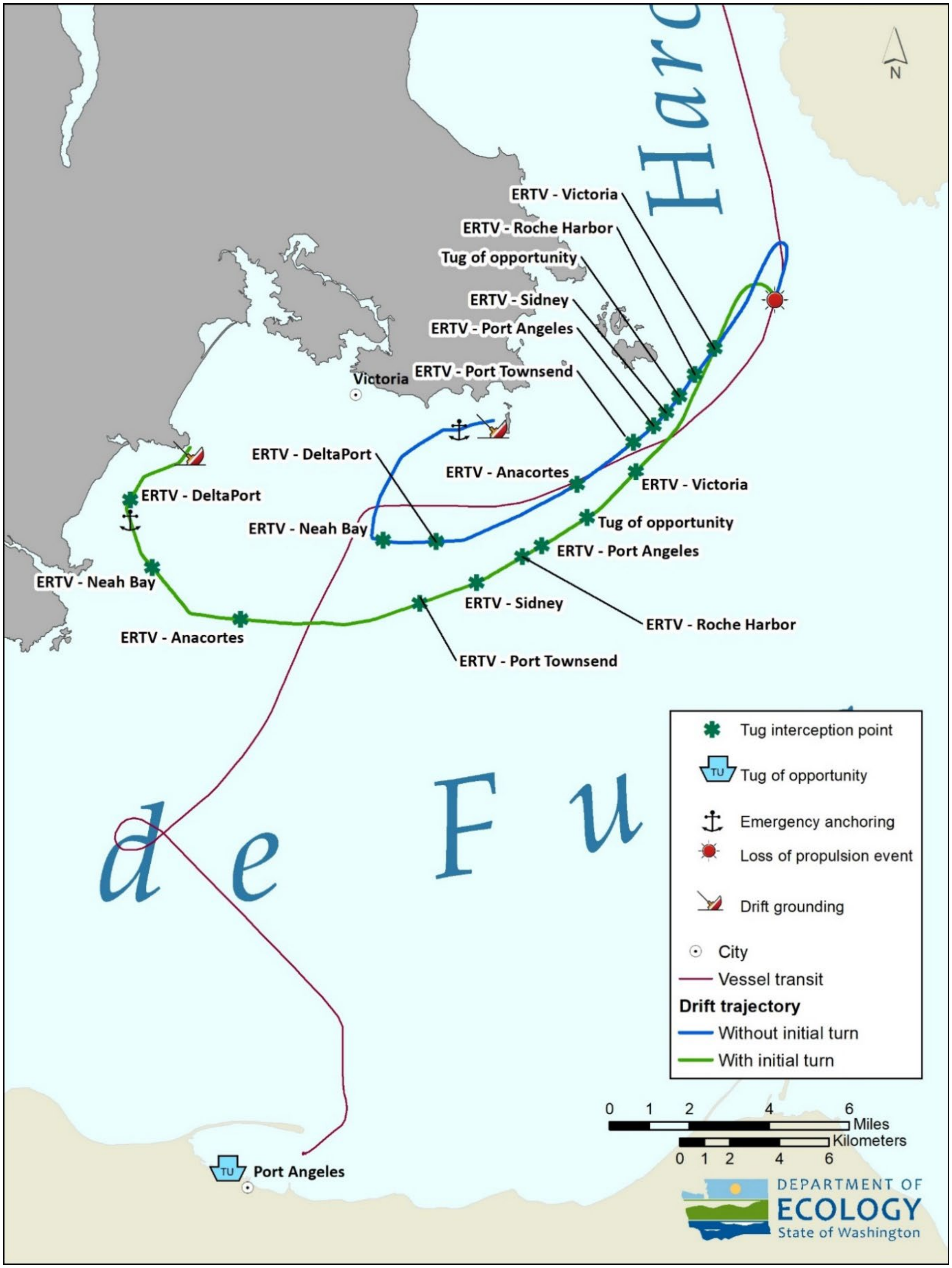


Figure B-11: Map showing rescue tug interception points along drift trajectories.

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 provided real time and written responses to over 250 questions. 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

Tug escort analysis

Consultation outreach with potentially affected federally recognized Tribes

In December 2021, the Board of Pilotage Commissioners and Ecology sent joint 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 tug escort 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 tug escort analysis

With the assistance of Board of Pilotage Commissioners staff, Ecology developed a draft scope of work for the tug escort analysis. In late August 2021, we publicized the draft and solicited input from the public, and local and tribal governments.

The draft scope of work was presented to the Board of Pilotage Commissioners Oil Transportation Safety Committee on August 30, 2021. A separate invitation to provide input was sent to the everyone who had expressed interest in our model development work, the Spill Prevention Preparedness and Response general mailing list, the Board of Pilotage Commissioners maritime partner mailing list, and tribal mailing list.

We received 10 formal comments. We provided written responses and adjusted the scope of work as appropriate.

In November 2021, we presented the revised scope of work for the tug escort analysis at the Board of Pilotage Commissioners board meeting. The draft scope included modifications that came from the BPC Oil Transportation Safety Committee as well as public comment period in September. A question-and-answer session followed the presentation. The Board of Pilotage Commissioners formally approved the scope of work at their December 2021 meeting.

Tug escort analysis outreach events

Summer 2022

- Tug Escort and ERTV Analysis Projects - Introductory Webinar - 77 attendees.
- Final Model Analysis Plan - 48 attendees.
- Rescue Towing Analysis Model: Tug Escort and ERTV Analyses. Puget Sound Coastal Area Committee Meeting.

Winter 2023

- Tug Escort Rulemaking Overview and Analysis Discussion - 4 attendees.
- Tug Escort Rulemaking Overview and Analysis Discussion - 3 attendees.
- Presentation at Affiliated Tribes of Northwest Indians Winter Convention.

Spring 2023

- Preliminary Review of Analysis Results – 63 attendees.

Tug escort 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.

Tug escort analysis comments received

Each event provided an opportunity for questions, comments, and discussion. We provided real time and written responses to over 85 questions.

Tug escort 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

Appendix D: Ecology and Board of Pilotage Commissioners Interagency Agreement

IAA No. C2000090

INTERAGENCY AGREEMENT (IAA) BETWEEN THE STATE OF WASHINGTON, DEPARTMENT OF ECOLOGY AND WASHINGTON STATE BOARD OF PILOTAGE COMMISSIONERS

THIS INTERAGENCY AGREEMENT (“Agreement” or “IAA”) is made and entered into by and between the state of Washington, Department of Ecology, hereinafter referred to as “ECOLOGY,” and the Washington State Board of Pilotage Commissioners, hereinafter referred to as “BPC,” pursuant to the authority granted by Chapter 39.34 RCW and RCW 88.16.260.

THE PURPOSE OF THIS AGREEMENT is to establish guidelines, roles, and responsibilities for collaboration between ECOLOGY and BPC in the effective implementation of Sections 2, 3, 4, and 5 of Reducing Threats to Southern Resident Killer Whales by Improving the Safety of Oil Transportation Act, ESHB 1578 (Laws of 2019, Ch. 289) (hereinafter referred to as the “Act”).

