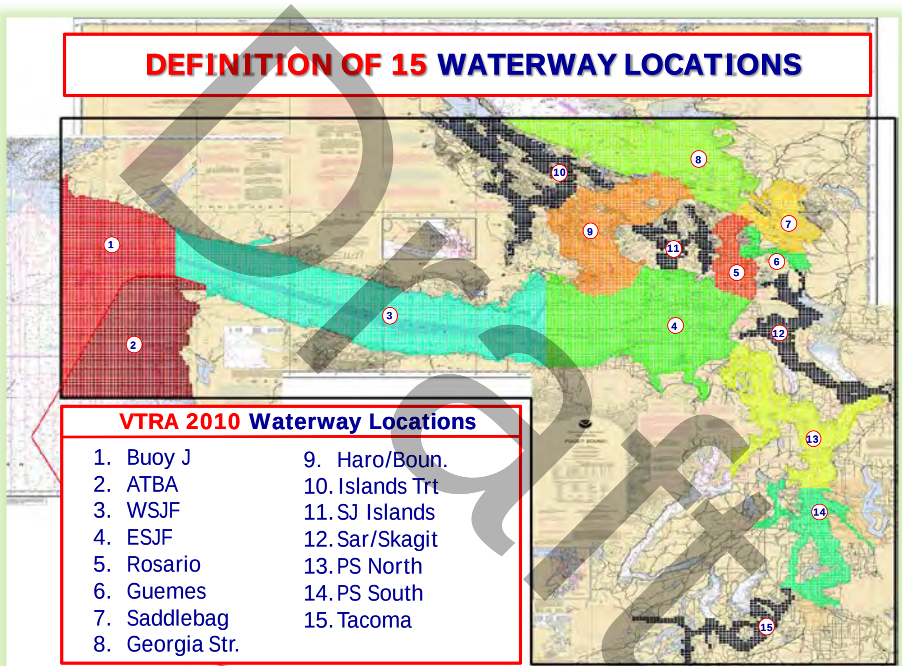
Final Report

Vessel Traffic Risk Assessment (VTRA):

Preventing Oil Spills from Large Ships and Barges

In Northern Puget Sound & Strait of Juan de Fuca



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Prepared for:
Washington State Puget Sound Partnership

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PREFACE

This report is submitted by Johan Rene van Dorp (GW) and Jason R.W. Merrick (VCU). The content of the report describes the 2010 Vessel Traffic Risk Assessment (VTRA). To distinguish the study described herein from the previous 2005 VTRA study conducted 2006-2008 it will be labeled the 2010 VTRA or VTRA 2010. The starting point for the 2010 VTRA analysis is the updated 2005 VTRA model with 2010 VTOSS data, as agreed upon in the scope of work between GWU and the PSP. The update of VTRA Maritime Transportation System (MTS) simulation model from using 2005 Vessel Traffic Operational Support System (VTOSS) data to using 2010 VTOSS data was separately funded by the Makah Tribal Council.

Both this Puget Sound Partnership (PSP) and the Makah effort utilize the extensive technical work already completed by the George Washington (GW) University and Virginia Commonwealth University (VCU) under previously funded maritime risk assessment (MRA) projects. Specifically, the Prince William Sound Risk Assessment (1996), The Washington State Ferry Risk Assessment (1998), The San Francisco Bay Exposure Assessment (2004) and the 2005 Vessel Traffic Risk Assessment (VTRA). GW/VCU's VTRA analysis tool evaluates the duration that vessels travel through the VTRA study area by vessel type (referred to as exposure hereafter) and the potential accident frequency and oil losses from a pre-defined class of focus vessels. The inclusion of a time on the water element in the evaluation of exposure sets the GW/VCU methodology apart from count based approaches that focus on, for example, number of annual/monthly vessel transits, visits or calls. The GW/VCU VTRA analysis methodology has been well documented and peer-reviewed in the academic literature and continuously improved over the course of these MRA projects. A reference list is provided at the end of this document.

The VTRA study area includes: (1) portions of the Washington outer coast, (2) the Strait of Juan de Fuca and (3) the approaches to and passages through the San Juan Islands, Puget Sound and Haro-Strait/Boundary Pass. The VTRA area is divided in 15 separate waterway locations outlined on the cover of this report. This study has been funded wholly or in part by the United States Environmental Protection Agency (EPA) through their National Estuary Program, via a grant agreement (#2013-028) with the PSP.

From the outset of this project the support from the United States Coast Guard (USCG) District 13, including Sector Puget Sound, and the Puget Sound Harbor Safety Committee (PSHSC) have been unwavering. In particular, Mark Ashley's (USCG), John Veentjer's (Chair of the PSHSC), Del Mackenzie's (Puget Sound Pilots) and Norm Davis' (Department of Ecology) support have been instrumental in providing the necessary data for both the Makah funded VTRA update and the PSP funded VTRA 2010. The PSHSC unselfishly extended their hospitality to allow GW/VCU to present their progress over the course of this project during their meetings every two months starting in October 2012. The PSHSC provided GW/VCU a public platform to obtain feedback from and access to the maritime community during the VTRA update and the 2010 VTRA. A PSHSC steering committee served as an advisory group during both studies.

EXECUTIVE SUMMARY

PLACE HOLDER

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1. INTRODUCTION

Washington State shares the Salish Sea with the province of British Columbia. A large number of ships and barges operate in these shared waters, placing the area at risk for major and catastrophic oil spills. While citizens in the region enjoy a relatively safe marine transportation system compared to most other port states in the world, the potential for catastrophic spills continues to be a huge concern for the region's environment, economy and quality of life, and the impact of a major spill would likely be devastating on the long-term restoration and protection of Puget Sound.

The purpose of the 2010 VTRA is to inform the State of Washington and the United States Coast Guard on what potential actions should be taken to mitigate any increase in oil spill risk from large commercial vessel oil spills in the northern Puget Sound and the Strait of Juan de Fuca areas. The VTRA study area includes: (1) portions of the Washington outer coast, (2) the Strait of Juan de Fuca and (3) the approaches to and passages through the San Juan Islands, Puget Sound and Haro-Strait/Boundary Pass. The VTRA study area is divided in 15 separate waterway locations outlined on the cover of this report and is expected to experience significant changes in deep draft vessel traffic during the next decade. The 2010 VTRA is also intended to inform federal agencies, tribes, local governments, industry and non-profit groups in Washington State and British Columbia on potential risk management options and facilitate their input into achieving consensus risk management decisions regarding vessel operations in the study area

The development of the 2010 VTRA followed the collaborative analysis approach [1] involving coordination with a Puget Sound Advisory group/steering committee of stakeholders selected early on in the VTRA 2010:

"*In collaborative analysis, the groups involved in a policy debate work together to assemble and direct a joint research team, which then studies the technical aspects of the policy issue in question. Representative from all the participating groups are given the ability to monitor and adjust the research throughout its evolution. Collaborative analysis aims to overcome suspicions of distorted communication giving each group in the debate the means to assure that other groups are not manipulating the analysis. The ultimate goal is to generate a single body of knowledge that will be accepted by all the groups in the debate as a valid basis for policy negotiations and agreements. – George J. Busenberg, 1999.*"

In this study, the Puget Sound Advisory group/steering committee chose to model only the traffic level impacts of planned expansion and construction projects that were in advanced stages of a permitting process. Each planned project forms a What-If scenario and What-If vessels are added to a maritime simulation of the 2010 Base Case year. Four What-If scenarios were modeled in the study:

- The Gateway bulk carrier terminal
- The Trans-Mountain pipeline expansion
- The combination of proposed changes at Delta Port
- All three of above scenarios operating at the same time

The steering committee determined that the following numbers of What-If vessels would be added to the 2010 Base Case simulation in each scenario:

- The Gateway bulk carrier terminal
  - 487 bulk carriers (318 Panama class and 169 Cape Max class)
- The Trans-Mountain pipeline expansion
  - 348 crude oil tankers (each 100,000 DWT)
- The combination of proposed changes at Delta Port
  - 348 bulk carriers and 67 container vessels
- All three of above scenarios operating at the same time

Moreover, the steering committee recommended that bunkering operations supporting these potential expansion projects be represented as well in the 2010 VTRA.

The VTRA 2010 utilizes the extensive technical work already completed by the George Washington (GW) University and Virginia Commonwealth University (VCU) under previously funded maritime risk assessment (MRA) projects. Specifically, the Prince William Sound Risk Assessment (1996), The Washington State Ferry Risk Assessment (1998), The San Francisco Bay Exposure Assessment (2004) and the 2005 VTRA. GW/VCU's VTRA analysis tool evaluates the duration that vessels travel through the VTRA study area by vessel type (referred to as exposure hereafter) and the accident frequency and oil losses from a pre-defined class of focus vessels. The inclusion of a time on the water element in the evaluation of exposure sets the GW/VCU methodology apart from count based approaches that focus on, for example, number of annual/monthly vessel transits, visits or calls. The GW/VCU VTRA analysis methodology has been well documented and peer-reviewed in the academic literature and continuously improved over the course of these MRA projects. A reference list is provided at the end of this document.

A summary of the 2005 VTRA methodology is provided in Section 2 with references to peer-reviewed publications and technical report dispersed throughout this summary. Needless to say, to more closely approximate the present-day patterns in traffic for What-If scenario analysis representing potential traffic expansions, it would be desirable for the GW/VCU VTRA 2005 analysis model to be updated with the most recent VTOSS dataset. The 2010 year is the last full year of traffic data recorded for VTOSS. The items below summarize the improvements made to 2005 VTRA methodology while updating the GW/VCU VTRA analysis model using the VTOSS 2010 efforts over the course of both the Makah and PSP funded efforts:

1. The total focus vessel class in the VTRA 2010 accounts for approximately 25% of the total traffic picture, whereas the VTRA 2005 only accounted for 1% of the total traffic. The VTRA 2005 only considered BP Cherry point tankers, ATB's and ITB's within the focus vessel class[1]. As per the PSP SOW this focus vessel class was expanded to include all tankers, ATB's and ITB's, bulk carrier, container vessels and oil barges. Over the course of the VTRA 2010, also "Chemical Carriers" and "Other Cargo" were added to the VTRA 2010 focus vessel class. The chemical carrier class is about as large as the ATB one. The "Other Cargo" class is combined about as large as the container focus vessel class. The inclusion of both "chemical carrier" and "other cargo" to the focus vessel class provides for an even more comprehensive analysis.
2. Individual vessel routes segments are used in the VTRA 2010, rather than using representative routes that were used back in the VTRA 2005 to create a much more accurate traffic picture.
3. VTOSS 2010 data, which serves as the basis for the VTRA 2010, was validated against AIS 2010 data. This was not possible for the VTRA 2005 since at that time no AIS data was available. To accommodate this validation we:
    a. Introduced the notion of a vessel master type (Cargo-FV and Tank-FV) necessitated by vessel type misclassifications observed both in the VTOSS 2005 and VTOSS 2010 datasets.
    b. Added crossing line counting to the VTRA model to duplicate exactly the AIS 2010 crossing line count procedure.
4. Calculated speeds are used in VTRA 2010 model as opposed to sampled speeds in the VTRA 2005 to more accurately reflect exposure times of focus vessel classes.
5. In terms of potential oil outflow analysis we are considering overall oil loss, cargo oil loss and fuel oil loss and we are providing separate analyses for each. This is a change from the former "persistent oil" and "non-persistent oil" classification used in the VTRA 2005 and mentioned in the PSP SOW. However, the oil loss, cargo oil loss and fuel oil loss classification is more meaningful given the focus vessel class expansion.
6. Analysis capability was created to not only include more vessel types to the focus vessel class, but also allow for separation of the analysis by each focus vessel type, as well as the Tank-FV and Cargo-FV master type. Allowing for separation of analysis by focus vessel type may prove useful during the risk management phases.
7. The notion of What-If focus vessels was introduced to model the added traffic to the 2010 base year to represent the potential addition of Gateway, the Trans Mountain and Delta-Port expansions. This allows for a separation of added system risk into What-If focus vessel risk and risk added to the Base Case focus vessel class (as a result of adding What-If focus vessels).
8. A bunkering model was added to the VTRA 2010 model. Inclusion of a bunkering model to support these What-If focus vessels is an important part of the What-If analysis. The bunkering model addition to the VTRA model for What-If scenarios was not foreseen during

[1] During the 2005 VTRA, focus vessels were referred to as Vessels Of Interest (VOI's)

the initial SOW negotiations and was not included in 2005 VTRA. Analysis capability was created to allow for separation of What-If risk into "bunkering risk" and "Other What-If FV" risk.

9. The comprehensiveness of the analysis makes synthesis into an overall system view that highlights important aspects of analysis results more challenging. A great deal of time was spent to develop an analysis presentation format to arrive more easily at such a systems view of risk. Most importantly, these synthesized presentation and analysis results will allow stakeholders (hopefully) to still see "the forest through the trees". It is important for stakeholders to have this overall systems view prior to devising risk management suggestions.
10. Progress presentations and detailed scenario result presentations are available in electronic portable document format (pdf) from a VTRA 2010 project web-page:

    http://www.seas.gwu.edu/~dorpjr/tab4/publications_VTRA_Update.html

In Section 3, we describe the updating of the 2005 VTRA model to the 2010 VTRA in more detail. In Section 4, the validation of GW/VCU model crossing line counts using AIS 2010 crossing line counts is described. Section 5 describes VTRA 2010 focus vessel traffic movement and the movement of oil volume that these focus vessels carry. The information described in Section 5 serves as the starting point for the base case VTRA 2010 potential accident frequency and oil outflow analysis described in Section 6. The modeling of What-If scenario's and the changes in potential accident frequency and potential oil outflow from the VTRA 2010 Base Case is presented in Section 7. In Section 8, similar analysis results are presented for a variety of risk management scenario, whereas Section 9 describes the construction of two bench mark scenarios to compare the What-If and risk management scenario's against. The comparison of What-If, risk management and bench mark scenario's is presented in Section 10. We close the report with conclusions and recommendations in Section 11.

2. SUMMARY OF 2005 VTRA MODEL METHODOLOGY

Is it safer for a river gambling boat in New Orleans to be underway than to be dockside? Should wind restrictions for outbound tankers at Hinchinbrook Entrance in the Prince William Sound Alaska be lowered from 40 knots to 35 knots? Is investment in additional life craft on board Washington State Ferries in Seattle warranted or should the International Safety Management (ISM) code be implemented fleet wide? Can enhanced ferry service in San Francisco Bay and surrounding waters alleviate traffic congestion on roadways in a safe manner? Do potential traffic increases made possible through the addition of a pier terminal at a refinery located north of the San Juan Islands in Washington State increase or reduce oil transportation risk?

The risk management questions above were raised in a series of projects over a time frame spanning more than 10 years and were addressed using a single risk management analysis methodology developed over the course of these projects by a consortium of universities. This methodology centers around stakeholder involvement and dynamic maritime risk simulations of a Maritime Transportation Systems (MTS) that also integrate incident/accident data collection, expert judgment elicitation and consequence models [2]-[3]. Our model represents the chain of events that could potentially lead to an oil spill (see Figure 1).

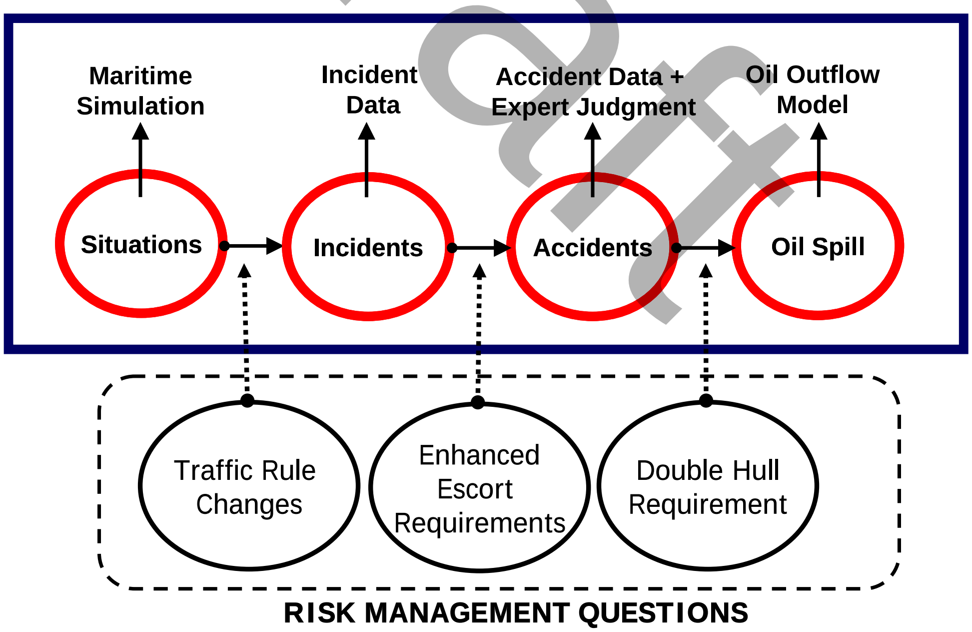


Figure 1.A causal chain of events inter-connected by causal pathways. Risk management questions attempt to block these causal pathways.

It has been peer reviewed by the National Research Council [4], top experts in the field of expert elicitation design and analysis, and has been continuously improved over time since its initial development in 1996. The model has previously been used in the Prince William Sound Risk Assessment ([5]-[8]), the Washington State Ferries Risk Assessment[9], and the Exposure Assessment of the San Francisco Bay ferries [10]. The model was most recently used during the 2005 VTRA [11] - [13]. Prior to updating with 2010 VTOSS data, data use and model assumptions of the VTRA model have been peer-reviewed [2] - [13].

Our analysis approach of involving stakeholders has been referred to in [1]as the collaborative analysis approach:

"In collaborative analysis, the groups involved in a policy debate work together to assemble and direct a joint research team, which then studies the technical aspects of the policy issue in question. Representative from all the participating groups are given the ability to monitor and adjust the research throughout its evolution. Collaborative analysis aims to overcome suspicions of distorted communication giving each group in the debate the means to assure that other groups are not manipulating the analysis. The ultimate goal is to generate a single body of knowledge that will be accepted by all the groups in the debate as a valid basis for policy negotiations and agreements. – George J. Busenberg, 1999."

The following is a brief description of this modeling approach. The updating of the 2005 VTRA model using 2010 VTOSS data shall occur in the same collaborative manner by making progress presentations to the Puget Sound Harbor Safety Committee.

Situations (see Figure 1):

Accidents can only occur when vessels are transiting through the system. Our maritime simulation model attempts to re-create the operation of vessels and the environment for one calendar year within the geographic scope of the study through maritime simulation/ replication. The traffic modeled re-plays the movement of VTS participating vessels (using 2005 VTOSS data) and simulates the movement of smaller fishing vessels, whale watchers, and organized regatta events over a set of representative routes using representative vessel speeds. Representative vessel routes were constructed by vessel type using the 2005 VTOSS data set. Figure 2provides a graphic of the 158 representative routes constructed for Oil Tankers.Vessels speeds are sampled from representative speed distribution by vessel type estimated using the West Strait of Juan de Fuca 2005 VTOSS data. Figure 3 plots example representative speed distributions for oil tankers, container vessels, bulk carrier and navy vessels used in the 2005 VTRA study. From Figure 3 one observes that the speed profile for oil tankers and bulk carriers is quite similar, whereas container vessels typically travel at higher speeds. The speed profile for navy vessels indicates a lot of variation in

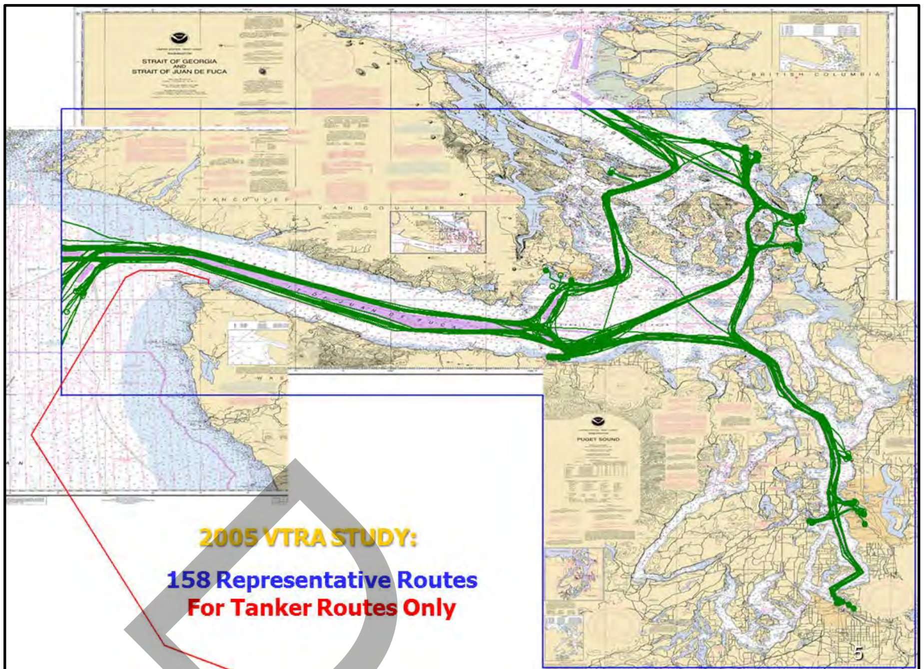


Figure 2.Graphic of 158 representative routes for oil tankers used in VTRA 2005 MTS simulation model.

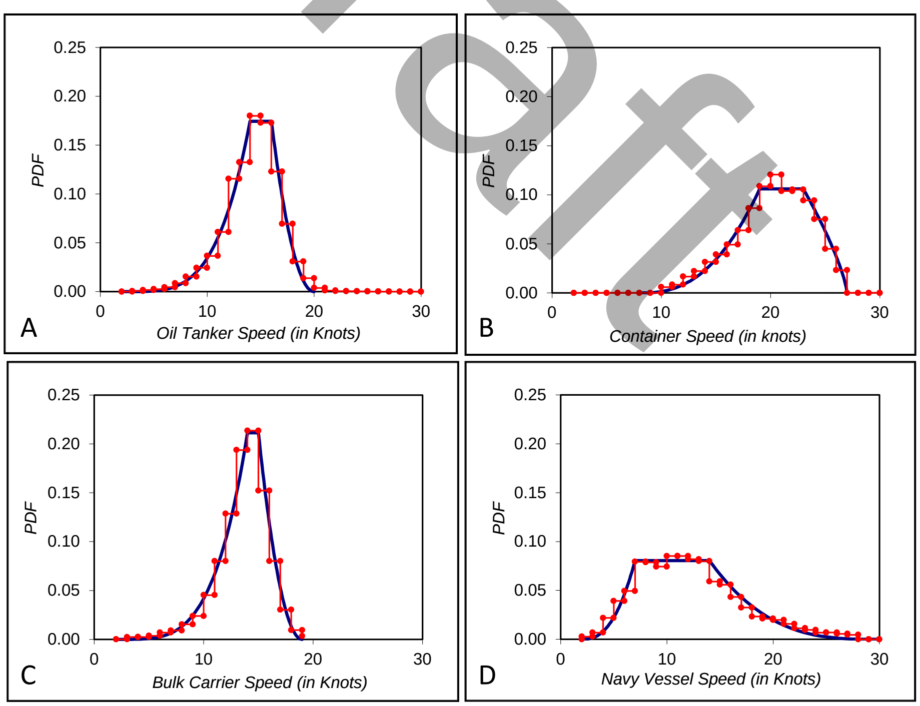


Figure 3.Example representative speed distribution for oil tankers (A), container vessel (B), bulk carriers (C) and navy vessels (D) estimated from VTOSS 2005 data. Step functions indicate the empirical probability distribution functions (pdf), whereas the solid lines are fitted Generalized Trapezoidal Distributions (GTD)[18].

their speeds compared to the other vessel types in Figure 3. For each vessel type a representative speed distribution was fitted from vessel West Strait of Juan de Fuca speeds observed in the VTOSS 2005 data. A vessel's sample speed is assumed constant throughout its transit, but subject to location speed changes trumped by traffic rules speed changes according to study area traffic rules implemented in the 2005 VTRA model. Location speed multipliers were estimated by comparing average speeds by vessel type for locations East Strait of Juan de Fuca, Haro-Strait/Boundary Pass, Rosario Strait, Georgia Strait, Guemes Channel, Saddelbag. Puget Sound North, and Puget Sound South to the average West Strait of Juan de Fuca speeds.

The environmental factors modeled include wind, fog, and current. They are replayed hourly using publicly available data sources, such as e.g. the National Climatic Data Center. (See, also [11], AppendixC). The update of the 2005 VTRA also includes updating to 2010 current tables. Other environmental conditions from the 2005 VTRA model are retained as well as traffic modeled therein not calling into VTS centers. Specifically, tribal and commercial fisheries, scheduled and USCG permitted regatta events and whale watching movements from the 2005 VTRA model are retained.

Every minute over a simulation calendar year, the 2005 VTRA model counts situations of moving vessels in which there is the potential for an accident to occur if things start to go wrong (see, e.g., [2]). The traffic conditions and environmental conditions are recorded in these situations and stored in a database representing a one year analysis scenario (for example the base case and various What-If traffic scenarios).

Incidents (see Figure 1):

Incidents are the events that immediately precede the accident. The types modeled include, propulsion losses, total steering losses, loss of navigational aids, and human errors. An exhaustive analysis of all possible sources of study area relevant accident, near miss, incident, and unusual event data was performed (see, e.g. [11], Appendices A and B).

Accidents (see Figure 1):

The accident types included in this study are collisions between two vessels, groundings (both powered and drift), and allisions that involving the FV's. The simulation counts the situations in which accidents could occur, while recording all the variables that could affect the chance that an accident will occur; these include the proximity of other vessels, the types of the vessels, the location of the situation and its wind, visibility and current. We know how often accidents do occur from our analysis of incident and accident data, but there is not enough data to say how each of these variables affect the chances of an accident; accidents are rare[2]! The VTRA model is calibrated to historically observed, but geographically restricted accident and incident data (see [11], Appendix E). As such, the annual accident and incident rates generated by the VTRA model for the base case scenario coincide with geographically restricted historically observed accident and incident rates.

To determine how accident situations differ in terms of relative accident likelihood, we must turn to the experts due to this lack of data. We ask experts to assess the differences in risk of two similar situations that they have extensive experience of (See Figure 4 for an example question). In each question we change only one factor and through a series of questions we build our accident probability model, incorporating the data where we can. Our expert judgment elicitation procedure is described in detail in [2], [14]. The experts involved include typically tanker masters, tug masters, pilots, Coast Guard VTS operators, and ferry masters. A full description of the process, experts and series of questionnaires conducted during the 2005 VTRA is provided in [11], Appendix E. No additional expert judgment elicitation is conducted forthe update of the 2005 VTRA Model using 2010 VTOSS data.

Oil Spill (see Figure 1):

An oil outflow model [3]for collision and grounding accidents explicitly links input variables such as hull design (single or double, see Figure 5), displacement and speed, striking vessel displacement and speed, and the interaction angle of both vessels to output variables (see Figure 6): longitudinal and transversal damage extents of the tanker. Overlaying these damage extents on a vessel's design (see Figure 6) yields an oil outflow volume totaling the capacity of damaged tank compartments. A similar model was developed for grounding accidents during the 2005 VTRA. A total of 80,000 simulation accident scenarios described in the National Research Council SR259 report [15]published in 2001 served as the joint data set of input and output variables used in this "linking" process. The oil outflow model was designed keeping computational efficiency in mind to allow for its integration with a maritime transportation system (MTS) simulation. A full description of the oil outflow model developed during the 2005 VTRA including its parameters and their estimation is provided in [11], Appendix D.

Format of Scenario Analysis Results and Comparisons (See Figure 7)

A potential risk mitigation scenario to be analyzed with the VTRA update is whether from a vessel risk perspective it makes sense to allow for bulk carriers docking at the Gateway

[2] Over the course of our various studies typically less than ten accidents were observed in a time frame of ten years or more to calibrate the VTRA model.

Situation 1	TANKER DESCRIPTION	Situation 2
Strait of Juan de Fuca East	Location	-
Inbound	Direction	-
Laden	Cargo	-
1 Escort	Escorts	-
Untethered	Tethering	-
	INTERACTING VESSEL	
Shallow Draft Pass. Vessel	Vessel Type	-
Crossing the Bow	Traffic Scenario	-
Less than 1 mile	Traffic Proximity	-
	VATERVAY CONDITIONS	
More than 0.5 mile Visibility	Visibility	-
Along Vessel	Vind Direction	-
Less than 10 knots	Vind Speed	25 knots
Almost Slack	Current	-
Direction	Current Direction	-

Complete Propulsion Loss		
More? : ____	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	____ : More?
Situation 1 is worse	<===================X===================>	Situation 2 is worse

Complete Steering Loss at a Moderate Angle		
More? : ____	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	____ : More?
Situation 1 is worse	<===================X===================>	Situation 2 is worse

Complete Navigational Aid Loss		
More? : ____	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	____ : More?
Situation 1 is worse	<===================X===================>	Situation 2 is worse

Human Error		
More? : ____	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	____ : More?
Situation 1 is worse	<===================X===================>	Situation 2 is worse

Nearby Vessel Incident (but you do not know the specifics)		
More? : ____	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	____ : More?
Situation 1 is worse	<===================X===================>	Situation 2 is worse

Figure 4.Example question during 2005 VTRA of a paired comparison questionnaire of situations for tanker collision accident attribute parameter assessment given all incidents.

facility being considered to travel north through Haro-Strait Boundary Passes as opposed to only using a northerly route through Rosario Strait. The 2005 VTRA only modeled a northerly route for Gateway vessels through Rosario Strait. 2005 VTRA model output allows for a visual assessment of the effectiveness of a risk mitigation scenario by comparing its geographic profile of vessel risk to that of other vessel traffic risk mitigations scenarios to a baseline geographic profile of vessel traffic risk (see Figure 7 for an example of such a geographic profile of vessel risk). An advantage of the geographical profile display format in Figure 7 is that it allows for a direct visual assessment of the distribution of the analysis results and thus provides for an understanding of system risk. For example, we immediately observe from Figure 7larger risk levels in the areas of Rosario Strait, Haro-Strait Boundary Pass, Guemes Channel and at route convergence locations at Buoy J and Port Angeles. A visual comparison of a baseline scenario generated geographic profile and

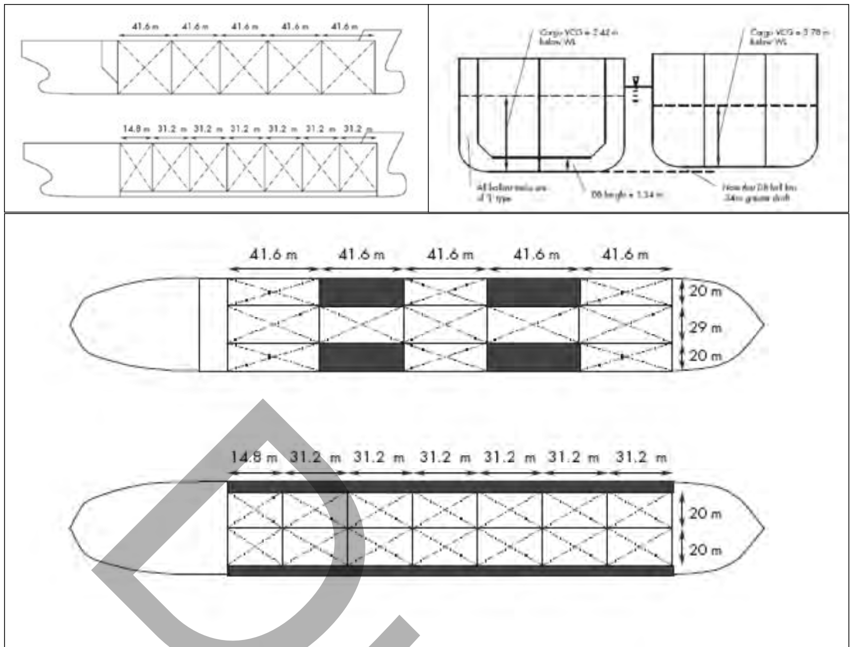


Figure 5. Single hull and double hull 150.000 DWT tanker designs used in 2005 VTRA taken from the National Research Council SR259 report [15].

