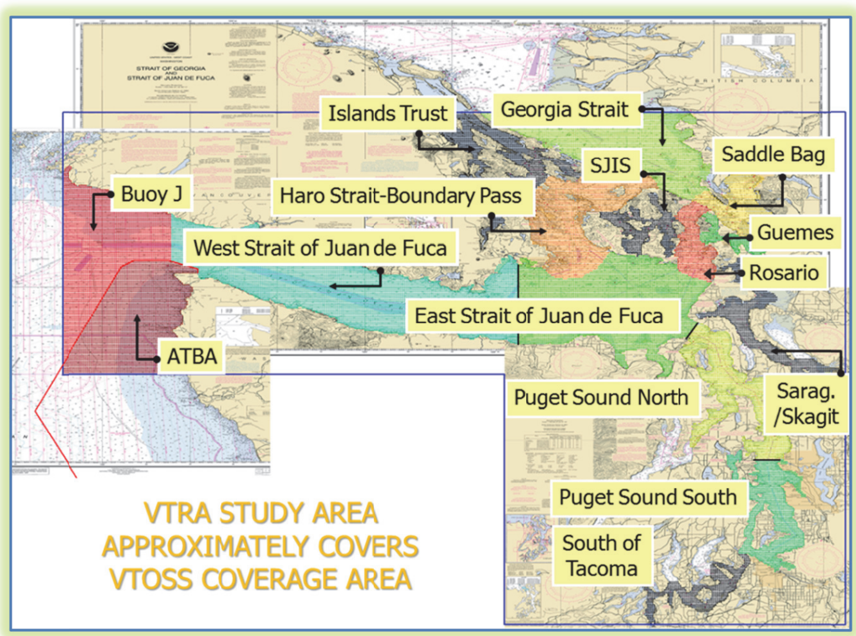
Final Report

Vessel Traffic Risk Assessment (VTRA):

Updating the 2005 VTRA GW/VCU MTS Simulation Model from VTOSS 2005 to VTOSS 2010 data



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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 update of a Vessel Traffic Risk Assessment (VTRA) Maritime Transportation System (MTS) simulation model developed from using 2005 Vessel Traffic Operational Support System (VTOSS) data to using 2010 VTOSS data. Henceforth this project shall be named the VTRA update. The VTRA update commenced in August 2012 and spanned eight months. 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 project was funded by a grant from the Environmental Protection Agency (EPA) to the Makah Tribe. This report is has been reviewed and approved by the Makah.

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) and John Veentjer's (Chair of the PSHSC) support have been instrumental in providing the necessary data for the VTRA update. 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. A PSHSC steering committee served as an advisory group during this update and will continue to serve as a steering committee in a follow-on project funded by the Puget Sound Partnership (PSP) using the VTRA update as its starting point.

This effort utilizes the extensive technical work already completed by the George Washington (GW) University and Virginia Commonwealth University (VCU) under previously funded 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 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 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 projects. A reference list is provided at the end of this document.

EXECUTIVE SUMMARY

While the Pacific Northwest enjoys a relatively safe marine transportation system (MTS), the potential impact of a catastrophic spill on the region's environment, economy and quality of life continues to be a major concern. The effects of a significant spill would likely be devastating on the long-term restoration and productivity of this region including the US-Canadian boundary waters of the Washington outer coast, the Strait of Juan de Fuca and the approaches to and passages through the San Juan Islands, Puget Sound and Haro-Strait/Boundary Pass. Recent developments have significantly elevated this level of concern given the number of commercial projects being proposed for northern Puget Sound and southern British Columbia over the next decade. Moreover, these proposed commercial projects, while adding many hundreds of deep draft ship transits, potentially increase significantly the amount of oil being transported throughout the area. The unique presence of Washington State Treaty tribes serving as resource trustees in this marine environment elevate the need for collaboratively developed protective measures.

The purpose of this project is to update to 2005 VTRA model using the 2010 VTOSS dataset to more closely approximate the present-day patterns in commercial traffic for future use of the GW/VCU VTRA analysis model regarding what potential actions be taken to mitigate potential increases in oil spill risk from large commercial vessel oil spills in the VTRA study area. In addition, this update will allow for a 2005 – 2010 VTRA model comparison in terms of changes in overall traffic in the VTRA study area.

The maritime traffic in this particular geographic area has been extensively studied by a variety of efforts in the past. One of the more recent being the VTRA conducted by GW/VCU from 2006-2008 (2005 VTRA hereafter) and funded by BP to inform a US Army Corp of Engineers' Environmental Impact Statement (EIS) regarding BP's dock expansion at Cherry Point. The primary data source for modeling commercial traffic participating in the Vessel Traffic Service (VTS) in the 2005 VTRA model was VTOSS 2005 data. Smaller vessel traffic not participating in these three VTS providers, but also modeled in the 2005 VTRA using a variety of data sources, include: state, tribal and Canadian fisheries, USCG permitted regatta events and whale watching activities.

A prime advantage of the VTOSS data is that it provides a single US-Canadian cross boundary data source of larger commercial vessel movements in the VTRA study area recorded by the three VTS providers: Seattle (US), Tofino (Canada) and Victoria (Canada). No doubt, current safety levels experienced in this MTS are to a great extent the benefit of the joint external vigilance risk management role the US and Canadian Coast guards play.

The 2005 VTRA model replicates vessel movement throughout the VTRA study area. The GW/VCU MTS VTRA methodology has been well documented and peer-reviewed in the academic literature. A summary of the methodology is provided in this document with references to peer-reviewed publications and technical reports dispersed throughout this summary. It is particularly well suited to evaluate potential future risk increases as a result of planned commercial projects alluded to above, as well as to test risk mitigation measures to counter such increases prior to implementing them. To more closely approximate the present-day patterns in commercial traffic for future scenario analysis, the 2005 VTRA model is updated with the 2010 VTOSS dataset. The 2010 year is the last full year of traffic data recorded by VTOSS. Subsequent years are recorded using a different system.

Not only does the VTRA updated model represent an unprecedented level of detail in the depiction of maritime traffic, but more importantly this update has been validated using a an independently collected data source. Specifically, the model update was validated using 2010 Automatic Independent Surveillance (AIS) crossing line count data provided by the Marine Exchange Puget Sound (MXPS).

The value of such an independent validating data source is illustrated in Figure 1. Figure 1 compares east bound and west bound crossing line counts at the entrance of the Strait of Juan de Fuca generated by the GW/VCU model updated with VTOSS 2010 data to those recorded by AIS in 2010. Observe from Figure 1 there is strong agreement in the number of cargo, tanker and passenger vessel entering and leaving the West Strait of Juan de Fuca.

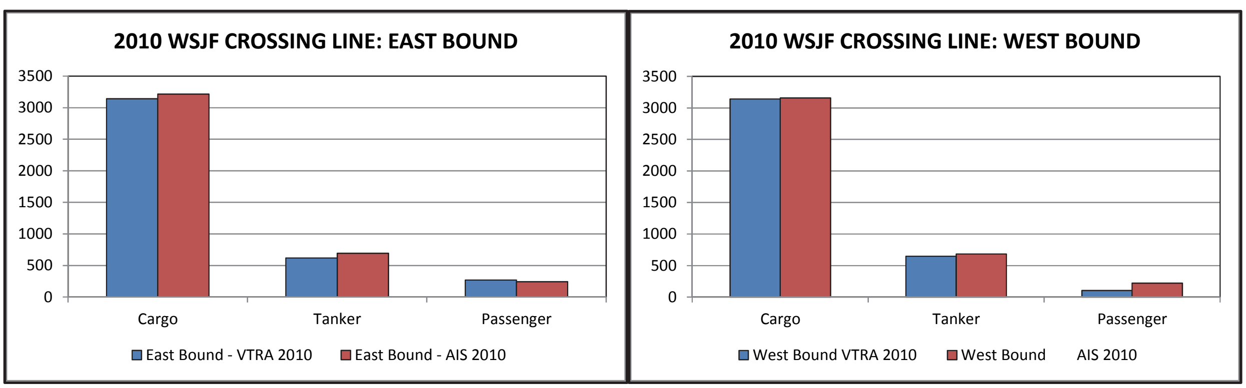

Figure 1. Comparison of AIS 2010 and VTOSS 2010 crossing line counts for cargo, tanker and passenger vessels for the West Strait of Juan de Fuca crossing line depicted in Figure 32B.

The updating of the 2005 VTRA model to 2010 VTOSS data described herein followed the collaborative analysis approach[1] involving coordination with Puget Sound stakeholders through the Puget Sound Harbor Safety Committee:

"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 validated 2010 VTRA update, combined with its unprecedented level of detail, and developed using this collaborative analysis approach, is particularly well suited to serve as such a single body of knowledge. The VTRA update provides a starting point for future vessel risk studies conducted in the area to inform federal agencies, tribes, local governments, industry and non-profit groups in Washington State and British Columbia on potential risk management options. A common starting point amongst these studies may further facilitate achieving consensus risk management decisions regarding vessel operations in the study area. One future vessel traffic risk study is currently funded by the Puget Sound Partnership through another Environment Protection Agency (EPA) grant award. This study has committed to using the VTRA update combined with the collaborative analysis approach that is integral to the GW/VCU VTRA methodology.

In addition to updating to VTOSS 2010 data, an overall traffic density comparison analysis is presented comparing the 2005 and 2010 VTOSS datasets by tankers, cargo, passenger, service, tug-tow and fishing vessels. However, caution should be exercised when interpreting such a comparison due to modeling enhancements included in the VTRA update. For example, a vessel’s individual route has been retained in the VTRA update, whereas in the 2005 VTRA representative vessel routes were constructed by vessel type. The lack of an AIS 2005 validation data source for the 2005 VTRA only adds to that caution. Hence, Figure 2only shows for the VTRA update by vessel type (including non-participating VTS traffic) the overall distribution of the total time vessels move through the VTRA study area.

In light of planned future commercial projects in the VTRA study area, and with an eye towards larger potential oil spills, we further restrict ourselves in the executive summary to describing a combined 2010 cargo, tanker and tug-tow vessel traffic profile. This subset of traffic totals 41.4% of the traffic depicted in Figure 2. This 41.4% breaks down as follows: tug-tows (47.5%), cargo (44.8%) and tankers (7.7%).

Table 1 shows the distribution of the durations that cargo, tanker, and tug-tow traffic move across the 15 waterway locations of the study area (depicted on the cover page). Specifically, the fourth column in Table 1 lists the annual number of days that cargo, tanker or tug-tow vessels move within a particular waterway location. Dividing the annual number of days by 365 provides the average number of such vessels moving in a waterway location at an arbitrary point in time (the fifth column in Table 1). If one divides the number of days such vessels move in a particular waterway location by the total number of days these vessels move in the overall study area, one obtains the location’s percentage of exposure (the sixth column in Table 1). Finally, by dividing the percentage of exposure by the relative size of a waterway location (the third column in Table 1) one obtains a waterway location's density factor (the last column of Table 1).

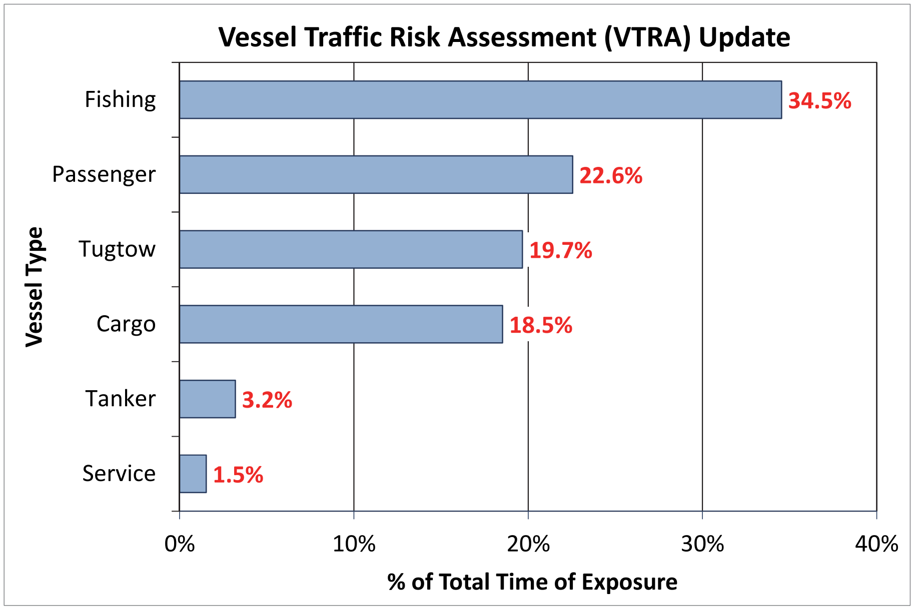

Figure 2. Percentage of time a vessel is moving in the VTRA system by master type in the VTRA Update

Table 1. Detailed exposure analysis of cargo, tanker and tug-tow vessels by the fifteen waterway locations on the cover by the GW/VCU VTRA model updated with VTOSS 2010 data.

Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*	*Column 6*	*Column 7*
LOCATION	**# Grid Cells**	**% Area**	**# Days Vessel is Moving per year**	**Average # of Vessels**	**% of Total Time of Exposure**	**Density Factor (DF)**
WSJF	2857	19.6%	2683.7	7.4	23.2%	1.18
PS North	983	6.8%	1896.7	5.2	16.4%	2.43
ESJF	2049	14.1%	1538.9	4.2	13.3%	0.94
Georgia Str.	1424	9.8%	1168.3	3.2	10.1%	1.03
Haro/Boun.	1066	7.3%	1145.1	3.1	9.9%	1.35
PS South	619	4.3%	1090.9	3.0	9.4%	2.22
Bouy J	1478	10.2%	701.5	1.9	6.1%	0.60
Rosario	307	2.1%	481.2	1.3	4.2%	1.97
Islands Trt	696	4.8%	324.0	0.9	2.8%	0.59
Tac. South	326	2.2%	166.7	0.5	1.4%	0.64
Saddlebag	375	2.6%	156.0	0.4	1.3%	0.52
Sar./Skagit	459	3.2%	80.8	0.2	0.7%	0.22
Guemes	127	0.9%	68.4	0.2	0.6%	0.68
ATBA	1520	10.5%	45.9	0.1	0.4%	0.04
SJ Islands	259	1.8%	15.6	0.0	0.1%	0.08
Total	**13246**	**100.0%**	**11563.8**	**31.7**	**100.0%**	**1.0**

In Figure 3 and Figure 4 waterway locations are ranked by their exposure and density factor evaluated in Table 1, respectively.

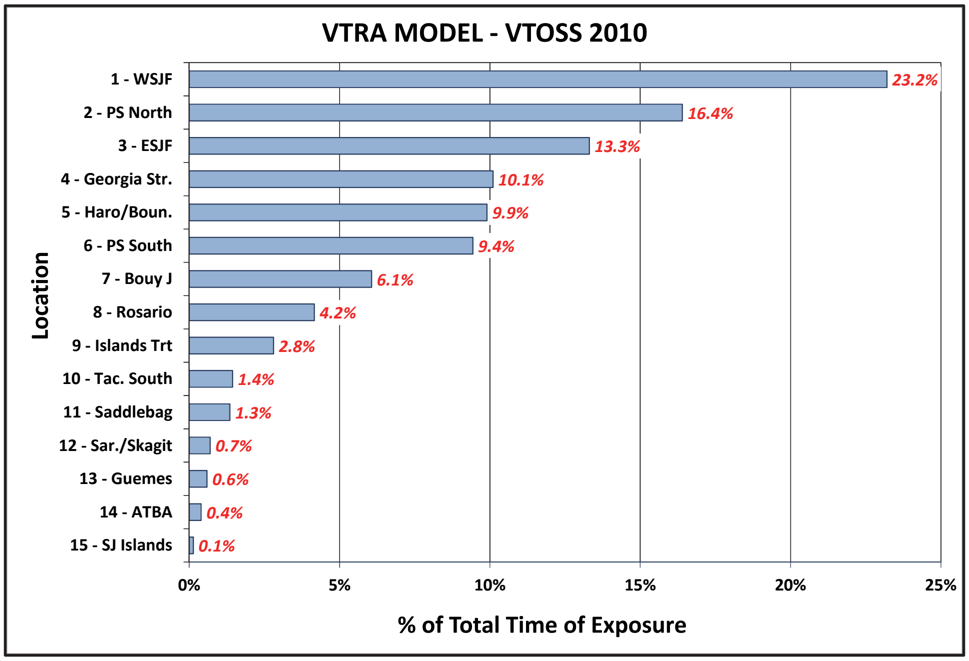

Figure 3. Waterway locations ranked by percentage of total time of exposure to cargo, tanker or tug-tow vessels as evaluated by the GW/VCU VTRA model updated using VTOSS 2010 data (see Table 1).

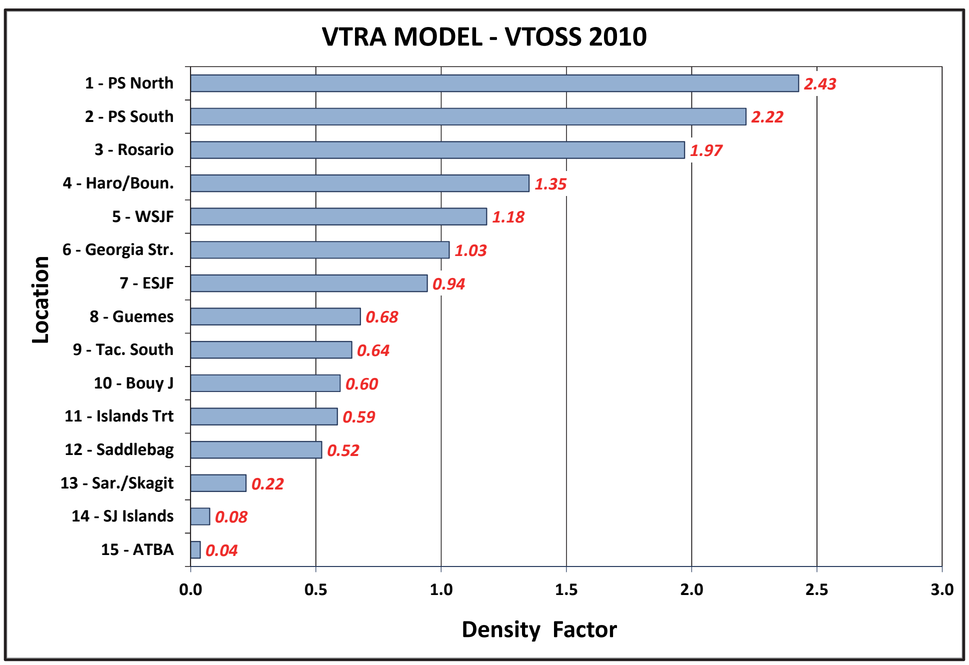

Figure 4. Waterway locations ranked by density factor restricted to cargo, tanker or tug-tow vessels as evaluated by the GW/VCU VTRA model updated using VTOSS 2010 data (Table 1).

Figure 3 shows that the West Strait of Juan de Fuca (WSJF) ranks first in terms of exposure. However, when accounting for its size, the WSJF ranks fifth in terms of density factor (see, Figure 4). Similar conclusions can be drawn for the other 14 waterway locations.

The analysis in Table 1 and presentations in Figure 3 and Figure 4 serve as a reminder that "the world is not average". To further emphasize this observation, Figure 5 plots the times series (plotted every 15 minutes}of the number of cargo, tanker and tug-tow vessels moving in the VTRA study area as evaluated by the VTRA update. From the left panel one observes that number of cargo and tanker vessels combined moving in the VTRA study area ranges from zero to 33. From the right panel one observes that the number of tug-tow vessels also ranges from zero to 33. Recall, that on average the total number of cargo, tanker and tug-tow vessels <u>combined</u> at any point in time values approximately 31.7(as evaluated in the last row of Table 1).

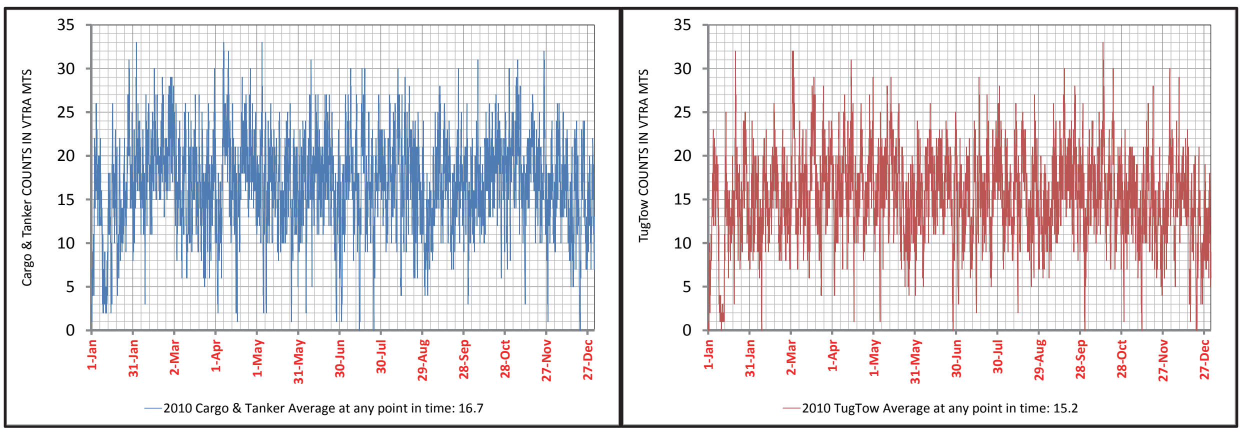

Figure 5. Time series of number of cargo, tanker and tug-tow vessels moving in the VTRA study area evaluated using the VTRA update. Left Panel: Cargo and tanker counts combined; Right Panel: Tug-tow counts.

Finally, Figure 6 below presents a geographic profile of exposure of cargo, tanker or tug-tow vessels moving in the VTRA study area, which is a unique output format of the GW/VCU VTRA model. About one quarter of cargo, tanker or tug-tow exposure (25%) occurs within the smaller red rectangle in Figure 6. About one half of this exposure (46%) occurs in the larger red rectangle. Thus about 54% of the remaining exposure is accounted for by the area outside the larger red rectangle within the VTRA study area. More importantly, through the use of its color scale, Figure 6 provides a refined visual representation of exposure by location.