WHEREAS, the Act authorized ECOLOGY and BPC to enter into an Interagency Agreement allowing ECOLOGY to assist BPC with modeling and rulemaking activities authorized by the Act.

WHEREAS, close coordination and consultation between ECOLOGY and BPC is essential to ensure successful and effective implementation of these activities given legislative direction for consultation and interdependence of outcomes.

WHEREAS, the Legislature provided funding to ECOLOGY in the 2019-21 Operating Budget to support activities required by the Act.

THEREFORE, IT IS MUTUALLY AGREED THAT:

1) RESPONSIBILITIES AND COORDINATION OF WORK

ECOLOGY and BPC will work together to:

- Develop project plans to accomplish the requirements of the Act Sections 2, 3, and 5, including projects to help inform the requirements of the Act.
- Coordinate on communication, consultation and outreach activities.
- Provide technical assistance to plan and prepare for activities.

ECOLOGY and BPC Meetings:

ECOLOGY and BPC will meet in-person quarterly and via conference call monthly, or as needed to accomplish these related projects. ECOLOGY and BPC may change the meeting schedule by mutual agreement. Each organization is responsible for keeping their respective leadership (e.g., the full Board of Pilotage Commissioners) apprised about the status of the projects and associated meetings, as appropriate.

Meeting topics will include:

- project planning
- status updates
- monitoring and evaluation of outcomes

Decision-making:

a) Coordination and project details decision: decided by consensus of the portfolio management team and documented in meeting notes.

    a. The portfolio management team: will consist at a minimum of the BPC Executive Director, ECOLOGY Spills Program Prevention and Statewide Resources Section Managers, and the ECOLOGY BPC representative.

    b) Policy decisions: made by ECOLOGY Spills Program Manager and/or a formal Board of Pilotage Commissioners vote. Decision-makers may elevate decisions within their organizations when appropriate.

Project-specific responsibilities:

In this section ‘BPC’ refers to BPC staff and ‘Board’ refers to the full Board of Pilotage Commissioners. Additional responsibilities will be assigned through mutually agreed upon project plans.

a) BPC to Implement Rosario Tug Escort Requirements (due September 1, 2020) Act Sec.2.(1)(a)(ii)
    a. Roles:
        i. BPC: Outreach to and inform tribes and stakeholders about tug escort requirements; determine monitoring and enforcement procedures; implement tug escort requirements.
        ii. Board: Vote on decisions including interpretive and policy statements.
        iii. ECOLOGY: Provide technical assistance to BPC.

b) BPC to Identify and define geographic waterway zones (due September 1, 2020) Act Sec.3.(1)(d)(i)
    a. Roles:
        i. BPC: Lead a process to define geographic regions, or zones, encompassing these waters.
        ii. Board: Make final decision on identifying and defining zones.
        iii. ECOLOGY: Provide technical assistance to BPC.

c) ECOLOGY to Develop and maintain risk model Act Sec.4.(1)
    a. Roles:
        i. ECOLOGY: Develop and maintain a vessel traffic risk model in consultation with the parties listed in 88.46.250. Consult with tribes and stakeholders.
        ii. BPC: Provide technical assistance to ECOLOGY as requested.

d) ECOLOGY to Report to the Legislature on the quantitative assessment of the Emergency Response Towing Vessel (due September 1, 2023) Act Sec.4.(2)
    a. Roles:
        i. ECOLOGY: Quantitatively assess whether an emergency response towing vessel serving Haro Strait, Boundary Pass, Rosario Strait, and connected navigable waterways will reduce oil spill risk; report findings to the Legislature (due September 1, 2023).
        ii. BPC: Provide technical assistance to ECOLOGY.

e) BPC to conduct an analysis of tug escorts using the model developed by ECOLOGY (due September 1, 2023) Act Sec.3.(1)(d)(iii)
    a. Roles:
        i. BPC: Develop scope of tug escort analysis using the model developed by ECOLOGY. Scope should include related outreach activities.
        ii. ECOLOGY: Provide technical assistance to BPC in the development of the scope. Perform tug escort analysis and related outreach activities based on the scope with input from BPC. Write and submit a summary of the tug escort analysis to the legislature by September 1, 2023.
        iii. Board: Vote to approve the analysis scope.

f) BPC to complete a synopsis of changing vessel traffic trends (due December 2021) Act Sec.3.(1)(d)(ii)
    a. Roles:
        i. BPC: Develop scope of changing vessel traffic trends synopsis and submit final synopsis to the legislature.
        ii. ECOLOGY: Provide technical assistance to BPC in the development of the scope. Develop report of Synopsis of changing vessel traffic trends.
        iii. Board: Vote to approve scope. Review and approve the Synopsis of changing vessel traffic trends.

g) BPC to conduct Tug escort rulemaking (due December 2025) Act Sec.3.(1)(a)
    a. Roles:
        i. Board: Make final decisions regarding tug escort requirements and adopt rules.
        ii. ECOLOGY: Lead rulemaking process and outreach efforts for BPC. Conduct regulatory analyses required by the Administrative Procedure Act, State Environmental Policy Act and the Regulatory Fairness Act.
        iii. BPC: Provide technical assistance to ECOLOGY as needed related to rulemaking process, outreach, and technical expertise.

External Communications:

ECOLOGY and BPC will create a joint Communications plan. External communications (e.g., emails, presentations, and letters) will align with the joint Communications plan and will be coordinated between ECOLOGY and BPC. Whenever possible and appropriate, communications products will be joint messages from both ECOLOGY and BPC.

Consultation responsibilities:

The Act directs ECOLOGY and BPC to consult with tribes and stakeholders during model development, risk analysis, and rulemaking. Consultation requirements will be incorporated into the joint Communications plan and project plans.

2) PERIOD OF PERFORMANCE

The period of performance of this IAA shall commence on December 1, 2019, (or the date of final signature, whichever comes later,) and be completed by December 31, 2025, unless terminated sooner as provided herein.

Amendments extending the period of performance, if any, shall be mutually agreed upon in writing by ECOLOGY and BPC.

3) ALTERATIONS AND AMENDMENTS

This Agreement may be amended by mutual agreement of the parties. Such amendments shall not be binding unless they are in writing and signed by personnel authorized to bind each of the parties. This agreement may be continually renewed via amendment for time periods that are mutually agreed upon.

4) FUNDING AVAILABILITY

ECOLOGY's and BPC's ability to perform work pursuant to the agreement is contingent on availability of funding. In the event funding from state, federal, or other sources is withdrawn, reduced, or limited in any way after the effective date and prior to completion or expiration date of this Agreement, ECOLOGY or BPC, at their sole discretion, may elect to terminate the Agreement, in whole or part, for convenience or to renegotiate the Agreement subject to new funding limitations and conditions. ECOLOGY or BPC may also elect to suspend performance of the Agreement until ECOLOGY or BPC determines the funding insufficiency is resolved. ECOLOGY or BPC may exercise any of these options with no notification restrictions, although ECOLOGY or BPC will make a reasonable attempt to provide notice.