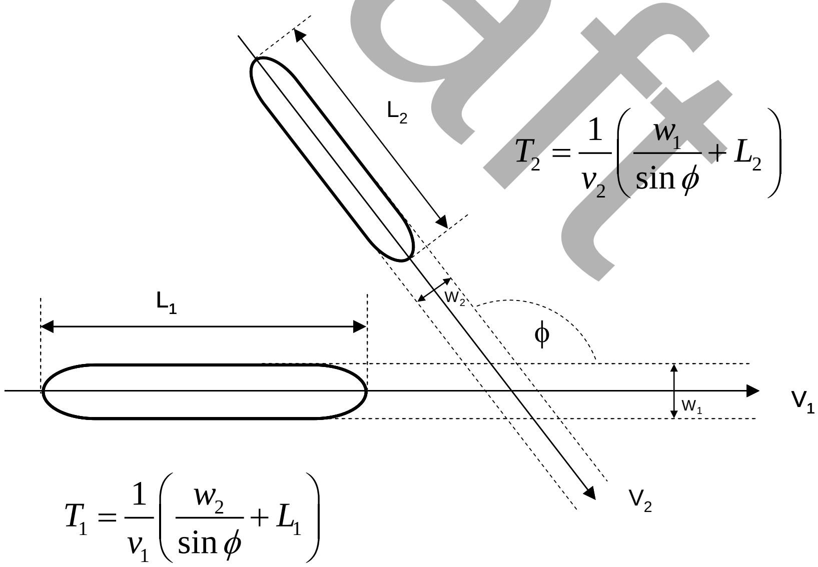


Figure 6.A schematic of a striking ship-struck ship probability model used in the 2005 VTRA.

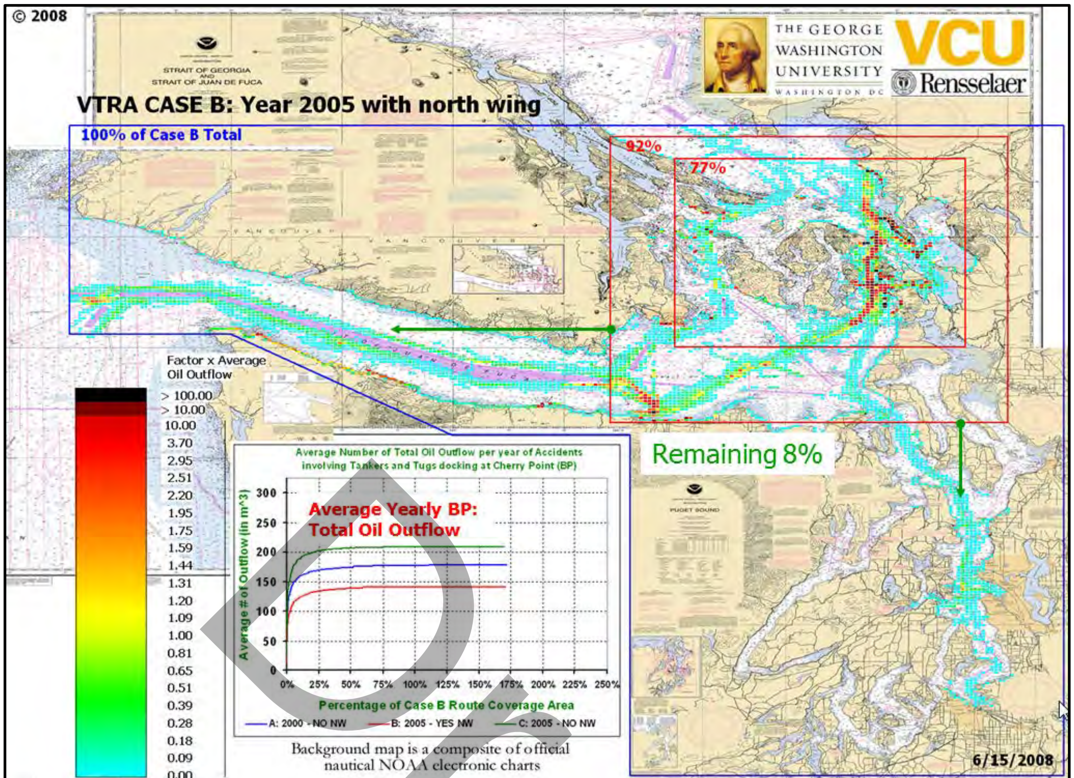


Figure 7.An example of a geographic profile of oil spill risk (generated during the 2005 VTRA).

that of a What-If and risk mitigation scenario allows for a visual assessment of potential increases and decreases in risk and their location. The percentages in the top left corners of the red rectangles and blue border of the study area in Figure 7 allow for a more quantitative evaluation of system risk and its changes from a baseline scenario to What-If and risk mitigation scenario analysis results. The fact that in Figure 7 the percentage in the top left of the blue border equals 100% implies that this is a baseline geographic profile. For a more detailed explain of geographic risk profile interpretation see [12].

Sensitivity and Uncertainty of Analysis Results

More data is being made available electronically over time allowing for an even more accurate representation of the movement of vessel traffic and modeling of the accident scenarios within an MTS simulation. As a result, the movement of traffic within the MTS simulation more resembles a replication of how vessels actually moved rather than simulating them. An example being that every vessel in the MTS simulation arrives and departs as per the VTOSS 2010 data while retaining its route segments and vessel characteristics, such as e.g. its own vessel name. No doubt, this added level of detail reduces model uncertainty to a great extent. The evaluation of model uncertainty is not accounted for in traditional sensitivity/uncertainty analysis approaches.

With the increased availability of this electronic data, however, the time to prepare it in an electronic format that can serve as input to an MTS simulation increases as well. Despite these advances, one should always bear in mind that any model is an abstraction of reality in which simplifying assumptions are often necessitated to maintain computational efficiency. The increase of computational complexity to reduce model uncertainty within the 2005 VTRA methodology, does unfortunately not allow for the application of traditional sensitivity/uncertainty analysis of output analysis results. We are pushing computational boundaries of existing computation platforms that the 2005 VTRA model runs on. As a result, we find that solely relative comparisons across accident types, across oil outflow categories and across risk intervention scenarios are particularly enlightening and informative and we concentrate less on the absolute values of the results in our analysis comparisons.

That being said, uncertainty of output analysis results for the 2005 VTRA methodology has been studied and funded by the National Science Foundation for smaller analysis context instances (See,[16],[17]). In these studies it was concluded that ranking of scenarios/alternatives are robust within our analysis methodology with respect to changes in vessel traffic.

3. UPDATING THE 2005 VTRA GW/VCU MODEL USING VTOSS 2010 DATA

By updating the 2005 VTRA model to a 2010 base year, it will more closely approximate the present-day patterns in traffic when using the GW/VCU VTRA analysis model to inform, for example, the State of Washington and the United States Coast Guard on what potential actions should be taken to mitigate increases in oil spill risk from large commercial vessel oil spills in the northern Puget Sound and the Strait of Juan de Fuca areas. The data source for modeling Vessel Traffic Service (VTS) responding traffic in the 2005 VTRA model was VTOSS 2005 data. Figure 8 displays the VTOSS coverage area including the Seattle, Tofino and Victoria VTS that service this area covering both US and Canadian waterways. An advantage of the VTOSS data is that it provides a single US -Canadian cross boundary data source for the three VTS providers. However, this too provides for one of the challenges when modeling vessel traffic as recording across these three VTS providers in the VTOSS data set is not consistent. For example, a vessel travelling through these three VTS areas on a single transit is assigned three separate trip ID's, one for each VTS.

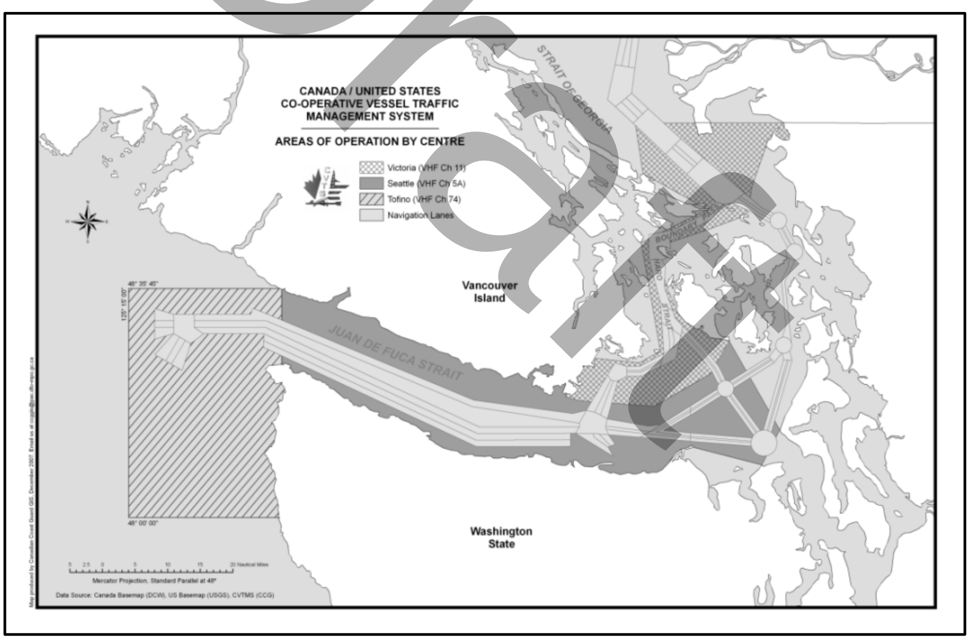


Figure 8.Coverage area of the Vessel Traffic Operational Support System (VTOSS).

To deal with thisparticulardata issue, a modeling decision was made during the 2005 VTRA to resort to the construction of representative vessel routes by vessel type. In total,1756 representative vessel routes, depicted in Figure 9, were constructed to model all VTS responding traffic (both US and Canadian). Of that, a relative large number of 158 representative routes, depicted in Figure 3, were constructed to model the movement of oil

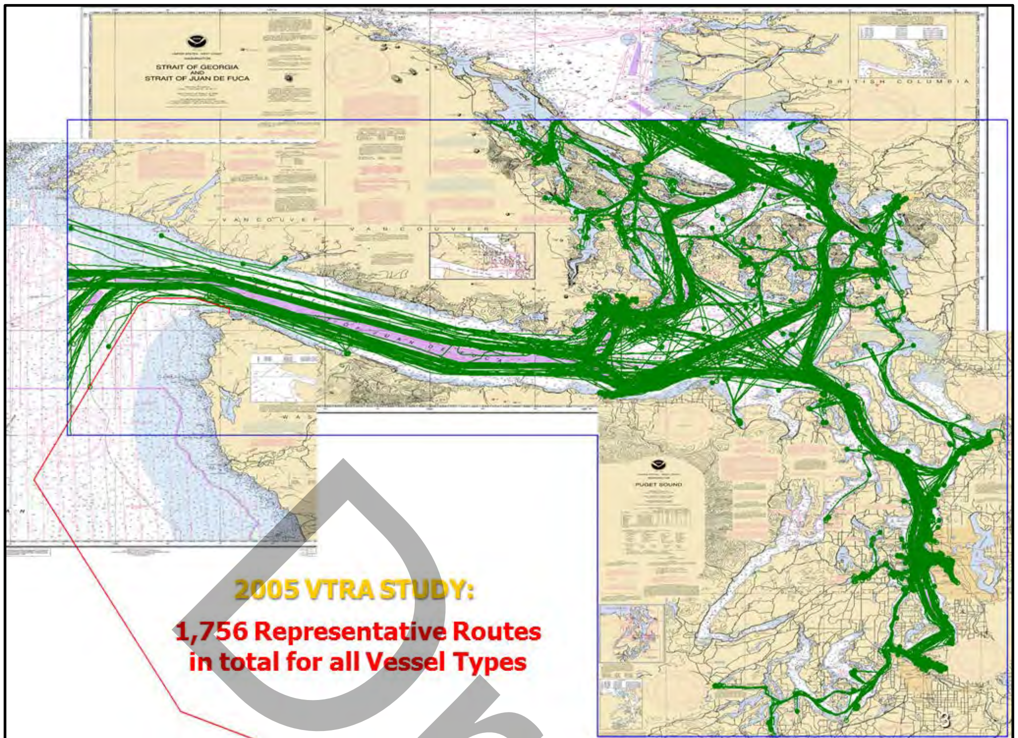


Figure 9. In total 1756 representative vessel route were constructed from 2005 VTOSS data during the 2005 VTRA to model the movement of VTS responding traffic in the GW/VCU MTS simulation model.

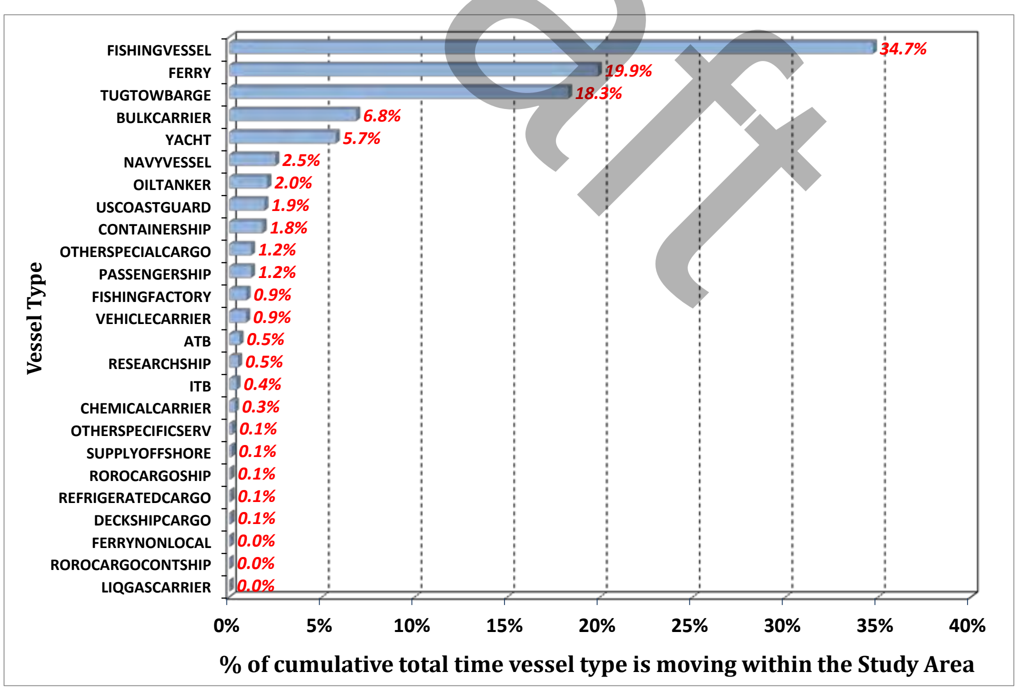


Figure 10. Tornado diagram displaying the cumulative percentage of time a vessel of a certain type is moving with the study area in the 2005 VTRA model over the course of one simulation year.

tankers (≈ 2% of all traffic, see Figure 10). For example, only 22 representative routes were utilized to model container traffic (≈ 2% of all traffic, see Figure 10) and 47 to model bulk carrier traffic (≈ 7% of all traffic, see Figure 10). The specific routes for container vessels and bulk carrier in the 2005 VTRA are depicted in Figure 11. A relative large number of representative routes was selected in modeling oil tanker traffic during the 2005 VTRA since oil tankers were part of the FV group in that study, whereas container vessels and bulk carriers were considered IV's, not FV's.

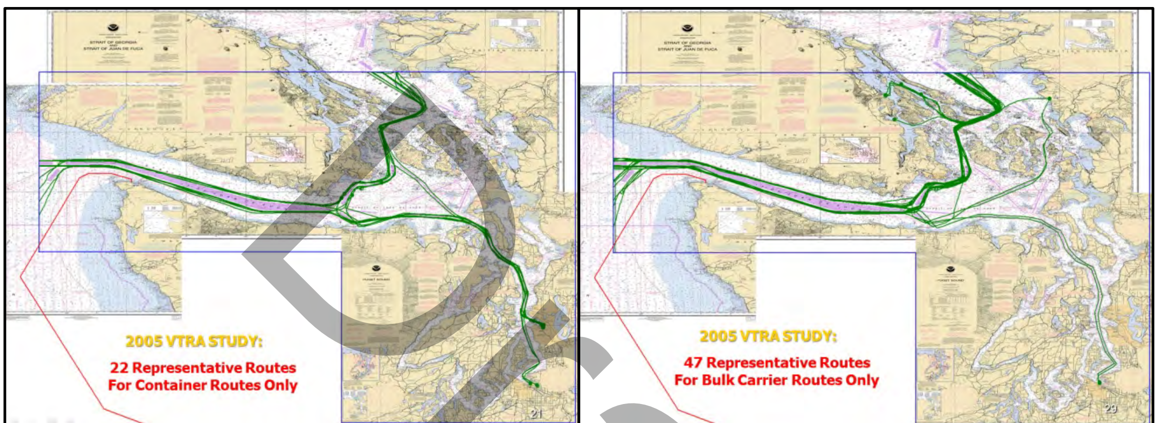


Figure 11. In total 22 (47) representative vessel route were constructed from 2005 VTOSS data during the 2005 VTRA to model the movement of container vessel (bulk carrier) traffic in the GW/VCU MTS simulation model.

To allow for inclusion of container vessel and bulk carriers in the focus vessel group for further analyses with the GW/VCU VTRA model, it would appear that a higher number of routes for these vessel types would be desirable. To that end, a modeling decision was made in updating the 2005 VTRA model to 2010 VTOSS data to attempt to retain a vessel's individual route throughout its transit rather than resorting to representative routes by vessel type. In that manner, FV group selection is not affected by a route modeling approach.

Algorithmic cleaning of VTOSS 2010 data

The VTOSS 2010 data consists of a set of waypoints of vessels along with identifying information about the vessel and the VTS center that collected the data point. Since 2005, VTOSS also added a trip identification number that indicates a set of waypoints for a particular vessel transiting through one VTS center's area. However, each VTS center assigns a different trip identification number to a vessel as it transits through the system leaving route segments and not complete routes. In addition, frequent alternative spellings of vessel names were observed. Once the vessel names were disambiguated, as many route segments as possible were connected algorithmically to make complete routes of vessels transiting the system.Figure 12's shows the result of algorithmically connecting route segments and depicts the remaining modeling challenges alluded to previously. Needless to say, remaining errors are apparent in the Figure 12.

Figure 12. Route plots of the VTOSS 2010 data after algorithmically joining route segments.

Multiple VTOSS data phenomena cause the errors observed in Figure 12. Firstly, the time of collection of each waypoint is recorded in the VTOSS data and is used to sort the waypoints in order to form a route. The time is recorded using a 24 hour clock, but points occurring in the hour after midnight are frequently recorded as 12:xx instead of 00:xx. This causes the points recorded as 12:xx to be a mixture of the vessel's location after midnight and after midday, causing the route to zigzag back and forth as shown inFigure 13.Another problem was caused by pieces of a route not being recorded by VTOSS, leaving non-contiguous pieces of a route connected by a straight line. In yet other cases, the same VTS center can assign a new identification number half way through a vessel's transit through their waters. Also simple errors were observed in identifying the location of the vessel as shown inFigure 14.

Additional algorithms were developed to remove a large proportion of the data inaccuracies depicted in Figure 12, Figure 13 and Figure 14. These algorithms were also designed to reduce the size of the VTOSS dataset by removing intermediate points when a vessel was in fact movingin a straight line. Once developed, these algorithms took one month to run on the approximately 50GBs of VTOSS 2010 data on a MacBrook Pro with a 2.7 Ghz Intel Core i7, 16 GB of 1600 Mhz DDR3 RAM, and 768GB SSD hard drive.

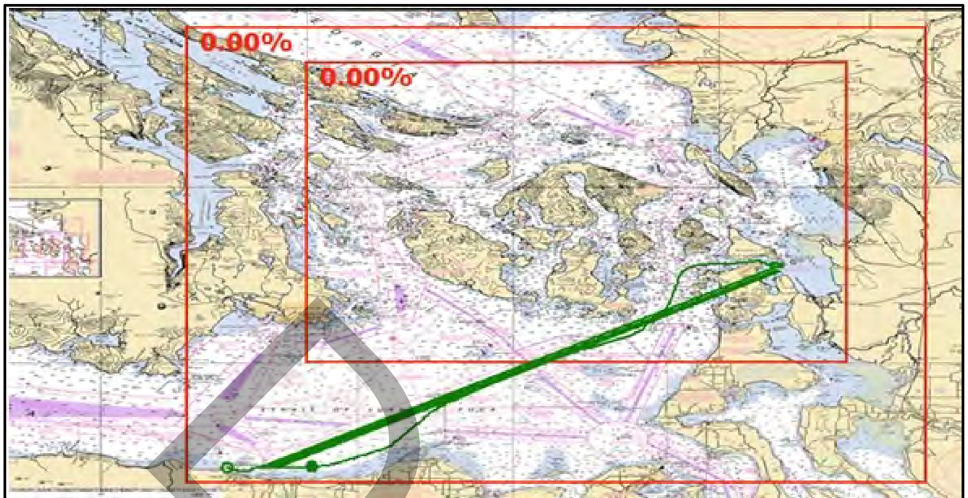


Figure 13.A route affected by the time problem after midnight in the VTOSS 2010 data.

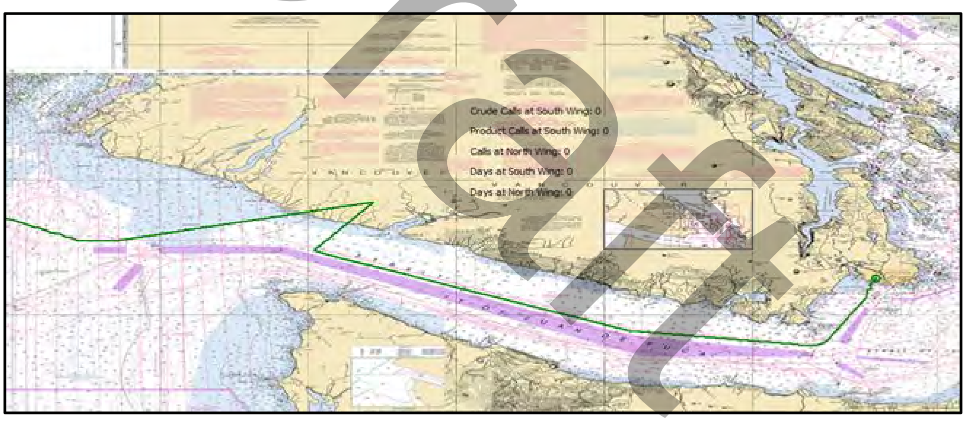


Figure 14.A route affected by problems identifying the correct location of the vessel.

Manual cleaning of VTOSS 2010 data

Unfortunately, as shown in Figure 15'sleft panel not all data inaccuracies can be resolved mathematically and removed algorithmically. Despite algorithmically cleaning the VTOSS 2010 data to construct contiguous routes for a single transit, some route segmentation remains. Algorithmic cleaning of oil tanker routes resulted in 2,345 route segments for oil tankers (see left panel of Figure 15). Observe from of Figure 15's left panel that following algorithmic cleaning only, oil tanker routes segments still display errors as a result of electronic transmission problems when recording a vessel transit in the VTOSS data. To further correct for those errors these 2345 route segments were manually cleaned resulting in 2328 route segments for oil tankers depicted in Figure 15's right panel using the VTOSS 2010 dataset. Recall that during the VTRA 2005 analysis a total of 1756 representative routes were constructed for all vessel types.

Comparing Figure 15's right panel with Figure 2 one observes a larger dispersion of oil tanker routes in of Figure 15 than in Figure 2. The same observation can be made when comparing the algorithmically and manually cleaned routes for container vessels and bulk carriers in Figure 16 using VTOSS 2010 data, with the representative routes depicted in Figure 11 for these vessel types in the 2005 VTRA. In total, following algorithmic cleaning only of VTOSS 2010 data to construct route segments by vessel type, 79,500 route segments remained. Needless to say, it would simply be too time consuming to subject all these route segments to a manual cleaning process. Instead, it is suggested to manually clean routes, as demonstrated in Figure 15 for oil tankers and for those vessel types that are selected to be in a FV group. In anticipation of inclusion of container vessels and bulk carriers in a FV group for scenario analyses their routes were manually cleaned as depicted in Figure 16.

Figure 17's left panel plots a route density for oil tankers generated using only the algorithmically cleaned routes displayed in Figure 15's left panel. Figure 17's right panel plots a route density for oil tankers using the both algorithmically and manually cleaned routes depicted in Figure 15's right panel. In Figure 17's left panel 99.6% of the tankers movements have a waterway location (see Figure 17) assigned, whereas in its right panel 100% of tanker movements have a location assigned. In plotting this density, vessel movements that have no assigned waterway location are not plotted. Figure 18 plots a graphic of the fifteen waterway location definitions to be used in the updated GW/VCU MTS model.

The locations ATBA (2), Islands Trust (10), San Juan Inlands (11), Saragota Skagit (12) and Tacoma were added as separate locations in the updated VTRA model. The location ATBA (2) was assigned an equivalency of the WSFJ (3) location for the purposes of accident probability model, whereas the other added locations were assigned an equivalency with the Guemes Channel location. The expansion of the number of waterway locations to accommodate an analysis for a larger class of focus vessels also required an expansion of the shoreline definition. The updated and expanded shoreline definition used in the VTRA 2010 model is depicted in Figure 19. Both the Department of Ecology and Puget Sound Pilots provided feedback on the shoreline definition in Figure 19 which plays an instrumental role in the analysis of grounding frequencies.

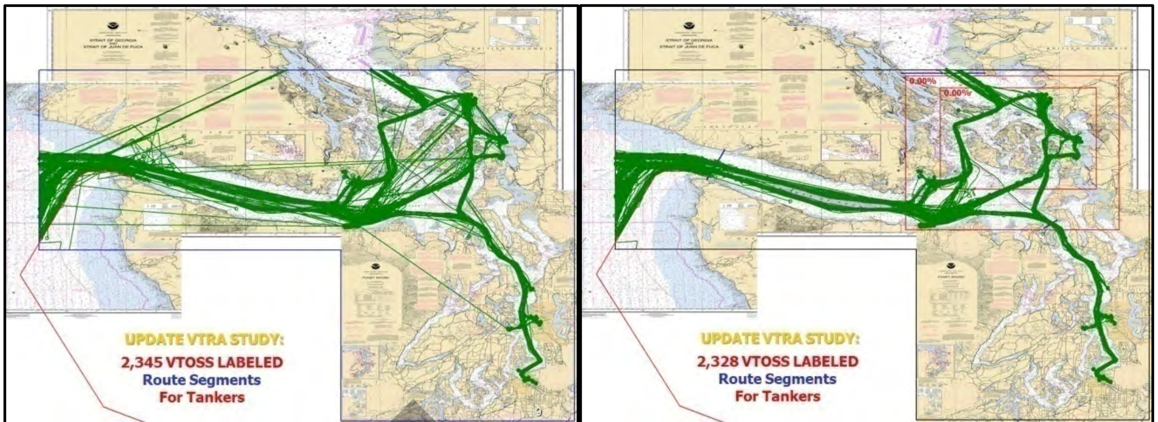


Figure 15. Left panel: 2,345 route segments after algorithmic cleaning of oil tanker routes. Right panel: 2328 route segments following manual cleaning of tankers routes following algorithmic cleaning.

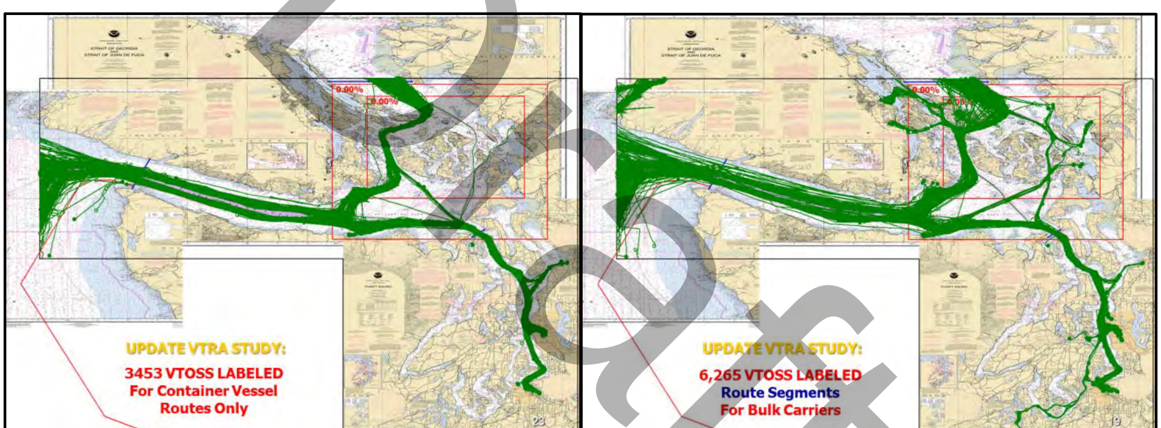


Figure 16. Left panel: 3,453 route segments after algorithmic and manual cleaning of container vessel routes. Right panel: 6265 route segments following algorithmic and manual cleaning of bulk carrier routes.