The color scale provides a relative comparison of (1) the amount of time a vessel is moving within a particular grid cell with (2) the average amount of time a vessel is moving within any grid cell in the VTRA study area. While the waterway locations listed in Table 1 differ in size, grid cells in Figure 6 are all 0.25 square nautical miles in size. The color yellow represents the average amount of time a cargo, tanker or tug-tow vessel grid cell is moving within a grid cell and is assigned the factor 1.0 depicted to the right of the color legend. Those grid cells with an exposure less than average are assigned a color below the yellow color and those that are above average get a color assigned above the yellow color. To the right of each color on the color legend it is indicated by what approximate factor the exposure in the particular grid cell differs from the observed average across all grid cells. Overall the grid cell exposure factors range in Figure 6 from zero to over 42. Stationary vessels, either at anchor or at the dock, are not reflected in this exposure profile.

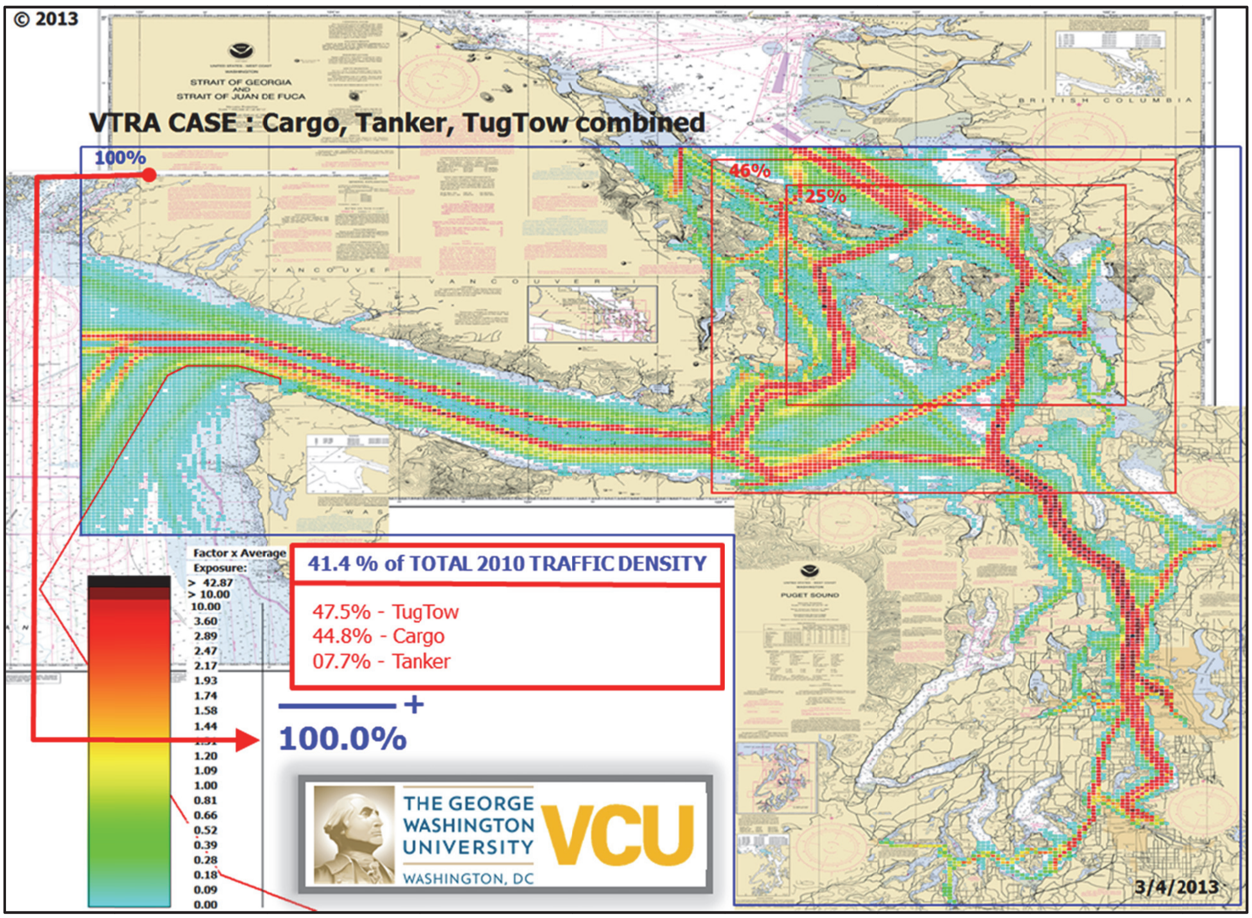

Figure 6.Geographic profile of time of exposure to tug-tow, cargo or tank vessels moving in the VTRA study area as evaluated by the updated GW/VCU VTRA model using VTOSS 2010 data.

Similar geographic profiles can be generated by vessel type using the VTRA update model. An additional accident analysis layer allows for the generation of geographic profiles in terms of accident frequency. Overlaying an oil outflow analysis model over the accident frequency profile allows for the generation of a geographic profile of potential oil loss. Development of these profiles will be the focus of the PSP grant utilizing the comprehensive and validated traffic picture presented herein as a starting point.

A detailed consideration of traffic levels is particularly important as one moves forward to considering risk and potential changes in risk from the commercial projects being proposed for the northern Puget Sound and southern British Columbia over the next decade. To put it simply, keeping everything else the same, when traffic increases risk increases, unless mitigated. Further, there is no guarantee that risk increases due to traffic increases can be fully mitigated.

This begs the question then, when faced with perhaps inevitable traffic increases how can one manage risk increases that cannot be fully mitigated? One approach could be to evenly distribute future risk across the affected area, i.e. to allow for risk increases in locations that currently have low risk levels compared to those that are already higher. On the other hand, should one aim for an equitable distribution of future risk allowing for each location to have a similar relative percentage increase in risk?

The challenge of risk management is for it to be location specific, taking into consideration the type and location of traffic and how it changes as a result of proposed traffic increases. One must realize that risk does not necessarily disappear when mitigated locally, but has tendency to migrate. Such risk migrations are preferably avoided, but may be inevitable. Needless to say, risk mitigation at one location ought not result in an increase in risk elsewhere that is larger.

These are important questions for the PSP project using the VTRA update as a starting point. In our opinion, they can only be answered utilizing the collaborative analysis approach (see, [1]), to which the PSP has committed. No doubt these questions are equally important in other ongoing studies considering the potential risk of traffic increases as a result of future planned commercial projects. We hope that other studies can benefit from the validated and vetted analysis of the VTOSS 2010 dataset performed in this project and presented in this report. Summarizing, we advocate a collaborative systems approach towards risk management, not one that is just locally targeted missing potential side effects or points of view.

In light of the observations in this VTRA update dispersed throughout this report, while considering a longer-term view of risk management in the VTRA study area, we close with the observation that there is a serious need for an electronic data source that is cross-boundary (US and Canadian waters) where the vessel type is consistently defined and verified. VTOSS and AIS are such cross-boundary electronic data sources and could serve this purpose. Moreover, with the same eye towards risk management analysis it would be equally beneficial if such datasets records capture cargo or at a minimum cargo levels (laden, unladen, 50% laden, etc.). In particular, we would like to call out the need for recording at a greater consistency the cargo type and levels of tug-tow barges.

However without VTOSS and AIS currently possessing such a common and consistently recorded vessel identifier, vessel type, cargo type and cargo level classifications, VTOSS and AIS unfortunately still require some vetting at the individual vessel level. In this study, we have performed vetting at the individual vessel level by vessel master type (see Table 3).

We hope that other studies can benefit from the validated and vetted analysis of the VTOSS 2010 dataset performed in this project and presented in this report.

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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.

By updating the 2005 VTRA model to a 2010 base year, it will more closely approximate the present-day patterns in traffic for future use of 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. This study area is expected to experience significant changes in deep draft vessel traffic during the next decade. Such future use of the GW/VCU VTRA analysis model may inform federal agencies, tribes, local governments, industry and non-profit groups in Washington State and British Columbia on potential risk management options and may facilitate their input into achieving consensus risk management decisions regarding vessel operations in the study area

The 2005 VTRA was developed using 2005 data from the federal Vessel Traffic Operational Support System (VTOSS) data, amongst other data sources. Although the 2005 VTRA incorporates the movement patterns of nearly all classes of vessels that can interact in the system, its analysis was limited to accidents involving Focus Vessels (FV) that dock at the BP Cherry Point refinery, specifically: Oil Tankers, Articulated Tug Barges (ATB) and Integrated Tug Barges (ITB) that dock at Cherry Point. Other vessels are considered Interacting Vessels (IV) with the FV's that may contribute to their accident frequency. Oil outflow from IV's is only taken into account when they collide with FV's.

The FV's in the 2005 VTRA represent only a very small percentage (≈1%) of modeled vessel traffic. Accident types included in the 2005 VTRA were collisions, powered groundings, drift grounding and allisions. Needless to say, to more closely approximate the present-day patterns in traffic for future scenario analysis, it would be desirable for the GW/VCU VTRA 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 update of the 2005 VTRA model using 2010 VTOSS data will allow for an expansion of the analysis to also, for example, non-BP tank vessels (≈another 2% of 2005 modeled traffic).

A summary of the GW/VCU VTRA methodology is provided in Section 2 with references to peer-reviewed publications and technical report dispersed throughout this summary. In Section 3, we detail the updating of the 2005 VTRA model to 2010 VTOSS data. In Section 4, a 2005-2010 comparison is provided in terms of traffic density across some vessel types. In Section 5, the validation of GW/VCU model crossing line counts using AIS 2010 crossing line counts is described. A detailed comparison analysis of GW/VCU model exposure analysis using the VTOSS 2005 and VTOSS 2010 dataset is presented in Section 6. In Section 7, we present a time series analysis comparison using the VTOSS 2005 and VTOSS 2010 dataset in terms of the number of vessels moving in the VTRA study area. In Section 8, a crossing line count comparison is provided for the West Strait of Juan De Fuca, Georgia Strait and Puget Sound crossing lines introduced in Section 5 using the VTOSS 2005 and VTOSS 2010 datasets. We close in Section 9 with some conclusions, finding and recommendations.

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 7).

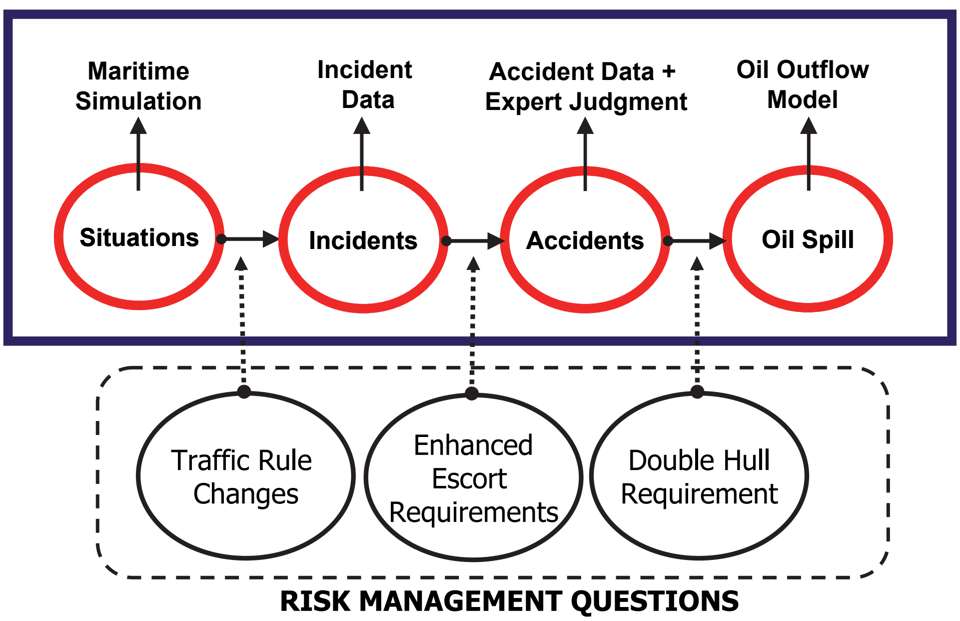

Figure 7. A causal chain of events inter-connected by causal pathways. Risk management questions attempt to block these causal pathways.

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 7):

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 8 provides 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 9 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

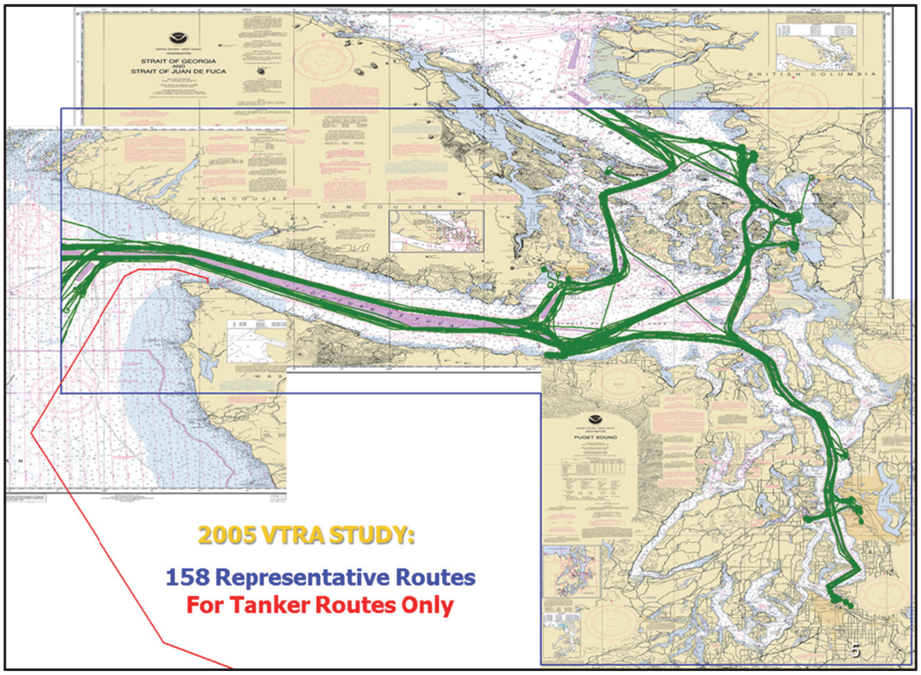

Figure 8. Graphic of 158 representative routes for oil tankers used in VTRA 2005 MTS simulation model.

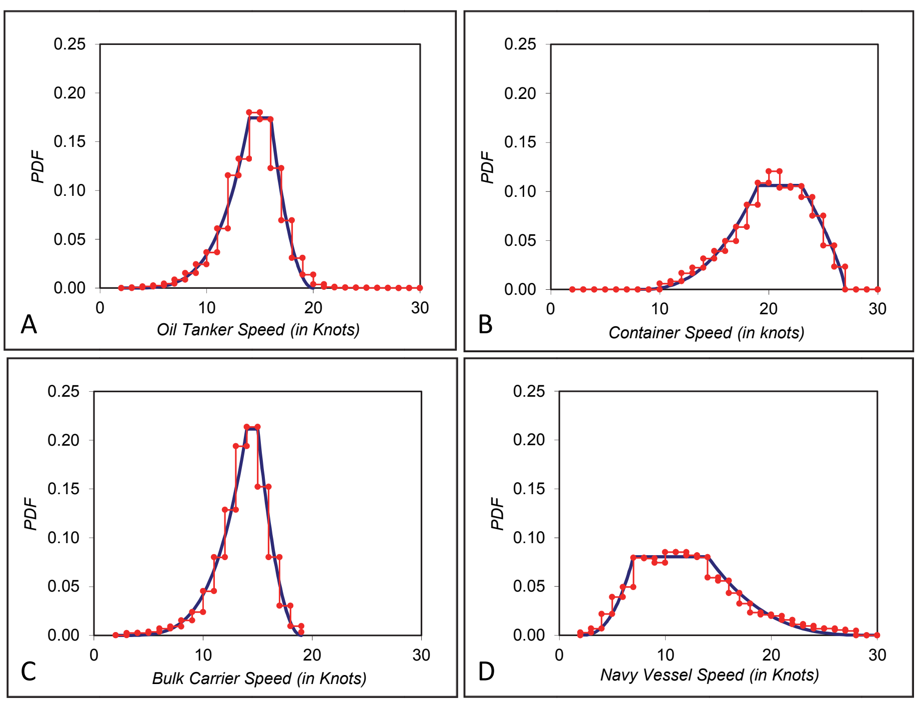

Figure 9. Example representative speed distribution for oil tankers (A), container vessel (B), bulk carriers (C) and navy vessels (D) estimated from VTOSS 2005 data. Step functions indicate the empirical probability distribution functions (pdf), whereas the solid lines are fitted Generalized Trapezoidal 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], Appendix C). 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 future traffic scenarios).

Incidents (see Figure 7):

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 7):

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 (typically, less than ten accidents were observed within theparticular geographic scope of our past studies over an extended time frame)! 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 10 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 for the update of the 2005 VTRA Model using 2010 VTOSS data.

Oil Spill (see Figure 7):

An oil outflow model [3]for collision and grounding accidents explicitly links input variables such as hull design (single or double, see Figure 11), displacement and speed, striking vessel displacement and speed, and the interaction angle of both vessels to output variables (see Figure 12): longitudinal and transversal damage extents of the tanker. Overlaying these damage extents on a vessel's design (see Figure 12) 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 13)

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 future

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 Tgpe**	-
Crossing the Bow	**Traffic Scenario**	-
Less than 1 mile	**Traffic Prozimitg**	-
	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 10. Example question during 2005 VTRA of a paired comparison questionnaire of situations for tanker collision accident attribute parameter assessment given all incidents.

Gateway facility 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 13 for an example of such a geographic profile of vessel risk). An advantage of the geographical profile display format in Figure 13 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 13 larger 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

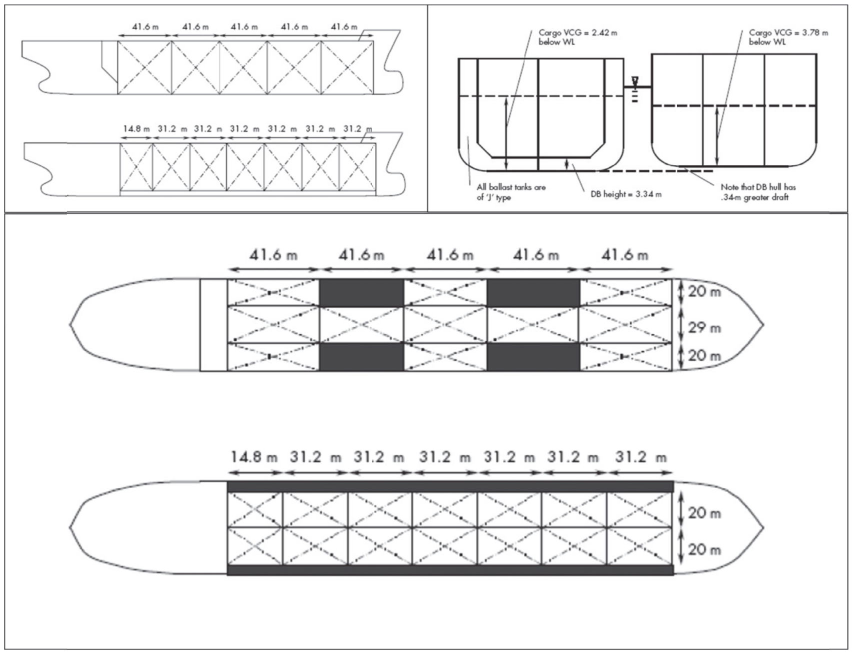

Figure 11. Single hull and double hull 150.000 DWT tanker designs used in 2005 VTRA taken from the National Research Council SR259 report [15].

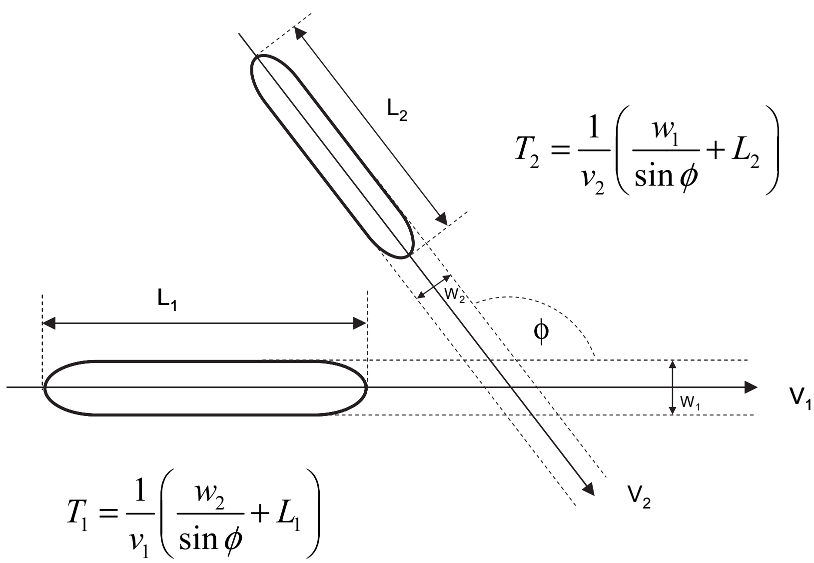

Figure 12.A schematic of a striking ship-struck ship probability model used in the 2005 VTRA.