5) ORDER OF PRECEDENCE

In the event of an inconsistency in the terms of this Agreement, or between its terms and any applicable statute or rule, the inconsistency shall be resolved by giving precedence in the following order:

a) Applicable federal and state of Washington statutes, regulations, and rules.
b) Mutually agreed upon written amendments to this Agreement.

c) This Agreement, number C2000090.
d) Any other provisions or term of this Agreement, including materials incorporated by reference or otherwise incorporated.

6) RECORDS MAINTENANCE

The parties to this Agreement shall each maintain books, records, and other documents, related to the activities covered by this agreement consistent with the records retention's requirements and procedures of their agency. Each party will utilize reasonable security procedures and protections for all materials related to this Agreement. All materials are subject to state public disclosure laws.

7) RESPONSIBILITIES OF THE PARTIES

Each party of this Agreement hereby assumes responsibility for claims and/or damages to persons and/or property resulting from any act or omissions on the part of itself, its employees, its officers, and its agents.

Neither party will be considered the agent of the other party to this Agreement.

8) RIGHTS IN DATA

Unless otherwise provided, data which originates from this Agreement shall be owned by state of Washington, ECOLOGY. Data shall include, but not be limited to, reports, documents, pamphlets, advertisements, books magazines, surveys, studies, computer programs, films, tapes, and/or sound reproductions. Ownership includes the right to copyright, patent, register, and the ability to transfer these rights.

9) SEVERABILITY

If any provision of this Agreement or any provision of any document incorporated by reference shall be held invalid, such invalidity shall not affect the other provisions of this Agreement which can be given effect without the invalid provision, if such remainder conforms to the requirements of applicable law and the fundamental purpose of this Agreement, and to this end the provisions of this Agreement are declared to be severable.

10) TERMINATION FOR CAUSE

If for any cause, either party does not fulfill in a timely and proper manner its obligations under this Agreement, or if either party violates any of these terms and conditions, the aggrieved party will give the other party written notice of such failure or violation. The responsible party will be given the opportunity to correct the violation or failure within fifteen (15) business days. If failure or violation is not corrected, this Agreement may be terminated immediately by written notice of the aggrieved party to the other.

11) WAIVER

A failure by either party to exercise its rights under this Agreement shall not preclude that party from subsequent exercise of such rights and shall not constitute a waiver of any other rights under this

Agreement unless stated to be such in a written amendment to this Agreement signed by an authorized representative of the parties.

12) AGREEMENT MANAGEMENT

The representative for each of the parties shall be responsible for and shall be the contact person for all communications, notifications, and billings questions regarding the performance of this Agreement. The parties agree that if there is a change in representatives that they will promptly notify the other party in writing of such change, such changes do not need an amendment.

The ECOLOGY Representative is:

Name: Brian Kirk, Prevention Section Manager
Address: 3190 160th Ave SE, Bellevue WA 98008-5452
Phone: 425-649-7292
Email: brian.kirk@ecy.wa.gov
Fax: 425-649-7098

The BPC Representative is:

Name: Jaimie C. Bever, Executive Director
Address: 2901 3rd Avenue, Suite 500 Seattle, WA 98121
Phone: (206) 515-3887
Email: BeverJ@wsdot.wa.gov
Fax: (206) 515-3906

13) ALL WRITINGS CONTAINED HEREIN

This Agreement contains all the terms and conditions agreed upon by the parties. No other understandings, oral or otherwise, regarding the subject matter of this Agreement shall be deemed to exist or to bind any of the parties hereto.

The signatories to this Agreement represent that they have the authority to bind their respective organizations to this Agreement.

IN WITNESS WHEREOF, the parties below, having read this Agreement in its entirety, including all attachments, do agree in each and every particular as indicated by their signatures below.

State of Washington, Department of Ecology -- Dale Jensen, Spills Program Manager

State of Washington, Board of Pilotage Commissioners -- Jaimie C. Bever, Executive Director

Appendix E: Geographic Zones

STATE OF WASHINGTON
BOARD OF PILOTAGE COMMISSIONERS

GEOGRAPHIC ZONES

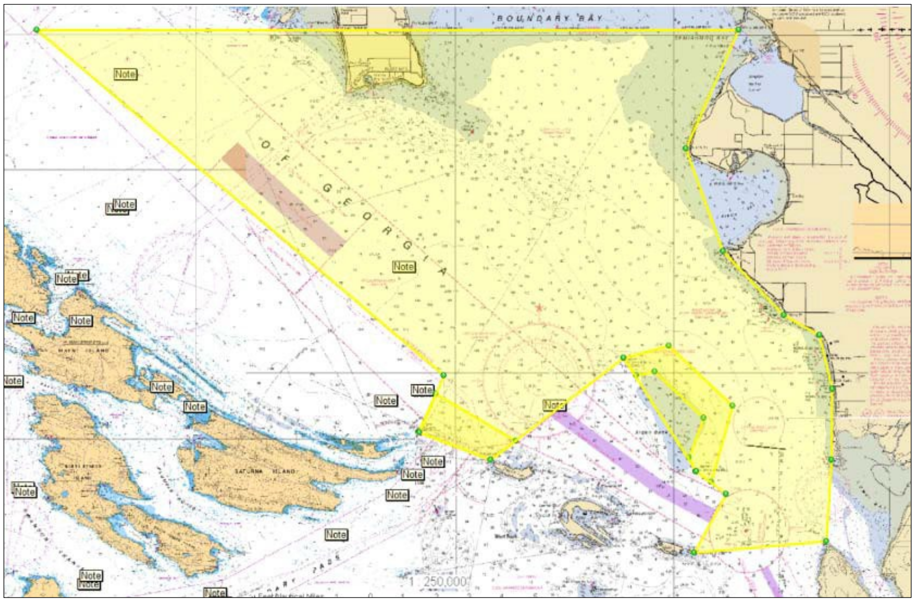
Per the Directives of ESHB 1578 *Reducing the threat to*
southern resident killer whales by improving the safety of oil transportation
and
Chapter 88.16 RCW Pilotage Act
88.16.190 Oil Tankers-Restricted Waters-Requirements

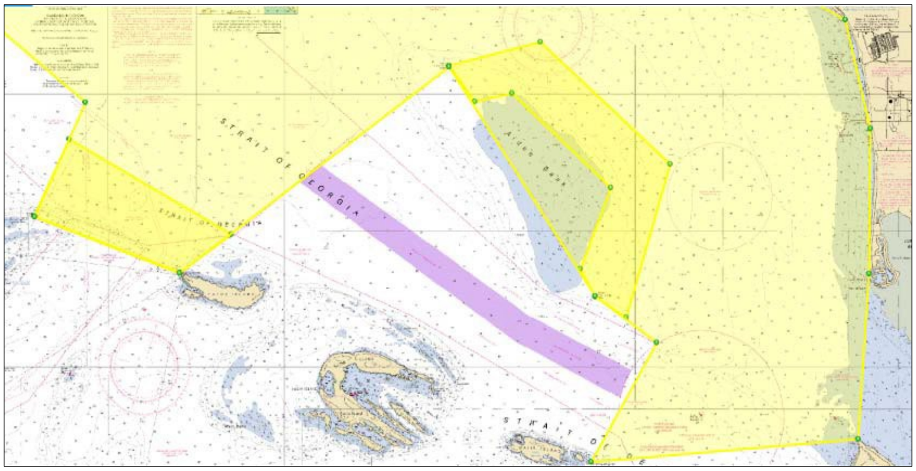
The following geographic zones for the waterways of Puget Sound were developed taking into account potential hazards including vessel distance to the ground, vessel traffic, weather conditions, currents, vessel capability, etc. Subzones are the critical spots in each passage and are indicated in the darker color of the overall zone.