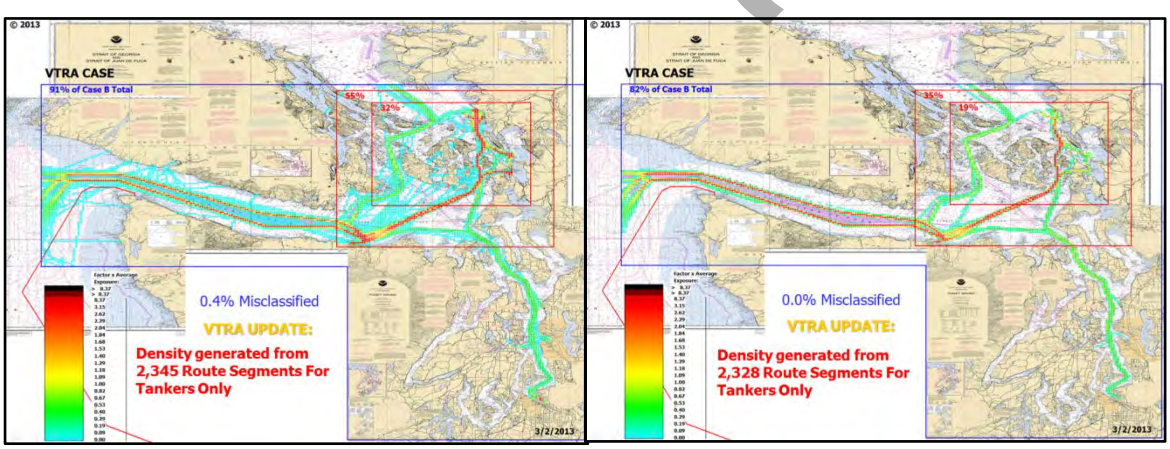


Figure 17.Left panel: Oil density tanker geographic profile generated using left panel routes in Figure 15. Right panel: Oil density tanker geographic profile generated using right panel routes in Figure 15.

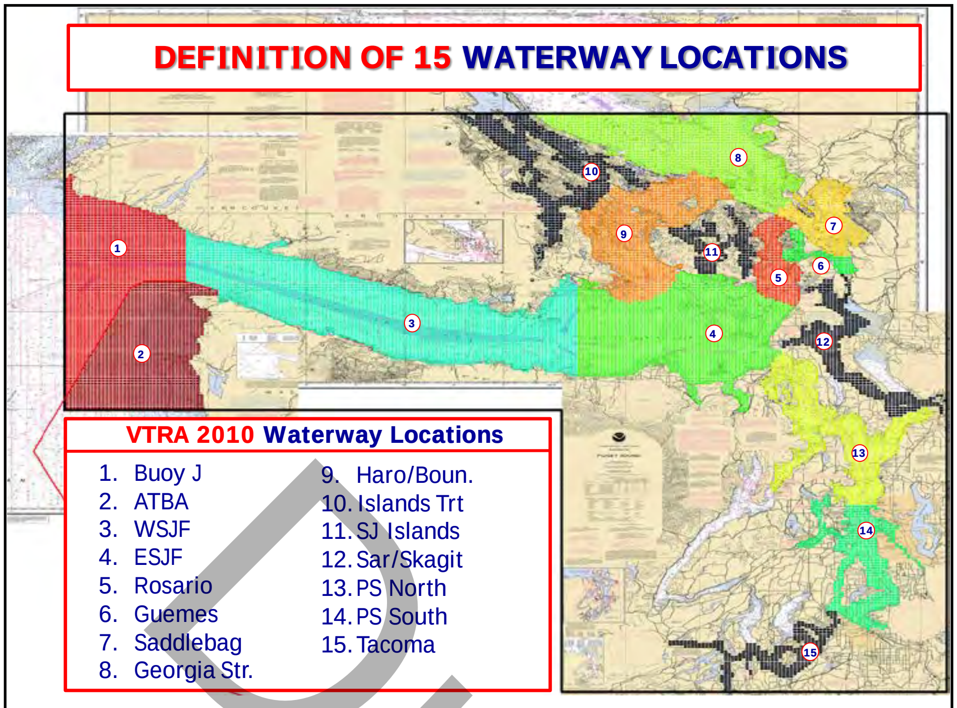


Figure 18. Location definitions used for the update of the GW/VCU MTS simulation from VTOSS 2005 to VTOSS 2010 data.

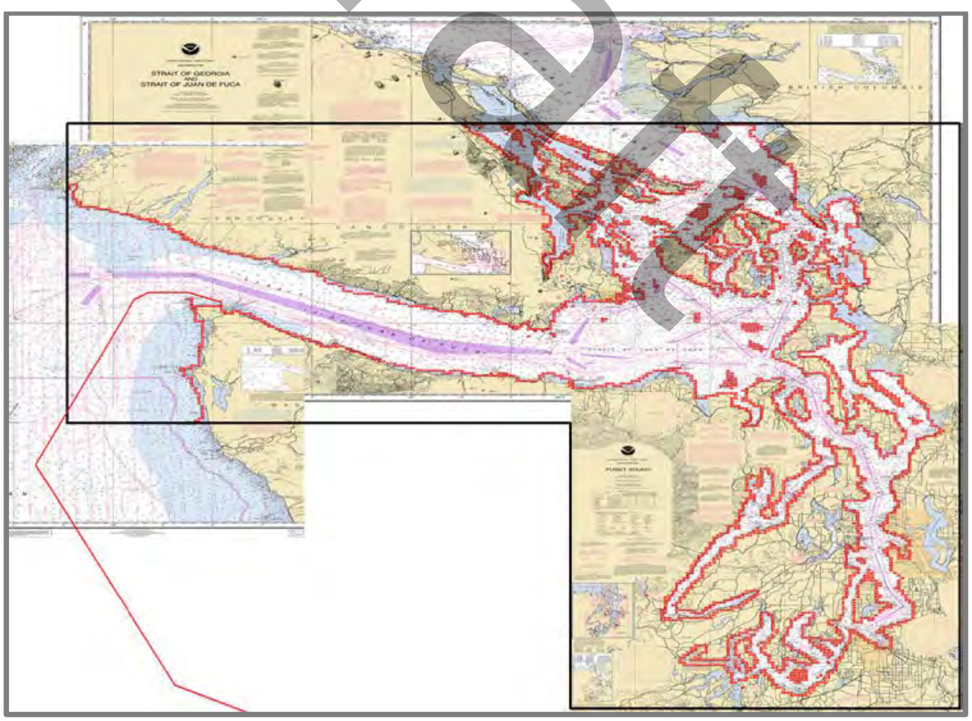


Figure 19. Expanded and revised shore line definition in VTRA 2010 model

Vessel master type definition

Table 1 shows a sample list of vessel names in the VTOSS 2010 data for which different vessel types are assigned. The number of route segments for each alternative vessel type is provided in the second columns. An examination of Table 1reveals different vessel types that are commonly assigned to the same vessel name.

Some of the entries in Table 1 will indeed refer to different vessels that share the same name. In that case the different vessel types may be correctly assigned to the same vessel name. One suggestion to differentiate between vessels sharing the same name is to use Lloyd's identification numbers or other vessel identification numbers. Unfortunately, these identification numbers are not consistently entered across the three VTS centers Seattle, Tofino and Victoria providing the data for the VTOSS datasets. Thus, complete disambiguation of vessel names to vessel types is not possible.

Further examination of Table 1 also reveals vessel names that are assigned similar vessel types. Frequent groups of vessel types assigned to the same vessel names are:

1. Tanker and chemical carrier.
2. Ferry, non-local ferry, and passenger vessel.
3. Passenger vessel and yacht.
4. Container, bulk carrier, deck ship cargo, other special cargo, ro-ro cargo ship, ro-ro cargo container ship, vehicle carrier.
5. Research ship and other specific service vessel.

These similar classifications may also have been used differently across the three different VTS centers included in VTOSS 2010 dataset. To allow for this similar misclassification of vessel types, the vessel master type definition in Table 2 is introduced for the 26 vessel types in the VTOSS data sets. Observe from Table 2 that the vessel types in the first entry in the list above are counted as tankers, the second and third entries as passenger vessels, the fourth entry as cargo vessels, and the fifth entry as service vessels. This allows for meaningful comparisons between the VTOSS 2005 dataset and VTOSS 2010 dataset that are not affected by these similar vessel type misclassifications.

Misclassification of vessel types described above was also observed in the VTOSS 2005 data. However, about twice the number of route segments was involved as compared to the VTOSS 2010 dataset. Moreover in the VTOSS 2005 set misclassification across the vessel master type definitions in Table 2 were observed as well. For example, Table 3 shows a sample in the VTOSS 2005 dataset of cargo vessels that were sometimes classified as passenger vessels. Observe that in Table 3 that 50 transits (or route segments) were classified as passenger vessels when they should have been classified as cargo vessels. Moreover, in the VTOSS 2005 dataset route segments of vessels classified as passenger vessels were observed that did not have route segments classified as cargo vessels, but turned out to be cargo vessels when researched further. This problem was not apparent in the VTOSS 2010 data.

Table 1. A sample list of vessel names that are designated as different vessel types in VTOSS 2010

Vessel Name	# Route Segments	Vessel Type	Vessel Name	# Route Segments	Vessel Type
ABAKAN	3	BULK CARRIER	ALEXANDRIA BRIDGE	1	BULK CARRIER
ABAKAN	2	OTHER SPECIAL CARGO	ALEXANDRIA BRIDGE	2	CONTAINER SHIP
ADMIRAL PETE	22	FERRY (NONLOCAL)	ALIOTH LEADER	1	OTHER SPECIAL CARGO
ADMIRAL PETE	3	PASSENGER SHIP	ALIOTH LEADER	2	VEHICLE CARRIER
ADRIA ACE	1	OTHER SPECIAL CARGO	ALJALAA	3	CHEMICAL CARRIER
ADRIA ACE	2	VEHICLE CARRIER	ALJALAA	1	OIL TANKER
ADVENTURE	3	FISHING VESSEL	ALPINE PENELOPE	4	CHEMICAL CARRIER
ADVENTURE	1	YACHT	ALPINE PENELOPE	15	OIL TANKER
AEGEAN LEADER	4	OTHER SPECIAL CARGO	ALUMINATOR	14	FISHING VESSEL
AEGEAN LEADER	4	VEHICLE CARRIER	ALUMINATOR	2	TUG TOW BARGE
AFFINITY	5	CHEMICAL CARRIER	AMBA BHAVANEE	3	CHEMICAL CARRIER
AFFINITY	2	OIL TANKER	AMBA BHAVANEE	3	OIL TANKER
AKEMI	3	FISH(ING) FACTORY	AMERICAN BEAUTY	3	FISH(ING) FACTORY
AKEMI	1	FISHING VESSEL	AMERICAN BEAUTY	1	FISHING VESSEL
ALASKAN LEGEND	43	OIL TANKER	AMERICAN HIGHWAY	1	OTHER SPECIAL CARGO
ALASKAN LEGEND	1	YACHT	AMERICAN HIGHWAY	1	VEHICLE CARRIER
ALEUTIAN BEAUTY	2	FISH(ING) FACTORY	AMERICAN NO. 1	4	FISH(ING) FACTORY
ALEUTIAN BEAUTY	1	FISHING VESSEL	AMERICAN NO. 1	1	FISHING VESSEL
ALEUTIAN LADY	1	FISH(ING) FACTORY	AMETHYST ACE	3	OTHER SPECIAL CARGO
ALEUTIAN LADY	1	FISHING VESSEL	AMETHYST ACE	1	VEHICLE CARRIER
ALEX GORDON	5	SUPPLY (OFFSHORE)	AMY USEN	1	FISH(ING) FACTORY
ALEX GORDON	4	TUG TOW BARGE	AMY USEN	6	FISHING VESSEL
ALEXANDRIA BRIDGE	1	BULK CARRIER	ANDES	1	CHEMICAL CARRIER
ALEXANDRIA BRIDGE	2	CONTAINER SHIP	ANDES	1	OIL TANKER

Table 2. Master vessel type definition for the 26 VTOSS vessel type classification used in the GW/VCU MTS simulation model.

#	VESSEL TYPE	MASTER TYPE	#	VESSEL TYPE	Master Type
1	BULKCARRIER	Cargo	14	PASSENGERSHIP	Passenger
2	CHEMICALCARRIER	Tanker	15	REFRIGERATEDCARGO	Cargo
3	CONTAINERSHIP	Cargo	16	RESEARCHSHIP	Service
4	DECKSHIPCARGO	Cargo	17	ROROCARGOSHIP	Cargo
5	FERRY	Passenger	18	ROROCARGOCONTSHIP	Cargo
6	FERRYNONLOCAL	Passenger	19	SUPPLYOFFSHORE	Service
7	FISHINGFACTORY	Fishing	20	TUGTOWBARGE	Tugtow
8	FISHINGVESSEL	Fishing	21	UNKNOWN	Service
9	LIQGASCARRIER	Tanker	22	USCOASTGUARD	Service
10	NAVYVESSEL	Cargo	23	VEHICLECARRIER	Cargo
11	OILTANKER	Tanker	24	YACHT	Passenger
12	OTHERSPECIALCARGO	Cargo	25	ATB	Tanker
13	OTHERSPECIFICSERV	Service	26	ITB	Tanker

Table 3.Cargo vessels that were classified as passenger vessels in the VTOSS 2005 dataset

Vessel Name	Cargo Transits	Passenger Transits	Vessel Name	Cargo Transits	Passenger Transits
BRIGHT STATE	15	3	MIDNIGHT SUN	8	3
BRIGHT STREAM	16	7	MORNING MELODY	3	2
CAPE HORN	7	5	NORTH STAR	4	4
DONG FANG GAO SU	2	2	REINA ROSA	3	3
GREAT LAND	3	4	SKAUBRYN	17	6
IGARKA	3	3	SKAUGRAN	18	2
IVORY ARROW	4	2	UNITED SPIRIT	5	4
Total	**50**	**26**	**Total**	**58**	**24**

Comparing representative routes approach to the route segment approach

The fifth column in Table 4 provides by vessel master type the percentage of time that a waterway location is assigned to a vessel movement for the GW/VCU MTS simulation model using VTOSS 2005 data. Similarly, the fifth column in Table 5 provides by vessel master type the percentage of time that a waterway location is assigned to a vessel movement for the updated GW/VCU MTS simulation model using VTOSS 2010 data. Recall Table 2 provides the vessel master type definition used in the generation of Table 4 and Table 5 for the 26 vessel types in the VTOSS data sets. These percentages (in Table 4 and Table 5) are evaluated by dividing the number of minutes per year a vessel is moving within the MTS simulation with a waterway location assigned by the total number of minutes a vessel is moving (see the third and fourth columns in Table 4 and Table 5).

Table 4. Route and density data for 6 vessel master types generated using the GW/VCU MTS simulation model with 2005 VTOSS data and location definitions in Figure 18.

Vessel Master Type	# Represent. Routes	# Minutes per Year	# Minutes per year No Location	% Time Location Assigned	% of Traffic	Average # Vessels
Cargo	106	5344799	6821	99.9%	13.7%	10.2
Tanker	164	1313096	444	100.0%	3.4%	2.5
TugTow	1185	7272609	17925	99.8%	18.7%	13.8
Service	5	1039769	942	99.9%	2.7%	2.0
Passenger	164	9701338	54771	99.4%	25.0%	18.5
Fishing	132	14201790	64223	99.5%	36.5%	27.0
Total	1756	38873401	145126	99.6%	100.0%	74.0

Table 5. Route and density data for 6 vessel master types generated using the updated GW/VCU MTS simulation model with 2010 VTOSS data and location definitions in Figure 18.

Vessel Master Type	# Represent. Routes	# Minutes per Year	# Minutes per year No Location	% Time Location Assigned	% of Traffic	Average # Vessels
Cargo	14640	7468850	51583	99.3%	18.5%	14.2
Tanker	3340	1287457	2838	99.8%	3.2%	2.4
TugTow	40704	7927747	171967	97.8%	19.7%	15.1
Service	2458	614972	6730	98.9%	1.5%	1.2
Passenger	14521	9090031	40756	99.6%	22.6%	17.3
Fishing	3837	13920520	68899	99.5%	34.5%	26.5
Total	79500	40309577	342773	99.1%	100.0%	76.7

The second column in Table 4 and Table 5 provides the number of route segments and representative routes used in the GW/VCI MTS simulation model using VTOSS 2005 and VTOSS 2010 data respectively. Although a slightly higher accuracy is observed in the fifth column in Table 4 (2005) compared to the fifth column in Table 5 (2010), a definite improvement in vessel route dispersion is observed by going from Figure 11 (2005) to Figure 16 (2010) for container vessels and bulk carriers. Thus by retaining a vessel's individual route using the VTOSS 2010 data, vessel movements in the updated GW/VCU MTS simulation are more representative than the former GW/VCU MTS model using the 2005 VTOSS dataset.

The percentage of total moving traffic by vessel master type, depicted in the sixth columns in Table 4 and Table 5, are evaluated by dividing the number of minutes in the third columns by the total sum of the third column. The average number of moving vessels by master type at any arbitrary point in time is evaluated by dividing the minutes in the third column in Table 4 and Table 5 by the total number of minutes in a calendar year. Thus in Table 4 (2005) the GW/VCU MTS model evaluated an average of 74.0 moving vessels in the system at any arbitrary point in time, whereas in Table 5 (2010) an average of 76.7 vessels was evaluated.

To illustrate the fluctuation in the number of vessels moving in the study area over a calendar year, however, Figure 20 plots the time series (every 15 minutes) of the number of vessels excluding ferries, yachts and fishing vessels for the GW/VCU MTS simulation model using VTOSS 2005 and VTOSS 2010 data. Figure 21 on the other hand plots this time series comparison for ferries, yachts and fishing vessels.

Both Figure 20 and Figure 21 serve as a reminder that "the world is not average" and that vessel risk, of which number of vessels moving in the system is a driver, is not a constant but a dynamic quantity that changes over time. The larger goal of vessel risk management is to reduce the overall average risk level while managing the variation of the time series of risk by avoiding “high” risk spikes.

Moving from Sampled Speeds to Calculated Speeds

As discussed in Section 2, the 2005 simulation sampled speeds from the distribution of all vessel speeds of a given type of vessel in the 2005 VTOSS database. So a given container vessel may actually transit at the speed of another container vessel in the database. The vessel also transited along a representative route for all vessels of that type traveling between its departure and destination points. In the 2010 simulation, the vessel travels along its own route and we have the time start time and the end time for that transit in the 2010 VTOSS database. Figure x shows one such route for the Westwood Rainier cargo vessel

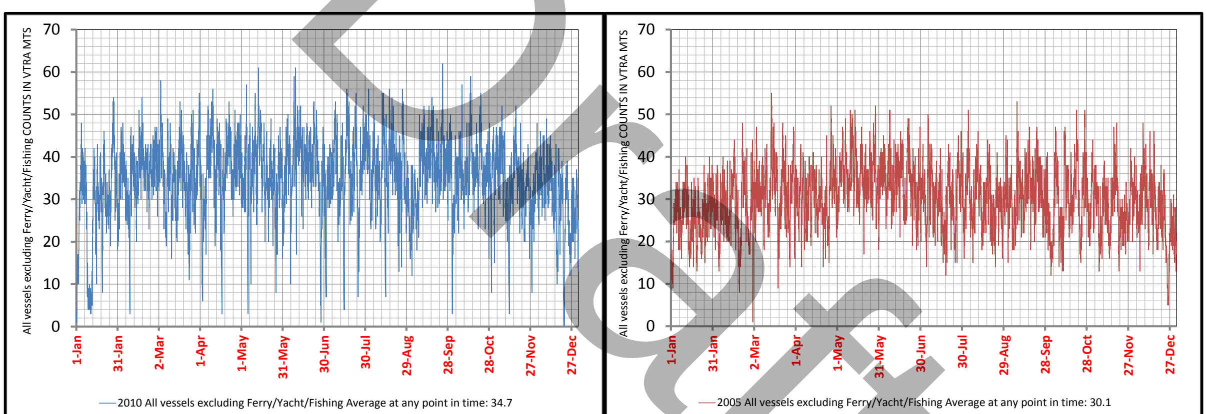


Figure 20.Left panel: Time series of counts of all vessels excluding ferries, yachts and fishing vessels in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

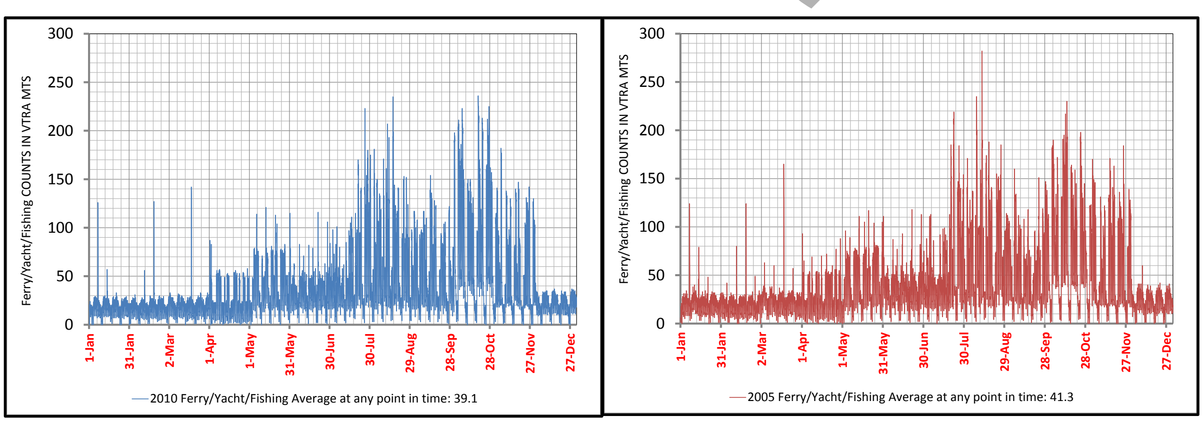


Figure 21. Left panel: Time series of counts of all ferries, yachts and fishing vessels in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

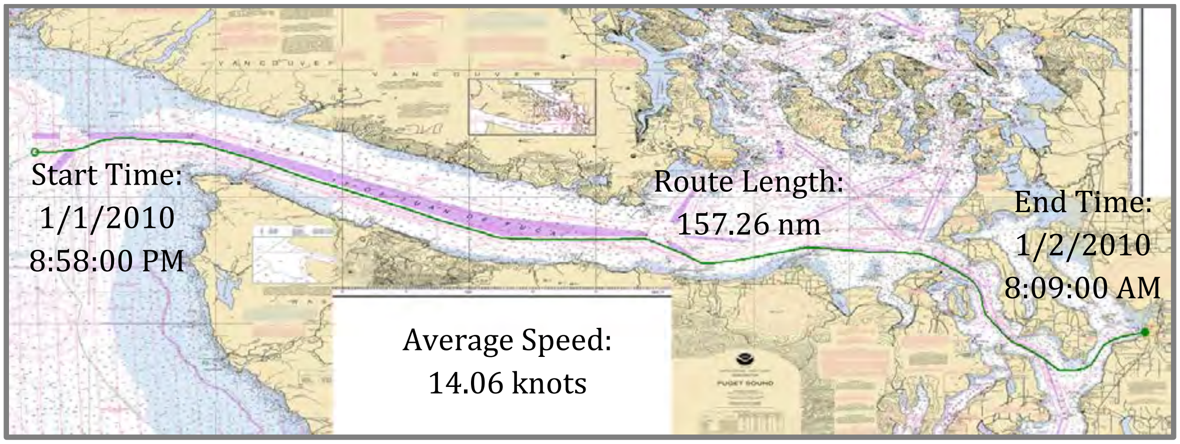
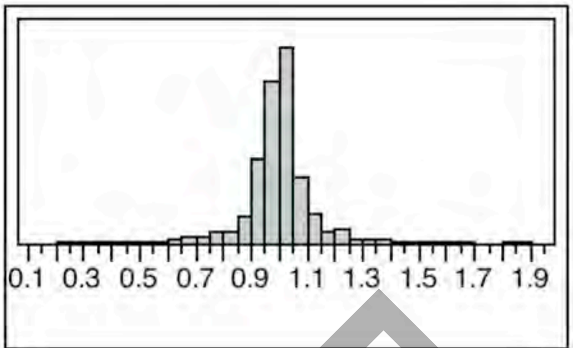


Figure 22. A route followed by the Westwood Rainier cargo vessel and its calculated average speed.

In the simulation, we can calculate the length of the route, so we can calculate the average speed of the vessel on that transit. The Westwood Rainier started its transit at 8:58 pm on January 1st, 2010 and ended its transit the next morning at 8:09 am. The transit took 11 hours and 11 minutes and was calculated (after the route cleaning discussed above) to be 157.26 nautical miles. This means the vessel average 14.06 knots over the transit. The Westwood Rainier has a maximum speed of 16.1 knots and an average speed of 14.1 knots (according to www.marinetraffic.com), so this calculation appears quite accurate.

One must consider, however, that the vessel would have slowed around the pilot station and as it approached dock, so it would not have moved at this average speed throughout the transit. It also had moderately strong currents in the direction it traveled throughout the transit, so it would have made more than 14.1 knots over land for other parts of the transit. Thus, we must start the simulated transit at a higher speed and then reduce the speed based on the location of the vessel and the traffic rules (one-way zones, pilot station, approaching dock, etc.). For each transit, we calculated a speed accuracy factor by taking the simulated length of the transit using the average speed as the starting point and divided by the length of the transit in the 2010 VTOSS database. We calculated speed calibration multipliers for each vessel type to ensure that the speed accuracy factor was as close to 1 as possible.

Figure 23 shows the overall distribution of the speed accuracy factor for all vessels once the speed calibration multipliers were used for the initial speed of the vessel. The mean is 1.0003 with a 95% confidence interval of [0.9995,1.0012]. It is not possible to achieve a value of 1 as each change to the speed calibration factors can change the dynamics of the system, but the calculations are accurate on average to four decimal places. This does not mean that every transit is accurate to four decimal places. However, only 10% had a speed accuracy factor below 0.9 and only 10% had a speed accuracy factor over 1.1. Speeds that were clearly inaccurate based on the VTOSS data were sampled from the original speed distributions. Thus, we could accurately model the actual speed for a given transit and only sample general vessel type speeds for a few transits.



Summary Statistics	
Mean	1.0003464
Std Dev	0.0974197
Std Err Mean	0.000419
Upper 95% Mean	1.0011676
Lower 95% Mean	0.9995253
N	54066

Figure 23. The distribution of the speed accuracy factor for all transits..

Extending VTRA 2005 incident and accident probability models

During the VTRA 2005 accident probability models given the occurrence of an incident were developed separately for tankers and ATB's. To accommodate the expansion of the focus vessel class to include also bulk carriers, container vessels, chemical carriers and oil barges, the tanker accident probability models shall be utilized for the container, bulk carrier and chemical carriers, whereas the ATB models shall be utilized for the barges.

In the VTRA 2005 annualized historical incident data was collected for the tankers and ATB's that visit the cherry point terminal and were carefully vetted incident by incident. The VTRA 2005 simulation model incident rates were calibrated to the annualized statistics and converted to an incident rate per unit time on the water, taking advantage of the VTRA 2005's model capability of distinguishing short routes from long ones while taking into account vessel speeds as well.

While incident data was collected for freighters as a vessel class during the VTRA 2005, it was not broken down by container, bulk carrier or any of the other 5 cargo vessel types and were not as carefully vetted as the incident date for tankers and ATB's. Hence, to accommodate the expansion to a larges focus vessel class we shall assume that the incident rates by unit time of the water for tanker apply also to the container, bulk carrier and other cargo vessel classes, whereas we shall apply the incident rates for ATB's to the oil barge class. Figure 24 visualizes the effect of these assumptions on the annualized incident rates

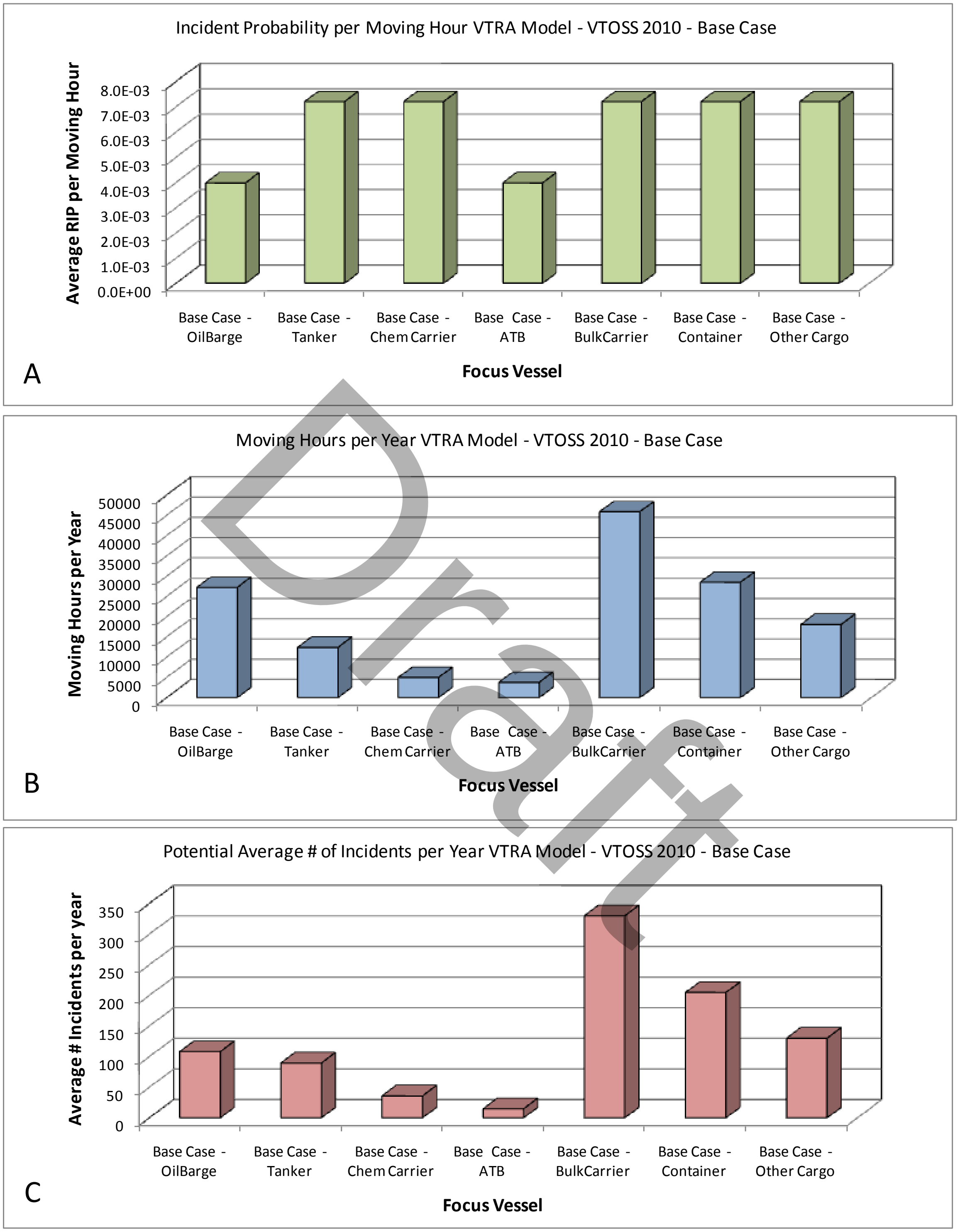


Figure 24. A: Incident rate per moving hour by focus vessel; B: Moving hours in VTRA 2010 model by focus vessel; C: Potential number incidents per year by focus vessel

by vessel class taking into account the amount of travel time of each vessel class in the VTRA 2010 model. Figure 24A displays the incident rates by moving hour and demonstrates that bulk carrier, container, other cargo and chemical carriers are assigned the same incident rates as tankers, whereas oil barges are assigned the same incident rate per moving hour as the ATB;s. Combining these rates per moving hour with the amount of moving hours per year (Figure 24A) in the VTRA 2010 model, results in the average number of incidents per year as depicted in Figure 24C. Observe from Figure 24C that the bulk carrier class has the largest potential number of incidents per year in the VTRA 2010 model which is primarily driven by the fact that the largest portion of the focus vessel traffic in the VTRA study area are in fact bulk carriers.