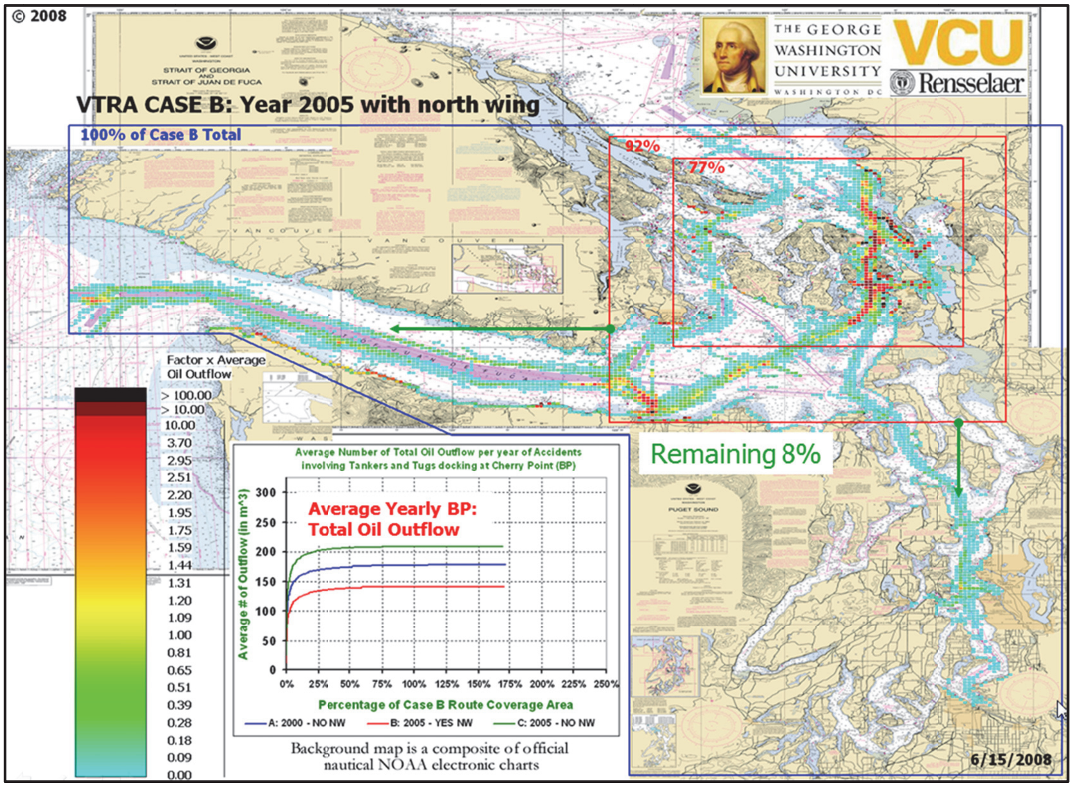

Figure 13.An example of a geographic profile of oil spill risk (generated during the 2005 VTRA).

that of a future 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 13 allow for a more quantitative evaluation of system risk and its changes from a baseline scenario to future and risk mitigation scenario analysis results. The fact that in Figure 13 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 Simulation 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 for future use of 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.

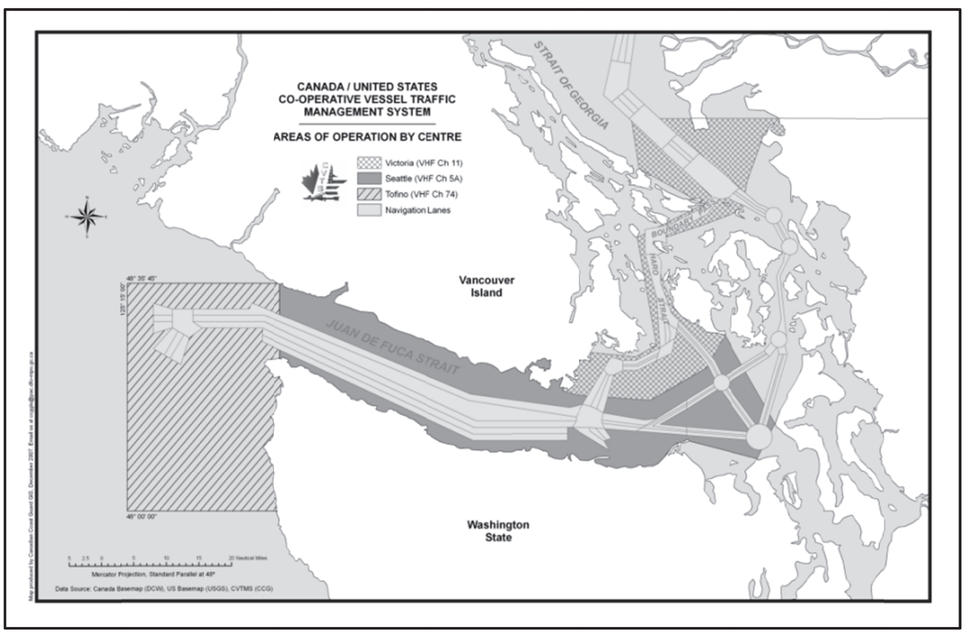

Figure 14.Coverage area of the Vessel Traffic Operational Support System (VTOSS).

To deal with this particular data 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 15, 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 9, were constructed to model the movement of oil

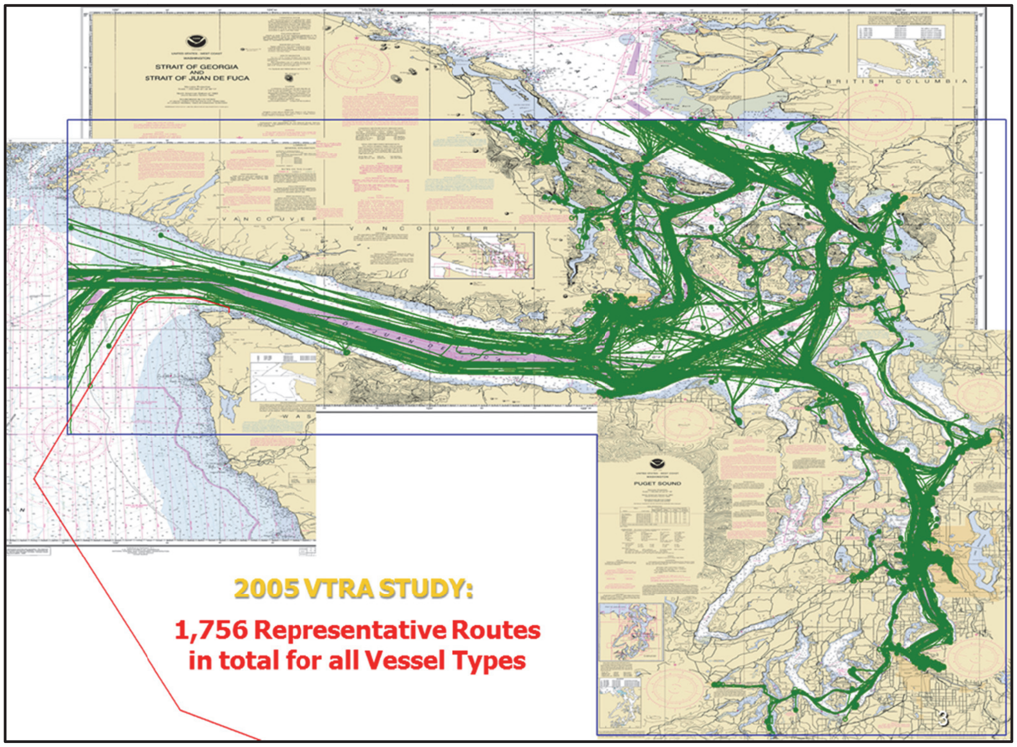

Figure 15. In total 1756 representative vessel route were constructed from 2005 VTOSS data during the 2005 VTRA to model the movement of VTS responding traffic in the GW/VCU MTS simulation model.

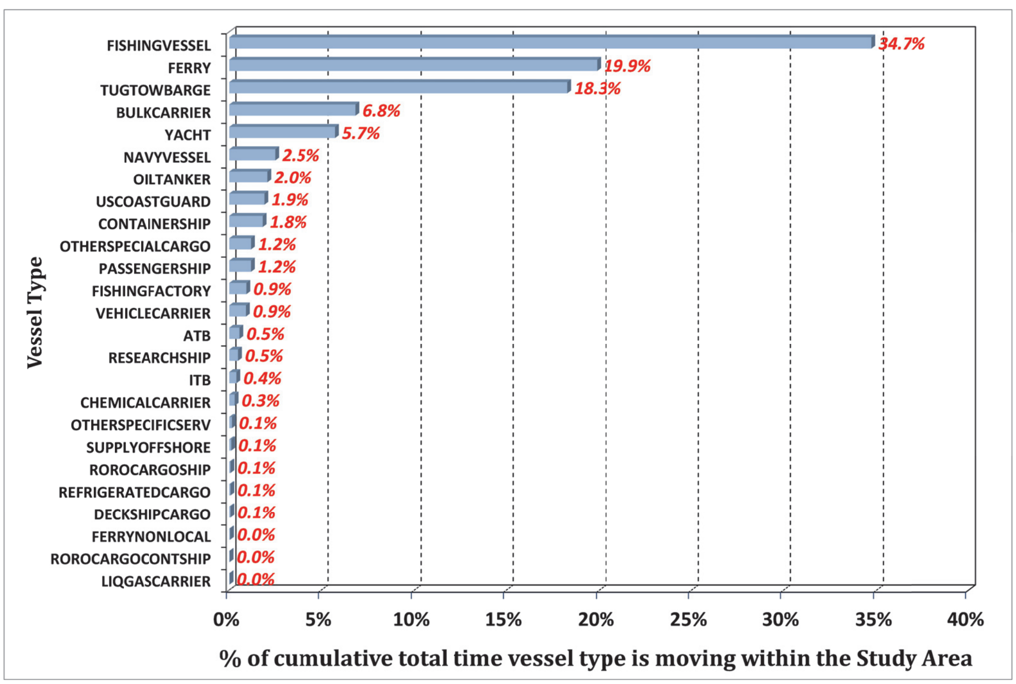

Figure 16. Tornado diagram displaying the cumulative percentage of time a vessel of a certain type is moving with the study area in the 2005 VTRA model over the course of one simulation year.

tankers (≈ 2% of all traffic, see Figure 16). For example, only 22 representative routes were utilized to model container traffic (≈ 2% of all traffic, see Figure 16) and 47 to model bulk carrier traffic (≈ 7% of all traffic, see Figure 16). The specific routes for container vessels and bulk carrier in the 2005 VTRA are depicted in Figure 17. 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.

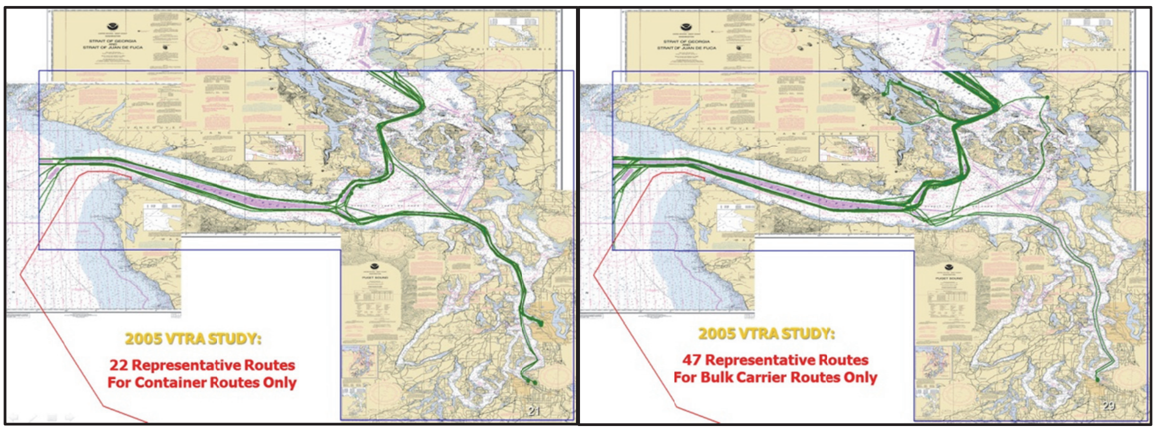

Figure 17. In total 22 (47) representative vessel route were constructed from 2005 VTOSS data during the 2005 VTRA to model the movement of container vessel (bulk carrier) traffic in the GW/VCU MTS simulation model.

To allow for inclusion of container vessel and bulk carriers in the focus vessel group for future 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 18'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 18.

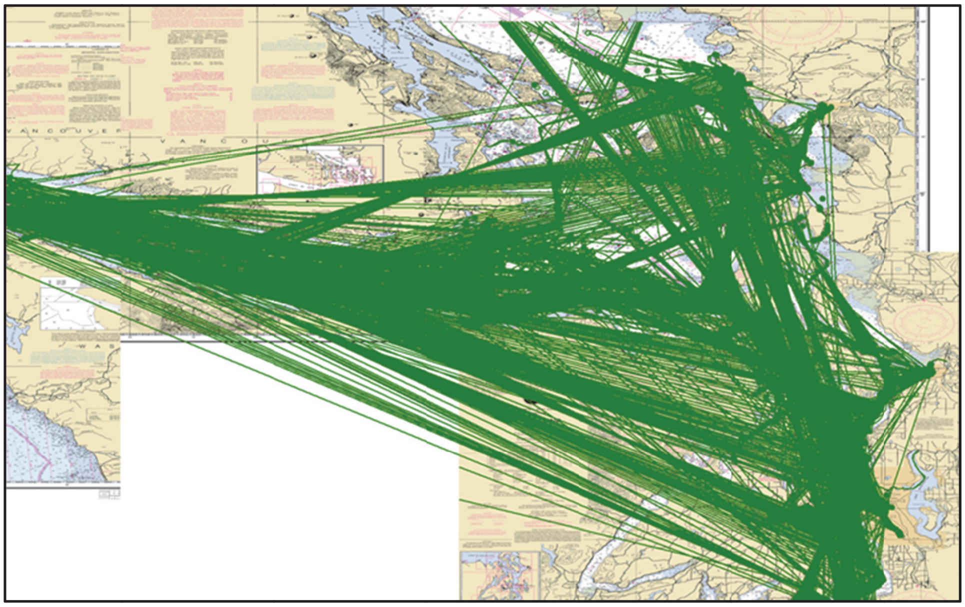

Figure 18. Route plots of the VTOSS 2010 data after algorithmically joining route segments.

Multiple VTOSS data phenomena cause the errors observed in Figure 18. 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 in Figure 19. 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 in Figure 20.

Additional algorithms were developed to remove a large proportion of the data inaccuracies depicted in Figure 18, Figure 19 and Figure 20. These algorithms were also designed to reduce the size of the VTOSS dataset by removing intermediate points when a vessel was in fact moving in 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.

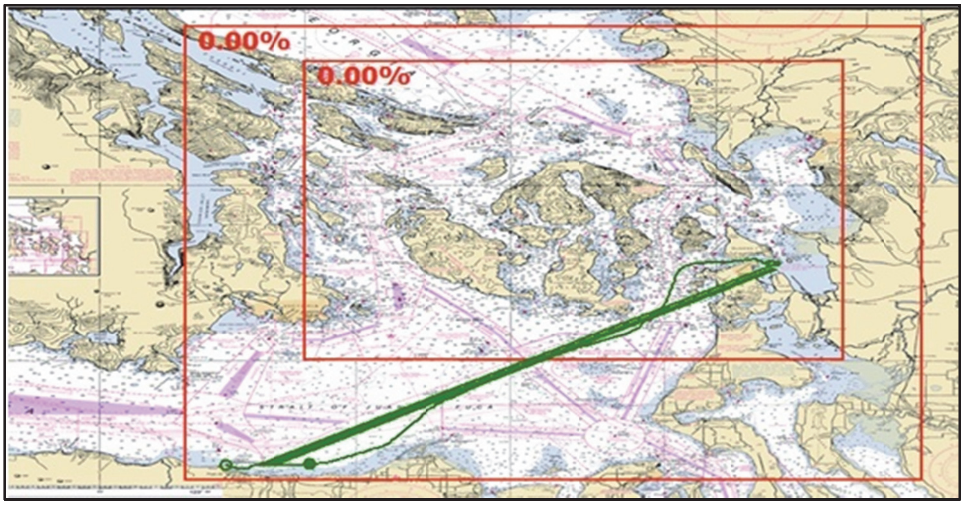

Figure 19. A route affected by the time problem after midnight in the VTOSS 2010 data.

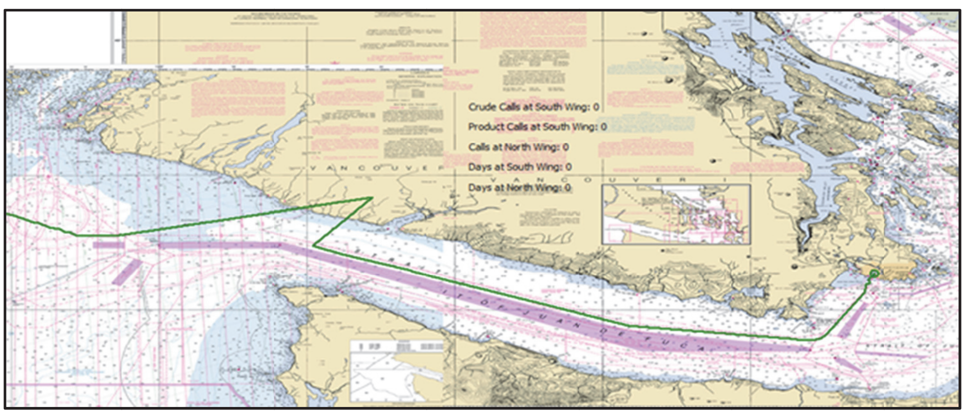

Figure 20. A route affected by problems identifying the correct location of the vessel.

Manual cleaning of VTOSS 2010 data

Unfortunately, as shown in Figure 21's left 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 21). Observe from of Figure 21'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 21's right panel using the VTOSS 2010 dataset. Recall that during the VTRA 2005 analysis a total of 1756representative routes were constructed for all vessel types.

Comparing Figure 21's right panel with Figure 8 one observes a larger dispersion of oil tanker routes in of Figure 21 than in Figure 8. The same observation can be made when comparing the algorithmically and manually cleaned routes for container vessels and bulk carriers in Figure 22 using VTOSS 2010 data, with the representative routes depicted in Figure 17 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 21 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 future analyses their routes were manually cleaned as depicted in Figure 22.

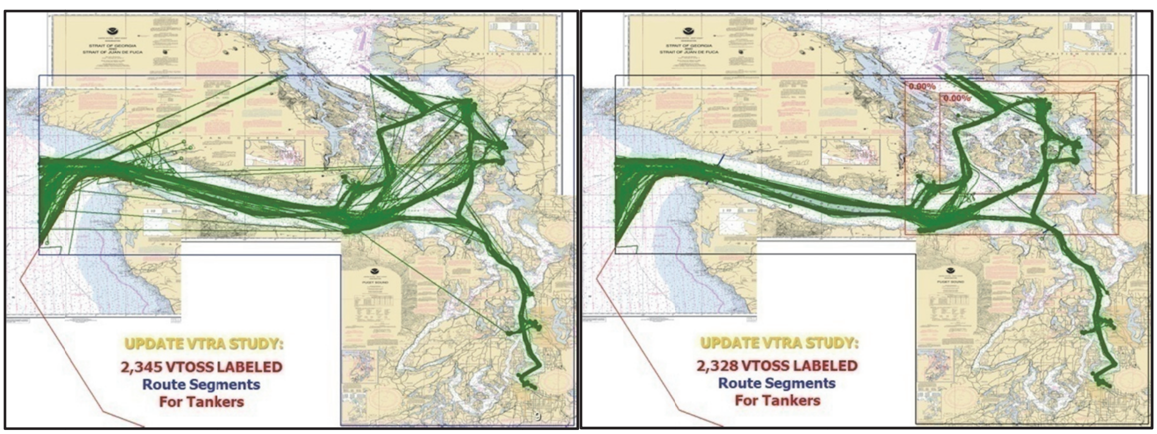

Figure 21. Left panel: 2,345 route segments after algorithmic cleaning of oil tanker routes. Right panel: 2328 route segments following manual cleaning of tankers routes following algorithmic cleaning.

Figure 23's left panel plots a route density for oil tankers generated using only the algorithmically cleaned routes displayed in Figure 21's left panel. In plotting this density, vessel movements that have no assigned waterway location are not plotted. Figure 24 plots a graphic of the fifteen waterway location definitions to be used in the updated GW/VCU MTS model. Figure 23's right panel plots a route density for oil tankers using the both algorithmically and manually cleaned routes depicted in Figure 21's right panel.

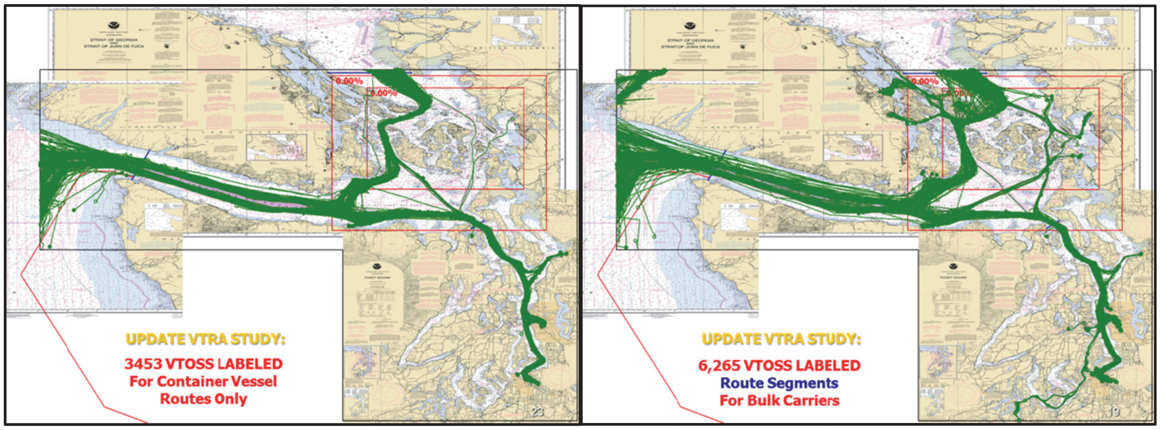

Figure 22. Left panel: 3,453 route segments after algorithmic and manual cleaning of container vessel routes. Right panel: 6265 route segments following algorithmic and manual cleaning of bulk carrier routes.

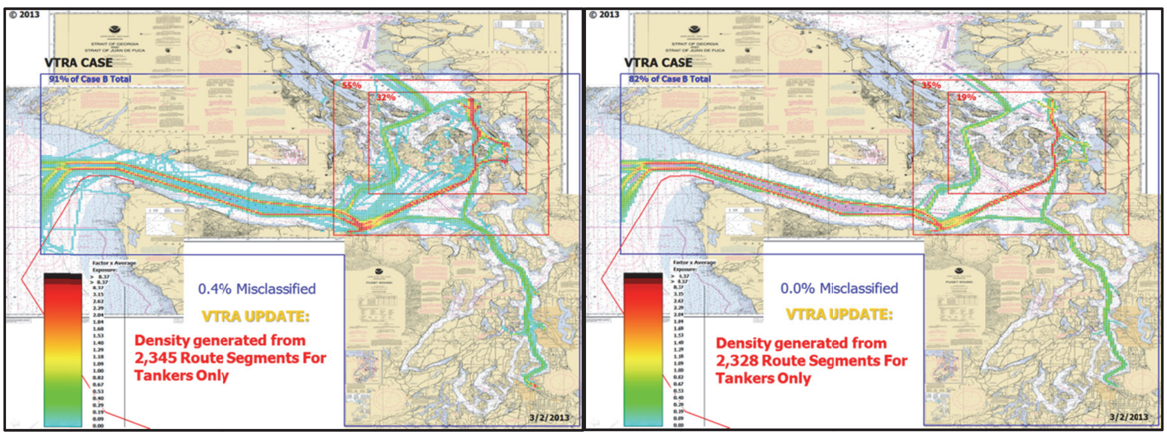

Figure 23. Left panel: Oil density tanker geographic profile generated using left panel routes in Figure 21. Right panel: Oil density tanker geographic profile generated using right panel routes in Figure 21.