Notes:

1) *The colors for each zone were chosen to distinguish them from one another and are not related to risk.*
2) *The written descriptions are the zone definitions. The visuals are provided as an aid to help visualize the zones.*
3) *The BPC recognizes that the U.S. and the state of Washington cannot regulate Canadian waters and that the Canadian VTS manages traffic in the areas of Haro Strait and Boundary Pass.*

1. Strait of Georgia





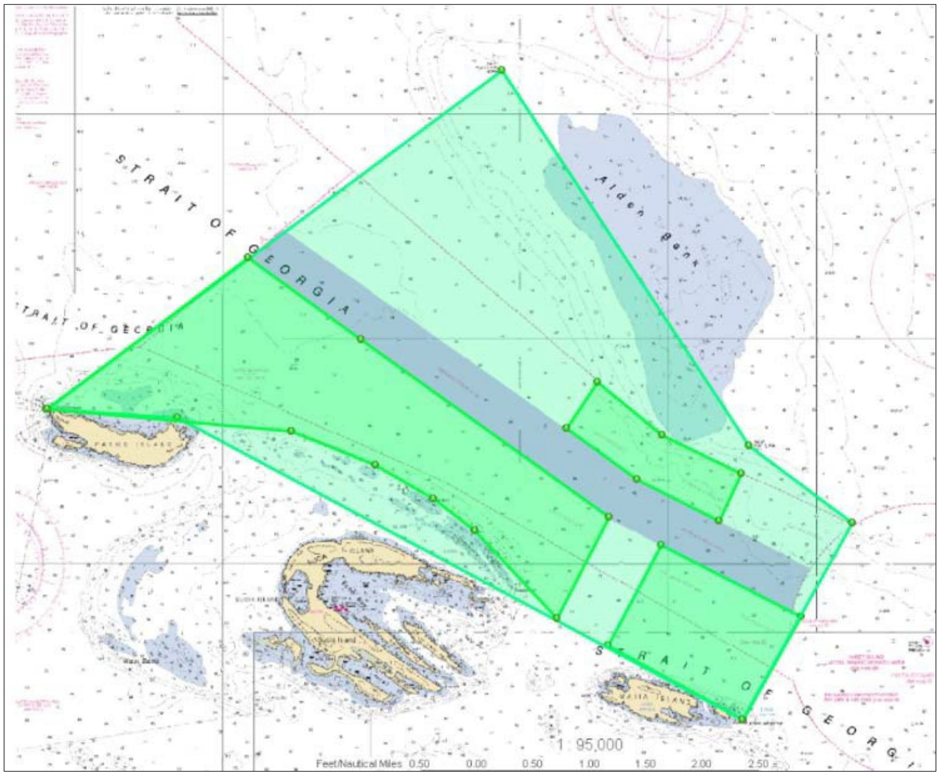
South: A line from Puffin Island light to Point Migley on Lummi Island.

West: From Puffin Island light, NE to Lat. 48° 46.4’N, Long 122° 47.5’W then to the South Alden Bank buoy, then to the North Alden Bank buoy, then to Alden Point light on Patos Island, then to Rosenfeld Rock buoy, then NE intercepting and following the international boundary.

North: Following the international boundary NW then East to the shore of Point Roberts.

East: Following the mainland shore from Point Roberts to Sandy Point then Point Migley.

2. Strait of Georgia South



Southwest: A line from Puffin Island light NW along the shores of Matia, Sucia, and Patos Islands to Alden Point light.

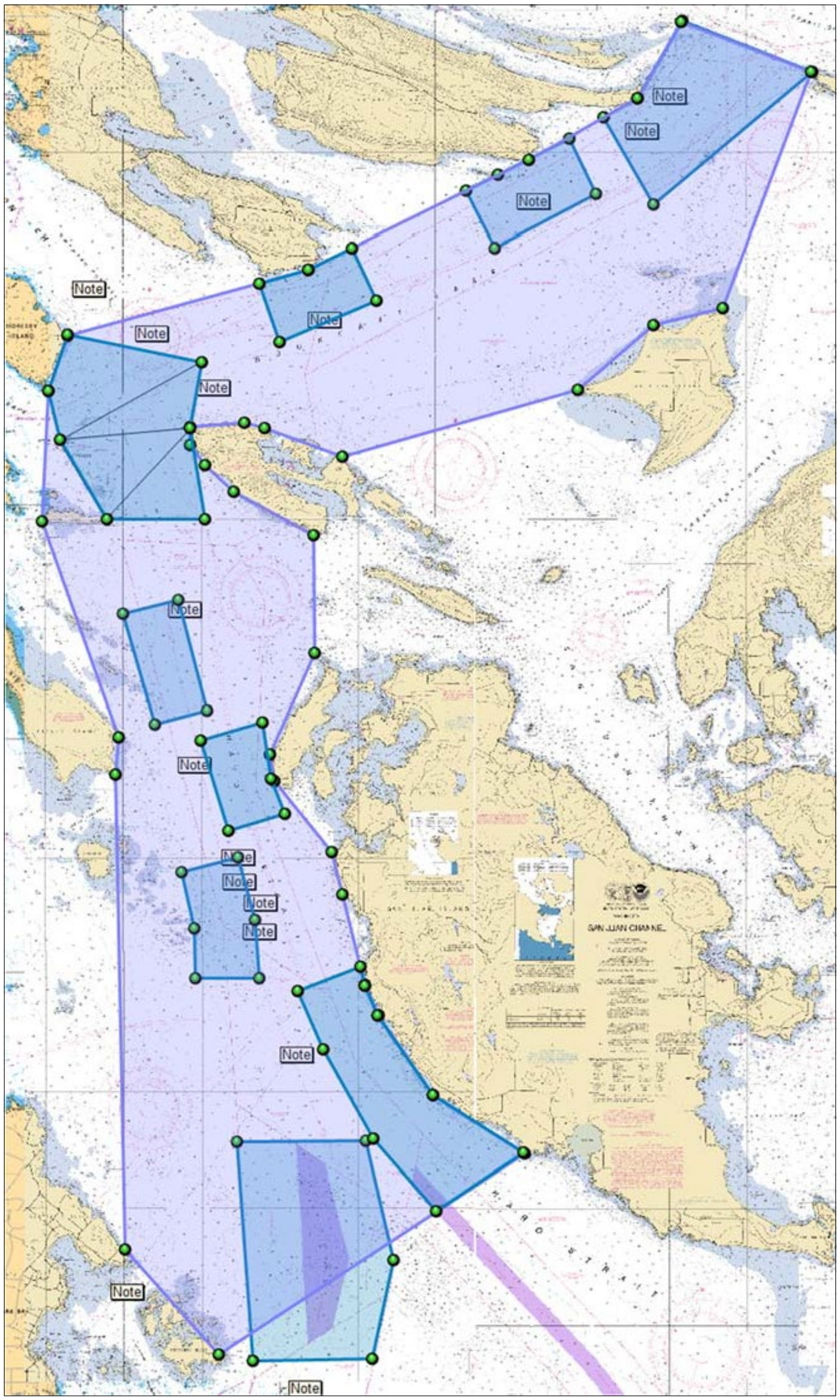
Northwest: A line from Alden Point light on Patos Island to the North Alden Bank buoy.