Oil carrying assumptions for focus vessels

Of the tank focus vessels, tankers and chemical carriers are identified in the vessel type record in VTOSS. ATBs and ITBs are not specifically identified, but there are a limited number of them, so they can be identified by name. However, oil barges are only listed a tug tow barge in VTOSS. The records for tugs sometimes indicate the barge type as bulk cargo, derrick, light, log barge, petroleum, or wood chip. However, a blank record can either mean there is no barge or that the data was not recorded by the VTS. To identify oil barges, we collected the list of all tug names that were listed as towing a petroleum barge at some point in 2010. These names were then provided to the Puget Sound Pilots who indicated whether they were exclusively used for petroleum based on their extensive knowledge of vessels in the study area. They were also asked to identify other tugs that were exclusively used for petroleum. In this manner, we could use the non-blank VTOSS records to identify the tug's barge and use the Puget Sound Pilot's information to identify oil barges with blank records.

The culmination of the oil barge movement modeling effort is depicted in Figure 25. Please observe from Figure 25 that oil barge movement modeling in the VTRA 2010 model accounts for about 54.5% of the movements of all tankers, chemical carriers and oil barges combined. The predominant movement of oil barges is a north south movement between the Cherry point, Ferndale and Anacortes refineries and the southern Puget Sound. However, quite a significant number of oil barges travel north and south to Canada. A lesser density is observed entering/leaving the Strait of Juan de Fuca.

Unfortunately, no information is collected within the VTOSS 2010 data set regarding the volume of cargo oil or type of cargo oil on board a particular tank vessel. While vessel traffic density movement is a driver of accident frequency analysis, the oil that vessel carry is a driver for oil outflow analysis. To represent oil movement within the VTRA 2010 model we have had to therefore rely on set of overarching assumptions regarding the amount and type of oil moved through the study area by vessels. These assumptions were made based

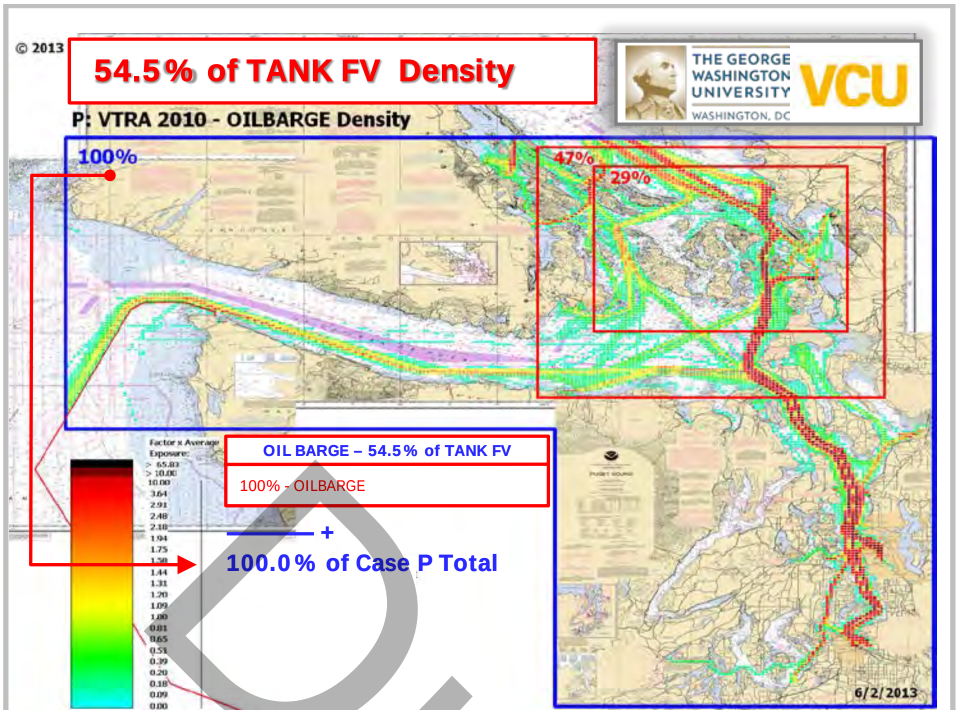


Figure 25. Traffic density of tugs towing/pushing oil barges in the VTRA 2010 model.

on interactions with the PGHSC committee and other stakeholders over the course of the study and are listed below.

List of oil carrying assumptions in VTRA 2010 model:

1. Tankers are classified as crude or product carriers by name
2. Chemical carriers transport product.
3. Oil barges are assumed to transport product.
4. Focus vessels fuel tanks are 50% full
5. US bound crude tankers are assumed fully laden as they arrive in study area and drop of equal amounts at their stops and leave empty.
6. Canadian bound crude tankers are assumed empty as they arrive and fully laden as they depart.
7. Product tankers and ATB's are assumed fully laden asthey depart study area, empty as they arrive.
8. Chemical carriers are assumed fully laden as they arrive in the study area, empty when they leave the study area
9. When ATB's go back and forth between two destinations within the study area they are assumed 50% full
10. Oil barges are assumed fully laden as they travel through study area.
11. Tank focus vessels not covered by 1-10 are assumed fully laden.

Combined with a validated picture of vessel traffic and data recorded in the VTOSS 2010 dataset regarding vessel size in terms of dead-weight tonnage, we hope the set of assumptions adds realism to the movement of oil throughout the VTRA study area. Such realism is important when comparing a base case scenario to another What-If traffic scenario in terms of oil spill transportation risk. The effect of these assumptions are summarized in separate geographic density profiles of product, crude and fuel movements which serve as a starting point of the VTRA 2010 potential oil loss analyses.

4. VALIDATION OF 2010 VTOSS AND AIS 2010 CROSSING LINE DATA

AIS data is collected on a regular basis by the MXPS. Amongst other reports the Marine Exchange AIS system is able to produce crossing line count reports by cargo, tanker and passenger vessel at a line drawn on a nautical map. At our request, the MXPS produced these reports for three counting lines depicted in Figure 26 for the year 2010. Panel A, provides an overview look of the three counting lines, whereas Panels B, C and D provide a close-up view of these three counting line separately. For the West Strait of Juan de Fuca line the crossing line count data separates eastbound and westbound traffic, whereas for the Georgia Strait and Puget Sound crossing lines count data is separated in north and southbound traffic as depicted in Panels B,C and D in Figure 26. Unfortunately, no AIS data is available for the year 2005 for the geographic area in Figure 26A.

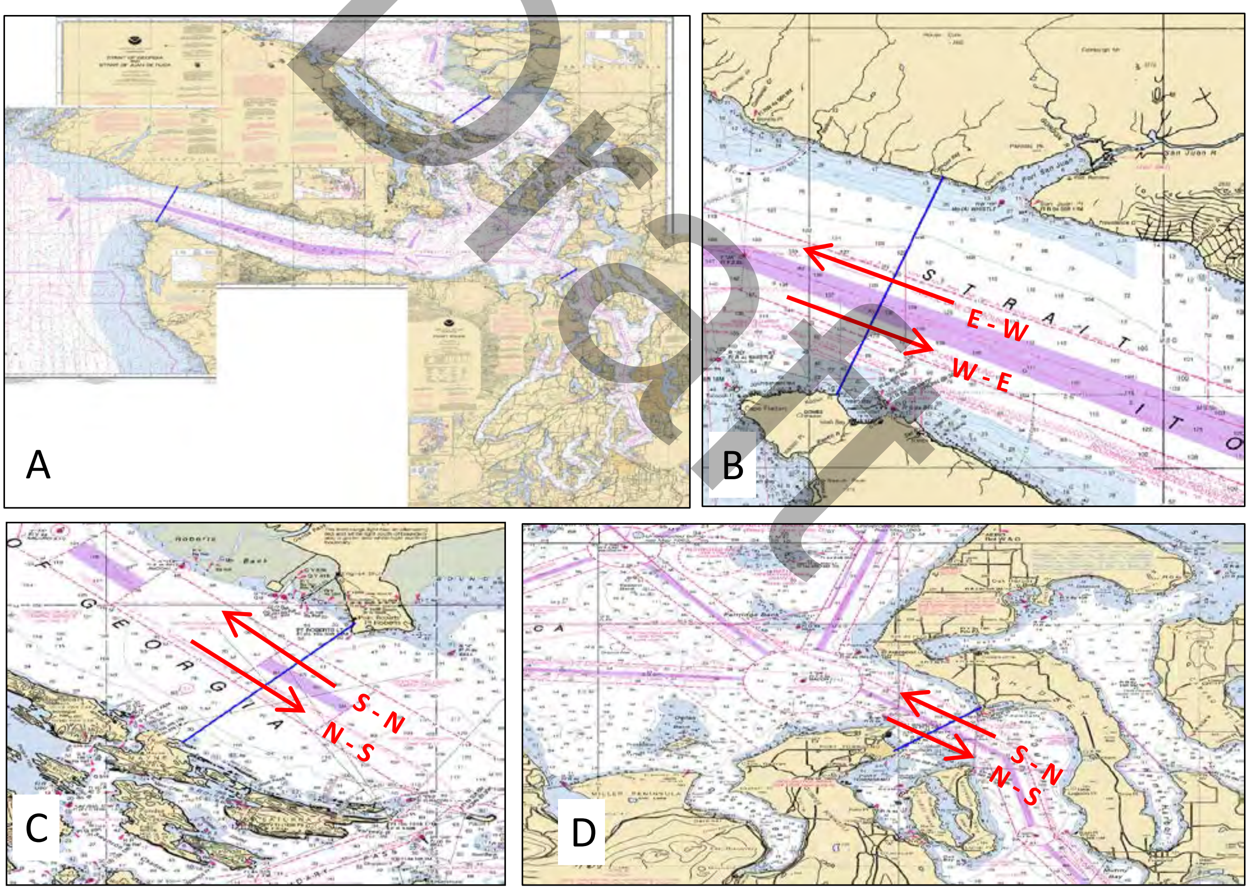


Figure 26. A: Overview of three AIS crossing definitions; B: Close-up view of crossing line at the West Strait of Juan de Fuca Entrance; C: Close-up view of crossing line at the George Strait entrance; D: Close-up view of the crossing line at the Puget Sound entrance.

Crossing line analysis of AIS 2010 data.

Table 6 provides the AIS 2010 crossing line counts for the three crossing lines depicted in Figure 26. From Table 4 one observe that per this data source it appears more traffic traveled north bound at the Georgia Strait Entrance (100%) than south bound (85%). For the West Strait of Juan de Fuca and Puget Sound crossing lines one observe a much more even distribution with about the same amount of traffic travelling in both directions. Moreover, a larger amount of traffic crosses the WSFJ crossing line (8217 – 150%), followed by the Puget Sound crossing line (5639 – 103%) and Georgia Strait crossing line (5471 – 100%). Hence, approximately 50% more traffic crosses the WSJF crossing line than the Georgia Strait crossing line, whereas only 3% more crosses the Puget Sound crossing line.

Table 6. AIS 2010 Crossing line counts by vessel types: cargo, tanker and passenger vessel. A: West Strait of Juan de Fuca crossing Line counts; B: Georgia Strait crossing Line counts; C: Puget Sound crossing line counts.

A: WSJF CROSSING LINE

Ship Type	East Bound	West Bound	Grand Total
Cargo	3216	3157	6373
Tanker	694	685	1379
Passenger	244	221	465
Grand Total	4154 - 100%	4063 - 98%	8217

B: GEORGIA STRAITE CROSSING LINE

Ship Type	North Bound	South Bound	Grand Total
Cargo	2278	2133	4411
Tanker	267	266	533
Passenger	414	113	527
Grand Total	2959 - 100%	2512 - 85%	5471

C: PUGET SOUND CROSSING LINE

Ship Type	North Bound	South Bound	Grand Total
Cargo	1754	1766	3520
Tanker	95	95	190
Passenger	958	971	1929
Grand Total	2807 - 100%	2832 - 101%	5639

Matching VTOSS 2010 Vessel Types to AIS 2010 Vessel Types.

The AIS crossing line counting feature depicted in Figure 26 was programmed into the GW/VCU MTS simulation model to mimic the same counting procedure for each of the 26 different vessel type classifications listed in Table 2. Table 7provides the crossing counts by vessel type and Table 8by vessel master type as defined in Table 2using the VTOSS 2010 dataset.

Table 7. GW/VCU MTS Crossing line counts using VTOSS 2010 data by 26 different vessel type classifications.

VESSEL TYPE	Master Type	TOT WSJF W-E	TOT WSJF E-W	TOT G_STR N-S	TOT G_STR S-N	TOT PS N-S	TOT PS S-N
BULKCARRIER	Cargo	1446	1493	1034	1023	300	309
CHEMICALCARRIER	Tanker	152	155	142	127	18	18
CONTAINERSHIP	Cargo	1045	1047	440	547	1004	994
DECKSHIPCARGO	Cargo	2	26	2	17	10	35
FERRY	Passenger	0	0	0	0	572	572
FERRYNONLOCAL	Passenger	1	5	1	3	423	450
FISHINGFACTORY	Fishing	83	117	20	51	108	133
FISHINGVESSEL	Fishing	3368	3330	227	220	320	329
LIQGASCARRIER	Tanker	2	4	0	0	0	0
NAVYVESSEL	Cargo	49	101	215	239	136	153
OILTANKER	Tanker	406	415	33	86	83	76
OTHERSPECIALCARGO	Cargo	251	253	334	166	102	4
OTHERSPECIFICSERV	Service	7	26	1	9	7	18
PASSENGERSHIP	Passenger	241	62	56	40	164	43
REFRIGERATEDCARGO	Cargo	0	5	0	22	15	27
RESEARCHSHIP	Service	35	51	1	6	42	45
ROROCARGOSHIP	Cargo	5	72	0	10	9	79
ROROCARGOCONTSHIP	Cargo	147	47	0	14	118	46
SUPPLYOFFSHORE	Service	0	5	0	2	33	27
TUGTOWBARGE	Tugtow	333	319	1201	1052	1631	1696
UNKNOWN	Service	0	0	0	0	0	0
USCOASTGUARD	Service	35	49	48	41	72	43
VEHICLECARRIER	Cargo	197	97	5	119	103	130
YACHT	Passenger	29	37	45	21	71	82
ATB	Tanker	58	74	45	48	34	35
ITB	Tanker	0	0	0	0	0	0
	Total	7892	7790	3850	3863	5375	5344

Table 8.GW/VCU VTRA model crossing line counts using VTOSS 2010 data by vessel master type.

Master Type	TOT WSJF W-E	TOT WSJF E-W	TOT G_STR N-S	TOT G_STR S-N	TOT PS N-S	TOT PS S-N
Cargo	3142	3141	2060	2158	1797	1777
Tanker	618	648	222	261	135	129
TugTow	333	319	1206	1053	1631	1696
Service	77	131	49	57	154	133
Passenger	271	104	97	60	1230	1147
Fishing	3451	3447	249	272	428	462
Total	7892 - 100%	7790 - 99%	3883 - 100%	3861 - 99%	5375 - 100%	5344 - 99%

Observe from the last row in Table 8 that contrary to Table 6 the same flow is observed going north bound and south bound at the Georgia Strait crossing line. In contrast for the AIS data in Table 6 85% is travelling southbound . Similarly, one observes that at the WSJF and Puget Sound crossing lines about the same amount of traffic flows in both directions.

Comparing VTOSS 2010 crossing line counts to AIS 2010 crossing line counts.

Observe from Table 7and Table 2that the master type category “tanker” includes: chemical carrier, oil tanker, atb and itb. This is consistent with the “tanker” category definition used in the generation of the AIS crossing count data in Table 6. The VTOSS classification “Navyvessel” was given a master type “cargo” classification also for consistency between the VTOSS 2010 master crossing line and AIS 2010 crossing line counts. For the remainder of the 26 vessel types in Table 7, its vessel master type was assigned based on the vessel type classification in Table 7andTable 2.

In Figure 27, Figure 28 and Figure 29 a comparison is provided between the VTOSS 2010 GW/VCU MTS crossing line counts and AIS 2010 crossing line in Table 6 and Table 8 for cargo, tanker and passenger vessels. The “tug-tow“ master type crossing line counts in Table 8are not included in the AIS 2010 crossing line counts. The “fishing” VTOSS 2010 master type counts in Table 8 includes the “Fishingvessel” counts from Table 7 that result from fishing vessel tribal and commercial fishing openers that are modeled in the GW/VCU MTS simulation model, but are not recorded in the VTOSS 2010 data, nor the AIS 2010 data. Final, no service vessel classification is provided in the AIS 2010 crossing line counts. Hence, only the comparison provided for the three crossing lines in Figure 26 for the vessel types: cargo, tanker and passenger.

From Figure 27 one observes that the crossing line counts for these three vessel types agree between the two datasets AIS 2010 and VTOSS 2010 both in the east and west bound directions. Overall, one observe a general agreement for the cargo and tanker vessel types in Figure 28 and Figure 29, except for the cargo category travelling northbound in the Georgia Strait where a higher number of crossing counts are reported for the AIS 2010 data. Certainly, some discrepancies are observed for the passenger vessel classification for both the Georgia Strait and Puget Sound crossing lines. We attributed those discrepancies to vessel type misclassification in the VTOSS 2010 dataset. For example, at times the same oil tanker travelling is both classified as a cargo vessel and as a tanker across the three different VTS systems recorded in the VTOSS 2010 dataset. Similar misclassifications are observed for the passenger vessel category. Overall, however, especially when concentrating on the cargo and tanker classifications, there is more agreement between the AIS 2010 and VTOSS 2010 crossing line counts in Figure 27, Figure 28 and Figure 29 than there is disagreement, leading to the conclusion that these two dataset reconcile well. Hence, the validation of VTOSS 2010 crossing line counts in the GW/VCU MTS simulation model by AIS 2010 crossing line counts.

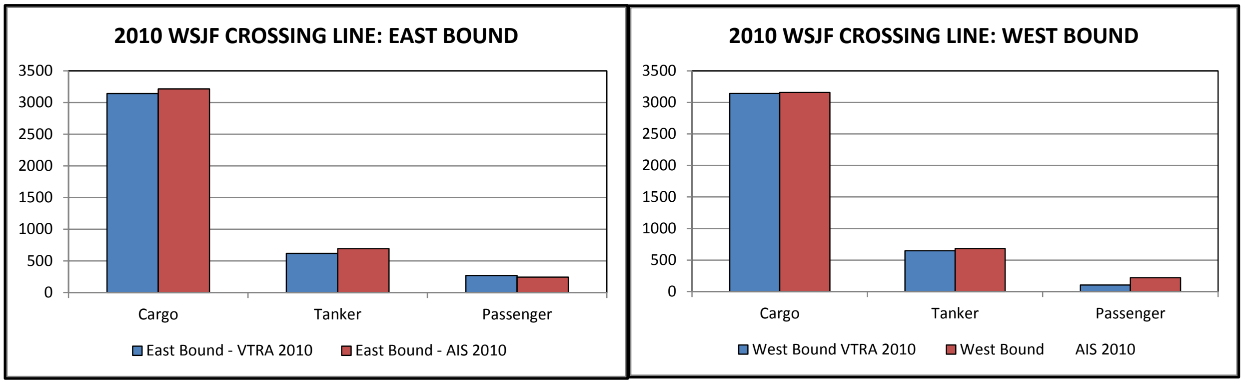


Figure 27. Comparison of AIS 2010 and VTOSS 2010 crossing line counts for cargo, tanker and passenger vessels for the West Strait of Juan de Fuca crossing line depicted in Figure 26B.

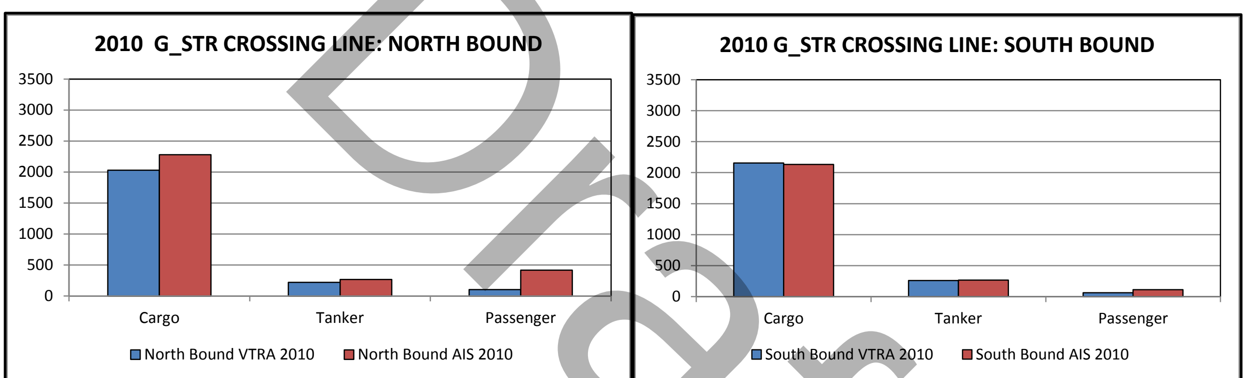


Figure 28. Comparison of AIS 2010 and VTOSS 2010 crossing line counts for cargo, tanker and passenger vessels for the Georgia Strait crossing line depicted in Figure 26C.

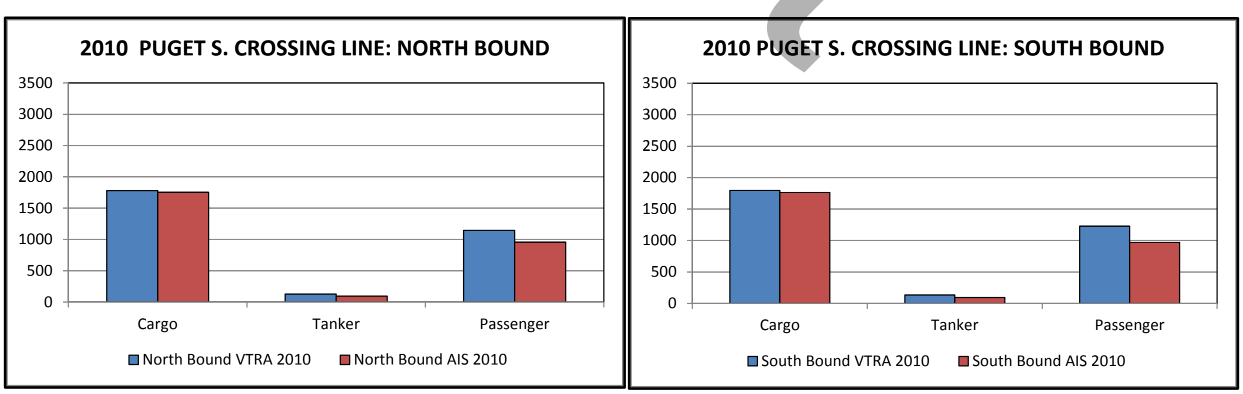


Figure 29. Comparison of AIS 2010 and VTOSS 2010 crossing line counts for cargo, tanker and passenger vessels for the Puget Sound crossing line depicted in Figure 26D.

5. TRAFFIC PATTERNS AND OIL MOVEMENTS IN VTRA 2010 BASE CASE

Running a simulated year 2010 using the methods discussed in Sections 2 and 3, we obtain a comprehensive picture of vessel traffic in the study area. We classify vessel traffic in the VTRA 2010 as focus vessel traffic and non-focus vessel traffic. For focus vessel traffic potential collision and grounding accident frequencies and oil losses shall be evaluated in the remainder of this report. Focus vessel traffic consists of the vessel types: Oil Tankers, ATB's, Chemical Carriers, Bulk Carriers, Container Vessels and a class Other Cargo, capturing other larger cargo vessels. The non-focus vessel traffic is an important modeling aspect of the VTRA 2010 model to evaluate focus vessel collision risk since focus vesselscan potentially collide with non-focus vessels[3]. In fact, 75.2% of the total traffic modeled in the 2010 VTRA model is non-focus vessel traffic; the remainder 24.8% is focus vessel traffic. Figure 30 summarizes the focus vessel classification of vessel types in the VTRA 2010 model.

#	VESSEL TYPE	FOCUS VESSEL?	#	VESSEL TYPE	FOCUS VESSEL?
1	BULKCARRIER	CARGO - FV	14	PASSENGERSHIP	NO
2	CHEMICALCARRIER	TANK - FV	15	REFRIGERATEDCARGO	CARGO-FV
3	CONTAINERSHIP	CARGO - FV	16	RESEARCHSHIP	NO
4	DECKSHIPCARGO	CARGO - FV	17	ROROCARGOSHIP	CARGO-FV
5	FERRY	NO	18	ROROCARGOCONTSHIP	CARGO-FV
6	FERRYNONLOCAL	NO	19	SUPPLYOFFSHORE	NO
7	FISHINGFACTORY	NO	20	TUGTOWBARGE	NO
8	FISHINGVESSEL	NO	21	UNKNOWN	NO
9	LIQGASCARRIER	TANK - FV	22	USCOASTGUARD	NO
10	NAVYVESSEL	NO	23	VEHICLECARRIER	CARGO-FV
11	OILTANKER	TANK - FV	24	YACHT	NO
12	OTHERSPECIALCARGO	CARGO - FV	25	ATB	TANK - FV
13	OTHERSPECIFICSERV	NO	26	OIL BARGE	TANK - FV

Figure 30. Focus Vessel Classification of VTRA 2010 vessel types.

Figure 31 displays a geographic profile of non-focus vessel traffic, which predominantly consists of fishing vessels (31.0%), Tug-barge traffic[4] (17.2%) and ferry traffic (15.7%). The remaining 11.2% comprises of yachts, navy vessels, passenger ships and service vessels. In the sections to come, we shall provide separate geographic profile analyses for

[3] Of course focus vessel can also potential collide with other focus-vessel.
[4] This 17.2% does not include oil barge traffic which is consider a focus vessel class

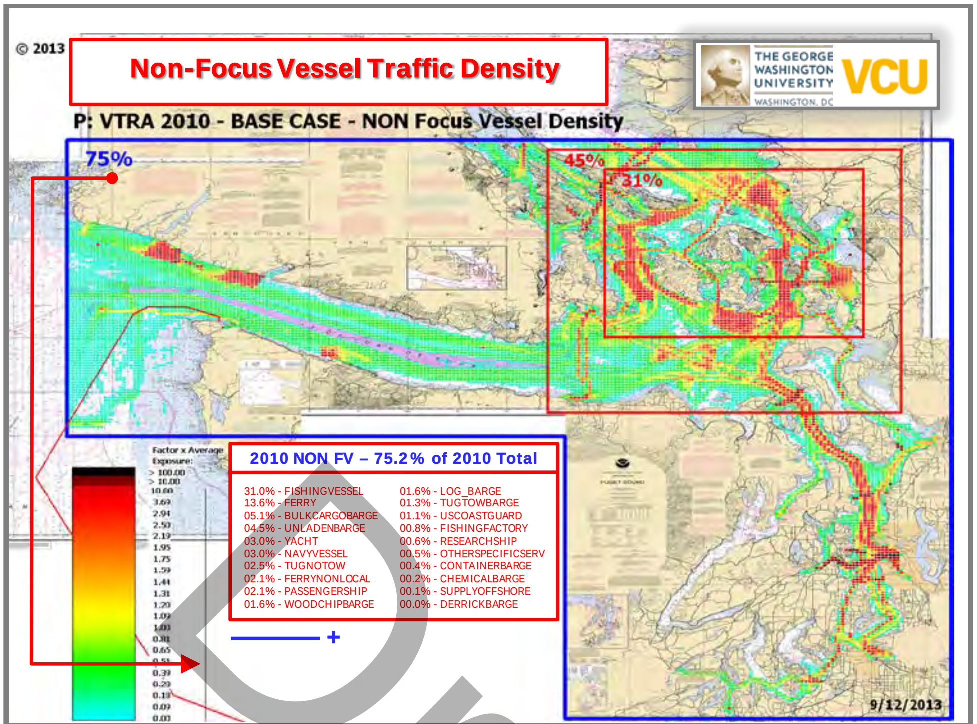


Figure 31. The traffic density for all non-focus vessels.

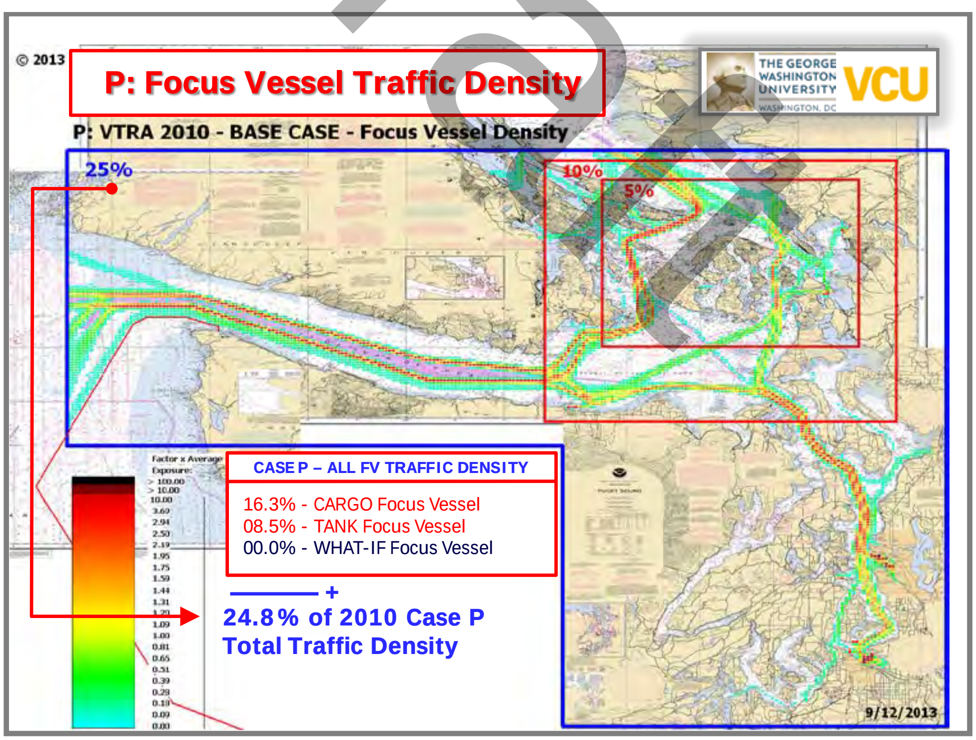


Figure 32. The traffic density for all focus vessels.

the focus-vessel class (24.8% of total traffic) of which its traffic density is depicted in Figure 32.

In sections to come, traffic movements representing time of focus vessels on the water are summarized in terms of cargo focus vessel (bulk carrier, container and other cargo) density profiles and tank focus vessel (oil barge, oil tanker, chemical carrier and atb) density profiles. The oil (crude, product and fuel) that cargo and tank focus vessels transport are summarized in oil movement density geographic profiles. For contrast purposes focus-vessel density profiles shall be presented using their own color legend rather than the color legend used in Figure 31 and Figure 32.