In Figure 23's left panel 99.6% of the tankers movements have a waterway location (see Figure 23) assigned, whereas in its right panel 100% of tanker movements have a location assigned.

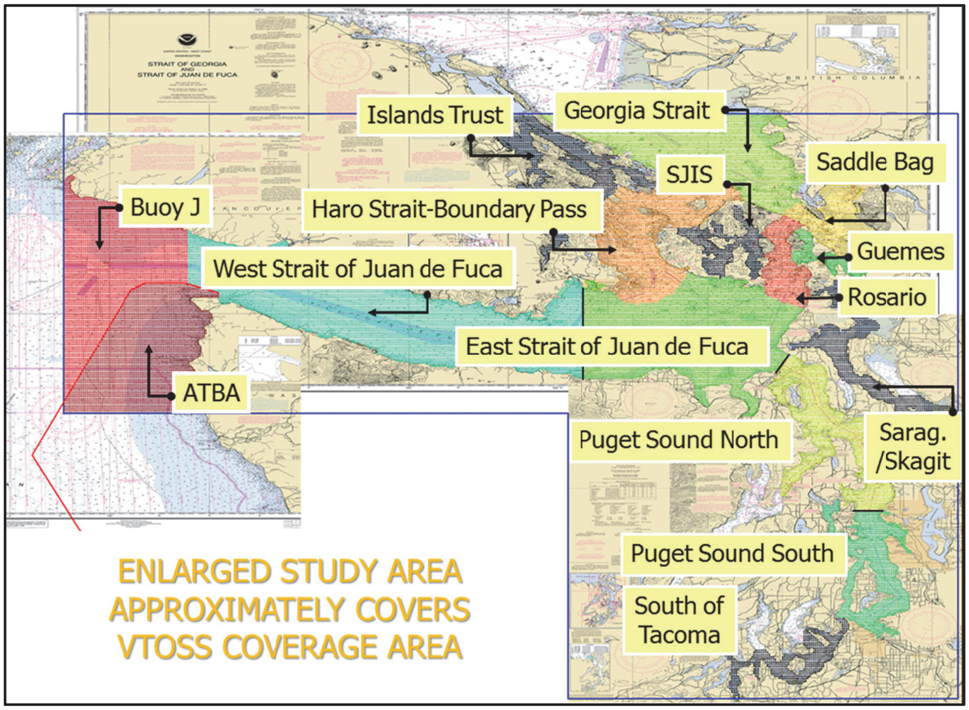

Figure 24. Location definitions used for the update of the GW/VCU MTS simulation from VTOSS 2005 to VTOSS 2010 data.

Vessel master type definition

Table 2 show 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 2 reveals different vessel types that are commonly assigned to the same vessel name.

Some of the entries in Table 2 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 2 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.

Table 2. 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

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 3 is introduced for the 26 vessel types in the VTOSS data sets. Observe from Table 3 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 3 were observed as well. For example, Table 4 shows a sample in the VTOSS 2005 dataset of cargo vessels that were sometimes classified as passenger vessels. Observe that in Table 4 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 3. 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 4. 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 5 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 6 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 3 provides the vessel master type definition used in the generation of Table 5 and Table 6 for the 26 vessel types in the VTOSS data sets. These percentages (in Table 5 and Table 6) 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 5 and Table 6).

Table 5. 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 24.

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 6. 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 24.

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 5 and Table 6 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 5 (2005) compared to the fifth column in Table 6 (2010), a definite improvement in vessel route dispersion is observed by going from Figure 17 (2005) to Figure 22 (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 5 and Table 6, 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 5 and Table 6 by the total number of minutes in a calendar year. Thus in Table 5 (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 6 (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 25 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 26 on the other hand plots this time series comparison for ferries, yachts and fishing vessels.

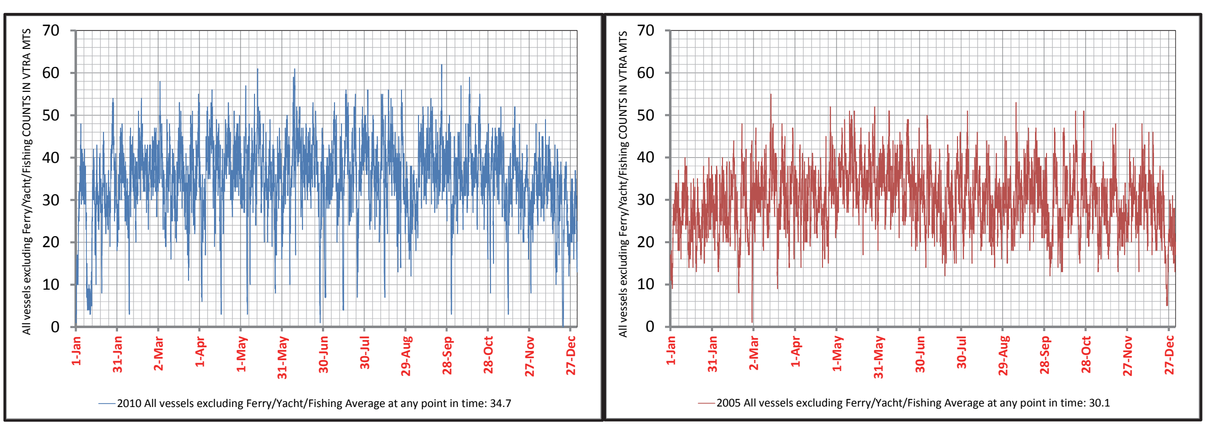

Figure 25. Left panel: Time series of counts of all vessels excluding ferries, yachts and fishing vessels in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

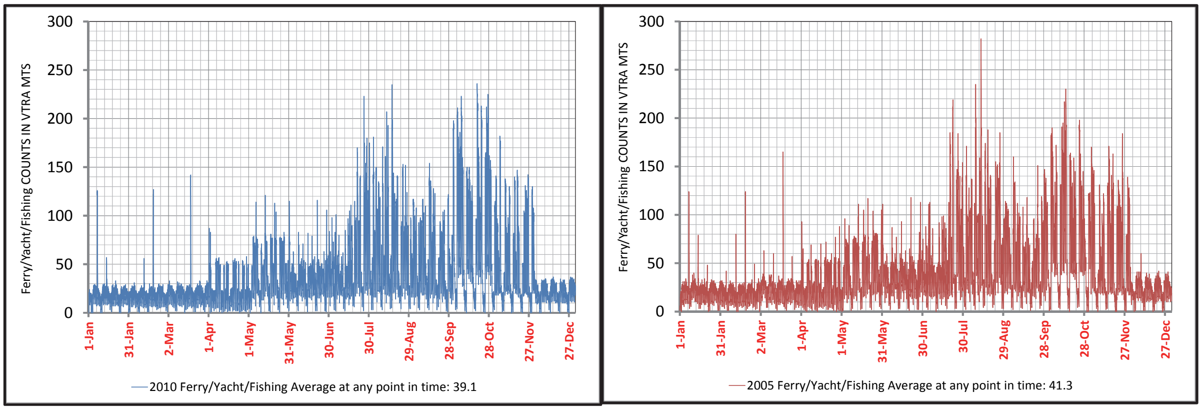

Figure 26. Left panel: Time series of counts of all ferries, yachts and fishing vessels in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

Both Figure 25 and Figure 26 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.

4. A comparison of some 2005 and 2010 traffic densities

Following the route update procedure as described in the previous section the left panels in Figure 27, Figure 28 and Figure 29 depict traffic densities generated using the VTOSS 2005 data whereas the right panels depict associated traffic densities using the VTOSS 2010 data. In Figure 27, Figure 28 and Figure 29, the left panel serves as the comparison panel as indicated by the factor 1.00 in the top left corner. Also, these left panels determine the colors scales of both panels chosen for contrast in a particular figure. Hence, one can visually compare the left and right panels in in Figure 27, Figure 28 and Figure 29 and observe changes in vessel movement distribution across the VTRA area by their vessel types: oil tanker, bulk carrier and container vessel, respectively. The factor in the top left corner of the right panel provides for the relative increase in traffic from the left panel to the right panel. Hence, we observe a factor 0.82 decrease going from VTOSS 2005 to VTOSS 2010 for oil tankers in Figure 27 over the study area. Similarly, one observes a factor 1.11 increase for bulk carriers in Figure 28 and what appears to be a factor 2.81 increase for container vessels in Figure 29.

The latter factor, however, appears to be not consistent with changes in container vessel traffic as reported by other data sources. For example, from vessel visit count data from the Marine Exchange Puget Sound (MXPS) in Figure 30 one observe factors 0.95 for oil tankers and 1.18 for bulk carriers, but one observes a factor 0.81 for container vessels. In Figure 31, transit counts provided by the USCG Seattle VTS are displayed, depicting a factor 1.09 increase for tankers from 2005 to 2010 and a factor increase of 1.07 for freighters. Hence, one concludes that neither data sources appear to be consistent in terms of the factor increases they provide by vessel type, except perhaps the factors 1.11, 1.18 and 1.07 in Figure 30, Figure 28 and Figure 31.

A number of explanations can be provided for these potential inconsistencies. First of all, visit counts provided by the Marine Exchange only count vessels visiting the US, whereas the generated traffic densities also count those vessels that only travel through Canadian waters. Secondly, transit counts provided by the US Coast guard count multiple transits per visit to the USCG Seattle coverage area, which is also smaller than the VTRA study area. Thirdly, the density evaluations in Figure 27, Figure 28 and Figure 29 display the distribution by vessel type of the amount of time that vessels spent within the system as explained in Table 6 and Table 5. Neither the Marine Exchange data nor the USCG data exhibit such a time element.

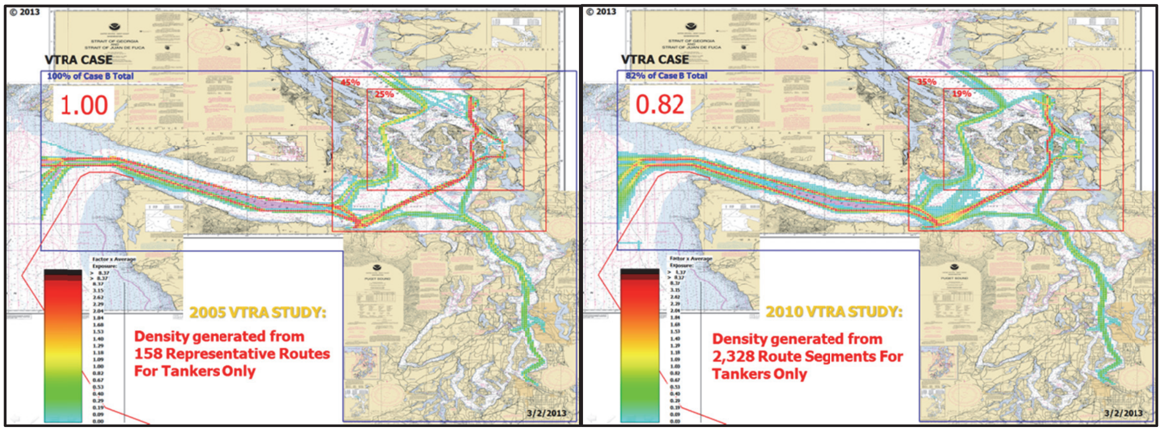

Figure 27. Left Panel: Oil tanker density generated using 2005 VTOSS data; Right Panel: Oil Tanker density generated using 2010 VTOSS data.

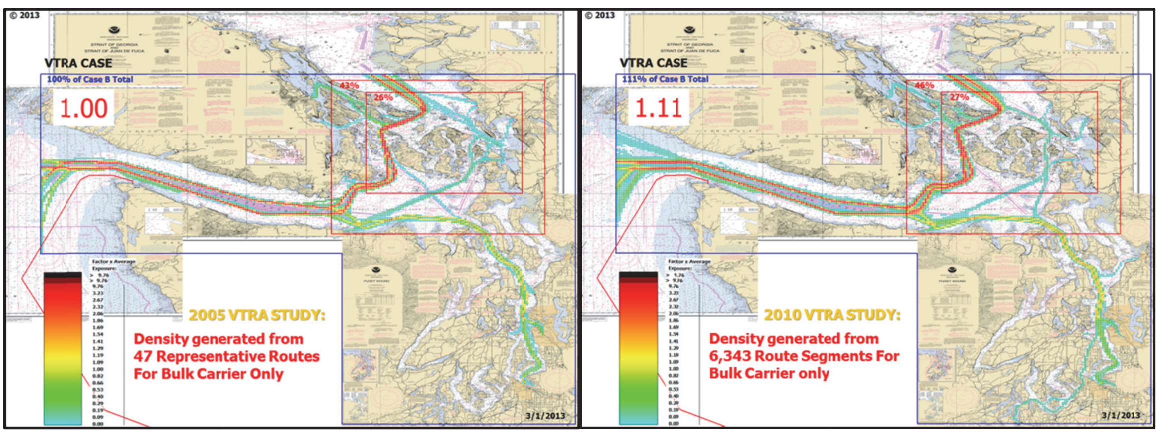

Figure 28. Left Panel: Bulk Carrier density generated using 2005 VTOSS data; Right Panel: Bulk carrier density generated using 2010 VTOSS data.

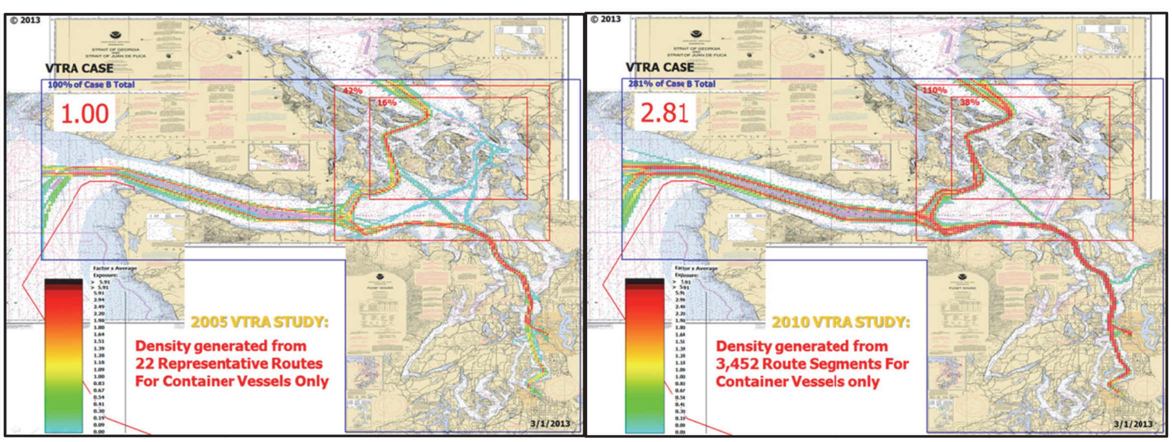

Figure 29. Left Panel: Container vessel density generated using 2005 VTOSS data; Right Panel: Container vessel density generated using 2010 VTOSS data.

2005 Marine Exchange Puget Sound VESSEL VISIT COUNTS

Vessel Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2005
BULK	32	25	32	24	33	26	23	34	21	28	28	26	332
CONTAINER	111	97	100	99	101	110	112	124	121	127	113	118	1333
GENERAL	15	8	17	11	17	16	15	21	16	18	14	14	182
PASSENGER	0	0	0	0	27	32	37	31	37	4	0	0	168
RO/RO	11	10	12	12	12	13	10	10	12	11	10	10	133
ATB	INCLUDED IN PETROL TANKER COUNTS												
VEHICLES	15	15	19	16	13	17	16	17	12	17	18	15	190
PETROL TANKER	49	46	49	46	51	49	55	51	51	48	47	58	600
NON-PETROL TANKER	0	3	0	0	3	0	1	1	1	2	1	2	14
OTHER*	2	0	4	2	2	4	5	6	5	1	4	0	35

1.18

0.81

2010 Marine Exchange Puget Sound VESSEL VISIT COUNTS

Vessel Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2010
BULK	35	32	35	36	31	30	40	34	21	31	37	31	393
CONTAINER	91	88	95	90	100	86	95	92	84	98	87	84	1090
GENERAL	8	6	5	7	7	10	3	5	5	7	7	4	74
PASSENGER	1	0	0	1	42	45	50	49	37	1	0	0	226
RO/RO	9	10	11	10	9	9	11	14	14	12	9	12	130
ATB	17	13	17	12	12	9	9	10	11	15	11	12	148
VEHICLES	12	19	17	18	14	18	17	15	22	19	19	15	205
PETROL TANKER	40	46	36	36	36	32	34	33	33	34	33	34	427
NON-PETROL TANKER	1	1	1	2	1	0	1	1	2	2	2	1	15
OTHER*	0	0	1	3	6	6	1	1	6	1	1	0	26

0.95

Figure 30. Vessel visit counts by vessel type for 2005 and 2010. Data provided per courtesy of the Marine Exchange Puget Sound.

2005 USCG SEATTLE VTS VESSEL TRANSIT COUNTS

Vessel Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2005
TANKER	166	181	163	178	170	184	180	192	188	155	183	177	2117
FREIGTHER	425	520	452	485	454	461	446	455	545	573	662	620	6098
TUGTOW	1874	2043	1838	1992	1901	1989	1947	2158	1986	1803	1921	2023	23475
FERRY	13441	13900	13232	13795	14089	14857	14869	14172	14205	13545	13739	12241	166085
PUBLIC	183	146	192	228	197	224	189	176	223	190	261	225	2434
OTHER	160	48	111	161	207	179	112	260	206	143	172	104	1863

1.07

1.09

2010 USCG SEATTLE VTS VESSEL TRANSIT COUNTS

Vessel Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2010
TANKER	191	232	165	221	195	178	149	220	173	200	195	199	**2318**
FREIGHTER	365	507	460	590	532	630	597	616	629	565	499	519	**6509**
TUGTOW	1684	2207	1809	2025	2075	2046	2058	2330	2281	2151	2059	1957	**24682**
FERRY	13543	12263	13640	13433	13879	13626	14406	14408	13874	13781	13301	13811	**163965**
OTHER FERRY	210	260	330	390	420	450	450	450	410	380	235	235	**4220**
EXCURSION	1087	1073	1124	1213	1135	1246	1369	1365	1036	938	880	906	**13372**
CRUISE	2	2	0	2	84	90	100	98	74	2	0	0	**454**
PUBLIC	95	238	199	324	311	323	246	364	270	244	241	219	**3074**
OTHER	135	149	146	214	278	413	392	660	507	383	286	151	**3714**

Figure 31. Vessel transit counts by vessel type for 2005 and 2010. Data provided per courtesy of the USCG Seattle VTS.

While differences in recording data methodology for these data sources may easily account for the variation in the factors for oil tankers and bulk carriers, the factor that asks for additional explanation is the factor 2.81 observed in Figure 29 for container vessels. Both the density counts for the VTOSS 2005 data source (serving as the denominator of the factor 2.81) and the VTOSS 2010 data source (serving as the numerator of the factor 2.81) may provide for this explanation. In moving forward using 2010 VTOSS data with future analysis, at a minimum it would be desirable to reconcile the 2010 VTOSS data with another 2010 datasource, since neither the Marine Exchange 2010 visit counts nor the USCG 2010 transit counts can serve this purpose. In the next section, we suggest the use of Automatic Independent Surveillance (AIS) 2010 data for that purpose.

5. Validation of 2010 VTOSS crossing line data to 2010 AIS 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 32 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 32. Unfortunately, no AIS data is available for the year 2005 for the geographic area in Figure 32A.

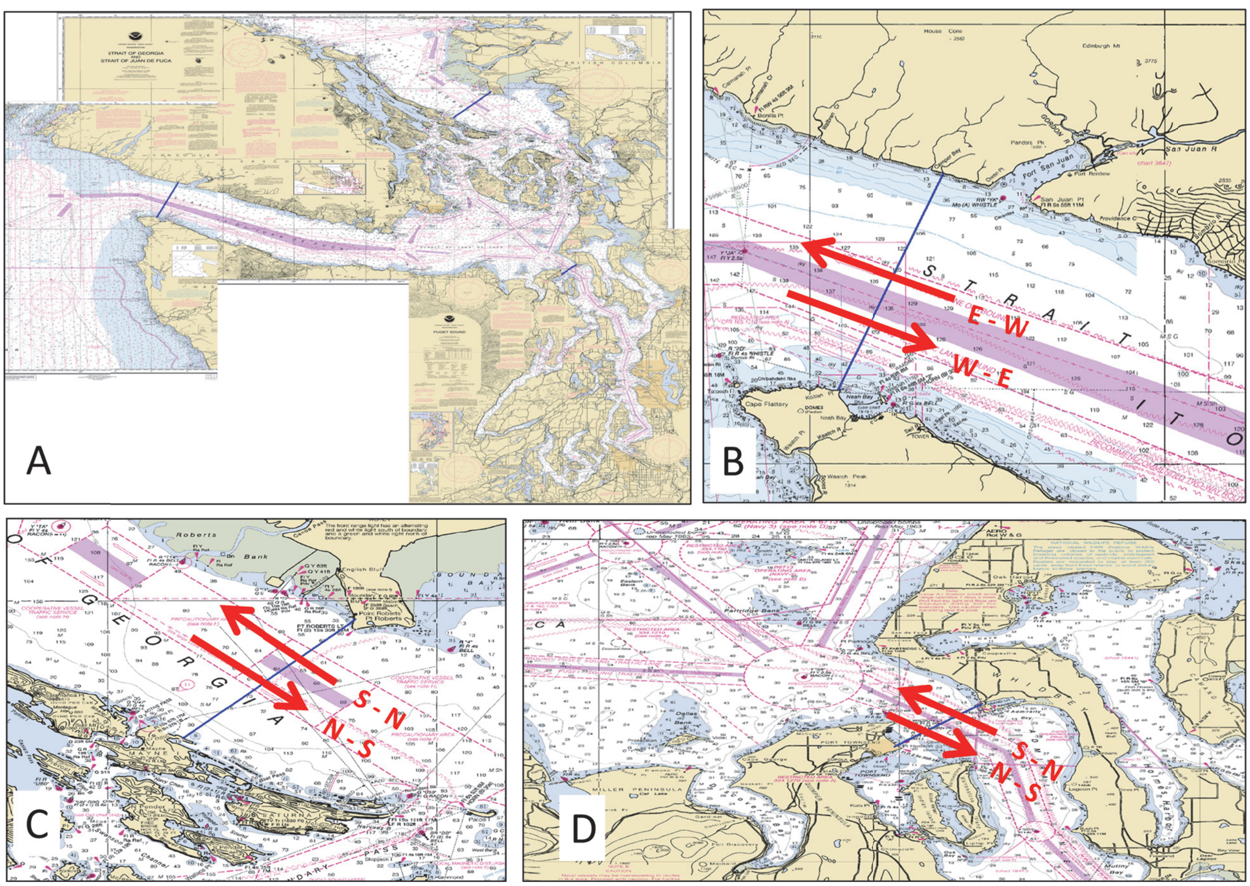

Figure 32. A: Overview of three AIS crossing definitions; B: Close-up view of crossing line at the West Strait of Juan de Fuca Entrance; C: Close-up view of crossing line at the George Strait entrance; D: Close-up view of the crossing line at the Puget Sound entrance.