Northeast: A line from the North Alden Bank buoy to the South Alden Bank buoy then to Lat. 48° 46.4’N, Long. 122° 47.5’W.

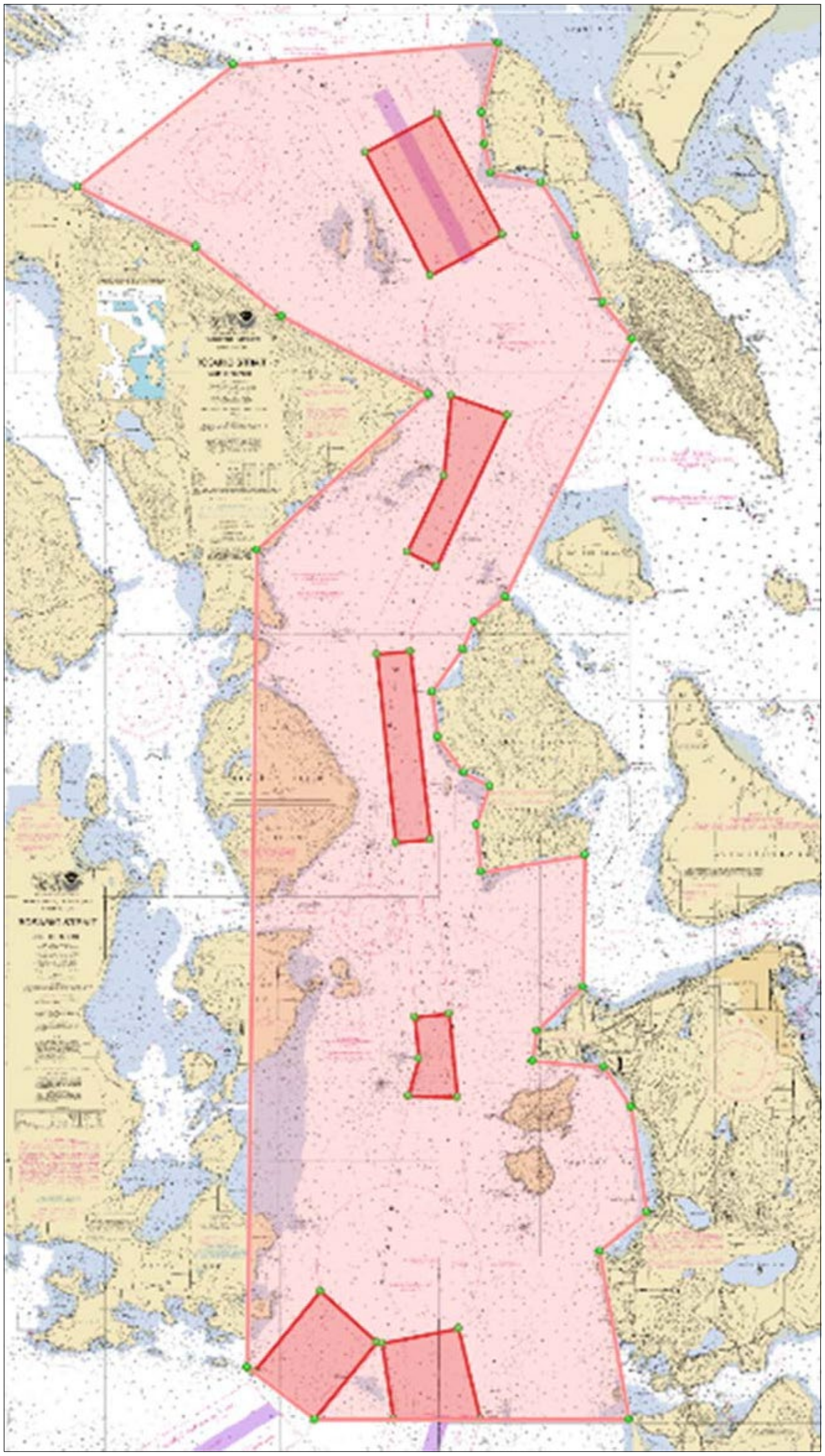
Southeast: A line from Lat. 48° 46.4’N, Long. 122° 47.5’W to Puffin Island light.

3. Haro Strait and Boundary Pass

Southern boundary: A line from Discovery Island light to Pile Point on San Juan Island. Following the adjacent shorelines of Haro Strait North to Tun Point on Stuart Island then following the adjacent shorelines of Boundary Pass Northeast. **Northeast boundary:** A line from Alden Point light on Patos Island to Rosenfeld Rock buoy off East Point, Saturna Island.