Focus Vessel Time of Exposure

Let us first examine the time each type of focus vessel spends in the system; 65.7% of the focus vessel total time of exposure is cargo focus vessels, with the remaining 34.3% being tank focus vessels. Of the cargo focus vessels total time of exposure, 49.6% is bulk cargo, 30.8% is container vessels, and 19.6% is other cargo vessels. Of the tank focus vessels total time of exposure, 56.3% is oil barges, 25.7% tankers, 10.3% chemical carriers, and 7.7% articulated tug barges. To find the contribution of oil barges, for example, to the focus vessel total time of exposure, we consider that 34.3% of the focus vessel total is tank focus vessels and 56.3% of the tank focus vessel total time of exposure is oil barges, so 34.3% multiplied by 56.3% gives 19.3% of the focus vessel total time of exposure. Figure 33 shows the contribution of each focus vessel type to the total focus vessel time of exposure calculated in this manner.

Oil Time of Exposure

Thus far, we have examined the focus vessel time of exposure, where we count the amount of time that vessels move through study area by grid cell. Rather than focusing on vessels it is also instructive to examine the amount of time a unit of oil (measured in either barrels or cubic meters) is moving through the study area. This includes cargo (product and crude) oil and fuel oil that focus vessels transport; so all focus vessels contribute to the total oil time of exposure; 39.4% of the total oil time of exposure is product, 36.9% is crude, and 23.7% is fuel. Figure 34 shows the total oil time of exposure broken down by vessel type. Tankers comprise almost half of the total oil time exposure at 48.1%. Oil barges comprise about a fifth at 20.6%. However, the vessel type with the next largest contribution is container vessels, which carry only fuel oil, at 8.9% and not chemical carriers. This is of course a result of the fact more container vessels travel through the VTRA study area than chemical carriers. In fact, overall fuel oil from cargo focus vessels comprises 19.7% of the total oil time exposure.

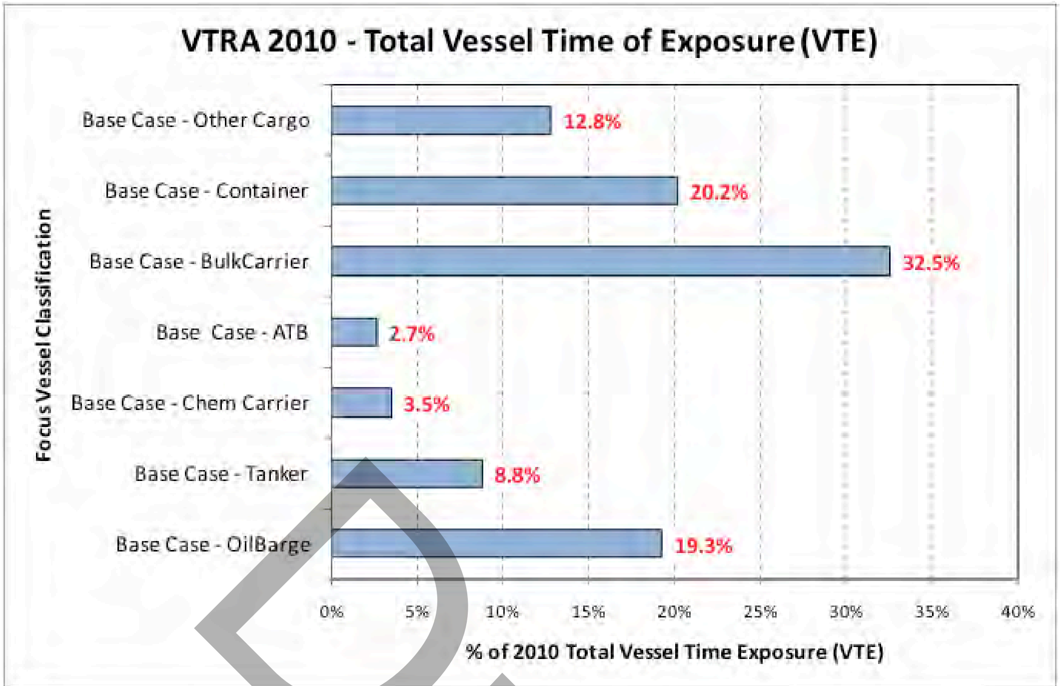


Figure 33. Comparison of the total vessel time of exposure by focus vessel classification

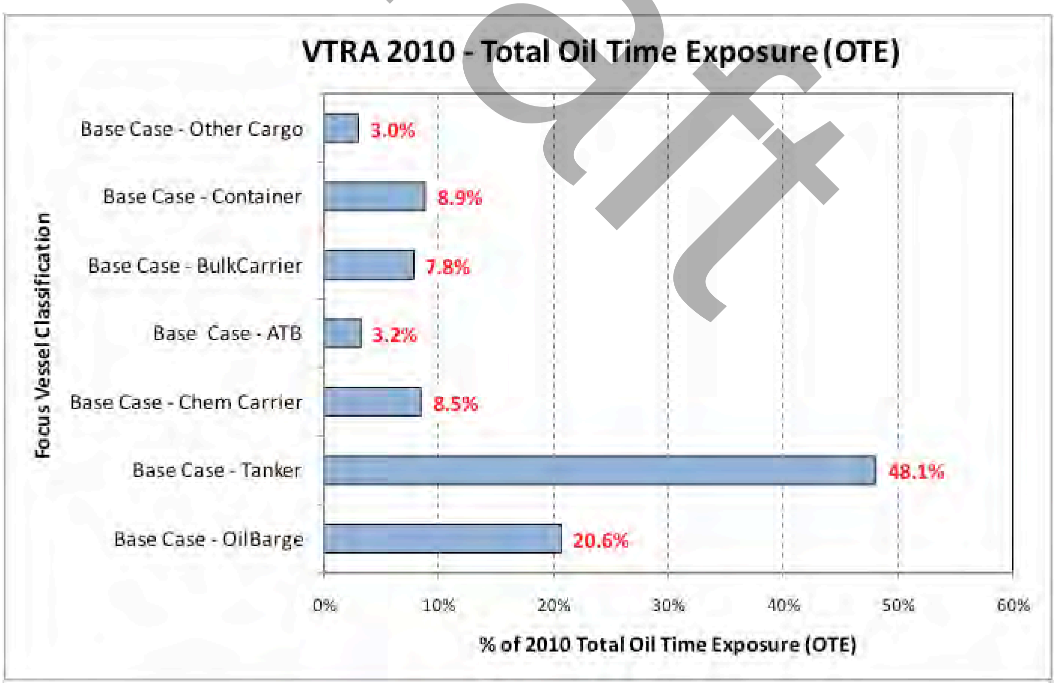


Figure 34. Comparison of the total oil time of exposure by focus vessel classification

Traffic Densities Profiles

Figure 33 shows that bulk carriers spend the most time transiting the study area at 32.5% of the total, followed by container vessels at 20.2%, and oil barges at 19.3%. Oil tankers comprise 8.8% of the total. While these aggregate statistics are useful, we are also interested in where these vessels spend time in the VTRA study area. Figure 35 and Figure 36 show the cargo focus vessel and tank focus vessel traffic densities respectively.

Comparing Figure 35 and Figure 36 is quite instructive. Apparently, cargo focus vessels transit the Straits of Juan de Fuca and then Haro Strait, Boundary Pass, and Georgia Strait going north and the Puget Sound going south. Meanwhile, the traffic density for tank focus vessels is most significant in Rosario Strait and Puget Sound (and near the pilot station in Port Angeles). Thus, cargo and tank focus vessels mostly transit different areas of the system, except for the Puget Sound where they converge.

Oil Movement Density

Again it is instructive to view the geographic spread of the oil movement exposure, called the oil movement density. Figure 37, Figure 38, Figure 39 shows the oil movement densities for product, crude, and fuel oil respectively. Figure 40 shows the total oil movement density. Figure 38 shows that crude oil moves predominantly from Buoy J to the Cherry Point, Ferndale, and Anacortes refineries. Figure 39 shows that fuel oil moves predominantly in the areas where cargo focus vessels transit in Figure 35. Product oil moves throughout the system in Figure 37. Thus, Figure 40 shows the oil moves on all major traffic lanes in the study area. The highest density areas are on the approaches to refineries and near the pilot station.

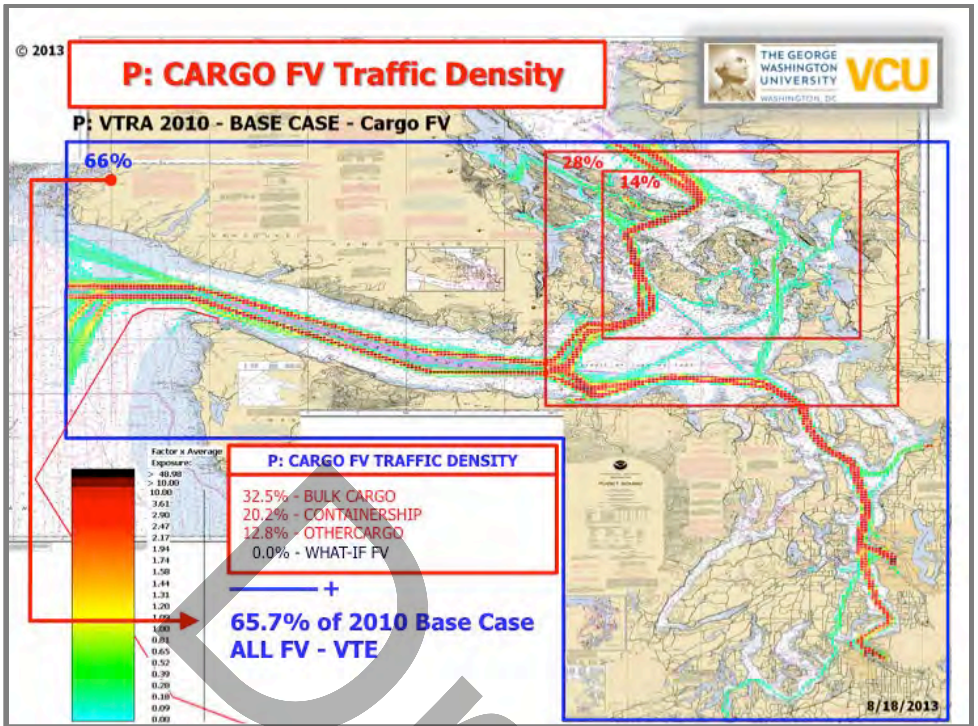


Figure 35. The traffic density for cargo focus vessels.

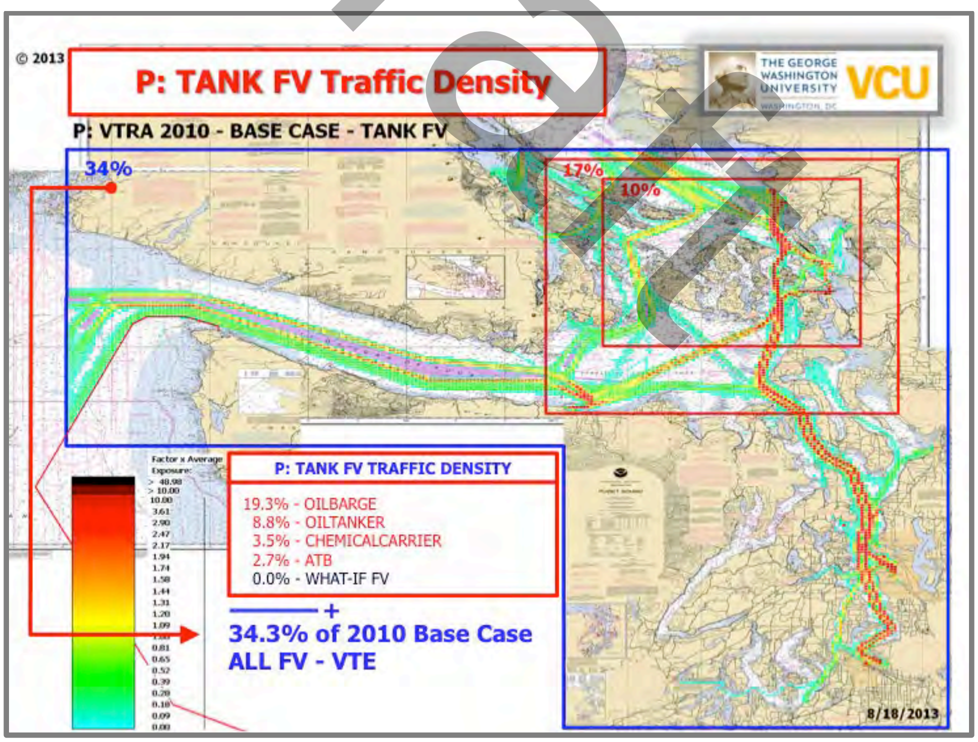


Figure 36. The traffic density for tank focus vessels.

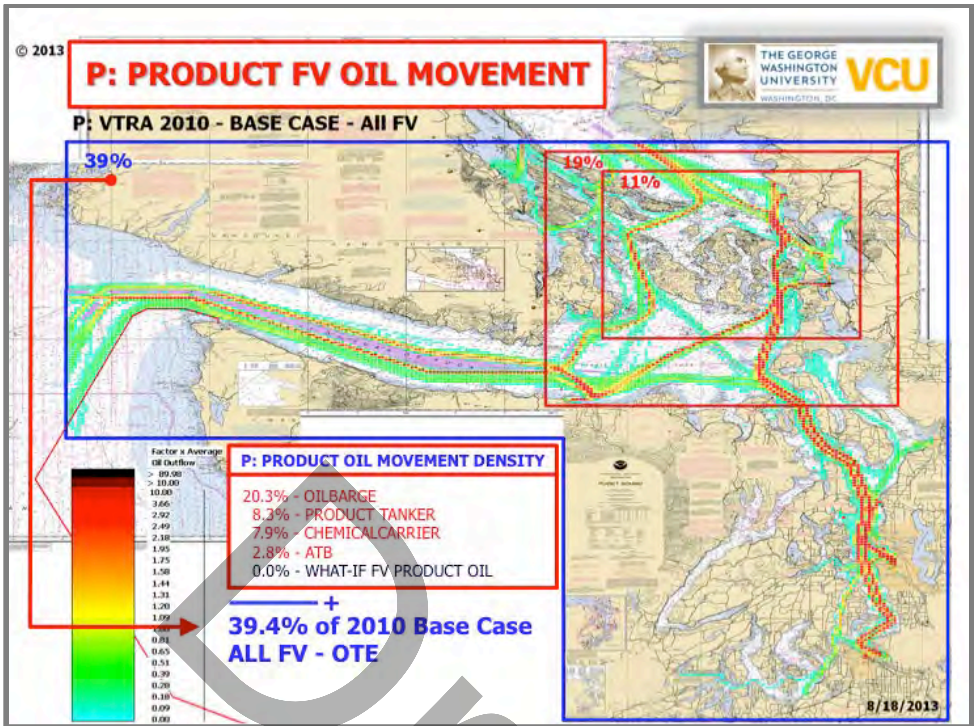


Figure 37. The product oil movement density for all focus vessels.

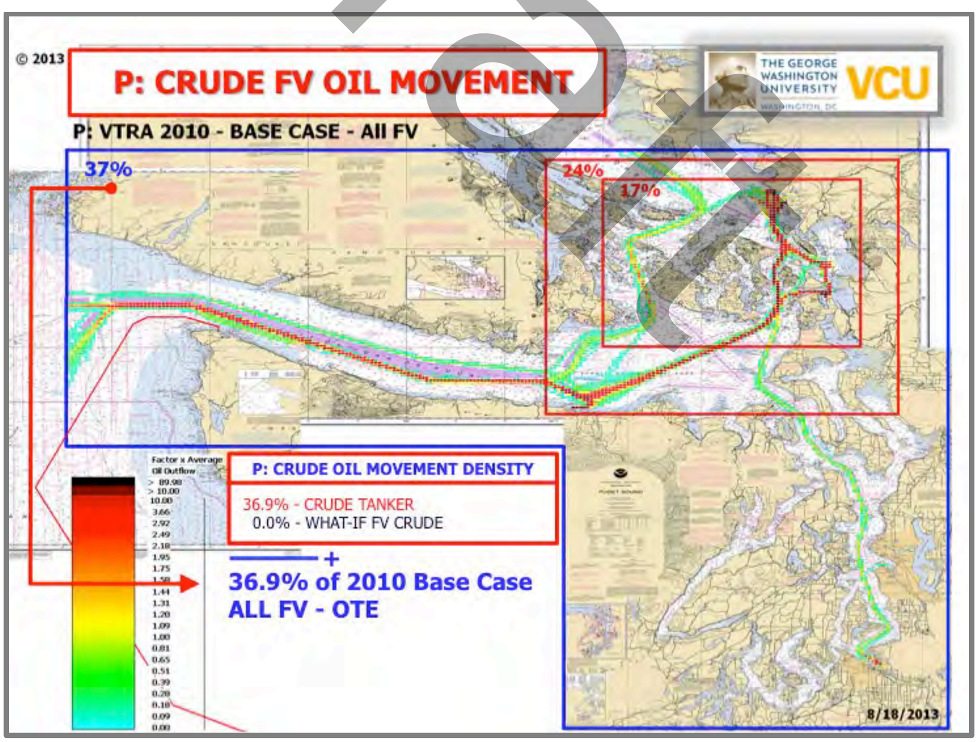


Figure 38. The crude oil movement density for all focus vessels.

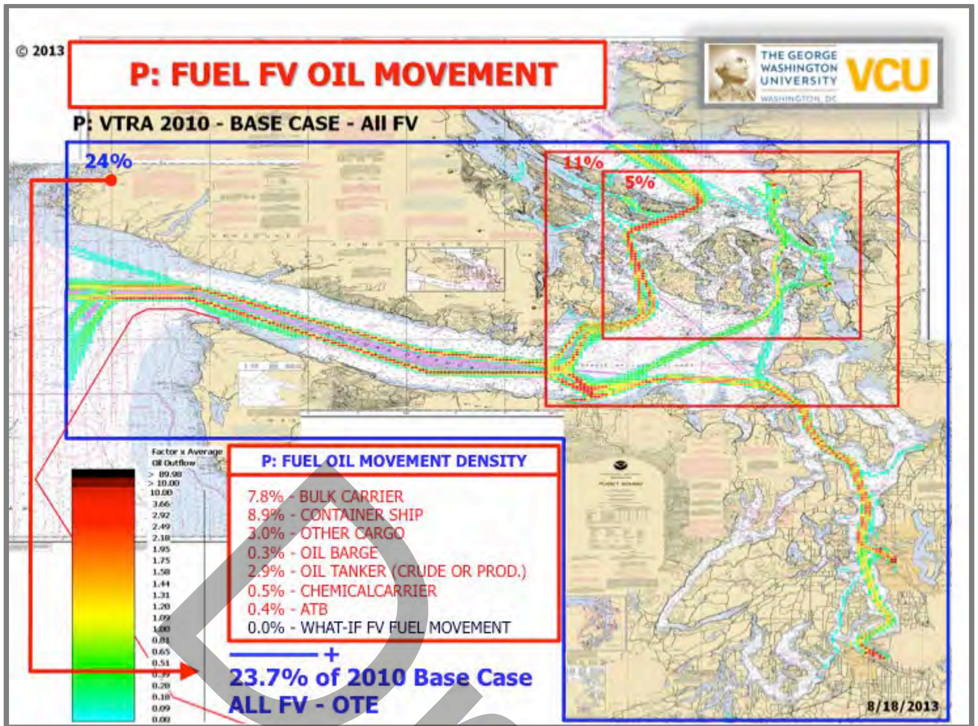


Figure 39. The fuel oil movement density for all focus vessels.

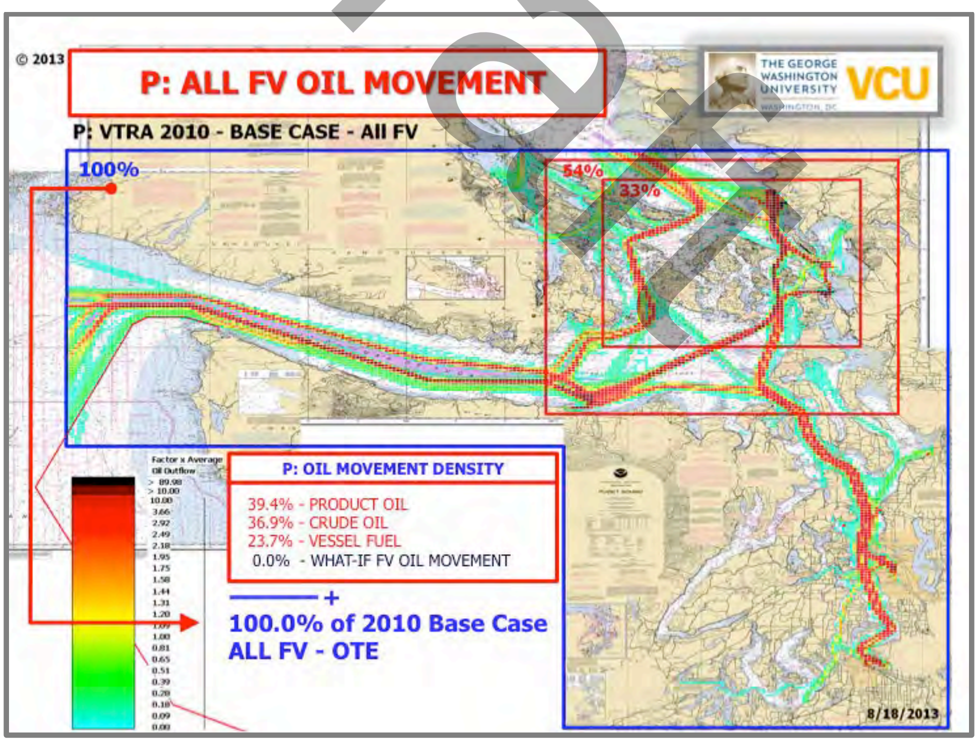


Figure 40. The total oil movement density for all focus vessels.

6. ACCIDENT FREQUENCY AND OIL OUTFLOW RESULTS FOR VTRA 2010 BASE CASE

Figure 1 shows the accident causal chain, with the situations in which an accident can occur, the incident that causes the accident, the accident itself, and the consequences of the accident. We call the situations in which an accident could occur an accident exposure. For each accident exposure, the incident and accident probability models are used to calculate the POTENTIAL accident frequency. This is not a prediction of an accident, but shows a relative propensity that an accident could occur in one accident exposure versus another or the relative propensity for one type of accident versus another. The accident exposure and the POTENTIAL accident frequency are then combined with the oil outflow model to calculate the POTENTIAL oil outflow.

Overall Accident and Oil Outflow Results

Figure 41 shows the accident exposure (A), the POTENTIAL accident frequency (B), the POTENTIAL accident cargo oil loss (C), and the POTENTIAL accident fuel oil loss (D) for each accident type. Figure 41A shows that more power grounding accident exposures are counted in the 2010 simulation than other accident types, with drift grounding accident exposures next as the vessel drifts assure after losing power, and collision accident exposures next as two vessels must interact to be counted. Allisions have the lowest exposure as they only occur as the vessel is near to the dock.

All exposures do not have the same potential for an accident, however. Figure 41B shows that collisions have a higher POTENTIAL accident frequency than either grounding even though the collision accident exposure is lower. The accident probability varies from accident exposure to accident exposure based on the specifics of the situation in which it occurs, but on average the collision exposures have a higher potential to result in an accident than the grounding exposures. Powered groundings have the next highest potential. In fact, collisions and powered groundings together comprise 79.7% of the POTENTIAL accident frequency.

Again, not all accidents have the same potential for oil outflow. While collisions have a higher POTENTIAL accident frequency, powered groundings have the highest POTENTIAL accident cargo oil loss (Figure 41C) and the highest POTENTIAL accident fuel oil loss (Figure 41D).

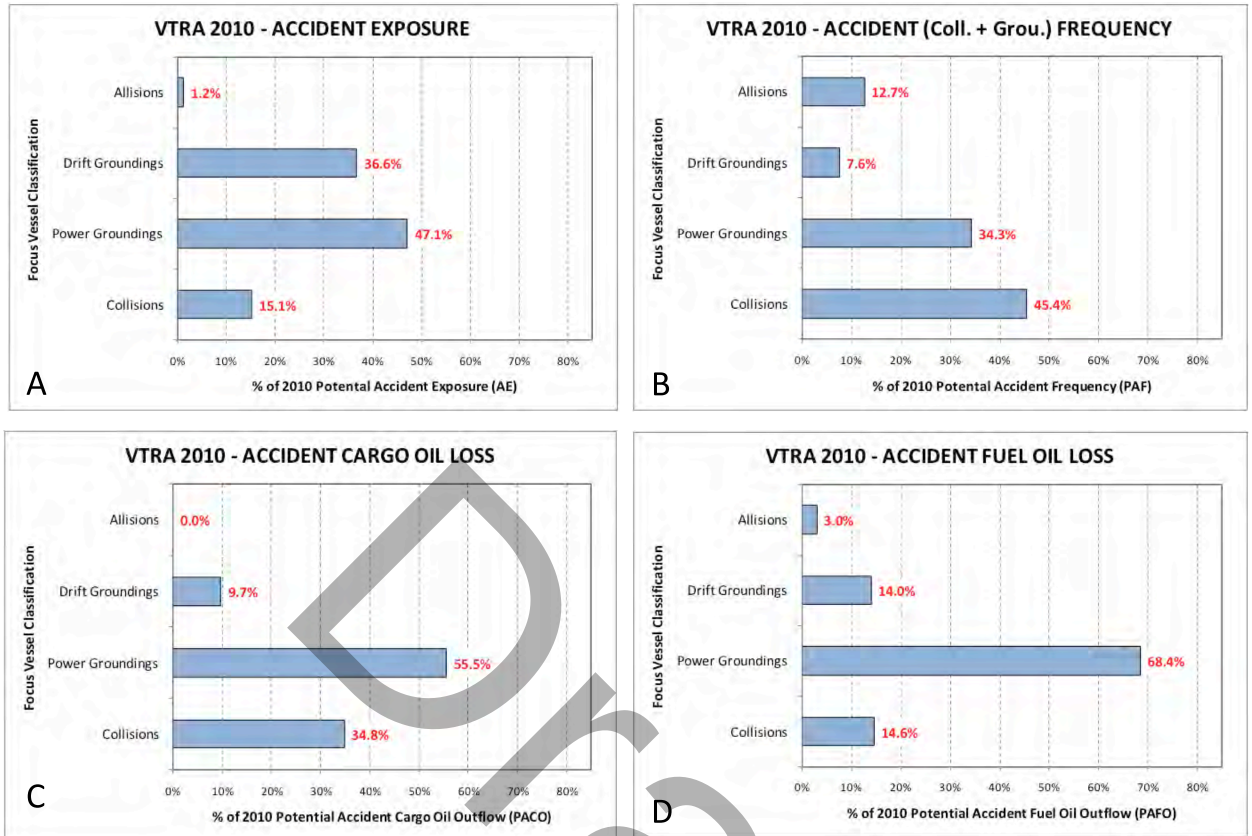


Figure 41. Accident exposure (A), accident frequency (B), cargo oil loss (C), and fuel oil loss (D) contributions by accident type..

Accident and Oil Outflow Results by Focus Vessel Type

Figure 42 breaks down the POTENTIAL accident frequencies by the type of focus vessels that has the initiating incident. This is the first figure to have an accidents-per-year scale. However, this is again not a prediction of a number of accidents each year, but a relative propensity for each accident type involving each focus vessel type. The highest potential is for collisions involving oil barges, with as much collision potential as tankers, chemical carriers, and cargo vessels combined. Powered grounding potential is more spread across oil barges and cargo vessels.

Figure 43 breaks down the POTENTIAL oil loss by the type of focus vessels that has the initiating incident. This figure has a cubic-meters-per-year scale. Again this is not a prediction of an amount of oil outflow each year, but a relative propensity for oil outflow for each accident type involving each focus vessel type. Clearly, tankers have the highest potential as they carry the highest volume of cargo. However, container vessel powered groundings have the next most contribution as they carry the most fuel oil. Oil barges do

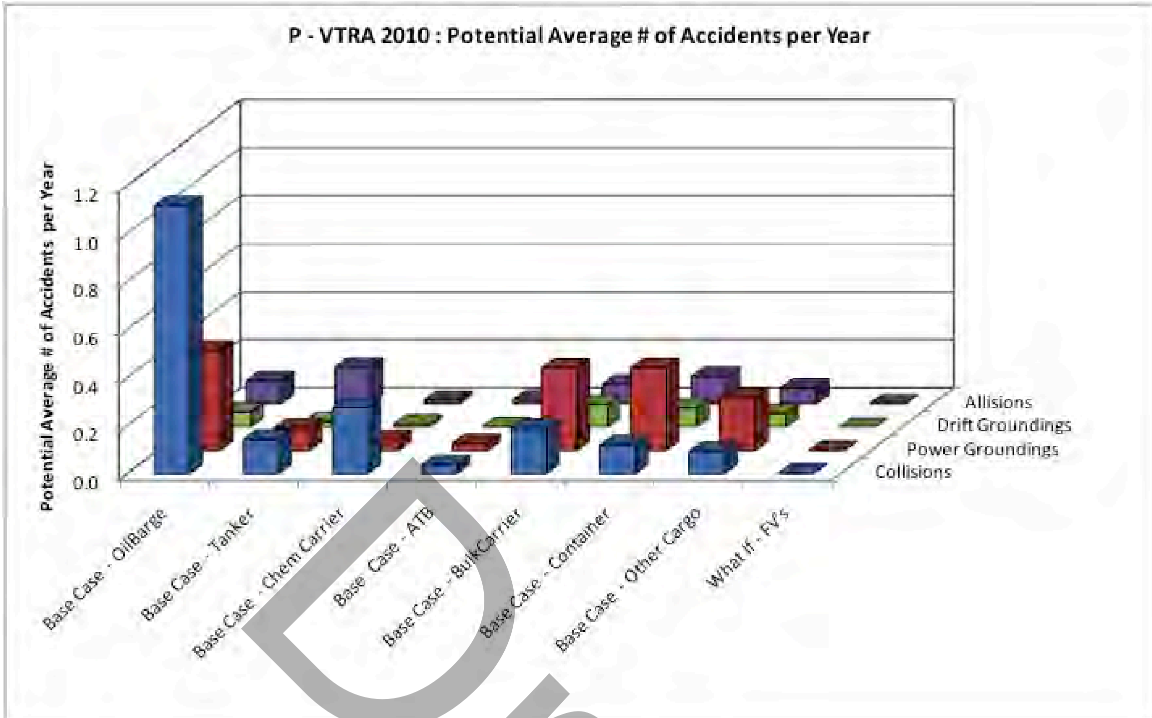


Figure 42. The potential accident frequency by accident type and focus vessel type.