Crossing line analysis of AIS 2010 data for the West Strait of Juan de Fuca, Georgia Strait and Puget Sound crossing lines depicted in Figure 32.

Table 7 provides the AIS 2010 crossing line counts for the three crossing lines depicted in Figure 32. 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 7. 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 32 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 3. Table 8 provides the crossing counts by vessel type and Table 9 by vessel master type as defined in Table 3 using the VTOSS 2010 dataset.

Table 8. 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 9. 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 9 that contrary to Table 7 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 7 85% is travelling south bound . 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 8 and Table 3 that 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 7. The VTOSS classification “Navy vessel” 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 8, its vessel master type was assigned based on the vessel type classification in Table 8 and Table 3.

In Figure 33, Figure 34 and Figure 35 a comparison is provided between the VTOSS 2010 GW/VCU MTS crossing line counts and AIS 2010 crossing line in Table 7 and Table 9 for cargo, tanker and passenger vessels. The “tug-tow“ master type crossing line counts in Table 9 are not included in the AIS 2010 crossing line counts. The “fishing” VTOSS 2010 master type counts in Table 9 includes the “Fishing vessel” counts from Table 8 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 32 for the vessel types: cargo, tanker and passenger.

From Figure 33 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 34 and Figure 35, 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 33, Figure 34 and Figure 35 than there is disagreement, leading to the conclusion that these two dataset reconcile well.

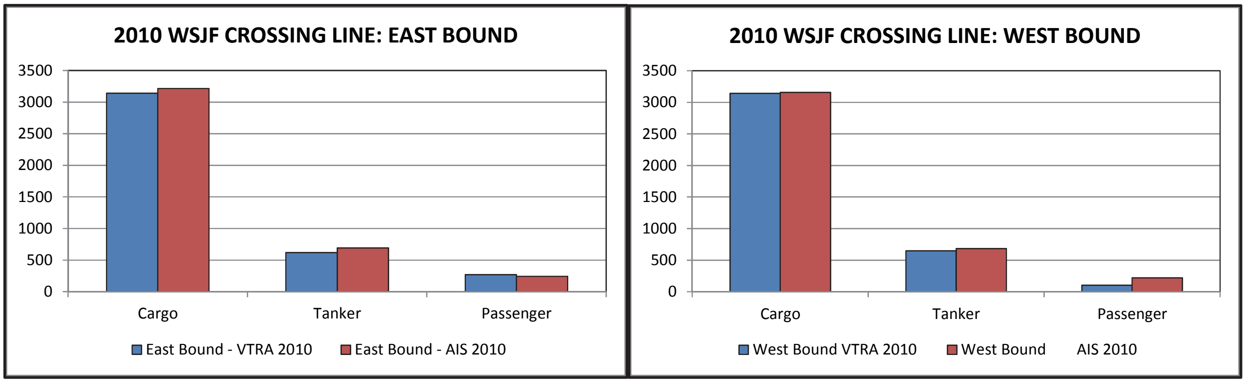

Figure 33. Comparison of AIS 2010 and VTOSS 2010 crossing line counts for cargo, tanker and passenger vessels for the West Strait of Juan de Fuca crossing line depicted in Figure 32B.

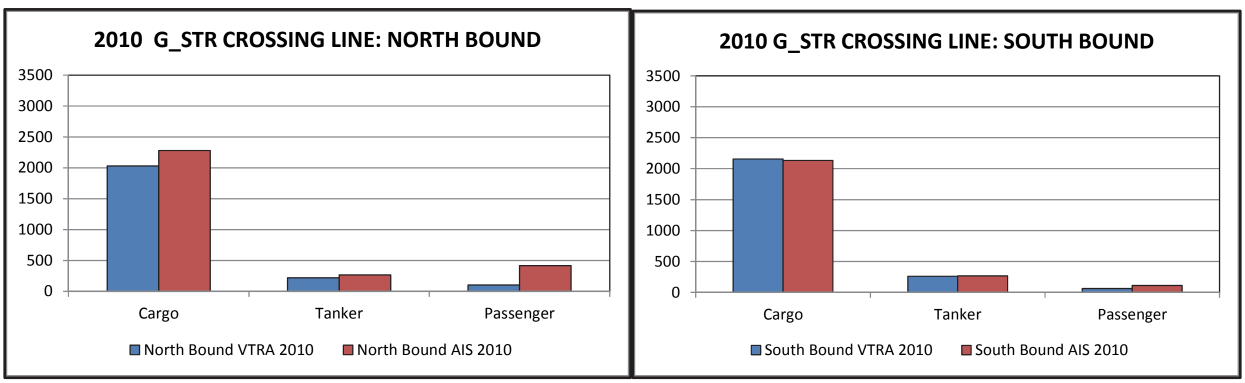

Figure 34. Comparison of AIS 2010 and VTOSS 2010 crossing line counts for cargo, tanker and passenger vessels for the Georgia Strait crossing line depicted in Figure 32C.

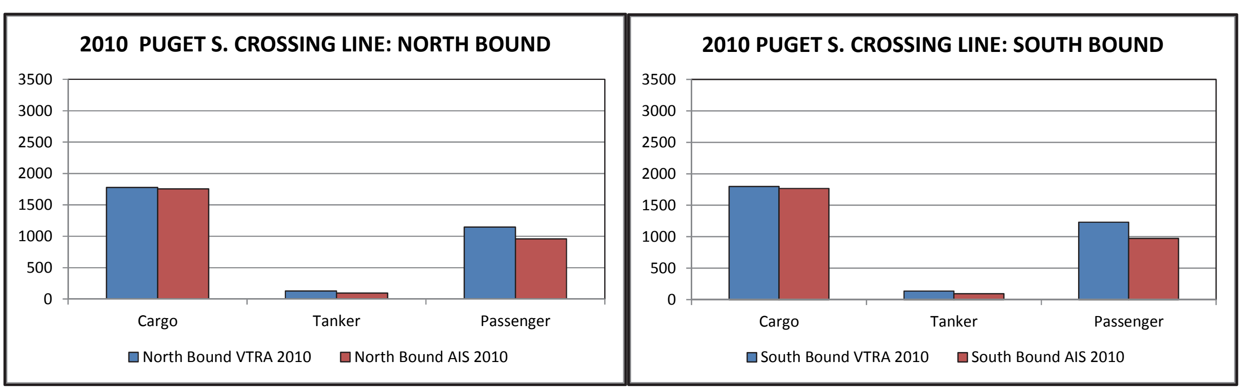

Figure 35. Comparison of AIS 2010 and VTOSS 2010 crossing line counts for cargo, tanker and passenger vessels for the Puget Sound crossing line depicted in Figure 32D.

Hence, the validation of VTOSS 2010 crossing line counts in the GW/VCU MTS simulation model by AIS 2010 crossing line counts.

6. An Exposure comparison of VTOSS 2005 and VTOSS 2010 traffic

Figure 36 shows the distribution by vessel master type as a percentage of the total time vessels move through the VTRA study area evaluated using the GW/VCU VTRA model using VTOSS 2005 and VTOSS 2010 data. The percentages in the left panel figure are listed in Table 5 (2005) and those of the right panel in Table 6 (2010). From Figure 36 one observes that the main difference between the VTOSS 2005 and VTOSS 2010 evaluated percentages is a decrease of 2.4% in passenger vessels and an increase of 4.8% in cargo vessels of their yearly TTE's. Recalling the factor 2.81 increase depicted in the right panel of Figure 29, and what would appear to be its inconsistency with the data presented in the USCG data (Figure 31) and MXPS data (Figure 30), a potential explanation could therefore be a misclassification of cargo vessels as passenger vessels in the VTOSS 2005 dataset (see also Table 4).

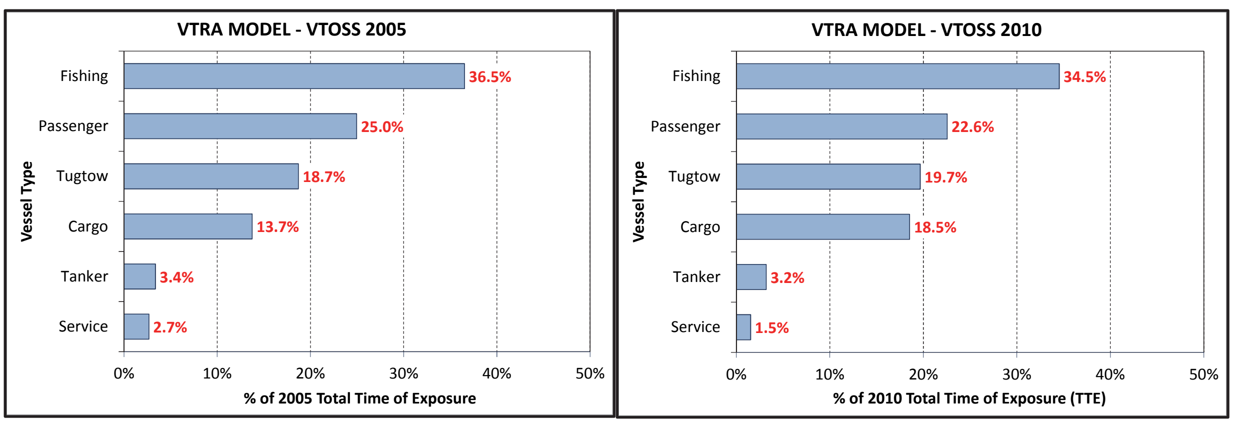

Figure 36. Percentage of Time a vessel is moving in the VTRA system by master type. Left panel: VTOSS 2005; Right Panel: VTOSS 2010.

Comparison by waterway locations

Table 10 (VTOSS 2005) and Table 11 (VTOSS 2010) detail the distribution of the time vessels move across the 15 waterway locations depicted Figure 24. Each waterway location in Figure 24 is defined as a collection of grid cells of equal size. The second columns in Table 10 and Table 11 list the number of grid cells by waterway location. Hence, by dividing these grid cell numbers by the total number of grid cells one evaluates the relative area of a particular waterway location with respect to the total waterway coverage modeled in the VTRA study area. These percentages are listed in the third columns of Table 10 and Table 11. The number in brackets following this percentage is a waterways location ranking in size across these 15 waterway locations. Hence, for example, the largest area (WSJF) obtains rank 1 and the smallest area (Guemes) obtains rank 15.

The fourth columns in Table 10 and Table 11 list the number of days a vessel moves within a particular waterway location. Dividing the number of days by 365 provides the average number of vessels moving in a waterway location at an arbitrary point in time (the fifth columns in Table 10 and Table 11). If one divides the number of days vessels move in a particular waterway location by the total number of days these vessels move in the overall study area, one obtains the location's percentage of total time of exposure, abbreviated TTE (the sixth columns in Table 10 and Table 11). Finally, by dividing a waterway locations % TTE by the relative size of a waterway location (the third columns in Table 10 and Table 11), one obtains a waterway location's density factor (the last columns of Table 10 and Table 11). A density factor (DF) of 1.0 in Table 10 or Table 11 describes average density levels across the 15 waterway locations in that particular table. Hence from Table 10 (VTOSS 2005) it follows that in the Puget Sound South it was about 3.54 times as busy than average across the VTRA study area in 2005. The numbers in brackets in columns six and seven provide the rank of a particular waterway location in that column. Thus, for example, in Table 10 (VTOSS 2005) the WSJF ranks first in area, second in % TTE and finally tenth in terms of density factor.

Concentrating on the time of exposure rankings in Table 10 and Table 11, all rankings remained the same except for the following:

1. Georgia Strait, Buoy J, West Strait of Juan de Fuca, San Juan Islands and Saragota/Skagit waterway locations went up two, two, one, one and one positions in ranking, respectively, from the VTOSS 2005 analysis to the VTOSS 2010 analysis.
2. Puget Sound South, Tacoma South, Rosario and Saddlebag went down three, two, one and one positions in ranking, respectively, from the VTOSS 2005 analysis to the VTOSS 2010 analysis.

Concentrating on density factor rankings in Table 10 and Table 11, all rankings remained the same except for the following:

1. Buoy J and Puget Sound North waterway locations went up two and one positions in ranking, respectively, from the VTOSS 2005 analysis to the VTOSS 2010 analysis.
2. Tacoma South and Saddlebag waterway locations went down two and one positions in ranking, respectively, from the VTOSS 2005 analysis to the VTOSS 2010 analysis.

In Figure 37, the % TTE of the 15 waterway location in Figure 24 are depicted using a tornado diagram format. In the right panel of Figure 37, the same ranking is used as in the left panel to allow for a visual comparison of the change in TTE percentages going from VTOSS 2005 to VTOSS 2010 analysis. Moreover, % TTE in the right panel in Figure 37 are

Table 10. Route and density data by waterway location generated using the GW/VCU MTS simulation model with 2005 VTOSS data and location definitions in Figure 24.

LOCATION	# Grid Cells	% Area - Rank	# Vessel days moving per year	Average # of Vessels	% of TTE - Rank	Density Factor (DF) - Rank
WSJF	2857	19.6% - (1)	3816.9	10.5	14.2% - (2)	0.72 - (10)
PS South	619	4.3% - (9)	4054.0	11.1	15.1% - (1)	3.54 - (1)
Guemes	127	0.9% - (15)	574.3	1.6	2.1% - (11)	2.45 - (3)
ESJF	2049	14.1% - (2)	3546.9	9.7	13.2% - (3)	0.94 - (8)
Georgia Str.	1424	9.8% - (5)	3319.8	9.1	12.3% - (4)	1.26 - (7)
PS North	983	6.8% - (7)	2957.3	8.1	11.0% - (5)	1.63 - (5)
Saddlebag	375	2.6% - (11)	1289.0	3.5	4.8% - (8)	1.86 - (4)
Haro/Boun.	1066	7.3% - (6)	2725.4	7.5	10.1% - (6)	1.38 - (6)
Rosario	307	2.1% - (13)	1436.1	3.9	5.3% - (7)	2.53 - (2)
Bouy J	1478	10.2% - (4)	1263.4	3.5	4.7% - (9)	0.46 - (13)
ATBA	1520	10.5% - (3)	86.8	0.2	0.3% - (15)	0.03 - (15)
Tac. South	326	2.2% - (12)	349.7	1.0	1.3% - (12)	0.58 - (11)
SJ Islands	259	1.8% - (14)	237.0	0.6	0.9% - (14)	0.49 - (12)
Sar./Skagit	459	3.2% - (10)	270.2	0.7	1.0% - (13)	0.32 - (14)
Islands Trt	696	4.8% - (8)	967.8	2.7	3.6% - (10)	0.75 - (9)
Total	**14545**	**100.0%**	**26894.6**	**73.7**	**100.0%**	**1.0**

Table 11. Route and density data by waterway location generated using the GW/VCU MTS simulation model with 2010 VTOSS data and location definitions in Figure 24.

LOCATION	# Grid Cells	% Area - Rank	# Vessel days moving per year	Average # of Vessels	% of TTE - Rank	Density Factor (DF) - Rank
WSJF	2857	19.6% - (1)	4157.3	11.4	14.9% - (1)	0.76 - (10)
PS South	619	4.3% - (9)	3527.5	9.7	12.6% - (4)	2.97 - (1)
Guemes	127	0.9% - (15)	475.1	1.3	1.7% - (11)	1.95 - (3)
ESJF	2049	14.1% - (2)	3687.4	10.1	13.2% - (3)	0.94 - (8)
Georgia Str.	1424	9.8% - (5)	3862.5	10.6	13.8% - (2)	1.41 - (7)
PS North	983	6.8% - (7)	3420.7	9.4	12.3% - (5)	1.81 - (4)
Saddlebag	375	2.6% - (11)	1089.6	3.0	3.9% - (9)	1.51 - (5)
Haro/Boun.	1066	7.3% - (6)	2960.0	8.1	10.6% - (6)	1.45 - (6)
Rosario	307	2.1% - (13)	1349.6	3.7	4.8% - (8)	2.29 - (2)
Bouy J	1478	10.2% - (4)	1414.8	3.9	5.1% - (7)	0.50 - (11)
ATBA	1520	10.5% - (3)	170.5	0.5	0.6% - (15)	0.06 - (15)
Tac. South	326	2.2% - (12)	227.2	0.6	0.8% - (14)	0.36 - (13)
SJ Islands	259	1.8% - (14)	240.7	0.7	0.9% - (13)	0.48 - (12)
Sar./Skagit	459	3.2% - (10)	302.6	0.8	1.1% - (12)	0.34 - (14)
Islands Trt	696	4.8% - (8)	1017.5	2.8	3.6% - (10)	0.76 - (9)
Total	**14545**	**100.0%**	**27903.1**	**76.4**	**100.0%**	**1.0**

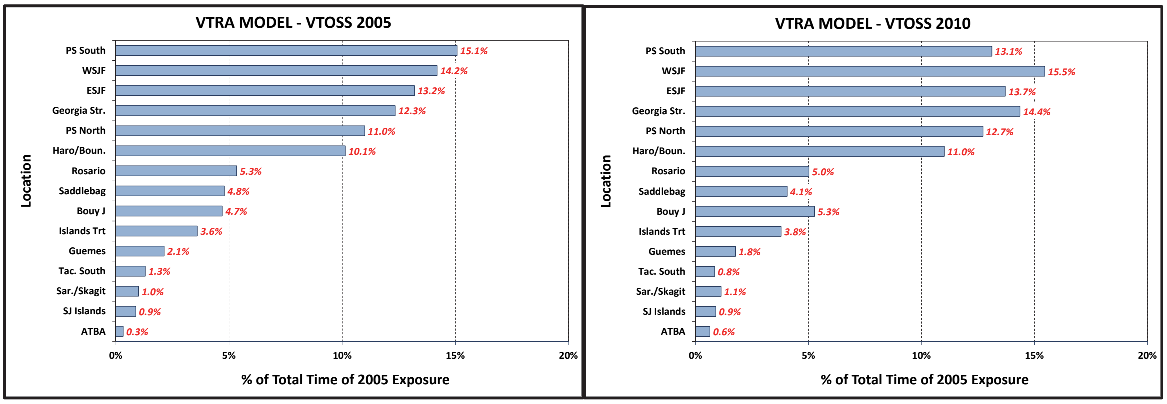

Figure 37. % of total time of exposure (TTE) of VTRA model using VTOSS 2005 data by waterway location. Left Panel: VTOSS 2005 percentages of 2005 TTE; Right Panel: VTOSS 2010 percentages of 2005 TTE

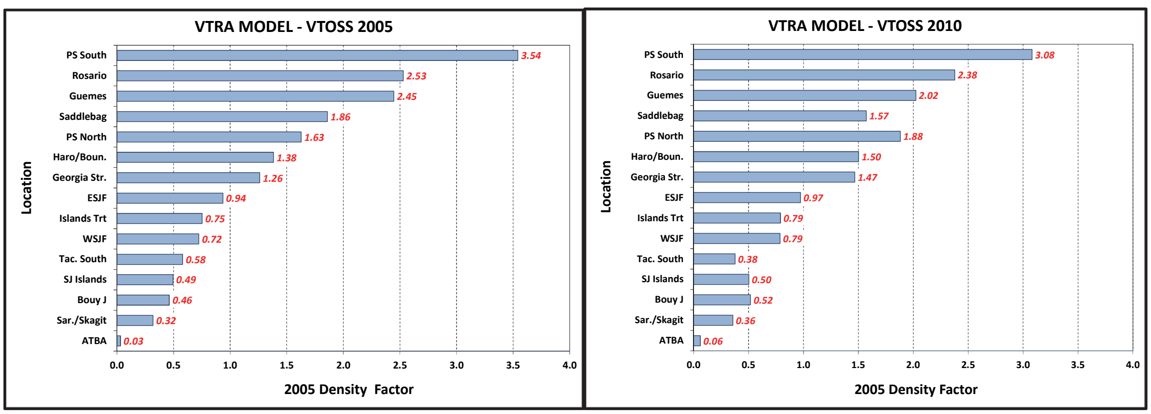

Figure 38. 2005 density factors of VTRA model using VTOSS 2005 data by waterway location. Left Panel: VTOSS 2005 density factors using VTOSS 2005; Right Panel: 2005 density factor using VTOSS 2010.

expressed in terms of 2005 TTE. Hence, in terms of VTOSS 2005 TTE, the Puget Sound South went down from 15.1% to 13.1%. Similar conclusions can be drawn for the other locations from Figure 37.

In Figure 38, the density factors and rankings of the 15 waterway location in Figure 24 are depicted using a tornado diagram format. In the right panel of Figure 37, the same ranking is used as in its left panel to allow for a visual comparison of the change in density factors going from VTOSS 2005 to VTOSS 2010 analysis. Moreover, the density factor in the right panel of Figure 33 is expressed in terms of 2005 density factors. Hence, in terms of VTOSS 2005 density factor, the Puget Sound South went down from 3.54 to 3.08. Similar conclusions can be drawn for the other locations from Figure 38.

Comparison by waterway locations and vessel master type

In Figure 39 the % TTE is plotted by waterway location and vessel mastertype for the VTOSS 2005 analysis. The left panel plots these percentages for tanker, cargo and tug-tow vessels, whereas the right panel shows them for service, passenger and fishing vessels. The ordering along the waterway location axes in Figure 39 follows the ranking of the left panel tornado diagram in Figure 37 (i.e. the ranking that follows from the VTOSS 2005 analysis).