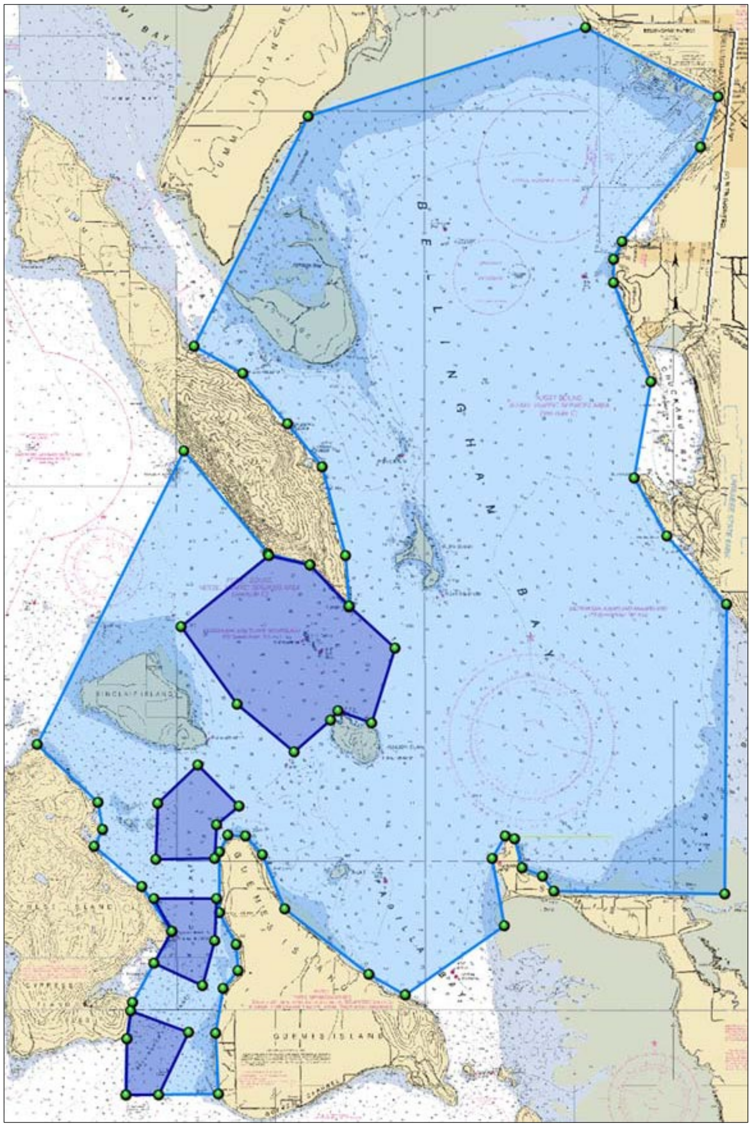
4. Rosario Strait



Southern: A line from Davidson Rock light, Southeast to position Lat. 48° 24.0’N, Long. 122° 47.15’W then East to the shore of Whidbey Island at Lat. 48° 24.0’N, Long. 122° 39.9’W. Following the adjacent shorelines of Rosario Strait to the North.

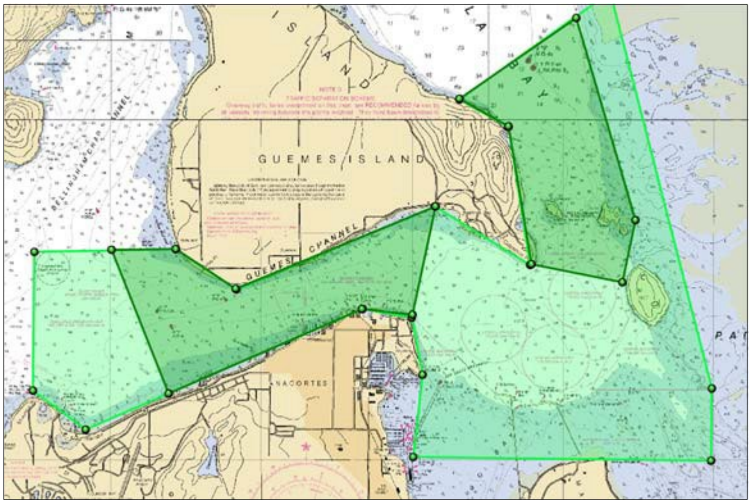
Northern: A line from Pt. Thompson on Orcas Island to Puffin Island light and then to Point Migley on Lummi Island.

5. Bellingham Channel, Sinclair Island, and waters to the East



West: All waters East of Rosario Strait with the exception of Guemes Channel and the waters East of Guemes Island from Padilla Bay buoy "5" South through the "Saddlebags" passage to Anacortes.

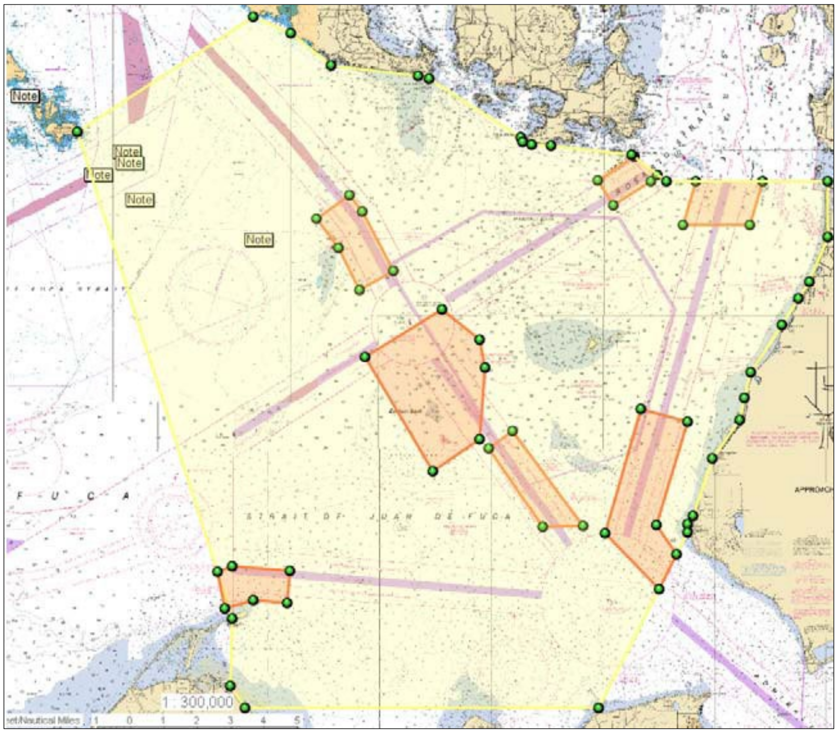
6. Guemes Channel and Saddlebags



West: The waters of Guemes Channel, East of Shannon Pt. and South of "Yellow Bluff" on Guemes Island. Following the adjacent shorelines of Guemes Channel to the March Point area then North between Guemes and Saddlebag Islands.

North: South of Padilla Bay buoy "5".

7. Eastern Strait of Juan de Fuca



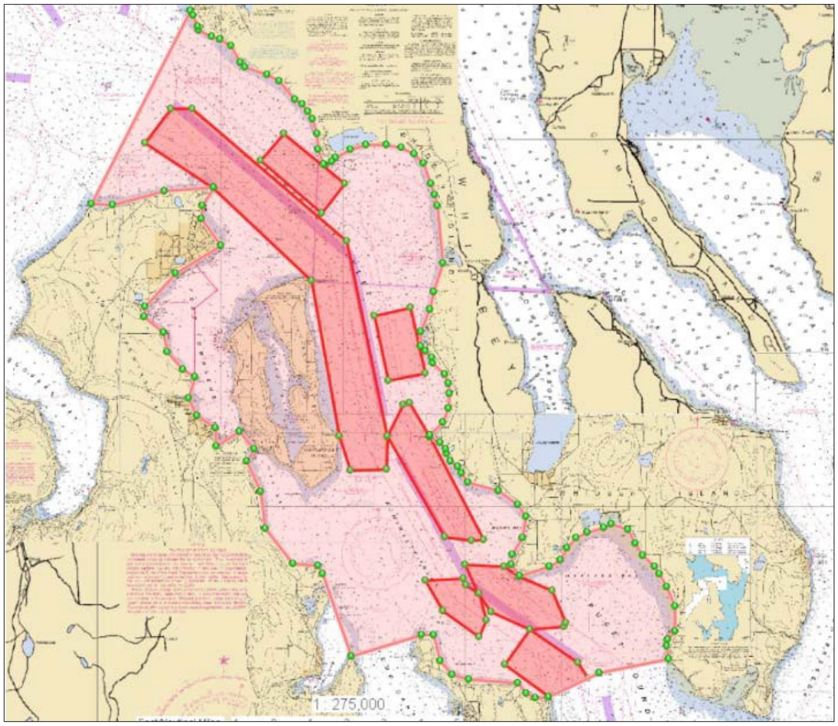
West: Line from Discovery Island light to New Dungeness light.