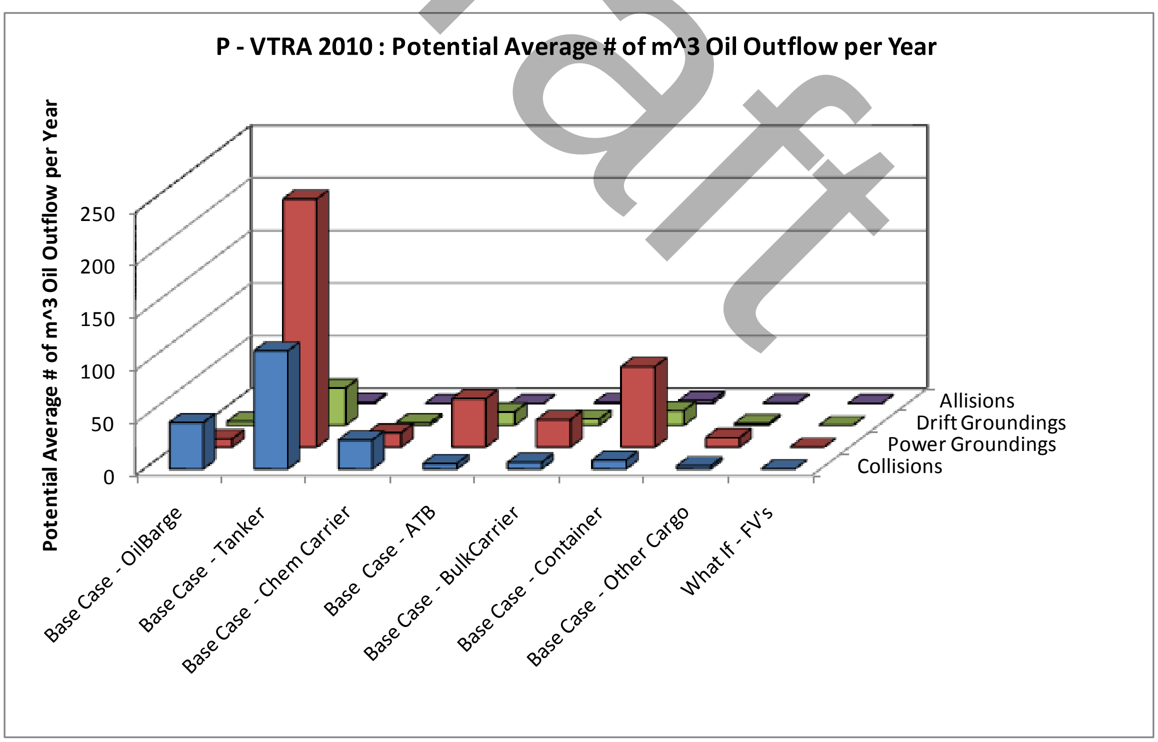


Figure 43. The potential oil loss by accident type and focus vessel type.

not have the same contribution to POTENTIAL oil loss as they do to POTENTIAL accident frequency, as they do not carry as much cargo or fuel oil.

Geographic Profiles of Accident and Oil Outflow Results

Figure 44 through Figure 49 show the same progression of accident exposure, POTENTIAL accident frequency, and POTENTIAL oil loss, but as geographic profiles. Figure 44, Figure 45 and Figure 46 show the geographic profiles of collision exposure, POTENTIAL collision frequency, and POTENTIAL collision oil loss respectively. Figure 47, Figure 48 and Figure 49 show the geographic profiles of grounding exposure, POTENTIAL grounding frequency, and POTENTIAL grounding oil loss respectively.

These figures demonstrate the importance of thinking about all phases of the accident event chain depicted in Figure 1. Figure 44 shows that there is exposure to collisions in the Straits of Juan de Fuca, while Figure 45 shows that exposure does not lead to as much POTENTIAL collision frequency as other areas with exposure. In fact, the POTENTIAL collision frequency appears in Haro Strait/Boundary Pass, Rosario Strait, and the Puget Sound. Comparing these figures to Figure 46, we can see that while the area around the Pilot Station does not have a relatively high POTENTIAL collision frequency it does have a concentration of POTENTIAL collision oil loss due to the size of the vessels involved. Rosario Strait, Guemes Channel, and Haro Strait all have concentrations of POTENTIAL collision oil loss. In fact, the inner red box contains 67% of the POTENTIAL collision frequency and 53% of the POTENTIAL collision oil loss. Similarly, the outer red box contains 83% of the POTENTIAL collision frequency and 70% of the POTENTIAL collision oil loss. In Rosario Strait and Guemes Channel, the vessels involved are oil tankers (with larger oil cargos) and ferries and other vessels that are large enough to penetrate the hull, but are not restricted by the one-way zone.

A similar effect is seen in Figure 47 through Figure 49. Again there is exposure to grounding along the shore of the Straits of Juan de Fuca, but there is not much POTENTIAL grounding frequency as the time to shore is relatively long in this area. The relatively more significant POTENTIAL grounding frequency and POTENTIAL grounding oil loss are in the red boxes. The inner red box contains 41% of the POTENTIAL collision frequency and 58% of the POENTIAL collision oil loss. Similarly, the outer red box contains 79% of the POTENTIAL collision frequency and 61% of the POTENTIAL collision oil loss.

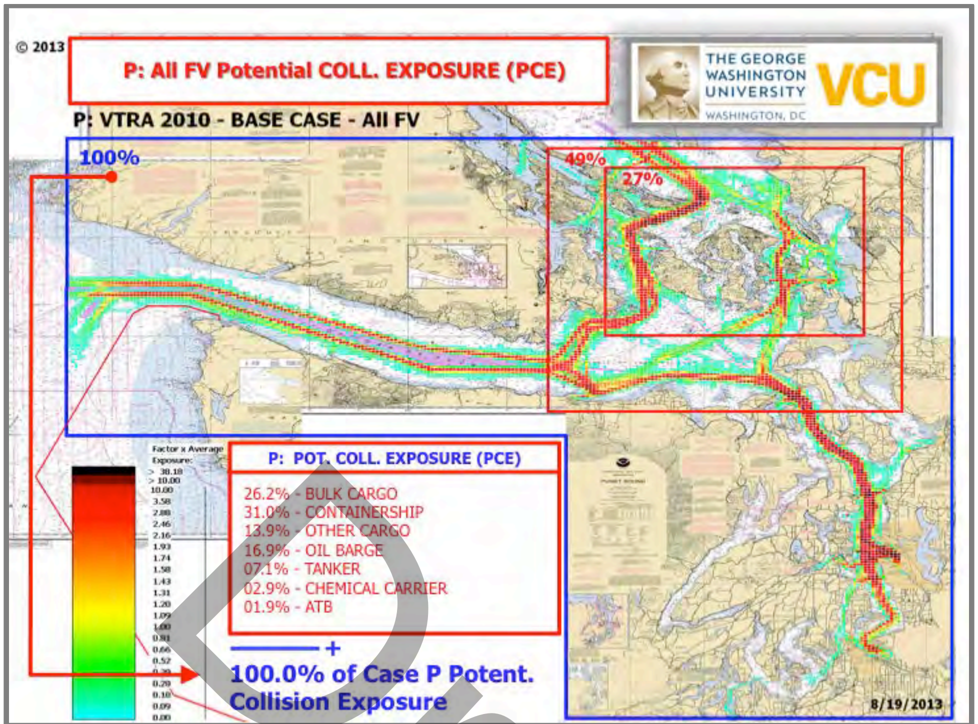


Figure 44. The geographic profile of the collision exposure.

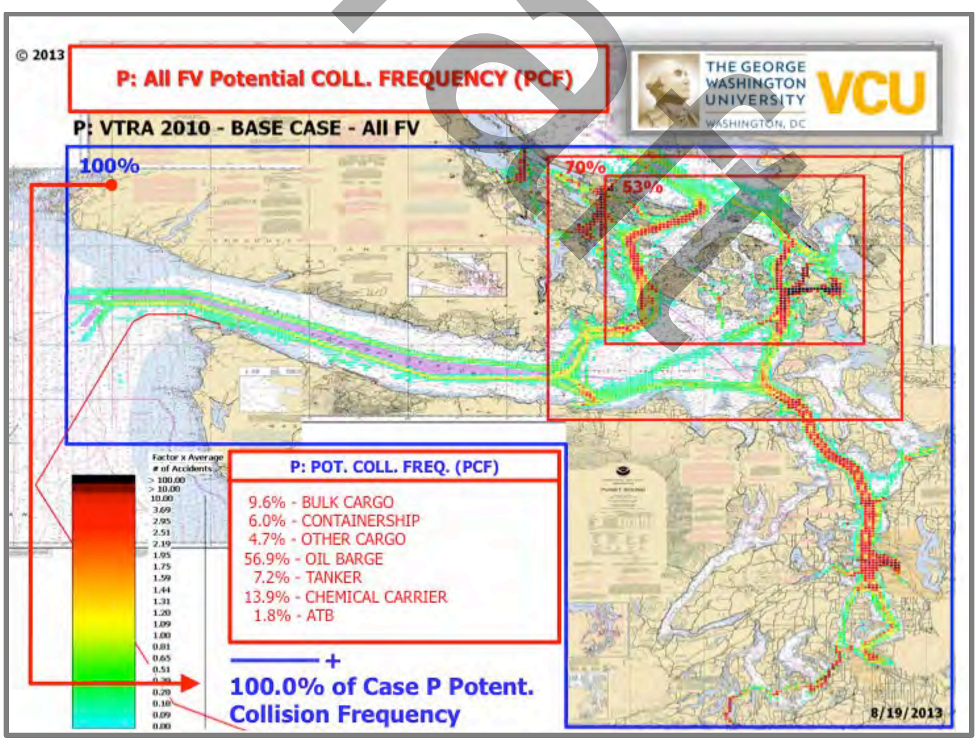


Figure 45. The geographic profile of the POTENTIAL collision frequency.

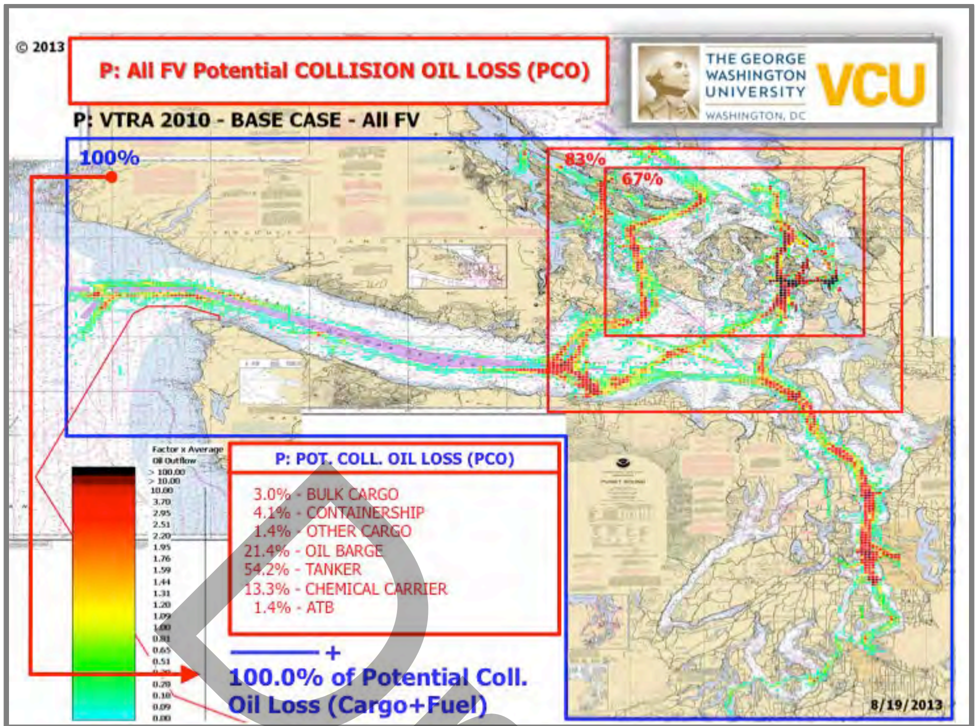


Figure 46. The geographic profile of the POTENTIAL collision oil outflow.

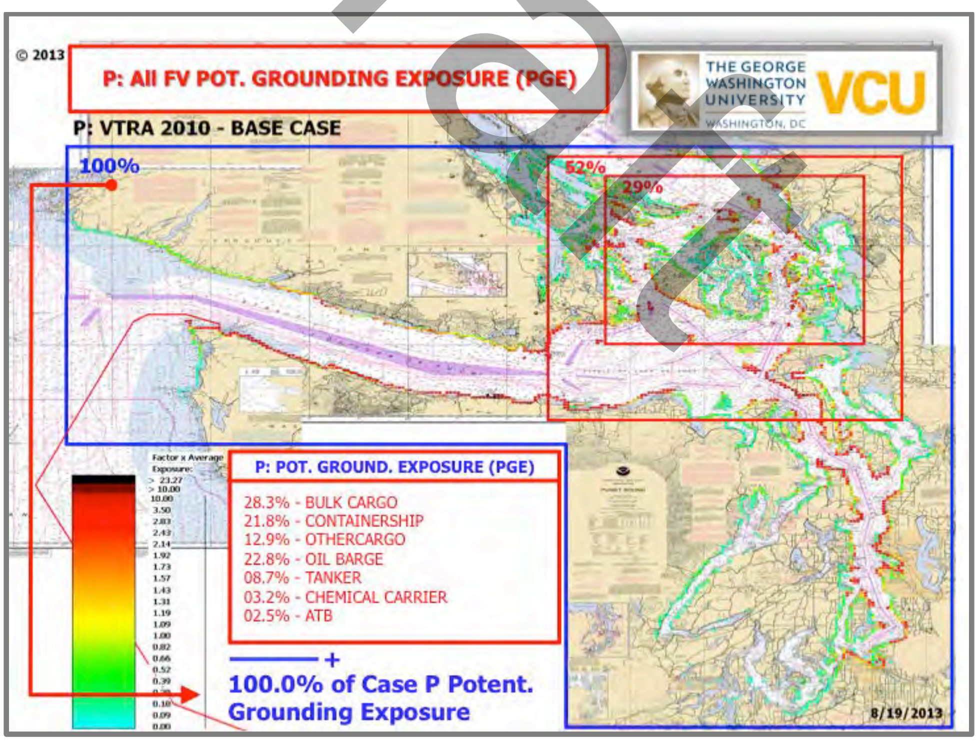


Figure 47. The geographic profile of the grounding exposure.

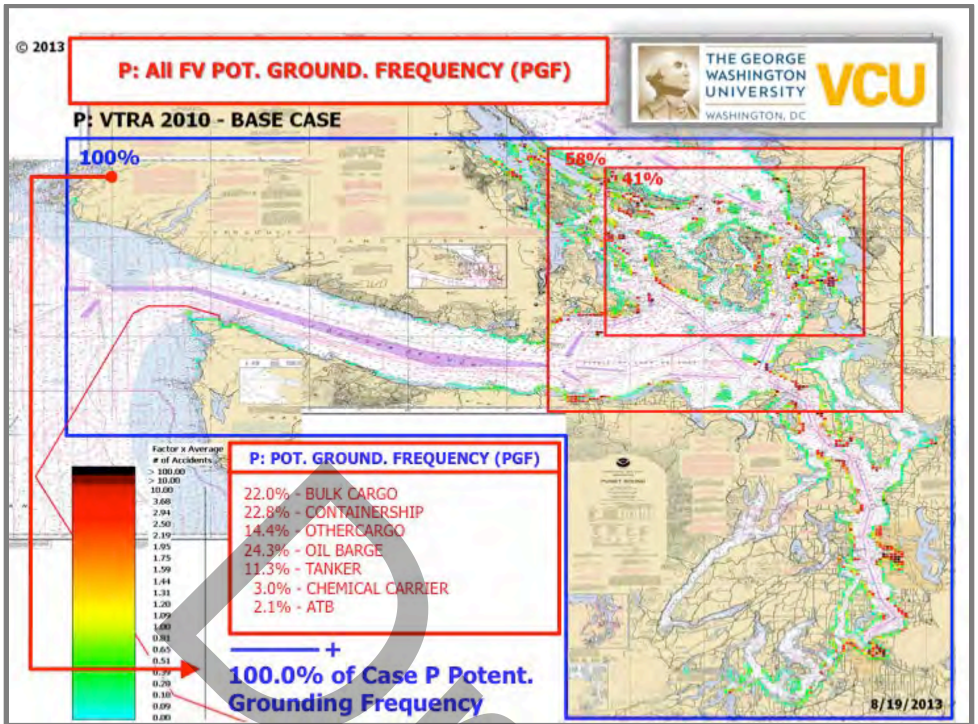


Figure 48. The geographic profile of the POTENTIAL grounding frequency.

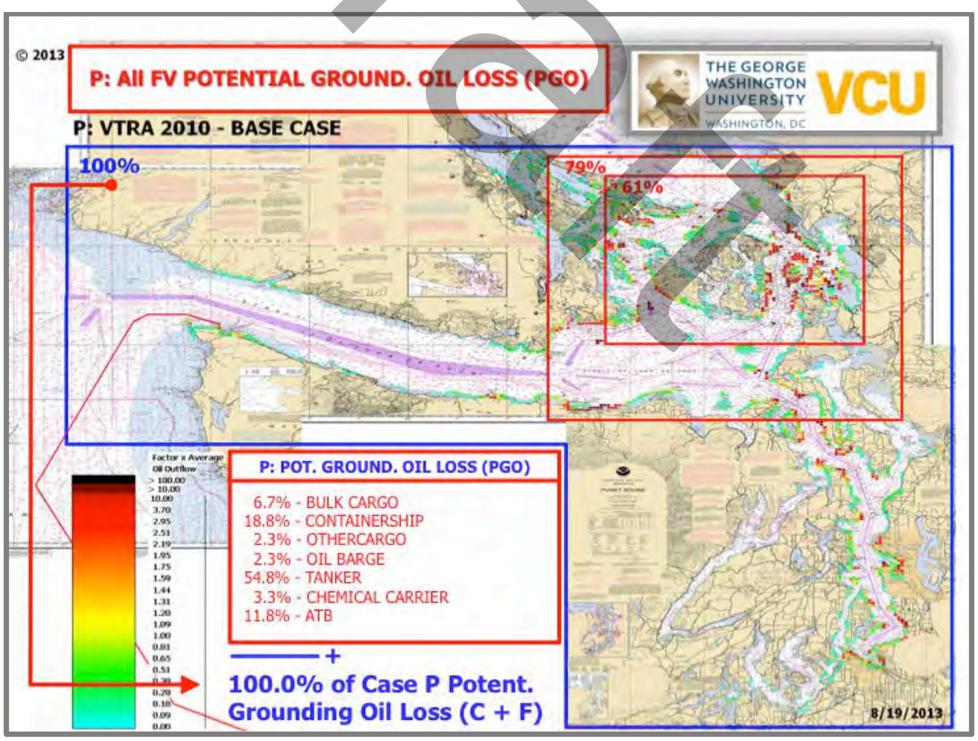


Figure 49. The geographic profile of the POTENTIAL grounding oil outflow.

7. WHAT-IF SCENARIOS

This study does not attempt to predict the future of vessel traffic in the study area. Such predictions are often made based on observable trends in the traffic levels or projections of potential economic changes and their possible impacts on traffic levels. As we have seen in the last decade, predicting global economic changes is difficult and unpredictable economic changes can lead to unforeseen changes in traffic levels and reversals in previously observed trends. This means predictions can prove to be inaccurate, particularly in the medium to long term.

Modeling the What-If Scenarios

In this study, the Steering Committee chose to model only the traffic level impacts of planned expansion and construction projects that were in the permitting process. Each planned project forms a What-If scenario and What-If vessels are added to the simulation of the 2010 Base Case year. Four What-If scenarios were modeled in the study:

- The Gateway bulk carrier terminal
- The Trans-Mountain pipeline expansion
- The combination of proposed changes at Delta Port
- All three of above scenarios operating at the same time

The steering committee determined that the following numbers of What-If vessels would be added to the 2010 Base Case simulation in each scenario:

- The Gateway bulk carrier terminal
    - 487 bulk carriers (318 Panama class and 169 Cape Max class)
- The Trans-Mountain pipeline expansion
    - 348 crude oil tankers (each 100,000 DWT)
- The combination of proposed changes at Delta Port
    - 348 bulk carriers and 67 container vessels
- All three of above scenarios operating at the same time

The next step in modeling the What-If scenarios is to determine the routes that the vessels will take in the simulation. Routes were chosen from the VTOSS 2010 data for vessels actually transited the system to each location. The only change to an actual route that was made was for the Gateway routes as the coal terminal is not yet in operations, so routes that went close to the planned terminal were chosen and modified to the correct location. Figures Figure 50, Figure 51, and Figure 52 show the What-If vessel routes for the Gateway case, the Trans-Mountain Pipeline Expansion case, and the Delta Port case respectively.

Adding this number of additional vessels will also lead to additional bunkering operations in the study area. The steering committee determined that 47% of Gateway vessels would bunker on the inbound transit and as a first analysis the bunkering would take place at the

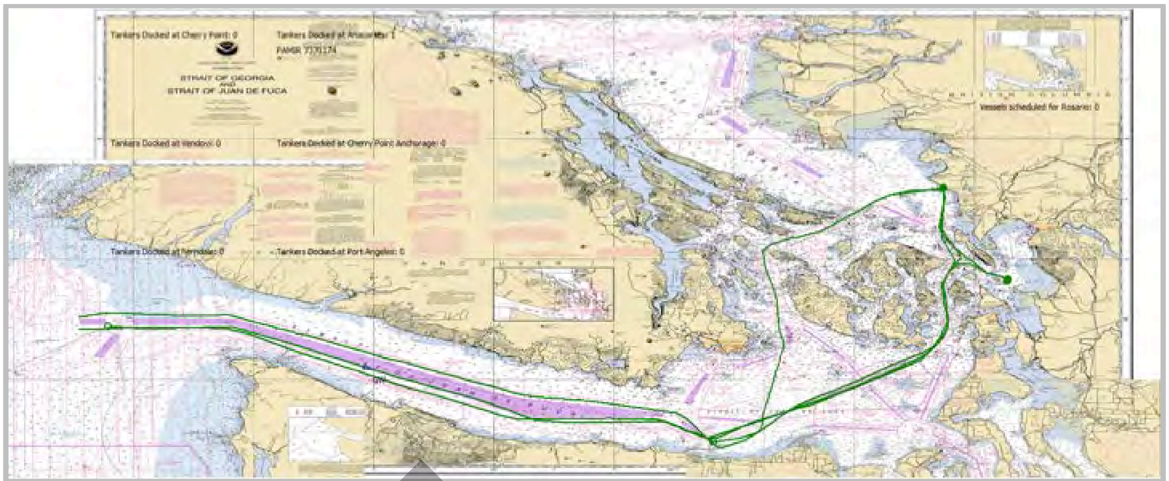


Figure 50. The routes used for the What-If vessels in the Gateway case.

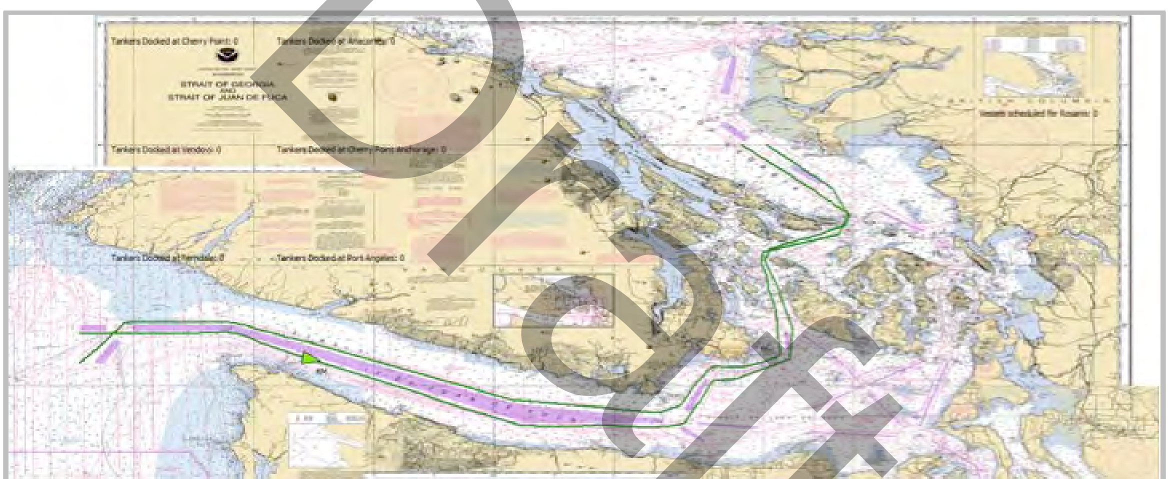


Figure 51. The routes used for the What-If vessels in the Trans-Mountain Pipeline Expansion case.

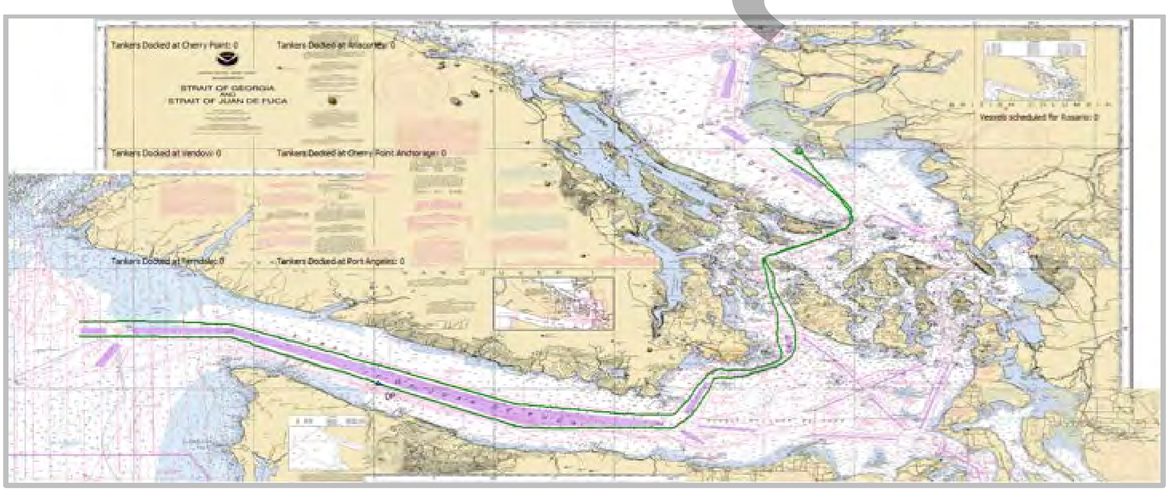


Figure 52. The routes used for the What-If vessels in the Delta Port case.

Vendovi anchorage. The bunkering tug would transit from Seattle to Vendovi anchorage laden and then return to Seattle. The steering committee decided that bunkering for the Trans-Mountain pipeline expansion scenario and the combination of proposed changes at Delta Port would take place out of the study area, but would require additional bunkering supply transits, 34 for the Delta Port bulk carriers, 6 for the Delta Port container vessels, and 21 for the Trans-Mountain pipeline expansion oil tankers. As a first analysis, the bunkering supply transits are modeled as transiting from the Cherry Point area and out of the study area to the north. Figure 53 shows the bunkering tug routes used for the what-of scenarios.

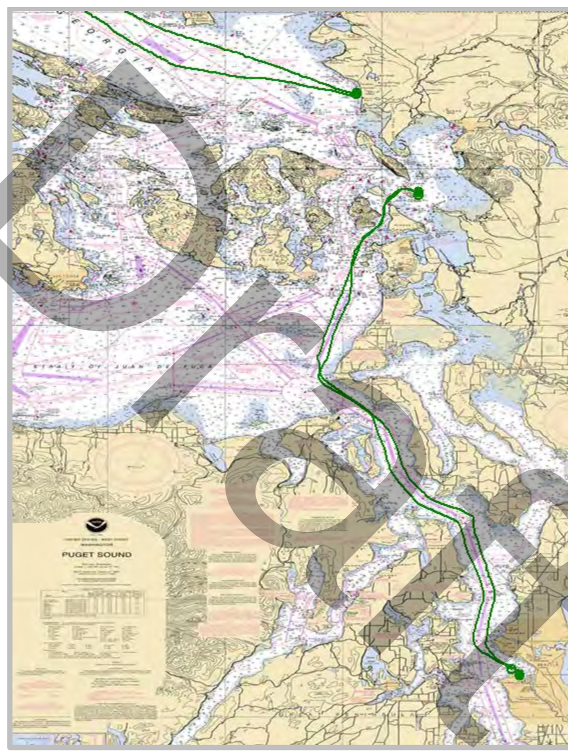


Figure 53. The tug routes used for additional bunkering in the What-If scenarios.

The final decision concerning modeling What-If scenarios is the arrival patterns. While knowing the count of the number of vessels of each type calling at a given dock or port is informative, to simulate the vessels over time one must know the time between one such vessel arriving in the system and the next. The variability in these inter-arrival times changes from destination to destination and from vessel type to vessel type. The variability in inter-arrival times for each of the projects in the What-If scenarios will not be known until the projects have been underway for a period of time. In modeling, if the specifics of a situation are unknown and there is no data upon which to base modeling decisions, the simplest assumption is preferable. In this case, the simplest assumption is to assume that the inter-arrival times are all equal and that the vessels arrive at a constant rate. This assumption can be changed in later analysis, but it is a reasonable approach to start modeling the What-If scenarios.

Summary of What-If Scenarios Results

Adding What-If vessels to the 2010 Base Case can have multiple effects. First, it directly increases the vessel exposure time and the oil exposure time. This means the What-If vessel will add to the collision and grounding exposure. With additional exposure the What-If vessels can have a triggering incident and so add to the POTENTIAL collision and grounding frequencies. Second, while the What-If vessel interacts with another vessel, the other vessel also may have a triggering incident and so there is another source of increase in the POTENTIAL collision and grounding frequencies. This source of increase is attributed to the vessel having the triggering incident, but would not be there without adding the What-If vessel to the simulation. Third, the What-If vessel passes through the one-way zone at Rosario Strait and the exclusion zone at Boundary Pass, which can cause delays or slow down other vessels that are part of the original 2010 Base Case. This changes the 2010 Base Case vessel's transit through the system and can either increase or decrease their exposure and hence collision and grounding POTENTIAL. As an example, Figure 54 shows two screenshots that occurred within a simulated hour of one another in a What-If simulation. The figure shows one northbound (left) and one southbound (right) tanker interacting with a fleet of fishing vessels returning to port at the end of the day. If the tankers transits had occurred two hours earlier (as occurred in the Base Case 2010 simulation) then the interactions would not have occurred. These interactions occurred because of a change in the timing of tankers and lead to an increased exposure and so an increased POTENTIAL for collision that is not caused directly by a What-If vessel. Thus, there are direct and indirect effects of adding What-If vessels to the 2010 Base Case simulation.

Figure 55 shows three graphs. Each shows the percentage change in a given simulation output from the 2010 Base Case results. The change is shown for each What-If scenario and for completeness the 2010 Base Case is shown as a 0% change from itself. The change is shown as a bar graph, but the actual percentage change is also shown in text. The top graph in Figure 55 shows the change in vessel time exposure, the middle graph shows the change in POTENTIAL collision frequency, and the bottom graph shows the change in POTENTIAL grounding frequency. One can observe in Figure 55 that the changes in both POTENTIAL collision frequency and POTENTIAL grounding frequency are driven by the changes in exposure time. The changes in POTENTIAL collision frequency are larger than the changes in POTENTIAL grounding frequency.