In Figure 40 the % of TTE is plotted by waterway location and vessel mastertype for the VTOSS 2010 analysis. The left panel plots these percentages for tanker, cargo and tug-tow vessels, whereas the right panel shows them for service, passenger and fishing vessels. The ordering along the waterway location axes in Figure 39 here too follows the ranking of the left panel tornado diagram in Figure 37 (i.e. the ranking that follows from the VTOSS 2005 analysis) to allow for a visual comparison between Figure 39 and Figure 40.

Concentrating on the distribution across the 15 waterway locations by vessel master type going from Figure 39 (VTOSS 2005) to Figure 40 (VTOSS 2010) one can visually (but cautiously) draw the following conclusions:

1. One observes a remarkable agreement and stability between these figures in terms of their overall patterns.
2. A decrease in passenger vessels is observed in the Puget Sound South going from the right panel in Figure 39 (VTOSS 2005) to the right panel in Figure 40 (VTOSS 2010).
3. One observes a slight increase for cargo vessel across the 15 waterway locations in the left panel of Figure 40 (VTOSS 2010) compared to the left panel in Figure 39 (VTOSS 2005) with the most notable increase in the West Strait of Juan de Fuca.
4. A similar increase in Tug-tow operations is observed in the Puget Sound North as a decrease in the Puget Sound South in the left panel of Figure 40 (VTOSS 2010) explaining the differences in tug-tow operations observed in Figure 39 (VTOSS 2005) and Figure 40.
5. Service level operations are down in the Strait of Juan de Fuca going from the right panel in Figure 39 (VTOSS 2005) to the right panel of Figure 40 (VTOSS 2010).
6. Tanker level operations seem to have stayed relatively stable going from Figure 39 (VTOSS 2005) to Figure 40 (VTOSS 2010).

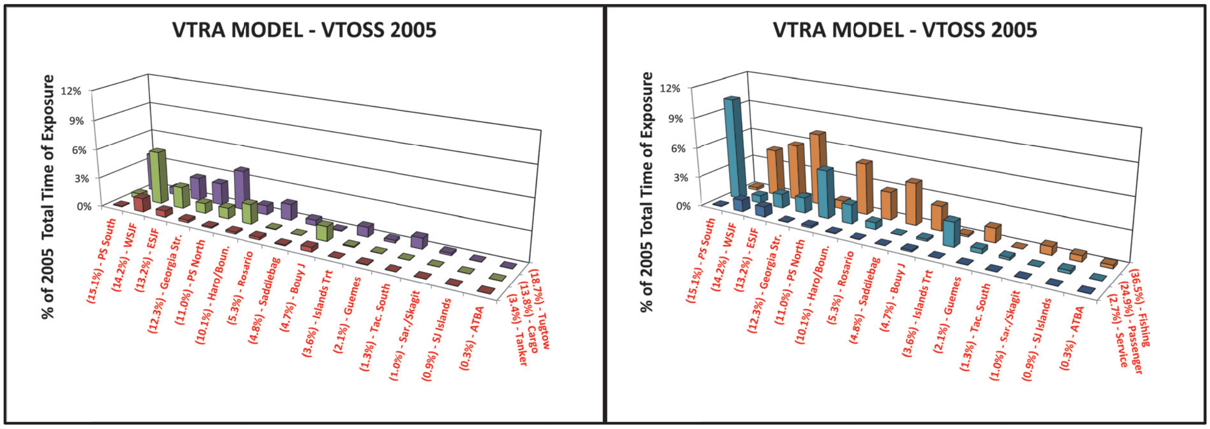

Figure 39.% of 2005 total time of exposure (TTE) of VTRA model using VTOSS 2005 data by waterway location and mastertype. Left Panel: Tug-tow, Cargo, Tanker; Right Panel: Fishing, Passenger, Service.

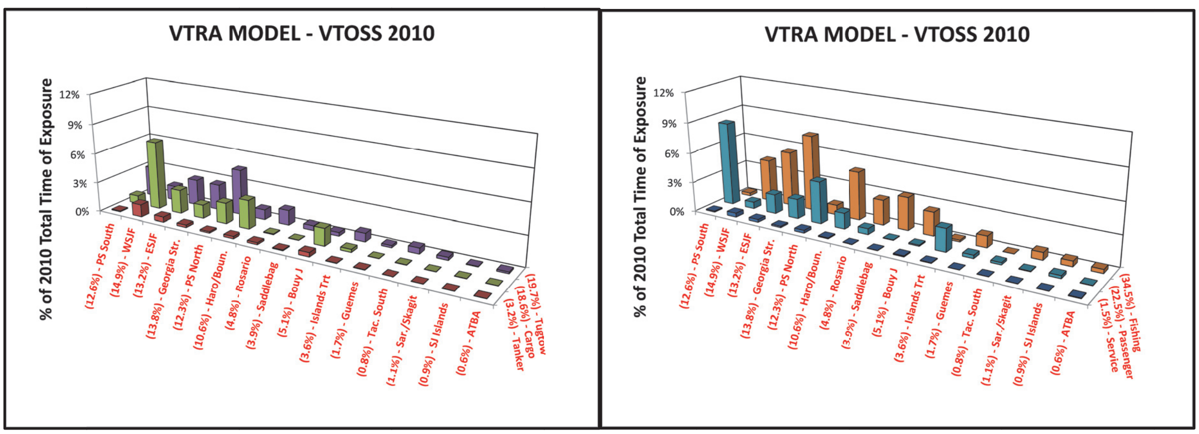

Figure 40. % of 2010 total time of exposure (TTE) of VTRA model using VTOSS 2010 data by waterway location and mastertype. Left Panel: Tug-tow, Cargo, Tanker; Right Panel: Fishing, Passenger, Service.

Comparison of traffic densities by vessel mastertype

In Figure 41 we present a geographic profile of all traffic combined for the GW/VCU model using VTOSS 2005 data, but also including whale watching, commercial and tribal fishing openers and organized regatta events modeled for the year 2005. The later "smaller" traffic does not get recorded in the VTOSS datasets. In the middle of Figure 41 the percentages in the left panel of Figure 36 are displayed totaling 100% of the combined 2005 traffic density. This is indicated by the 100% in the top left corner of the bleu border VTRA study area in Figure 41. In the top left corner of the larger red rectangle in Figure 41 it is indicated that 54% of the total 100% in the top left blue border is contained within this larger red rectangle. Similarly, 37% of the total traffic density is contained within the smaller red rectangle.

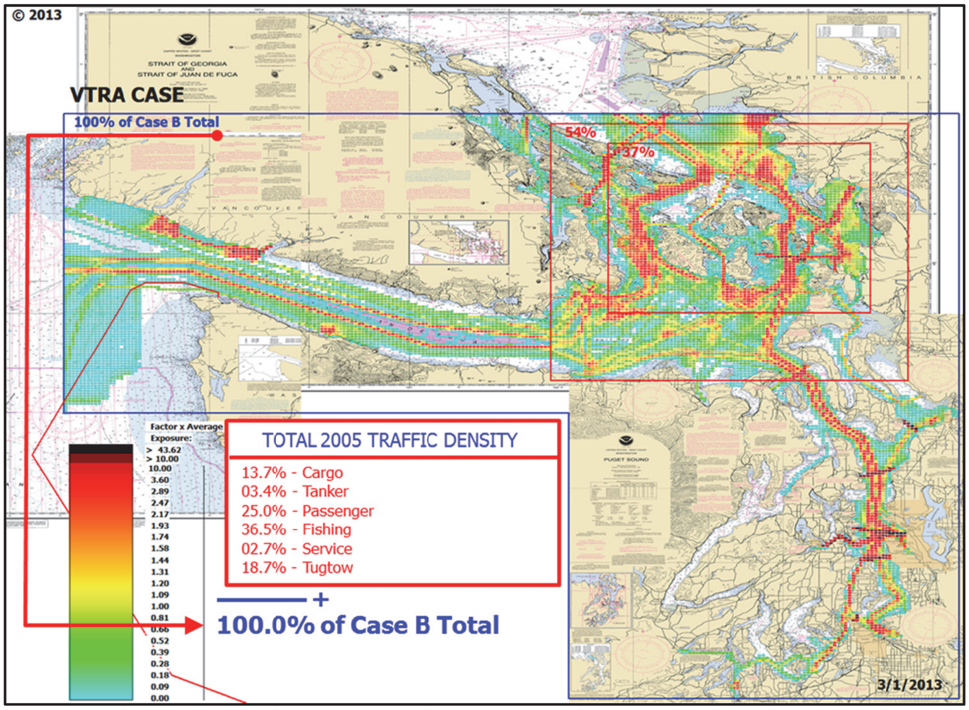

Figure 41.Geographic profile of 2005 total traffic density distribution across the VTRA study area.

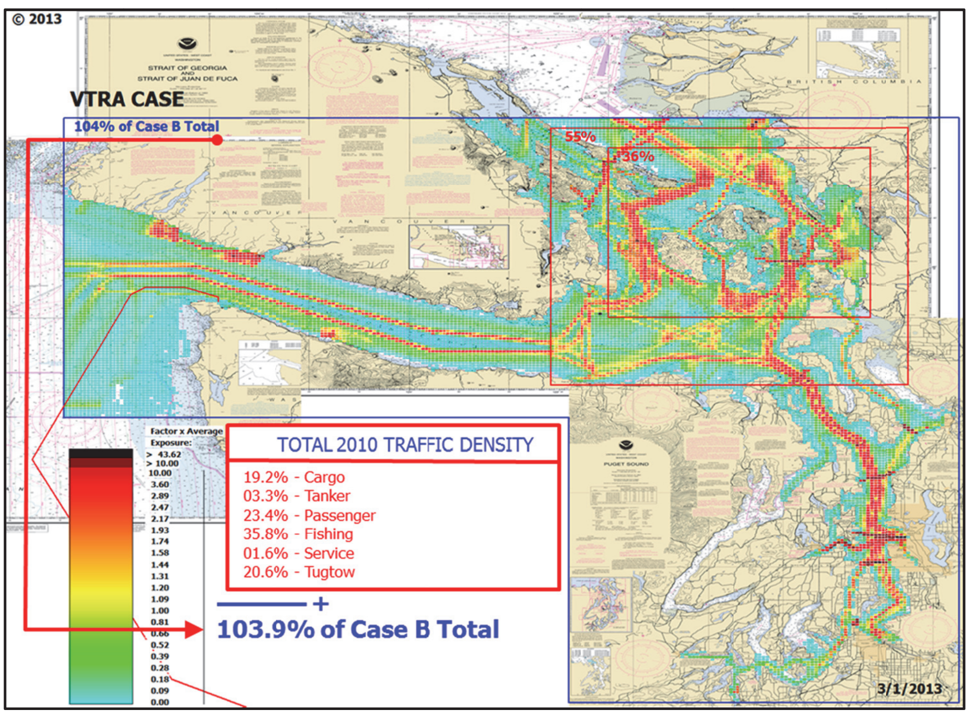

Figure 42. Geographic profile of 2005 total traffic density distribution across the VTRA study area.

From the above we can conclude that in the VTRA 2005 model (54%-37%) = 17% of the total traffic is accounted for inside the larger red rectangle, but outside the smaller one. Finally, one concludes from Figure 41 that (100%-54%) = 46% is accounted for outside the larger red square, but within the blue border of the VTRA study area. All these percentages are evaluated in terms of total 2005 traffic density.

The color scale in Figure 41 compares the time of exposure of a particular grid cell to a moving vessel within it to the average exposure of vessels moving within a grid overall grid cells in Figure 41. The color yellow coincides with this average as indicated by the factor 1.0 to the right of the yellow color in the color legend. Those grid cells with an exposure less than average are assigned a color below the yellow color and those that are above get a color assigned above the yellow color. To the right of each color on the color legend it is indicated by what approximate factor the exposure in the particular grid cell differs from the observed average across all grid cells.

In Figure 42, we present a geographic profile of all traffic combined for the GW/VCU model using VTOSS 2010 data, but as in the case of Figure 41 also including whale watching, commercial and tribal fishing openers and organized regatta events modeled for the year 2005 (which was not updated). The percentages in Figure 42 are all evaluated with respect to the total 2005 traffic density. Thus the percentages in the middle of Figure 42 do not coincide with the percentages evaluated in the right panel of Figure 36. The latter are evaluated in terms of 2010 total traffic density. The color legend in Figure 42 is also the same as the color legend in Figure 41. Hence, by observing color changes from Figure 41 to Figure 42 one observes changes in overall traffic density going from 2005 to 2010. For example, at about the middle of the larger red rectangle we see a reduction in traffic density going from Figure 41 to Figure 42.

In retaining percentage calculation in Figure 42 with respect to 2005 overall traffic the following conclusion can be drawn by comparing Figure 42 and Figure 41:

1. Overall the traffic went up from 100% to 104% going from 2005 to 2010.
2. The traffic density in the larger red rectangle increased from 54% to 55% going from 2005 to 2010.
3. The traffic density in the smaller red rectangle decreased from 37% to 36% going from 2005 to 2010.
4. The traffic density inside the larger red rectangle, but outside the smaller one, increased from (54%-37%)=17% to (55%-36%)=19%.
5. The traffic density outside the larger red rectangle, but within the blue border of the VTRA study area increased from (100%-54%)=46% to (104%-55%)=49%.

Of course, the conclusions above do not detail changes with respect to vessel master types. Hence, Figure 43 and Figure 44 provide for such a geographic profile comparison for just the cargo vessel master type. Now, the 100% in the top left blue border in Figure 43 relates to the total cargo traffic density in 2005, whereas the 140% in the top left blue border relates to the total cargo traffic density in 2010, but evaluated in terms of the 2005 total cargo density. Thus, overall it would appear that cargo density increased from 100% to 140% going from Figure 43 (2005) to Figure 44 (2010). As before, the color legend in Figure 44 is chosen the same as in Figure 43 so one can visually observe where those changes have occurred. Overall one observes the darker colors have gotten darker going from Figure 43 (2005) to Figure 44 (2010). This would indicate a distributed increase in cargo vessels consistent with the conclusion drawn by comparing the left panels in Figure 39 and Figure 40.

By comparing, the middle of Figure 39 and Figure 40 one concludes that the increase in cargo traffic primarily has to arise from the increase from 13.5% to 37.9% for container vessels. This is in fact consistent with the factor 2.81 reported in the top left corner of the right panel in Figure 29. However, it was this factor that led us to validate the VTOSS 2010 crossing line counts to AIS 2010 crossing line counts in Section 5, since what appeared to be an inconsistency with changes in cargo traffic reported in Figure 30 and Figure 31 by the MXPS and USCG. Unfortunately, such an AIS validating data source was not and is not available in 2005 leading to the following three possible explanations:

1. Container traffic did increase from 2005 to 2010.
2. Container traffic in 2005 was under reported in VTOSS 2005 due to a misclassification of vessel types.
3. Container traffic in 2010 was over reported in VTOSS 2010 due to a misclassification of vessel types.

We can only conjecture at this time that explanation two is the more likely explanation given our observation in Table 4 and the relative small number of percentage container traffic (13.5%) represents in Figure 43 as compared to the percentage container traffic (37.9%) representing in Figure 44. This is reinforced by the observation that all other major cargo types are up in the middle of Figure 44. Overall, however, the explanation of the factor 2.81 is quite likely a combination of the above three explanations. This lack of being able to provide a conclusive explanation only emphasizes more the value of the validation of the VTOSS 2010 crossing line counts to the AIS 2010 crossing line counts described in Section 5.

A comparison of traffic densities by other vessel master types is provided as follows:

1. Tanker traffic density: Figure 45 (2005) and Figure 46 (2010)

2. Tug-tow traffic density: Figure 47 (2005) and Figure 48 (2010)
3. Passenger traffic density: Figure 49 (2005) and Figure 50 (2010)
4. Fishing traffic density: Figure 51 (2005) and Figure 52 (2010)
5. Service vessel traffic density: Figure 53 (2005) and Figure 54 (2010)

We close the comparison of the geographic profile traffic densities by the summary analysis presented in Table 12 related the VTRA blue border, larger red rectangle and smaller red rectangle percentage comparisons by vessel master type. The bottom part of Table 12 evaluates the relative increase from 2005 to 2010 in a particular sub area. For example, the relative increase in total density outside the large red rectangle from 2005 to 2010 is 106% as opposed to an overall increase for the entire study area of 103.7%. As another example, we observe that cargo (136%) and Tug-tow (103%) are up in the smaller red rectangle, passenger (90%), fishing (95%), service (45%) are down and tanker traffic (100%) retained the same level.

Table 12. A comparison of VTOSS 2005 and VTOSS 2010 geographic profiles by areas indicated therein.

	MASTER TYPE	% TTE	VTRA STUDY AREA	INSIDE LARGER RED RECTANGLE	OUTSIDE LARGE RED RECTANGLE	INSIDE SMALLER RED RECTANGLE	OUTSIDE SMALL, INSIDE LARGE RED RECTANGLE
2005	Cargo	13.7%	100%	45%	55%	22%	23%
	Tanker	3.4%	100%	45%	55%	25%	20%
	Tugtow	18.7%	100%	47%	53%	30%	17%
	Passenger	25.0%	100%	37%	63%	20%	17%
	Fishing	36.5%	100%	72%	28%	59%	13%
	Service	2.7%	100%	57%	43%	20%	37%
	Total	100.0%	100%	54%	46%	37%	17%
2010	Cargo	19.2%	140%	61%	79%	30%	31%
	Tanker	3.3%	98%	44%	54%	25%	19%
	Tugtow	20.4%	109%	53%	56%	31%	22%
	Passenger	23.4%	94%	39%	55%	18%	21%
	Fishing	35.8%	98%	67%	31%	56%	11%
	Service	1.6%	59%	26%	33%	9%	17%
	Total	103.7%	104%	55%	49%	36%	19%
2010 / 2005	Cargo	139.70%	140%	136%	143%	136%	135%
	Tanker	98.00%	98%	98%	98%	100%	95%
	Tugtow	109.00%	109%	113%	106%	103%	129%
	Passenger	94.00%	94%	105%	87%	90%	124%
	Fishing	98.00%	98%	93%	111%	95%	85%
	Service	59.10%	59%	46%	77%	45%	46%
	Total	103.70%	104%	102%	106%	97%	112%

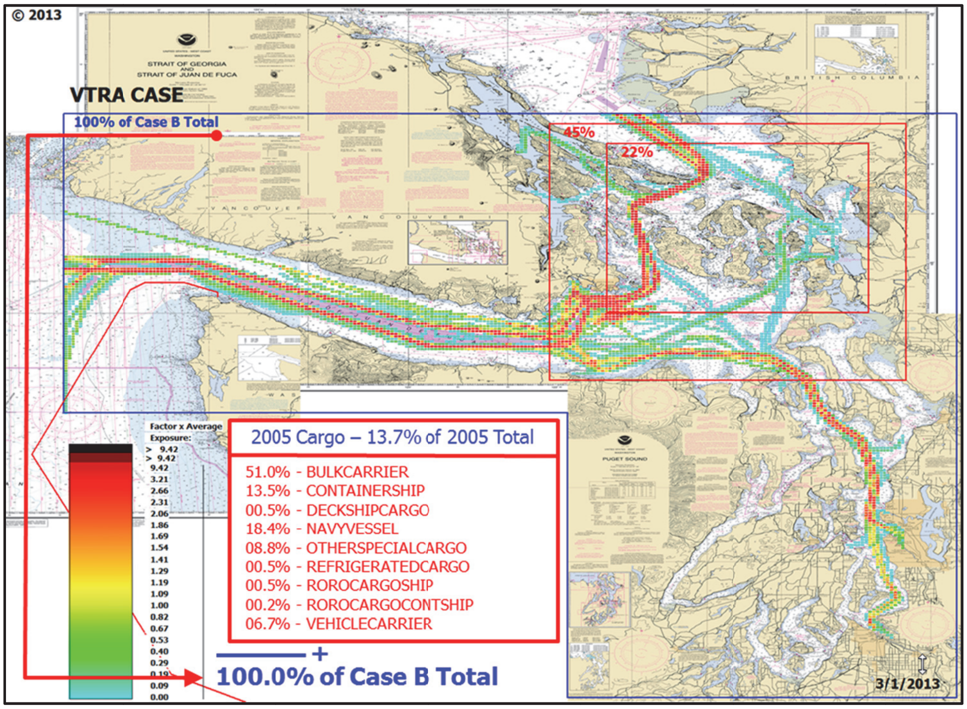

Figure 43. Geographic profile of 2005 cargo vessel traffic density distribution across the VTRA study area.

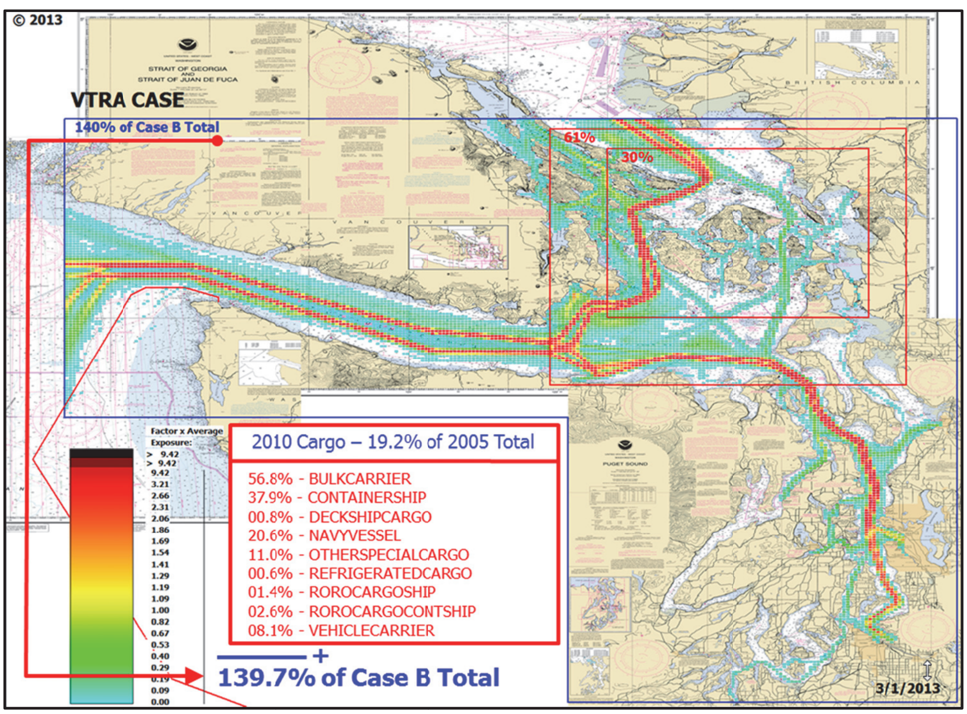

Figure 44. Geographic profile of 2010 cargo vessel traffic density distribution across the VTRA study area.