North: Line from Discovery Island light to Pile Pt. on San Juan Island, following the shore of San Juan Island East then crossing Cattle Pass and following the South shore of Lopez Island to Davidson Rock then following the defined Southern boundary of Rosario Strait to a point just South of West Point on Whidbey Island.

East: The Western shore of Whidbey Island from West Point to Point Partridge Point light then to McCurdy Point.

South: From New Dungeness light following the shore East to McCurdy Point.

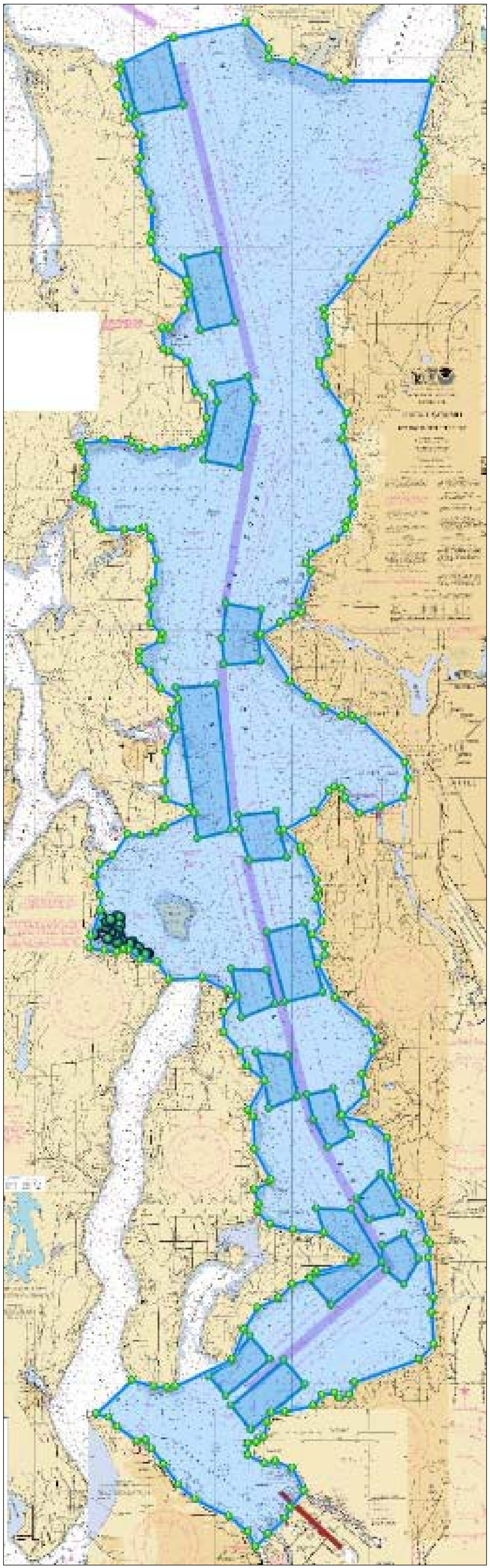
8. Admiralty Inlet



Northwest: A line from McCurdy Point to Point Partridge.
Following the shorelines of Whidbey Island on the Northeast and the shorelines of the Quimper Peninsula, Marrowstone Island and the North Shore of the Kitsap Peninsula.

Southeast: A line from Point No Point to buoy "SE" then to Indian Point on Whidbey Island.

9. Puget Sound



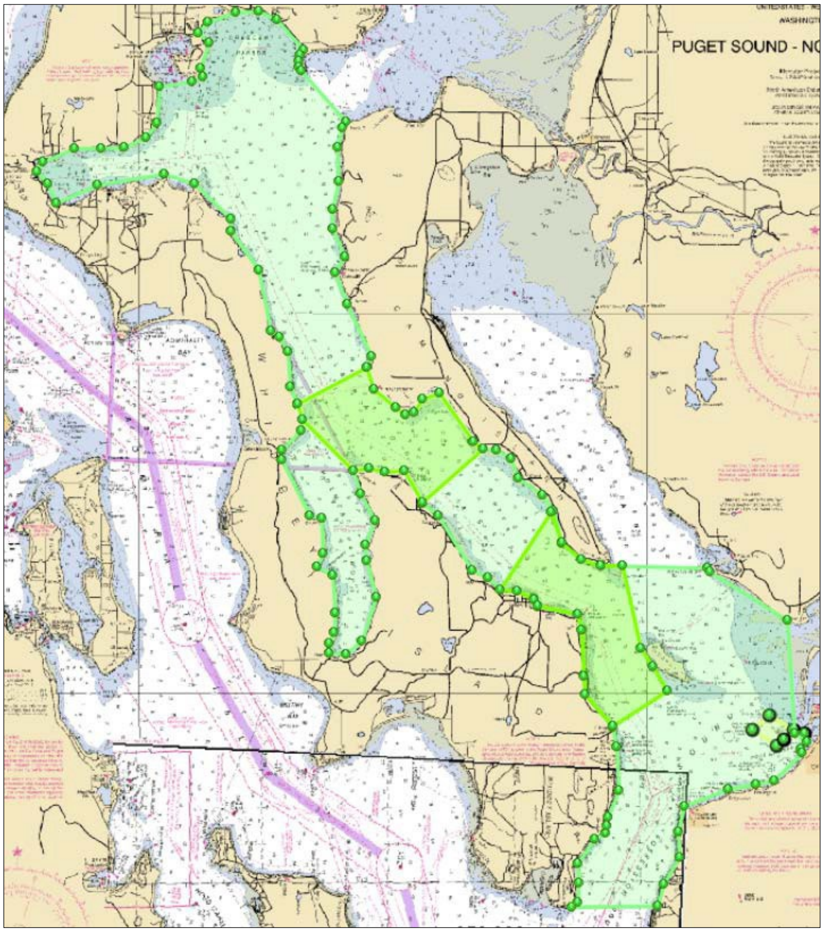
North: A line from Point No Point to buoy "SE" then to Indian Point on Whidbey Island then following the shore of Whidbey Island East to Possession Point then due East to the mainland shore.

East: Following the mainland shore from Possession Sound, South to Point Defiance including Seattle and Tacoma Harbors as well as East Pass.

South: The waters of Commencement Bay, West to Point Defiance.

West: South from Point No Point following the mainland and East shore of Bainbridge Island not including the waters South of Agate Point in Agate Pass, West of a line from Orchard Point to Beans Point in Rich Passage or South of a line from Point Southworth to Vashon Head. The West boundary continues South from Vashon Head along the shores of Vashon and Maury Islands to Point Dalco then ends at Point Defiance.