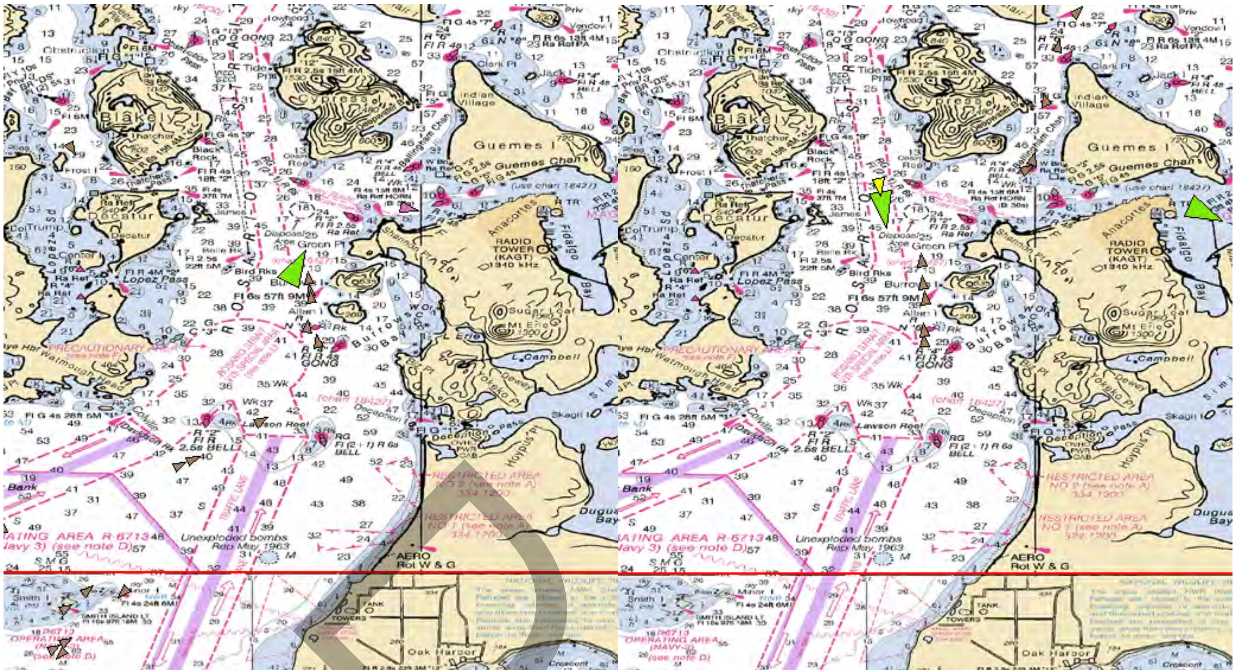


Figure 54. An indirect effect of a What-If scenario – the change in timing of the tanker transits causes two tankers to interact with a fishing fleet returning to port at the end of the day.

Figure 56 shows a similar set of graphs as Figure 57, but this time showing the changes in fuel oil time exposure in the top graph, POTENTIAL collision fuel oil loss in the middle graph, and POTENTIAL grounding fuel oil loss in the bottom graph. The exposure changes for fuel oil are not exactly the same as vessel time exposure changes in value (as different vessel types carry different amounts of fuel), the overall pattern across the What-If scenarios, however, is the same and the ensuing changes in POTENTIAL collision and grounding fuel loss display a similar pattern.

Figure 57 shows a similar set of graphs as Figure 55 and Figure 56, but this time showing the changes in cargo oil time exposure in the top graph, POTENTIAL collision cargo oil loss in the middle graph, and POTENTIAL grounding cargo oil loss in the bottom graph. The patterns in exposure changes shown in Figure 57 are not the same as in Figure 55 and Figure 56 as the bulk carriers and container vessels in Gateway and Delta Port What-If scenarios do not carry cargo oil. Thus, the Trans Mountain Pipeline Expansion project leads to the greatest increases in cargo oil time exposure. This leads to the higher increases in POTENTIAL collision cargo oil loss and POTENTIAL grounding cargo oil loss. However, there is another interesting result as the change in POTENTIAL collision cargo oil loss for the Gateway scenario is not proportional to the change in cargo oil time exposure. The additional What-If bulk carriers in the Gateway scenario do not carry cargo oil. There is only a modest increase in POTENTIAL collision frequency for the Gateway scenario in Figure 55, so this result must be cause by a change in the mix of vessels interacting with

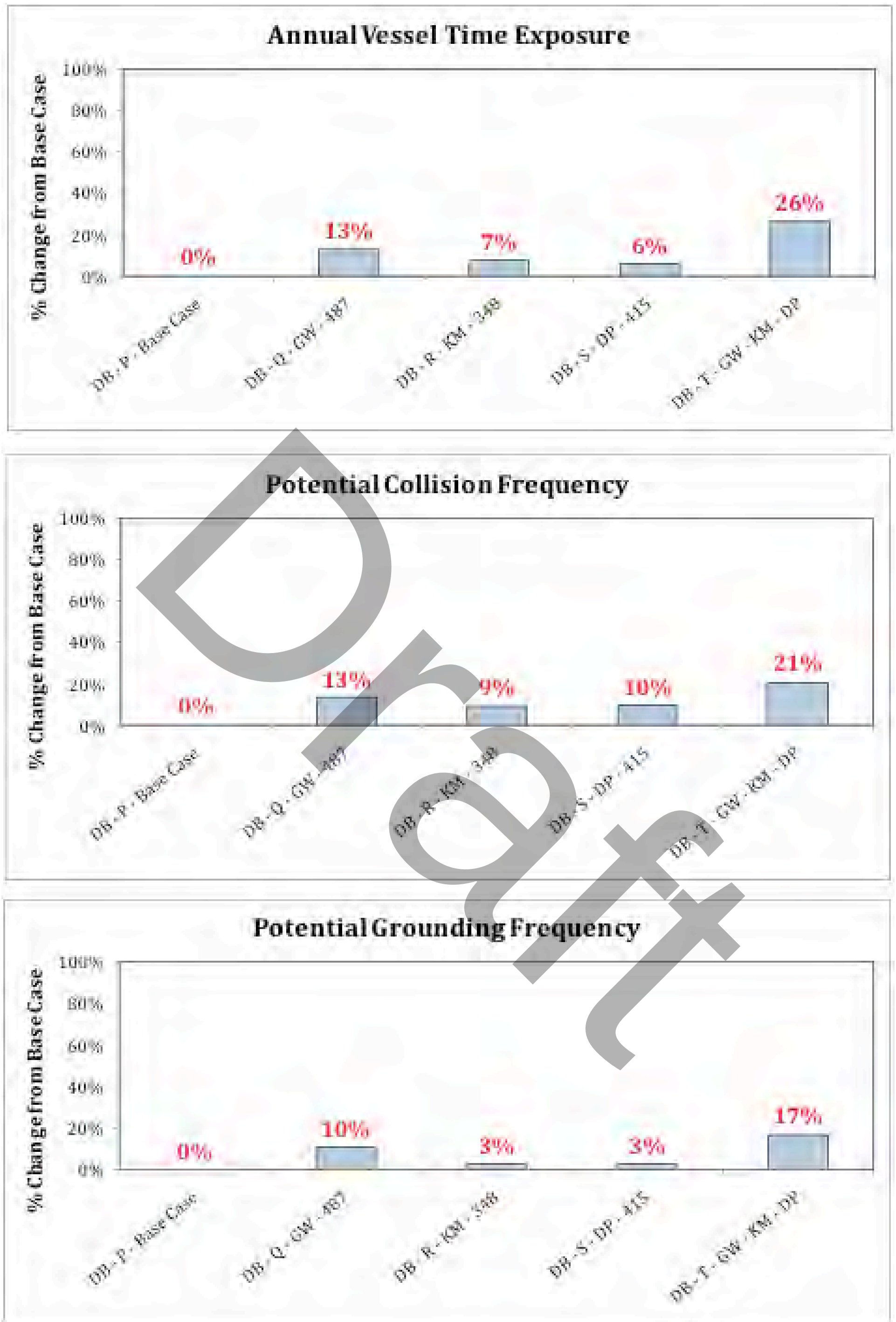


Figure 55. An overview comparison of the changes from the 2010 base case for each What-If scenario in terms of vessel time of exposure, POTENTIAL collision frequency, and POTENTIAL grounding frequency.

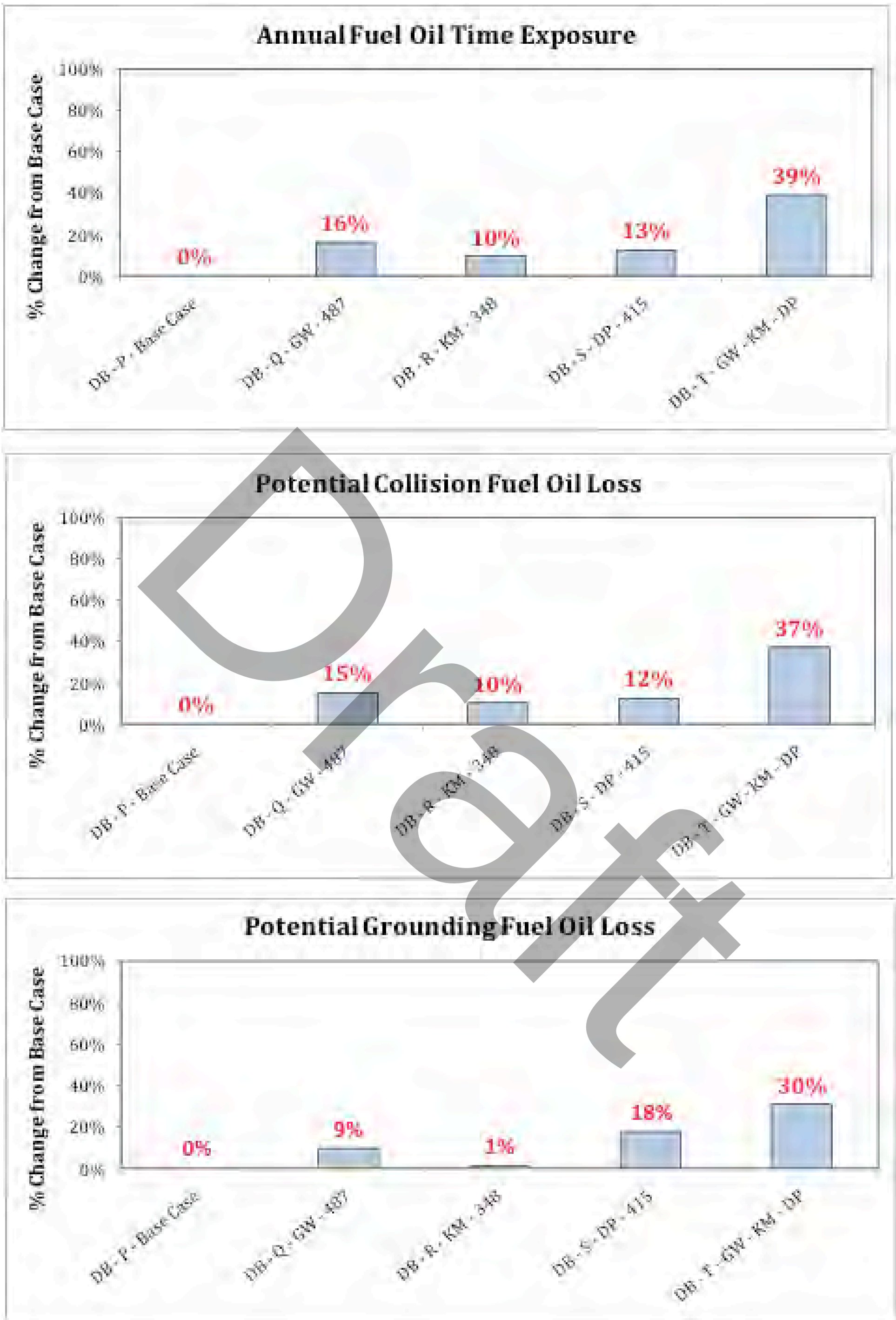


Figure 56. An overview comparison of the changes from the 2010 base case for each What-If scenario in terms of fuel oil movement exposure, POTENTIAL collision fuel oil loss, and POTENTIAL grounding fuel oil loss.

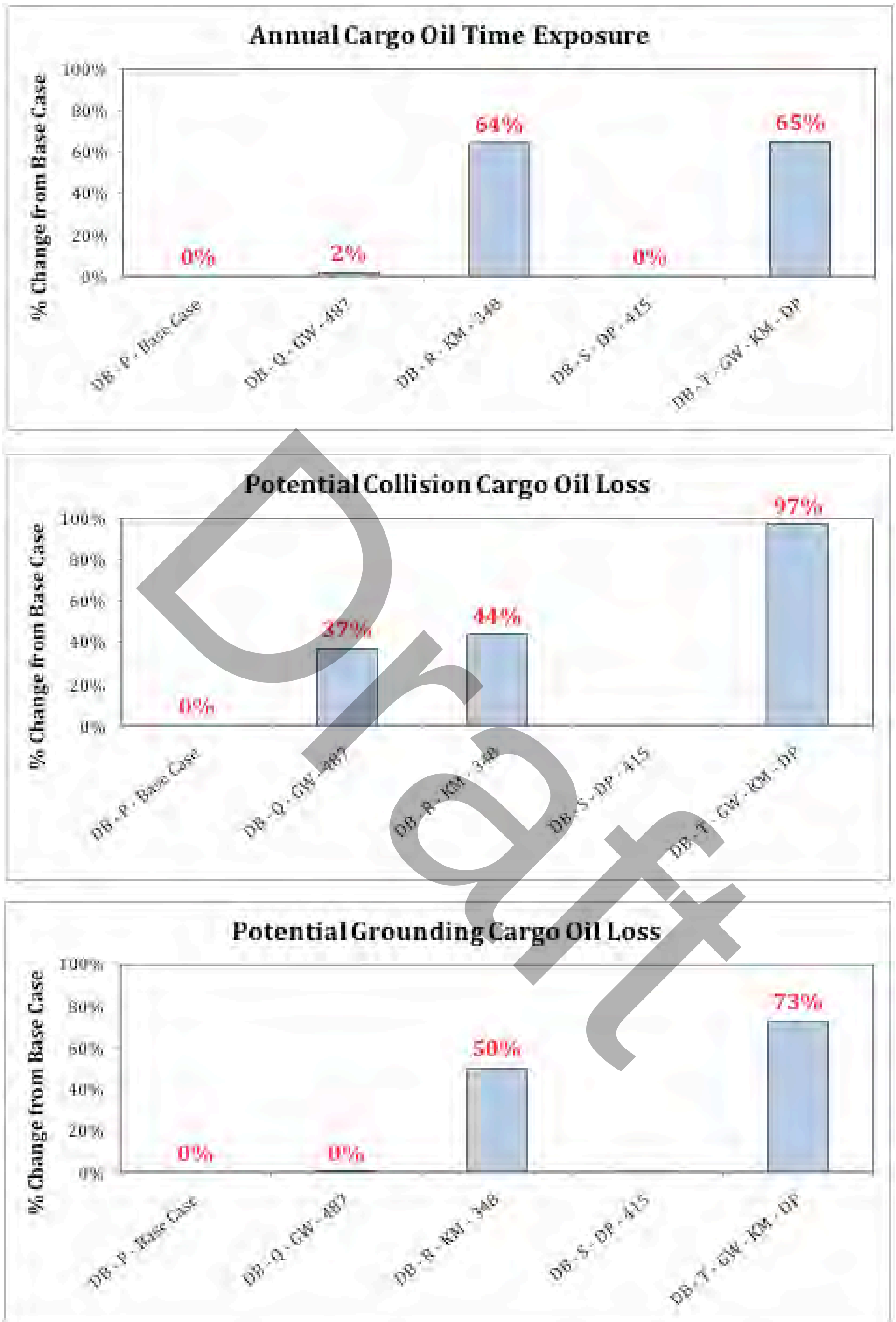


Figure 57. An overview comparison of the changes from the 2010 base case for each What-If scenario in terms of cargo oil movement exposure, POTENTIAL collision cargo oil loss, and POTENTIAL grounding cargo oil loss.

Base Case tank vessels that do carry cargo oil. One would expect that this result is driven by increased interactions between Base Case tank vessels and Gateway bulk carriers. However, the result is not so simple. There is a change in mix of interactions in the Gateway What-f Scenario with multiple types of vessels around the Rosario Strait one-way zone, including other oil tankers, ferries, fishing vessel and barges etc. This is the indirect effect discussed at the beginning of this section where the What-If vessel pass through the one-way zone at Rosario Strait, cause delays or slow down of other vessels that are part of the original 2010 Base Case, and leads to a change in the mix interacting with tank vessels. This is an interesting result and could not be found without building a detailed simulation model of the system to capture such indirect effects.

Gateway Terminal geographic profile results

Figure 58 to Figure 61 each show the geographic profile for the Gateway What-If scenario results for POTENTIAL collision frequency, POTENTIAL collision oil loss, POTENTIAL grounding frequency, and POTENTIAL grounding oil loss. Respectively. The locations of major changes from the 2010 Base Case results to the Gateway What-If scenario results are circled in black. One can observe that the major changes in terms of POTENTIAL collision frequency, POTENTIAL collision oil loss, and POTENTIAL grounding frequency are concentrated around Rosario Strait. Recall from the previous section that the changes in POTENTIAL collision and grounding frequency are proportional to the changes in vessel exposure from the additional What-If bulk carriers. However, the change in POTENTIAL collision oil loss is an indirect effect of the What-If vessels using Rosario Strait and causing more interactions of tank vessels with other vessels large enough to penetrate the hull.

Trans Mountain Pipeline geographic profile results

Figure 62 to Figure 65 show the geographic profile for the Trans-Mountain Pipeline Expansion What-If scenario results for POTENTIAL collision frequency, POTENTIAL collision oil loss, POTENTIAL grounding frequency, and POTENTIAL grounding oil loss. The locations of major changes from the 2010 Base Case results to the Trans-Mountain Pipeline Expansion What-If scenario results are circled in black. Neither the POTENTIAL collision frequency nor the POTENTIAL grounding frequency has as large a change as the POTENTIAL collision oil loss or the POTENTIAL grounding oil loss. There as not as many tankers added in this case as there are bulk carriers in the Gateway What-If scenario and apparently they do not cause as much increase in POTENTIAL accident frequency. However, their impact on POTENTIAL oil loss is more significant due to their cargo oil. The main increase is in Haro Strait and Boundary Pass, although there is an increase in POTENTIAL collision oil loss at the entrance to the Straits of Juan de Fuca.

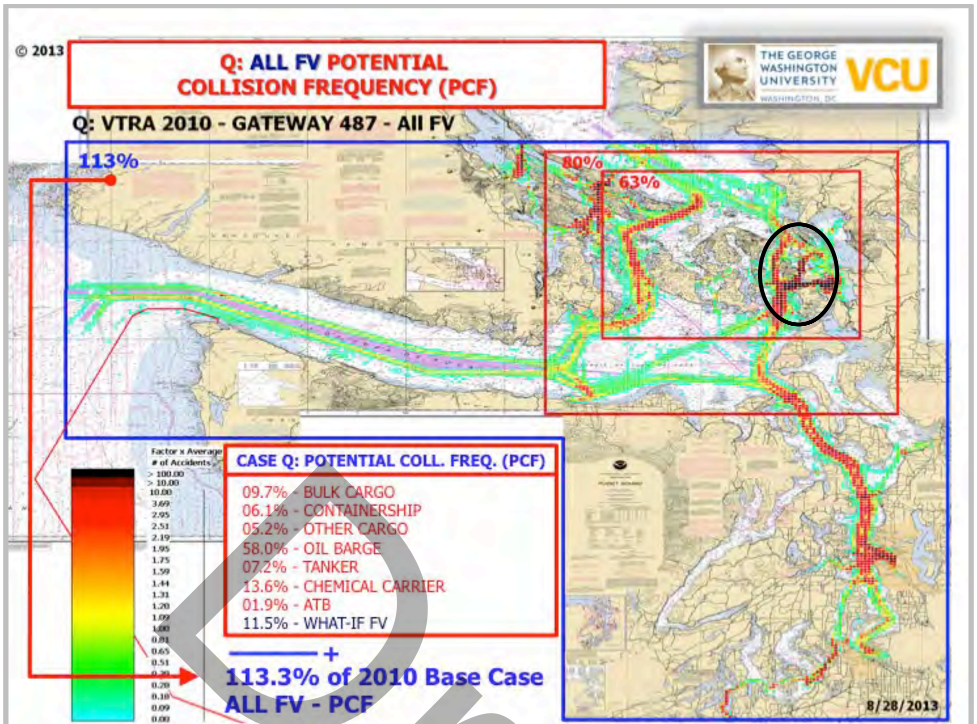


Figure 58. The geographic profiles of POTENTIAL collision frequency for the Gateway What-If scenario.

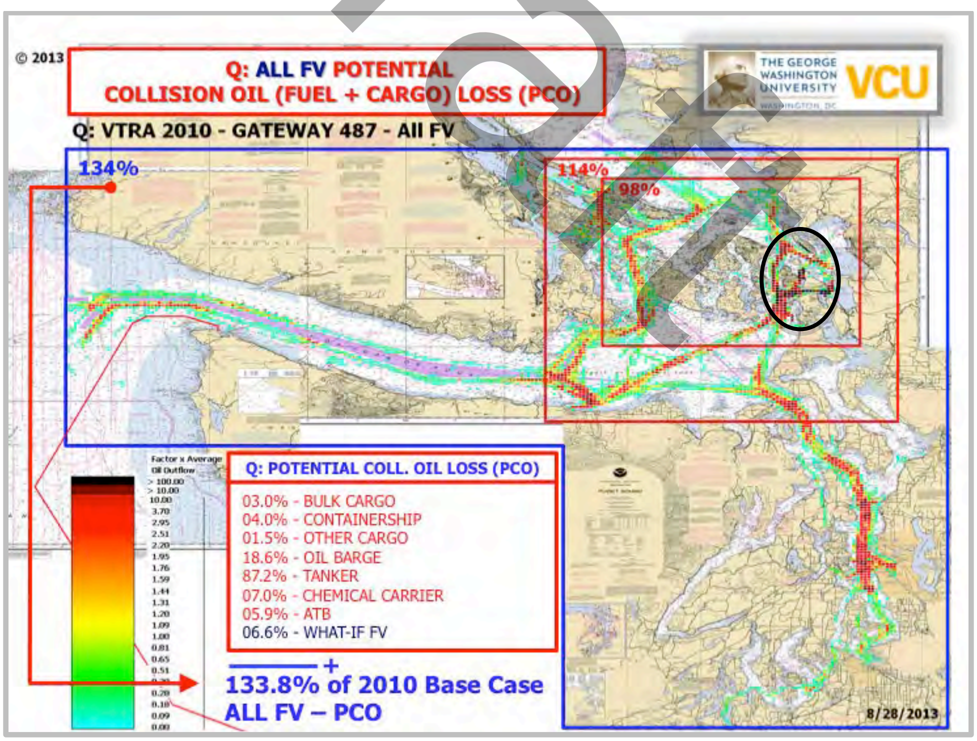


Figure 59. The geographic profiles of POTENTIAL collision oil loss for the Gateway What-If scenario.

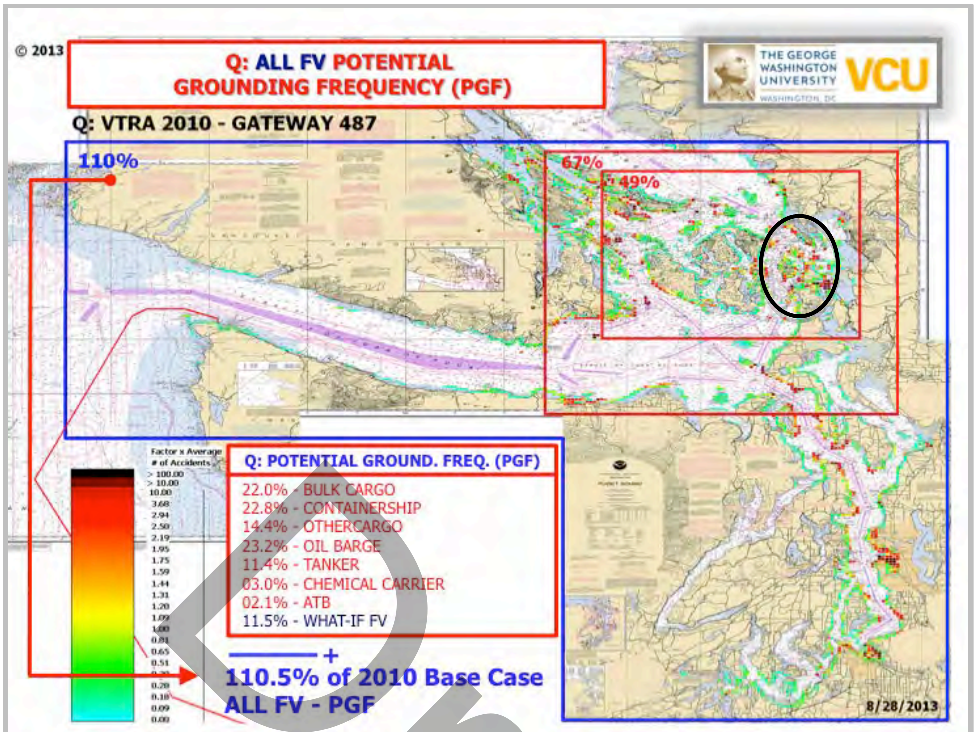


Figure 60. The geographic profiles of POTENTIAL grounding frequency for the Gateway What-If scenario.

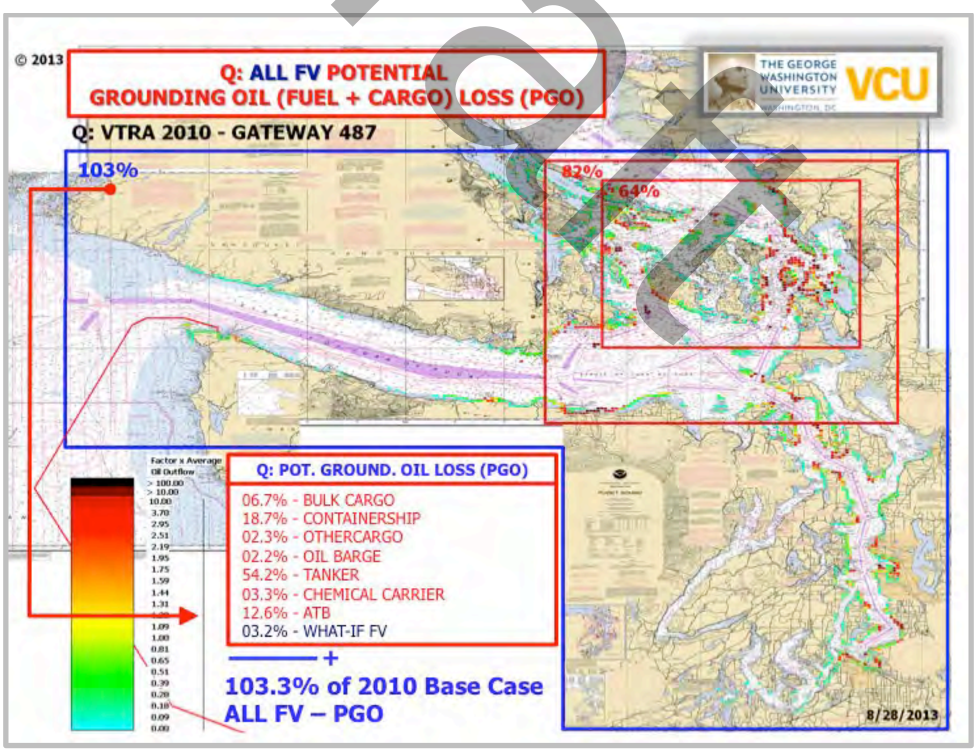


Figure 61. The geographic profiles of POTENTIAL grounding oil loss for the Gateway What-If scenario.

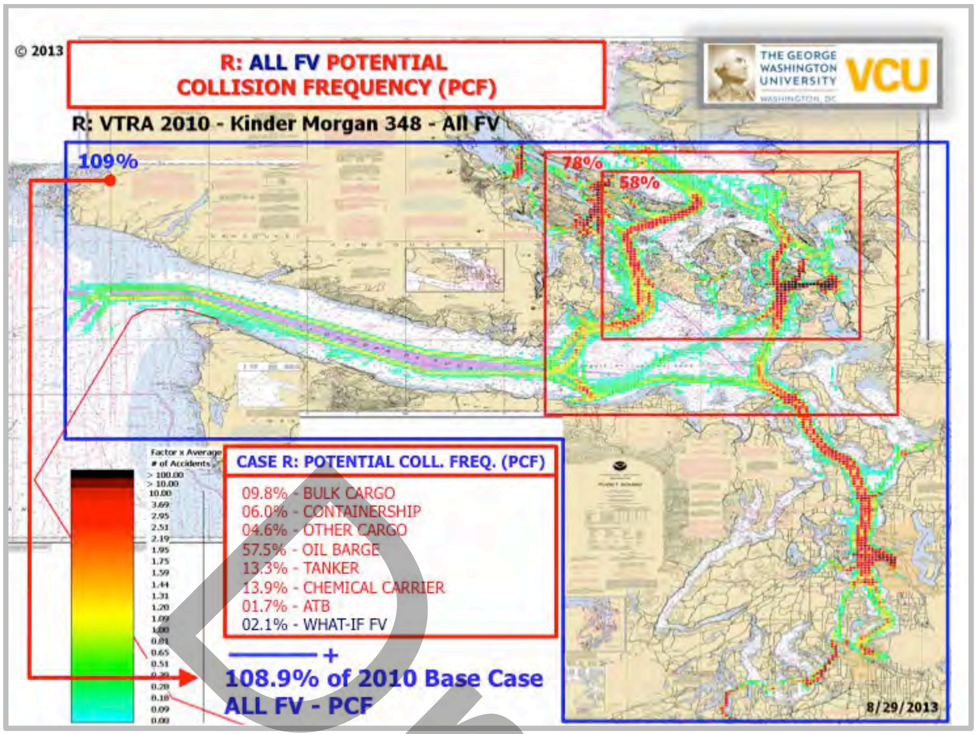


Figure 62. The geographic profiles of POTENTIAL collision frequency for the Trans-Mountain Pipeline Expansion What-If scenario.