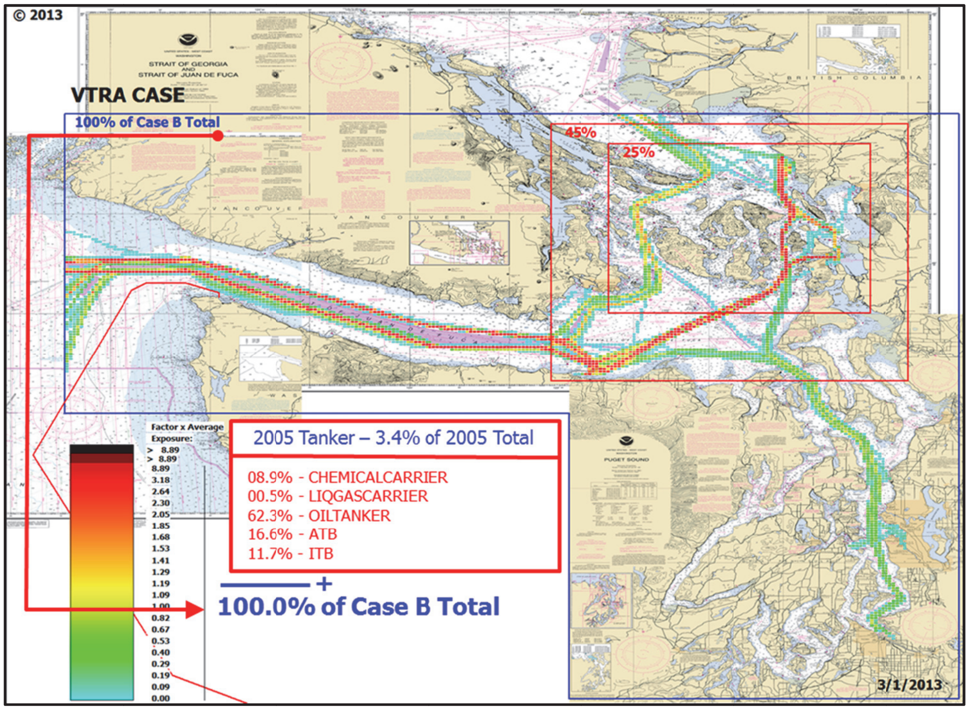

Figure 45. Geographic profile of 2005 tanker traffic density distribution across the VTRA study area.

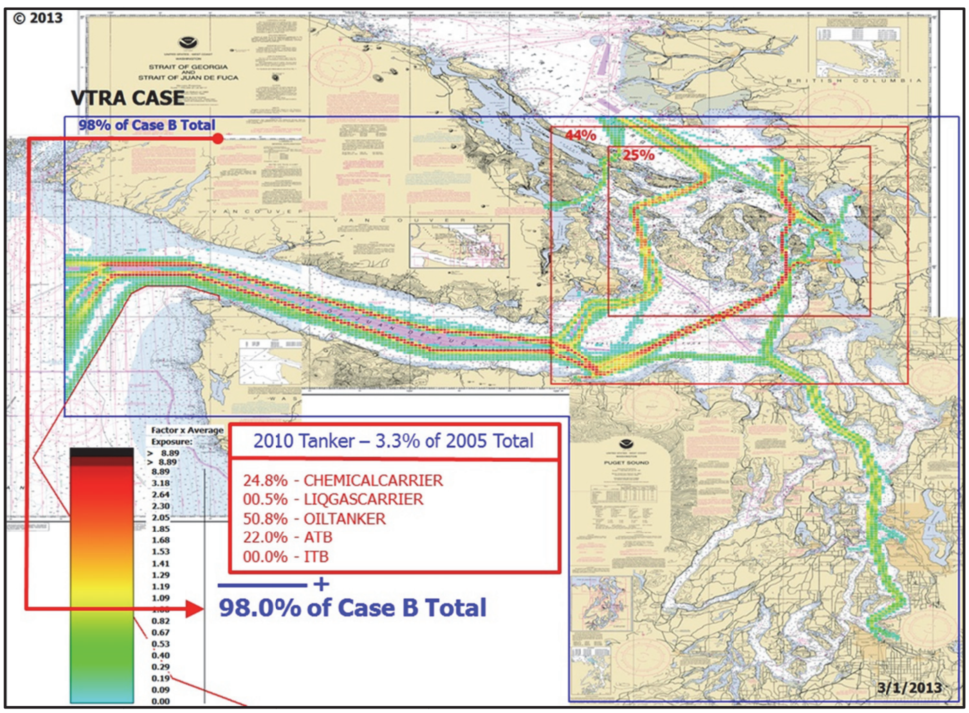

Figure 46. Geographic profile of 2010 tanker traffic density distribution across the VTRA study area.

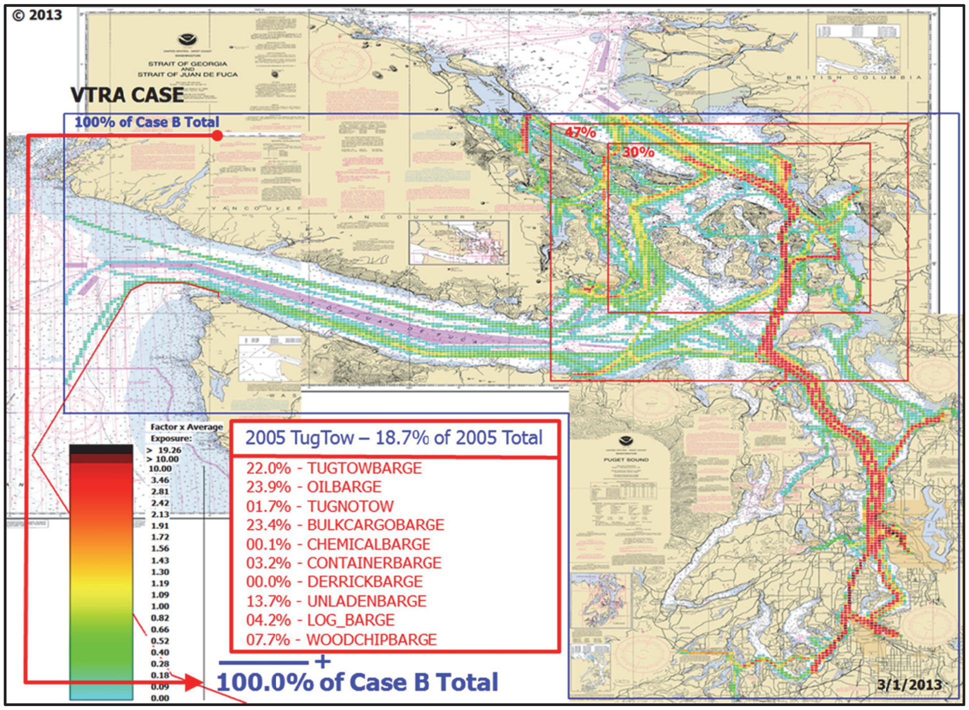

Figure 47. Geographic profile of 2005 tug-tow traffic density distribution across the VTRA study area.

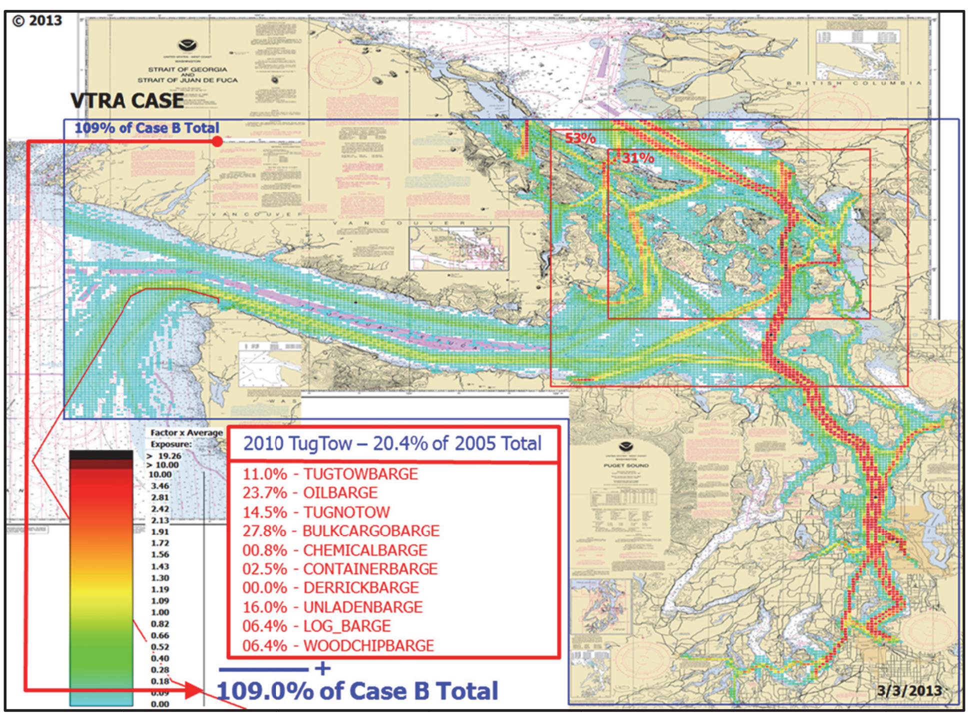

Figure 48. Geographic profile of 2010 tug-tow traffic density distribution across the VTRA study area.

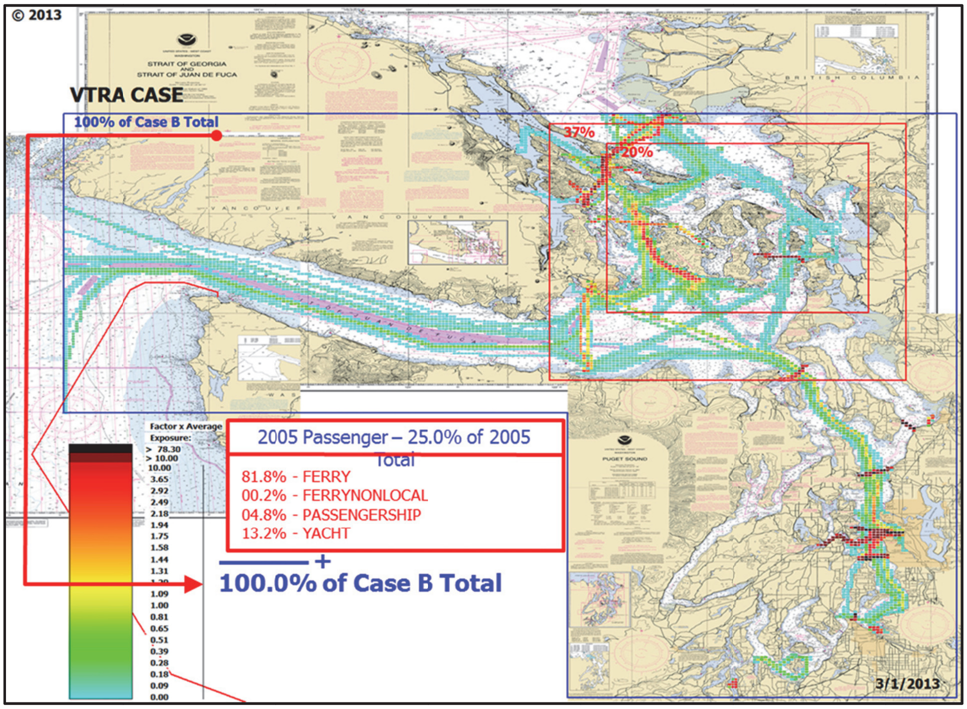

Figure 49. Geographic profile of 2005 passenger vessel traffic density distribution across the VTRA study area.

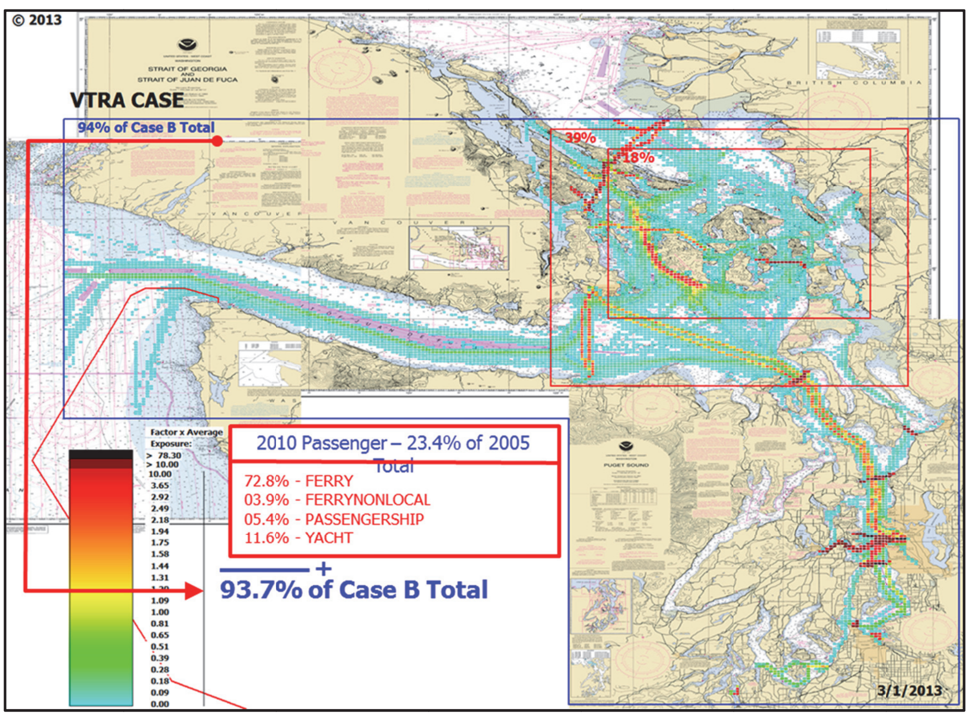

Figure 50. Geographic profile of 2010 passenger vessel traffic density distribution across the VTRA study area.

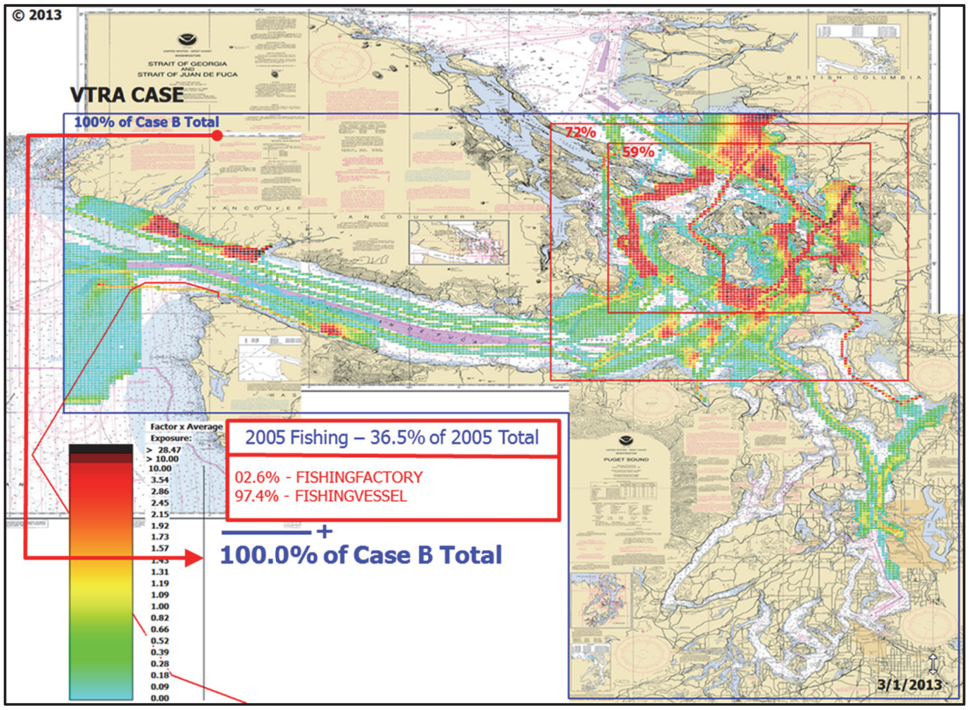

Figure 51. Geographic profile of 2005 fishing vessel traffic density distribution across the VTRA study area.

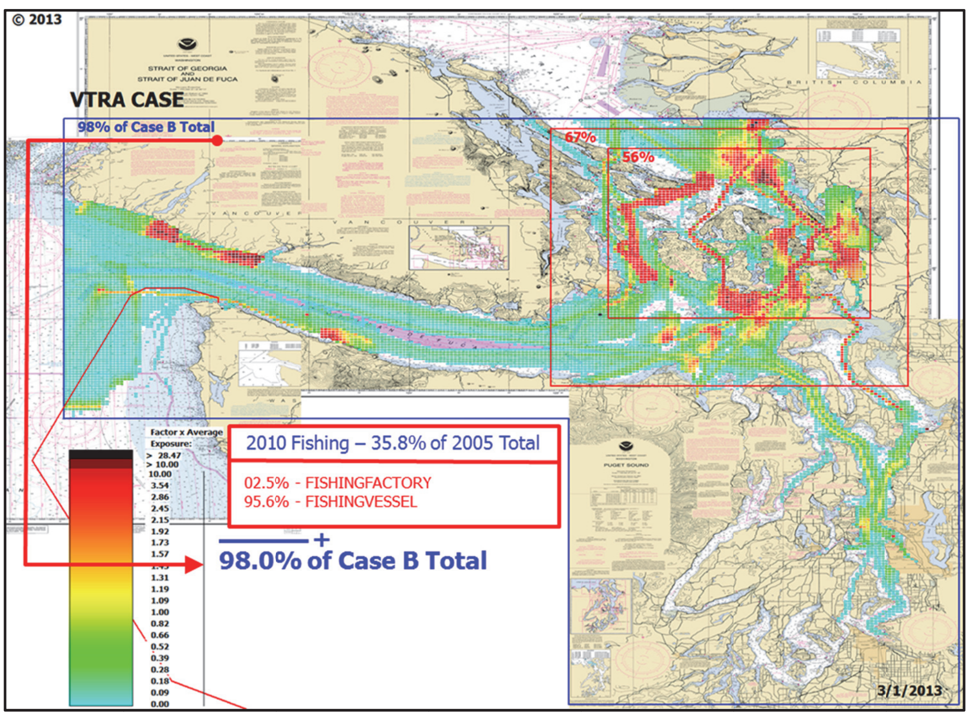

Figure 52. Geographic profile of 2010 fishing vessel traffic density distribution across the VTRA study area.

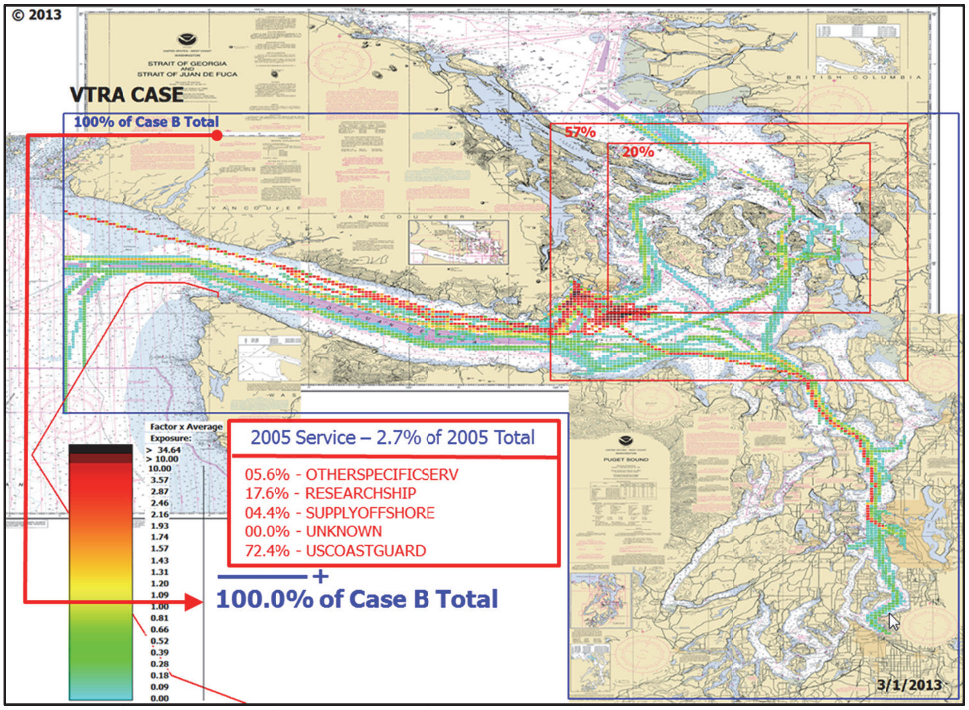

Figure 53. Geographic profile of 2005 service vessel traffic density distribution across the VTRA study area.