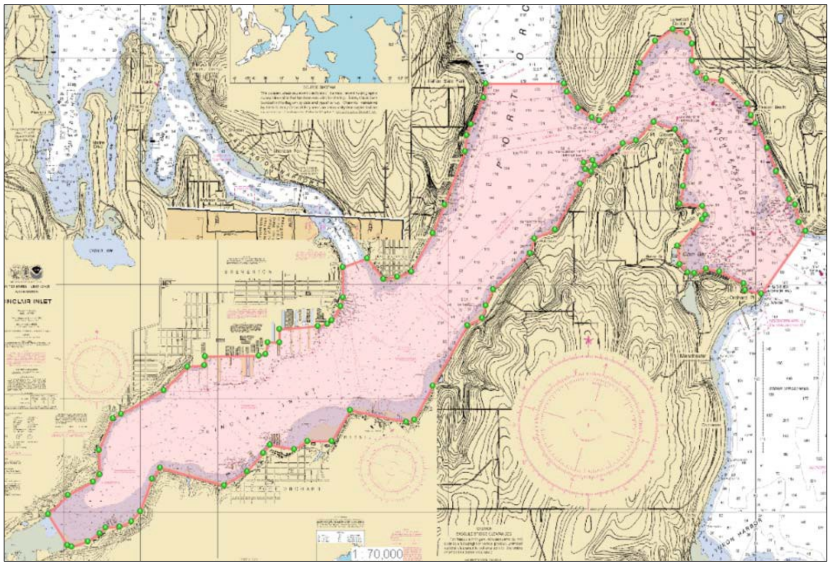
10. Possession Sound and Saratoga Passage



South: A line from Possession Point on Whidbey Island due East to the mainland shore. Following the shoreline of Possession Sound and Saratoga Passage North. Not including the waters of Port Susan.

North: A line from Ponell Point on Whidbey Island to Rocky Point on Camano Island.

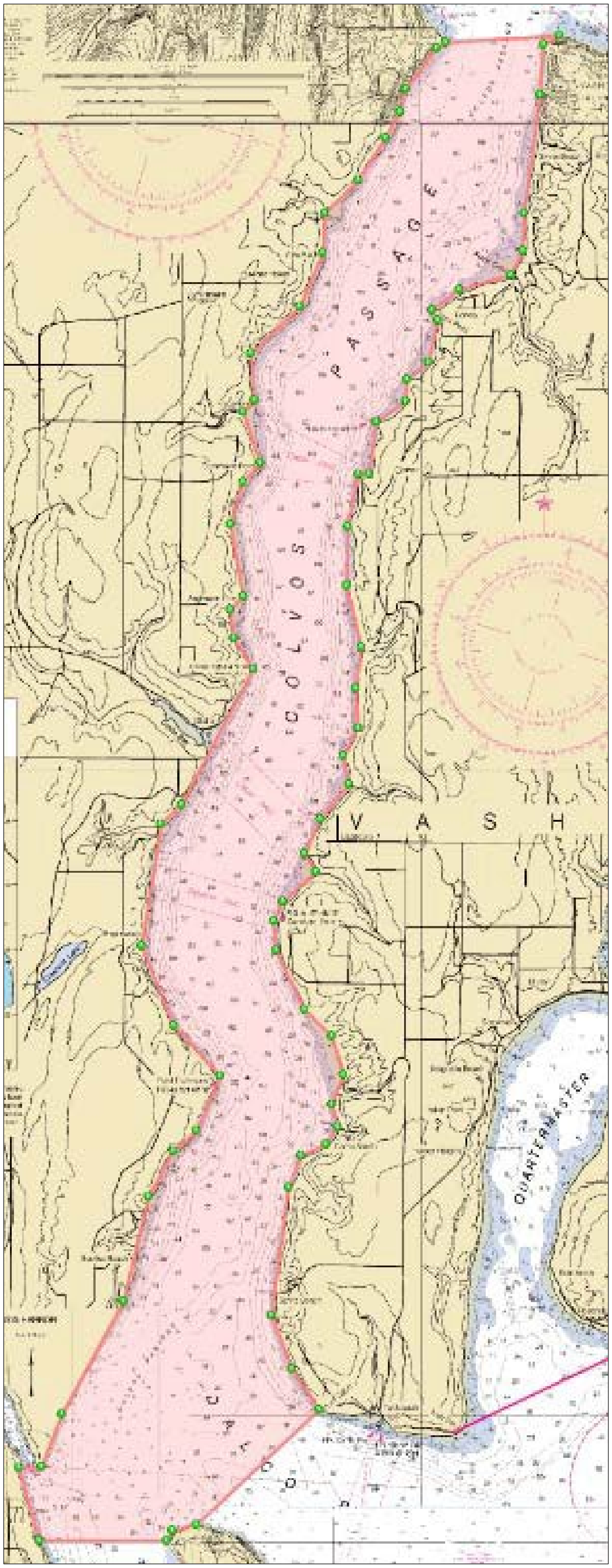
11. Rich Passage & Sinclair Inlet



The waters of Rich Passage and Sinclair Inlet West of a line from Orchard Point to Beans Point, not including the waters of Port Orchard North of White Point.

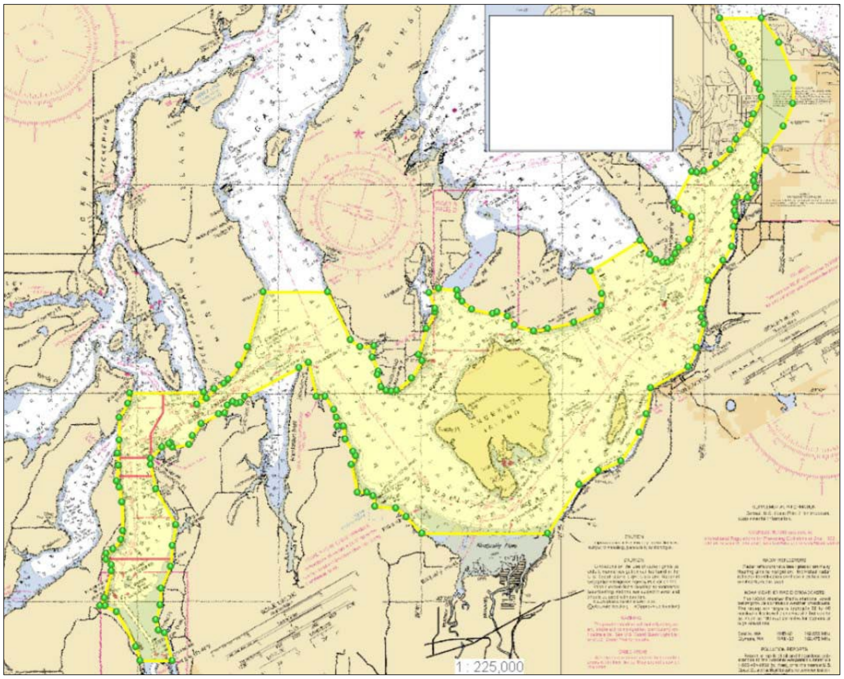
12. Colvos Passage

North: South of a line from Point Southworth to Vashon Head. Following the shores of Colvos Passage to the South.
South: West of a line from Point Defiance to Point Dalco and North of a line from Point Defiance due West to the mainland shore.



13. South Sound to Olympia

All waters South of a line from Point Defiance due West to the mainland shore.
Following the main channels via Nisqually Reach or Balch Pass and Dana Passage to Budd Inlet.



Adopted in regular session on July 16, 2020, by the State of Washington Board of Pilotage Commissioners.