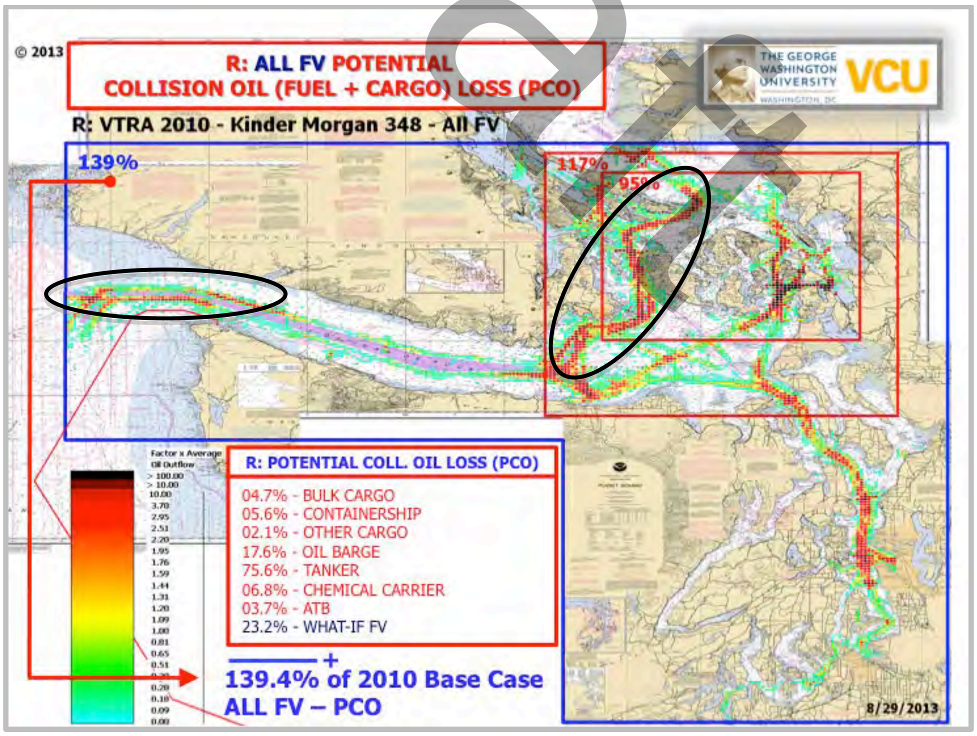


Figure 63. The geographic profiles of POTENTIAL collision oil loss fort the Trans-Mountain Pipeline Expansion What-If scenario.

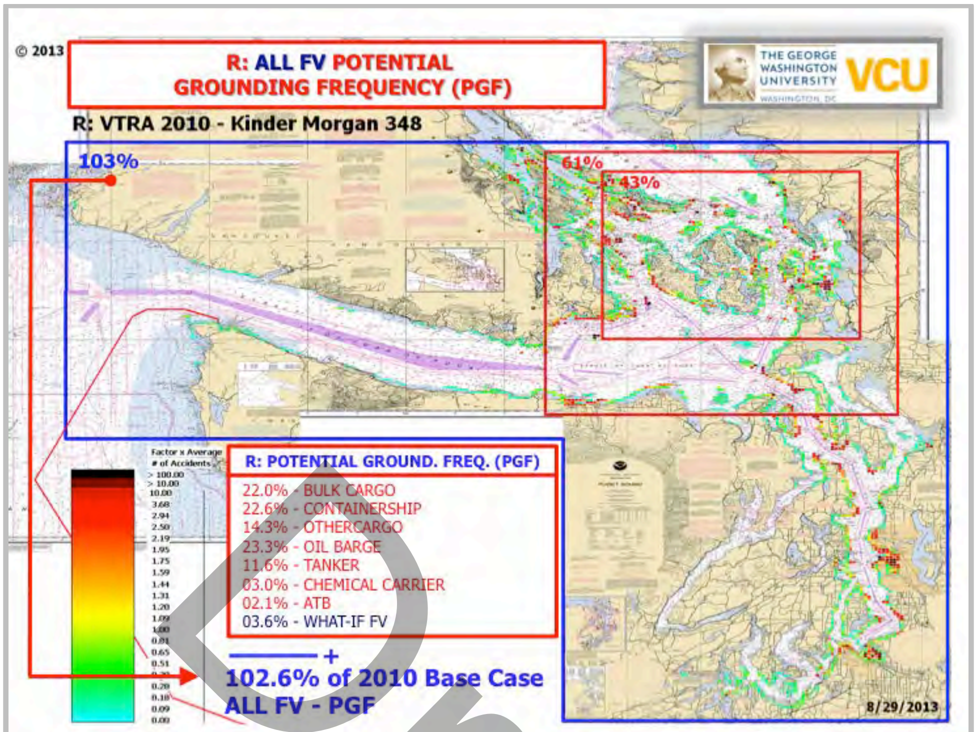


Figure 64. The geographic profiles of POTENTIAL grounding frequency for the Trans-Mountain Pipeline Expansion What-If scenario.

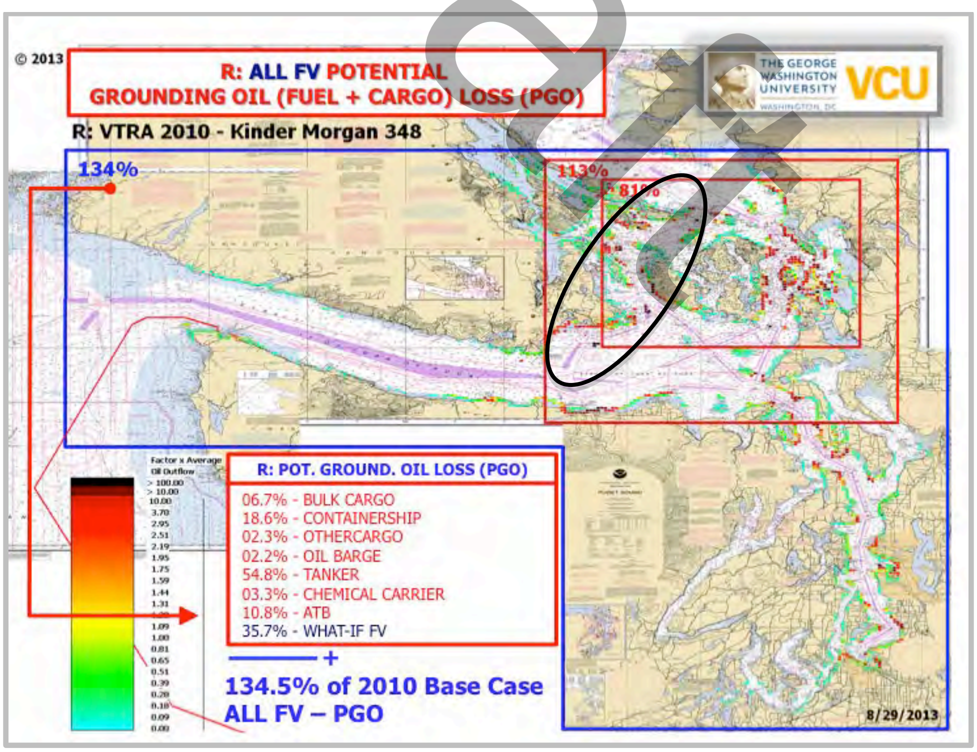


Figure 65. The geographic profiles of POTENTIAL grounding oil loss for the Trans-Mountain Pipeline Expansion What-If scenario.

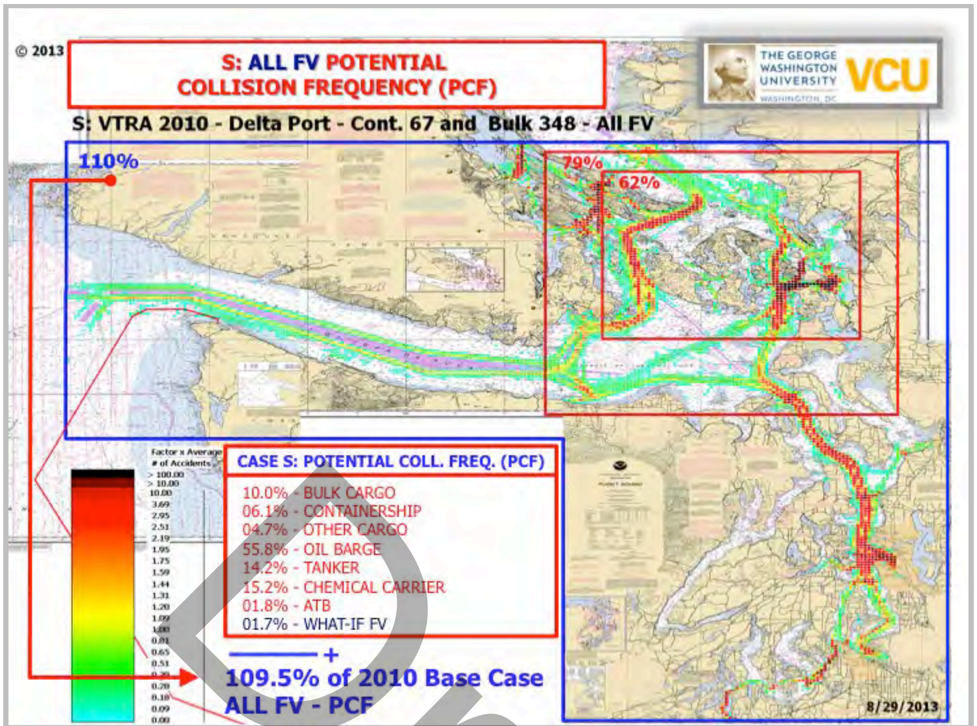


Figure 66. The geographic profiles of POTENTIAL collision frequency for the Delta Port What-If scenario.

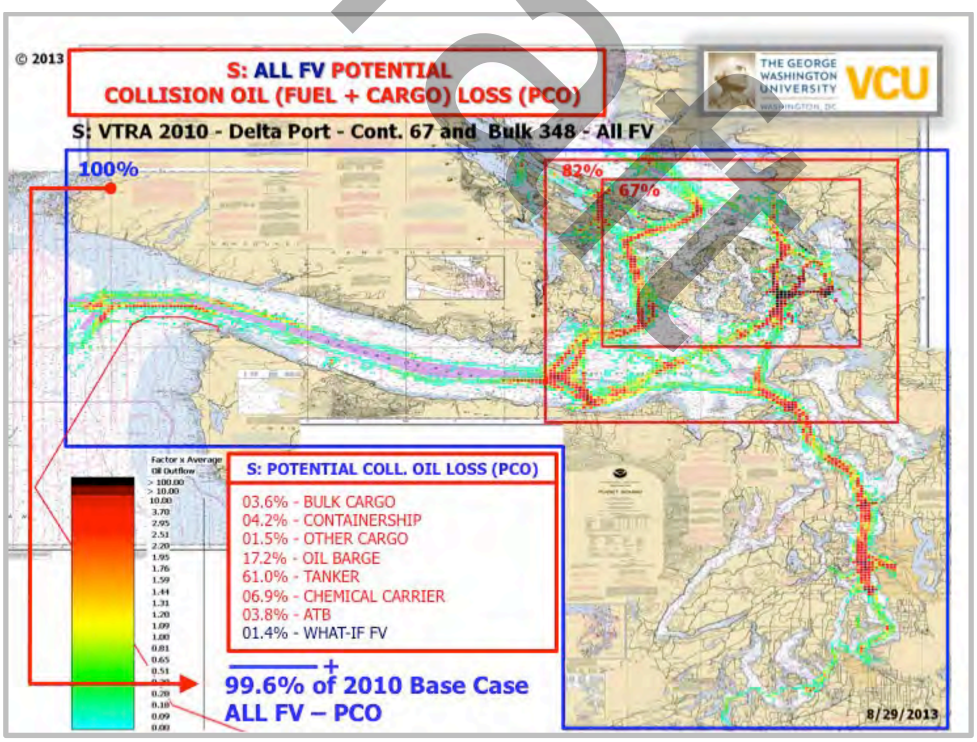


Figure 67. The geographic profiles of POTENTIAL collision oil loss for the Delta Port What-If scenario.

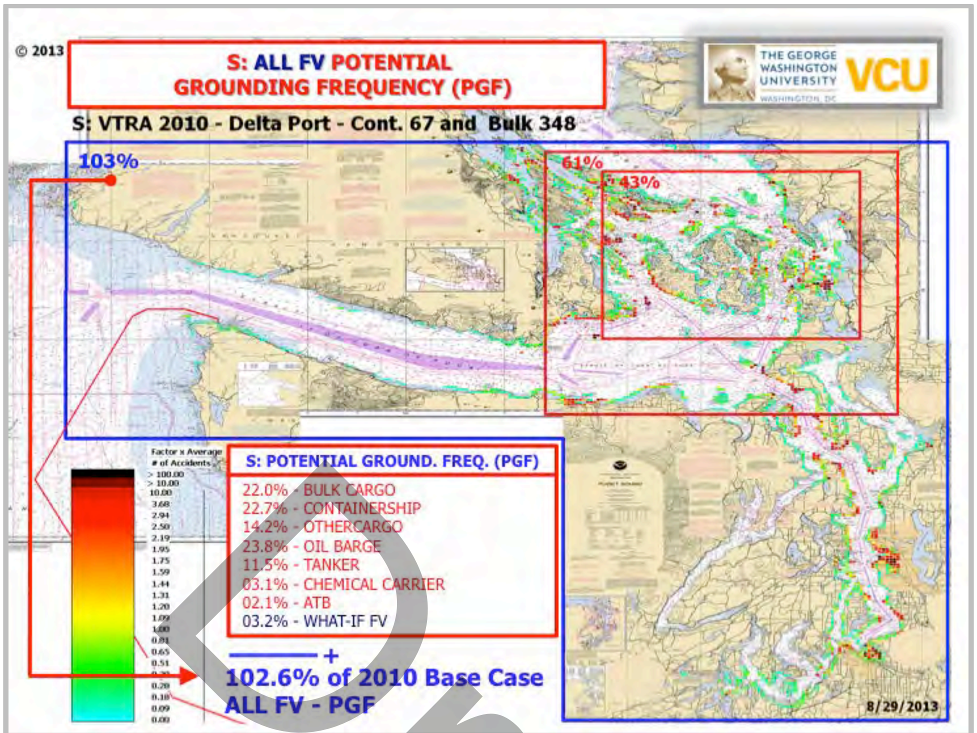


Figure 68. The geographic profiles of POTENTIAL grounding frequency for the Delta Port What-If scenario.

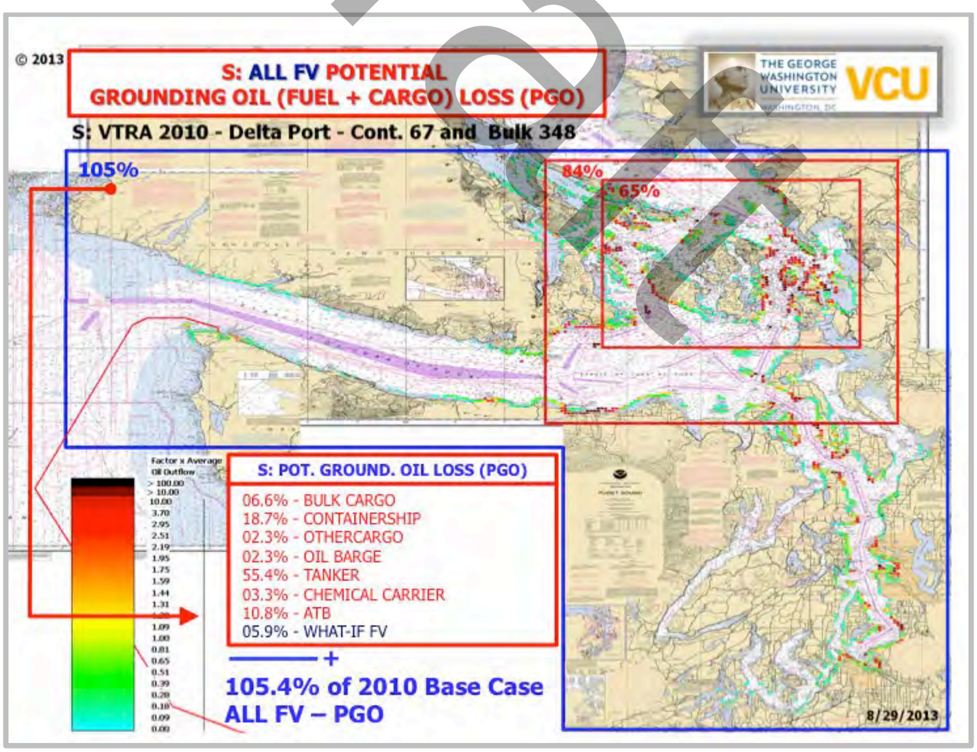


Figure 69. The geographic profiles of POTENTIAL grounding oil loss for the Delta Port What-If scenario.

Delta Port geographic profile results

Figure 66 to Figure 69 show the geographic profile for the Delta Port What-If scenario results for POTENTIAL collision frequency, POTENTIAL collision oil loss, POTENTIAL grounding frequency, and POTENTIAL grounding oil loss. The major changes from the 2010 Base Case results to the Trans-Mountain Pipeline Expansion What-If scenario results are smaller than other cases. The number of added in the Delta Port What-If scenario and the study area affected are similar to the Trans-Mountain Pipeline What-If scenario. The effects on POTENTIAL accident frequency are, therefore, similar. However, the containers and bulk carriers added do not cargo oil, so the impact on POTENTIAL oil loss is less. There is in fact a very small reduction in the POTENTIAL cargo oil loss. This seems anomalous as adding vessels to the 2010 Base Case decreases this measure. This effect is caused by a small change in the mix of vessels interacting with tank vessels.

Geographic profile results from adding all three What-If Scenarios

Figure 70 to Figure 73 show the geographic profile for the combinedWhat-If scenario results for POTENTIAL collision frequency, POTENTIAL collision oil loss, POTENTIAL grounding frequency, and POTENTIAL grounding oil loss. The major changes from the 2010 Base Case results to the combinedWhat-If scenario results are circled in black. The changes in POTENTIAL collision frequency are caused by vessels from all three What-If scenarios that have been combined. The changes in POTENTIAL collision oil loss are located where major changes from the Gateway What-If scenario and the Trans-Mountain Pipeline Expansion What-If scenario are located. The changes in POTENTIAL grounding frequency are again the located where major changes from the Gateway What-If scenario and the Trans-Mountain Pipeline Expansion What-If scenario are located. However, the changes in POTENTIAL grounding oil loss are only located where the major change for the Trans-Mountain Pipeline Expansion What-If scenario is located.

An interesting consideration is whether the changes caused by the combined What-If scenario is just the sum of the changes caused by each of the three separate What-If scenarios or whether there is an interaction between the scenarios. The changes in the POTENTIAL collision frequency from the three separate What-If scenarios add up to 13.3% + 8.9% + 9.5% = 33.7%. The change from the combined What-If scenario is only 20.6%. Thus the dynamics of the system are changed in a way that reduces collision risk.

The changes in the POTENTIAL collision oil lossfrom the three separate What-If scenarios add up to 33.8% + 39.4% - 0.4% = 72.8%. The change from the combined What-If scenario is 89%. Thus the mix of vessels from the three cases involved in interactions with tank vessels must lead to more oil spill. A plausible cause for this effect is the combination of

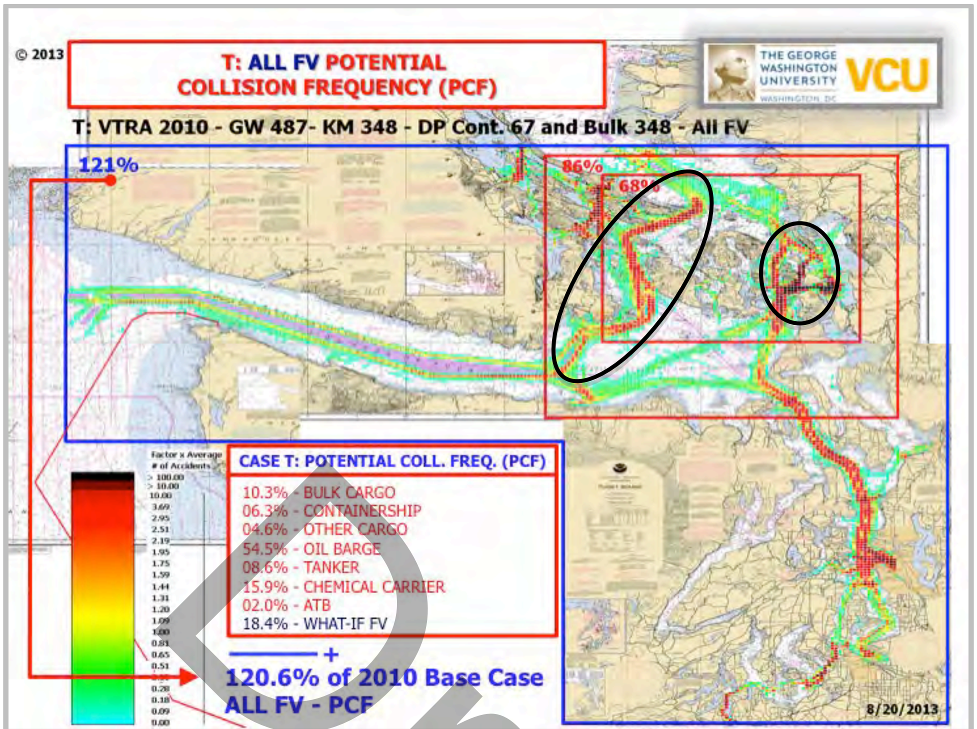


Figure 70. The geographic profiles of POTENTIAL collision frequency for the CombinedWhat-If scenario.

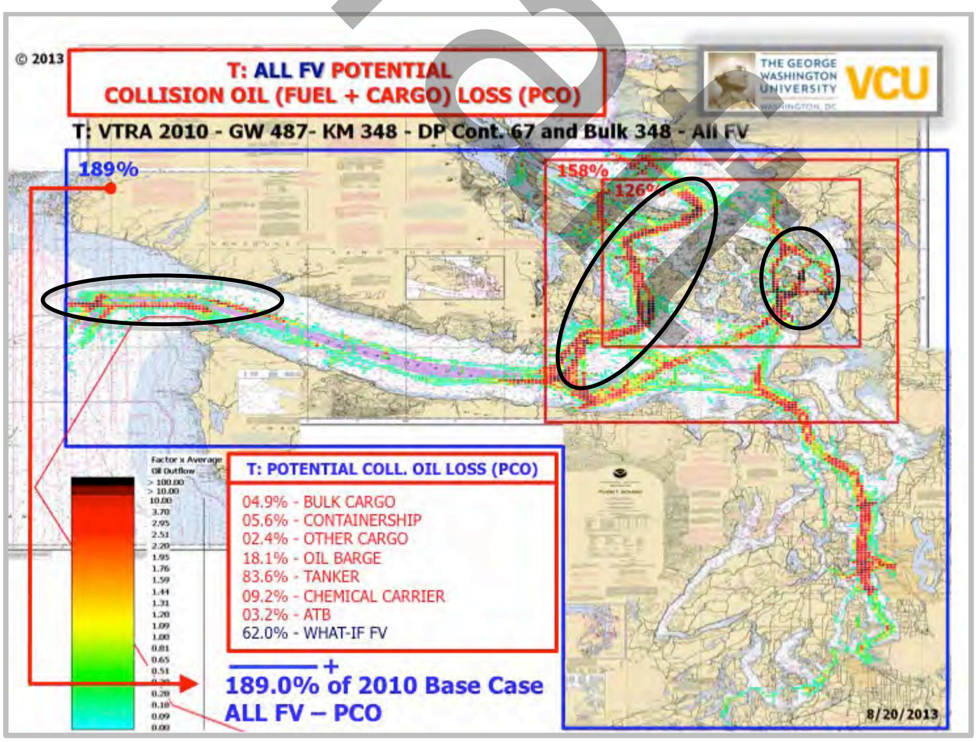


Figure 71. The geographic profiles of POTENTIAL collision oil loss for the CombinedWhat-If scenario.

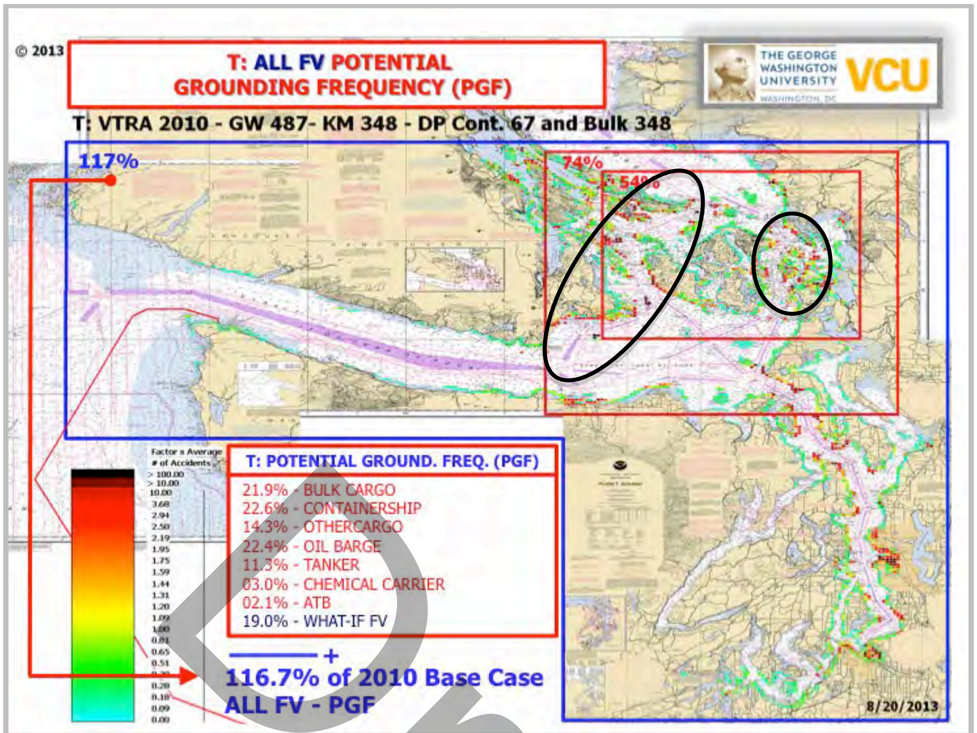


Figure 72. The geographic profiles of POTENTIAL grounding frequency for the CombinedWhat-If scenario.

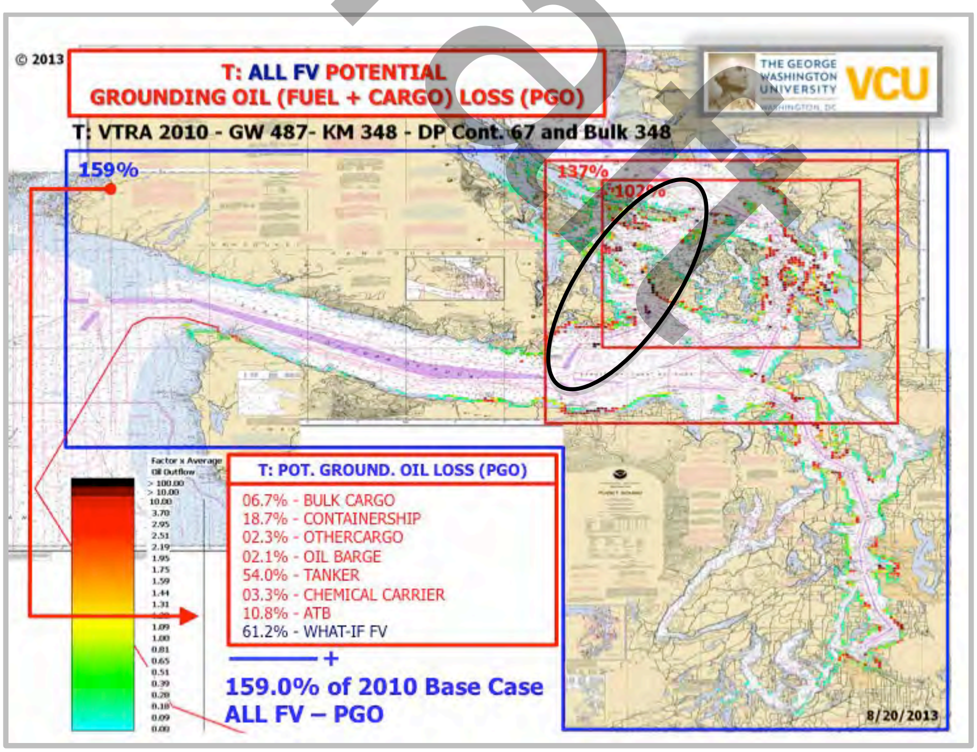


Figure 73. The geographic profiles of POTENTIAL grounding oil loss for the CombinedWhat-If scenario.

containers and bulk carriers using Haro Strait to transit to Delta Port and tankers using Haro Strait to transit to Vancouver.

The changes in the POTENTIAL grounding frequency from the three separate What-If scenarios add up to10.5% + 2.6% + 2.6% = 15.7%. The change from the combined What-If scenario is 16.7%. These are close, with a small interaction effect.

The changes in the POTENTIAL grounding oil loss from the three separate What-If scenarios add up to3.3% + 34.5% + 5.4% = 43.2%. The change from the combined What-If scenario is 59%. So again we have an increase beyond the sum of the three individual What-If scenarios, which must mean that the vessels involved in the additional grounding potential are tank vessels.

8. RISK MANAGEMENT SCENARIOS

PLACE HOLDER

9. BENCH MARK SCENARIOS

PLACE HOLDER

10.A COMPARISON OF WHAT-IF, RISK MANAGEMENT AND BENCH MARK SCENARIOS

PLACE HOLDER

11.CONCLUSIONS AND RECOMMENDATIONS

PLACE HOLDER

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Appendix: Glossary and List of Acronyms

- Allision–The collision of a vessel with its intended docking berth.
- ATB – Articulated Tug Barge
- Ecology – The Washington Department of Ecology's Spill Prevention, Preparedness and Response Program which is the primary state organization with authority and accountability for managing oil and hazardous material spill risk state-wide. Ecology is assisting PSP in conducting the VTRA with its expertise and experience.
- EPA – Environmental Protection Agency.
- MTS – Maritime Transportation System.
- FV – Focus Vessel.
- ITB – Integrated Tug Barge.
- IV – Interacting Vessel.
- MXPS – Marine Exchange Puget Sound.
- NGO – Non-Governmental Organization.
- NPO – Non-Persistent Oil
- Study Area – The Washington waters of Puget Sound east of Cape Flattery, north of Admiralty Inlet and west of Deception Pass, and their approaches.
- GW – George Washington University is the prime subgrant awardee.
- VCU – Virginia Commonwealth University is a sub-awardee to GW.
- GW/VCU – The technical team composed of GW and VCU.
- PO – Persistent Oil.
- PSP – The Puget Sound Partnership is the Washington state agency responsible for developing a Puget Sound Action Agenda, convening a Cross Partnership Oil Spill Work Group and for coordinating work to restore and protect Puget Sound.
- PSHSC – The Puget Sound Harbor Safety Committee.
- PSP Advisory Group – A steering committee of stakeholders advising the Puget Sound Partnership and GW/VCU over the course of this study.
- QAPP – Quality Assurance Project Plan
- USCG – US Coast Guard Sector Seattle, District 13.
- VTOSS – Vessel Traffic Operational Support System
- VTRA – Vessel Traffic Risk Assessment
- VTS – Vessel Traffic Service is thereal-time marine traffic monitoring system used by the USCG, similar to air traffic control for aircraft.