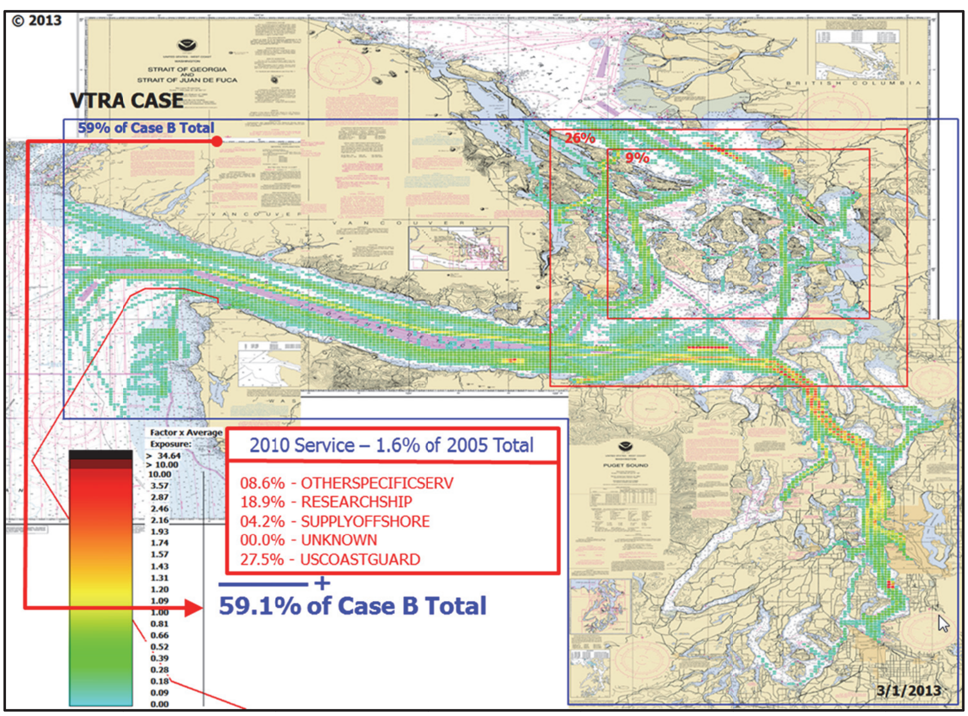

Figure 54. Geographic profile of 2010 service vessel traffic density distribution across the VTRA study area

7. Time series comparison of VTOSS 2005 and VTOSS 2010 traffic

Table 5 and Table 6 contain evaluations for the average number of vessels by master type at an arbitrary point in time during the year. The actually number of vessel by master type fluctuates considerably. To give an indication of the observed fluctuation we are providing below time series (at 15 minute intervals) of number of vessels within the VTRA study area by master type for the GW/VCU VTRA model using VTOSS 2005 and VTOSS 2010 data. Finally, one observes from the time series that passenger (Figure 59) and fishing vessels (Figure 60) exhibit seasonal components, whereas cargo (Figure 55), tanker (Figure 56), tug-tow (Figure 57) and service vessels (Figure 58) do not and exhibit the same fluctuations throughout the year.

Table 13. Minimum, Average and Maximum number of vessels evaluated in the GW/VCU VTRA model using VTOSS 2005 and VTOSS 2005 data.

	2005			2010		
MASTER TYPE	**Min**	**Average**	**Max**	**Min**	**Average**	**Max**
Cargo	0	10.2	25	0	14.2	31
Tanker	0	2.5	13	0	2.4	10
Tugtow	0	13.8	33	0	15.1	33
Passenger	0	18.5	159	0	17.3	134
Fishing	0	27.0	218	0	26.5	219
Service	0	2.0	10	0	1.2	8
Total	0	74.0	318	0	76.7	283

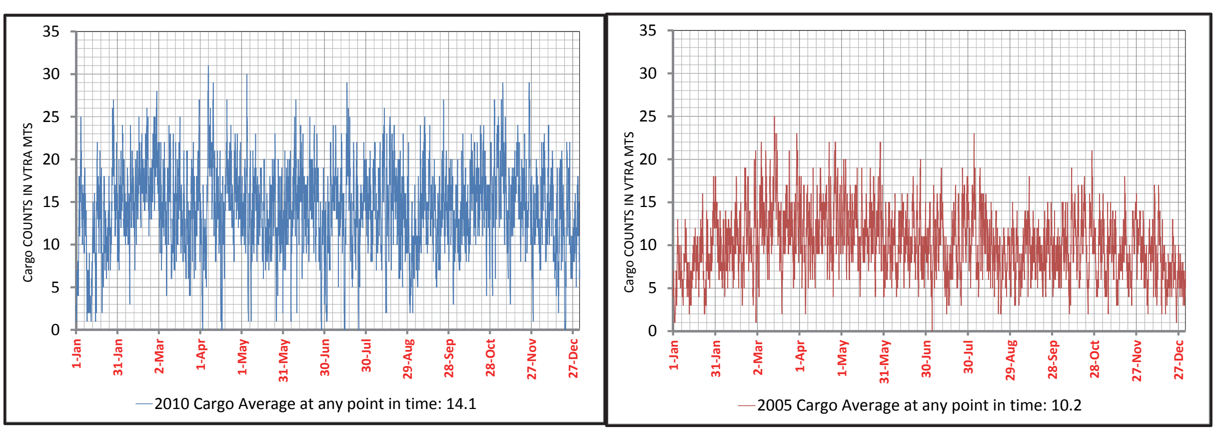

Figure 55. Left panel: Time series of counts of all cargo vessels in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

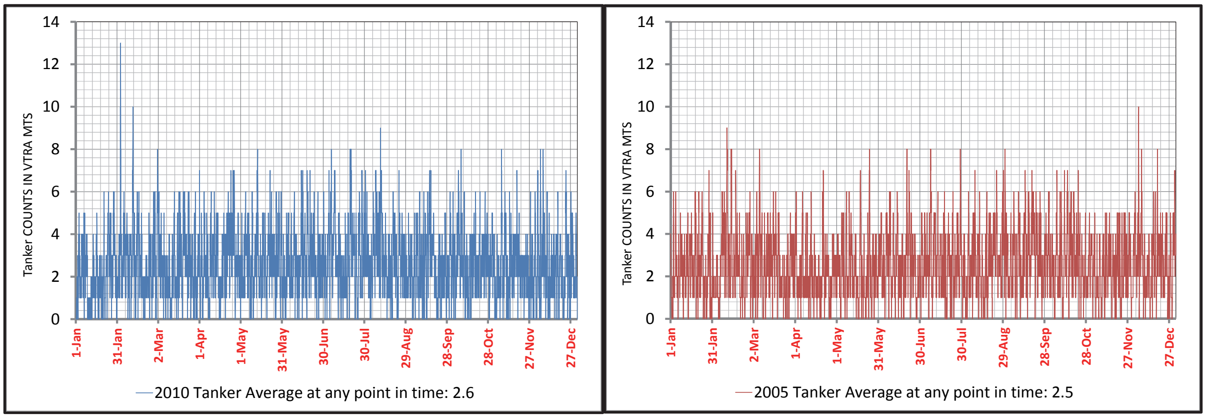

Figure 56. Left panel: Time series of counts of all tankers in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

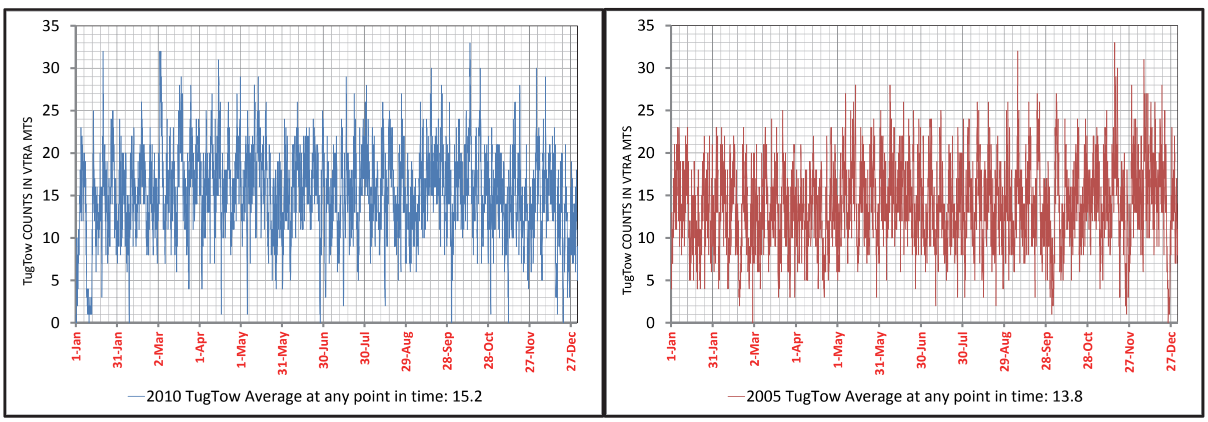

Figure 57. Left panel: Time series of counts of all Tug-tows in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

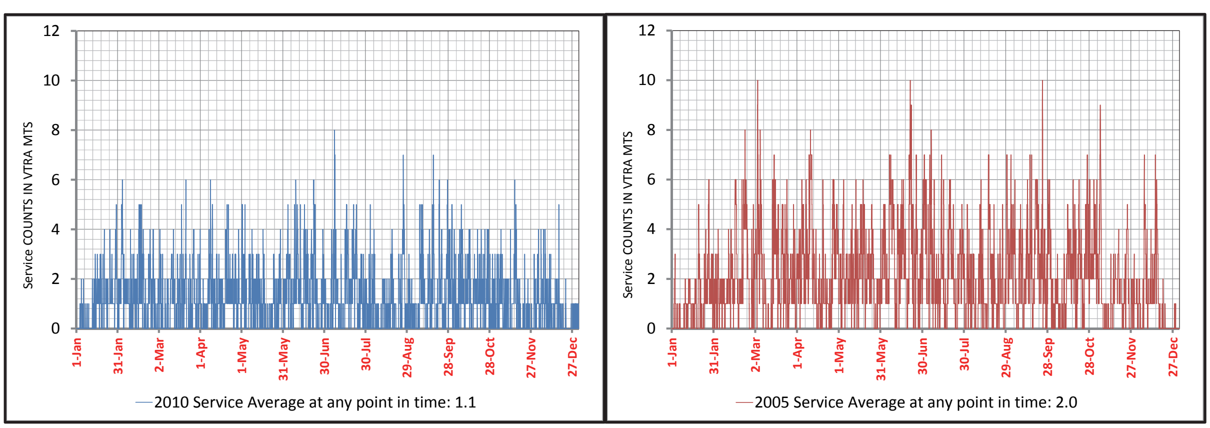

Figure 58. Left panel: Time series of counts of all service vessels in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

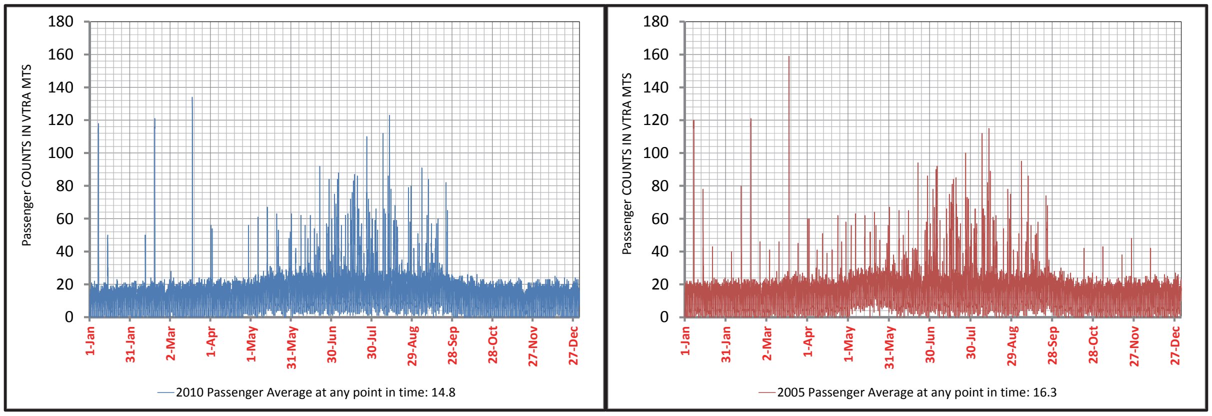

Figure 59. Left panel: Time series of counts of all passenger vessels in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

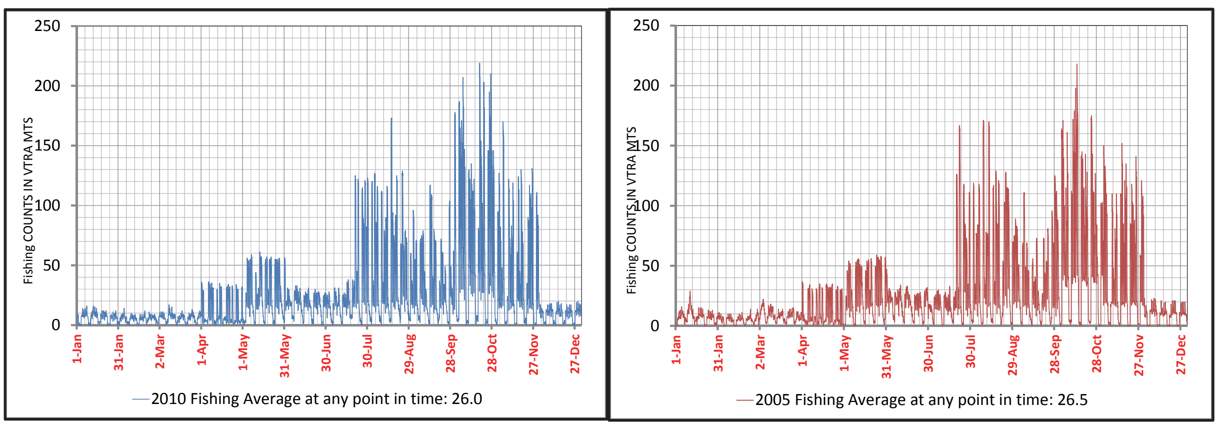

Figure 60. Left panel: Time series of counts of all fishing vessels in the system for the GW/VCU MTS simulation model using the VTOSS 2010 dataset; Right panel: Same using the VTOSS 2005 dataset.

8. Crossing line comparison of VTOSS 2005 and VTOSS 2010 traffic

As a matter of completeness, we provide in Table 14 the crossing line counts (see Figure 32) as evaluated by the GW/VCU VTRA model using VTOSS 2005 data. Crossing line counts as evaluated by the GW/VCU VTRA model using VTOSS 2010 data were provided in Table 9. The latter counts were validated for the vessel master types cargo, tanker and passenger against AIS 2010 crossing line counts in Section 5. Unfortunately such an independent validating data source was not and is not available to validate the VTOSS 2005 crossing line counts in Table 14. If such a data source would have been available and if VTOSS 2005 crossing line counts were validated therewith, one would have been able to extract specific findings from the comparison of Table 9 and Table 14 by vessel master types. However, due to the lack thereof, one ought to be extremely cautious in drawing such conclusions, if at all.

For this reason we shall restrict ourselves to a comparison of total counts of cargo vessels and tankers across counting line but restricted either Table 9 or Table 14, and compare those counts to the ones evaluated using AIS 2010 data. Overall there was agreement in terms of Cargo and tanker crossing line counts between AIS 2010 and VTOSS 2010, whereas some differences were observed in terms of passenger vessel crossing counts (see Figure 33, Figure 34 and Figure 35 in Section 5), in particular in the north bound Georgia Strait direction. Table 15 summarizes this comparison.

Table 14. GW/VCU VTRA model crossing line counts using VTOSS 2005 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	2192	1969	1532	1776	933	909
Tanker	706	640	135	185	98	97
TugTow	77	116	485	641	1839	1321
Service	43	279	46	10	166	84
Passenger	335	157	145	322	333	728
Fishing	3806	3725	157	407	244	467
Total	7159 - 100%	6886 - 96%	2500 - 100%	3341 - 134%	3613 - 100%	3606 - 100%

One observes from Table 15 that there is general agreement amongst AIS 2010, VTOSS 2010 and VTOSS 2005 that the crossing line count of cargo vessels and tankers at the West Strait of Juan de Fuca is about a factor 1.5 higher than at the Georgia Strait counting line (156.8%, 160.6% and 151.8%, respectively). Comparing the Puget Sound crossing line we have for AIS 2010, VTOSS 2010 and VTOSS 2005 75%, 81.6% and 56.1% of Georgia Strait counting line crossings. Hence, we conclude a stronger agreement here between AIS 2010 and VTOSS 2010, than AIS 2010 and VTOSS 2005 in this regard. Overall it is reasonable to conclude that in terms of crossing of tankers and cargo vessels the West Strait of Juan de Fuca counting line ranks first, followed by the Georgia Strait Counting line and next the Puget Sound crossing line.

Table 15. Total crossing line counts of cargo and tankers using AIS 2010 data, and those evaluated by the GW/VCU VTRA model using VTOSS 2010 and VTOSS 2005 data.

DATA SOURCE	WSJF	GEORGIA STRAIT	PUGET SOUND
AIS 2010	7752 - (156.8%)	4944 - (100.0%)	3710 - (75.0%)
VTOSS 2010	7549 - (160.6%)	4701 - (100.0%)	3838 - (81.6%)
VTOSS 2005	5507 - (151.8%)	3628 - (100.0%)	2037 - (56.1%)

9. Conclusions, Findings and Recommendations

The purpose of this project is to update the 2005 VTRA model using the 2010 VTOSS dataset to more closely approximate the present-day patterns in traffic for future use of the GW/VCU VTRA model to inform, for example, the State of Washington and the United States Coast Guard on what potential actions should be taken to mitigate potential increases in oil spill risk from large commercial vessel oil spills in the northern Puget Sound and the Strait of Juan de Fuca areas. In addition, this update will allow for a 2005 – 2010 VTRA model comparison in terms of overall traffic in the VTRA study area.

In updating the GW/VCU MTS model from VTOSS 2005 to VTOSS 2010, not only has an unprecedented level of detail been provided in replicating maritime traffic, but more importantly this update has been validated using a separate independently collected data source. Specifically, the model update was validated using 2010 Automatic Independent Surveillance (AIS) crossing line count data provided by the Marine Exchange Puget Sound (MXPS). For example, Figure 33 compares the number of cargo, tanker and passenger vessels entering or leaving the entrance of the Strait of Juan de Fuca evaluated by the GW/VCU model updated with VTOSS 2010 data to those recorded by AIS in 2010. During the development of the 2005 VTRA a similar validating data source was unfortunately not available.

An overall traffic density comparison analysis using the GW/VCU MTS model has been presented in this report comparing the 2005 and 2010 VTOSS datasets by cargo vessel, tankers, passenger, service, tug-tow and fishing vessels. One ought to exercise caution interpreting such a comparison due to modeling enhancements of the GW/VCU MTS model included in this update. For example, a vessel's individual route has been retained in the VTRA update whereas in the GW/VCU MTS model using VTOSS 2005 data representative vessel routes were constructed by vessel type. The lack of an AIS 2005 validation data source for the 2005 VTRA only adds to that caution.

In the VTOSS 2010 based model, fishing and passenger vessels account for over half the total traffic (in terms of time on the water), at 34.5% and 22.6% of the total (see the right panel of Figure 36). Tug-tow and cargo then account for 19.7% and 18.5% of the total traffic, while tankers account for 3.2%. The final 1.5% is service vessels. Restricting ourselves to tanker, cargo and tug-tow traffic (in light of planned future commercial projects in the VTRA study area and with an eye towards larger potential oil spills), Figure 3 depicts the percentage of time that such vessels move within the 15 waterway locations defined in Figure 24. Considering the geographic locations of tanker, cargo and tug-tow traffic in Figure 3, the largest proportion is in the west and east Straits of Juan de Fuca, at 23.2% and13.3%, the north and south Puget Sound, at 16.4% and 9.4%, and Haro Strait/Boundary Pass and Georgia Strait, at 9.9% and 10.1%.

However, one must also consider the size of these various waterways, so it is more informative to consider the density of tanker, cargo and tug-tow traffic in these locations. In terms of density factor (see Figure 4), the north and south Puget Sound are the highest at factors 2.43 and 2.22 times the average numbers of vessels at any given point in time. The next two densest geographic locations are Rosario Strait and Haro Strait/Boundary Pass with multipliers 1.97 and 1.35. The west and east Straits of Juan de Fuca factors are 1.18 and 0.94 respectively, while Georgia Strait's multiplier equates 1.03.

Even these statistics hide detail of the overall traffic distribution in the study area. Figure 44, 45, 47, 49, 51, and 53 display geographic profiles of traffic density by the six master vessel types for the VTOSS 2010 case. All these figures serve as a reminder that "the world is not average" and thus neither is a Maritime Transportation System (MTS). The density of each type of traffic varies across the various geographic locations and even within them. That is, different vessels go to different locations and so each location has a different traffic profile. Summarizing, the geographic profiles allow for a detailed and refined consideration of traffic density levels across the VTRA study area.

A detailed consideration of traffic levels is particularly important as one moves forward to considering risk and potential changes in risk from the commercial projects being proposed for the northern Puget Sound and southern British Columbia over the next decade. To put it simply, keeping everything else the same, when traffic increases risk increases, unless mitigated. Further, there is no guarantee that risk increases due to traffic increases can be fully mitigated.

The challenge of risk management is for it to be location specific, taking into consideration the type and location of traffic and how it changes as a result of proposed traffic increases. One must realize that risk does not necessarily disappear when mitigated locally, but tends to migrate. Such mitigations are preferably avoided in a sound risk management strategy, but some risk migration may be inevitable. Needless to say, risk mitigation at one location ought not result in an increase in risk elsewhere that is larger.

This begs the question, when faced with perhaps inevitable traffic increases how can one manage risk increases that cannot be fully mitigated? One approach could be to evenly distribute future risk across the affected area, i.e. to allow for risk increases in locations that currently have low risk levels compared to those that are already higher. On the other hand, should one aim for an equitable distribution of future risk and allow for each location to have a similar percentage increase in risk relative to that location? These are important questions to be considered for the Puget Sound Partnership project using the GW/VCU VTRA model VTOSS 2010 update as a starting point and can only be answered utilizing the collaborative analysis approach (see, [1]). No doubt these questions are equally important in other ongoing studies considering the potential risk of traffic increases as a result of future planned commercial projects. Summarizing, we advocate a systems approach towards risk management, not one that is just locally targeted missing potential side effects.

In light of the observations in this VTRA update, while considering a longer-term view of risk management in the VTRA study area, we close with the observation that there is a serious need for an electronic data source that is cross-boundary (US and Canadian waters) where the vessel type is consistently defined and verified. Moreover, with the same eye towards risk management analysis it would be equally beneficial if such datasets records capture cargo or at a minimum cargo levels (laden, unladen, 50% laden, etc.). In particular, we would like to call out the need for recording at a greater consistency the barge type and cargo of tug-tows.

VTOSS and AIS are such cross-boundary data sources and could serve this purpose. However without currently possessing such a common and consistently recorded vessel identifier or vessel type classification as defined herein (see Table 3), VTOSS and AIS unfortunately still require vetting at the individual vessel level to serve that purpose. In this study, we have performed this vetting by vessel master type (see Table 3). We hope that other studies can benefit from the validated and vetted analysis of the VTOSS 2010 dataset performed in this project and presented in this report.

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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 the real-time marine traffic monitoring system used by the USCG, similar to air traffic control for aircraft.