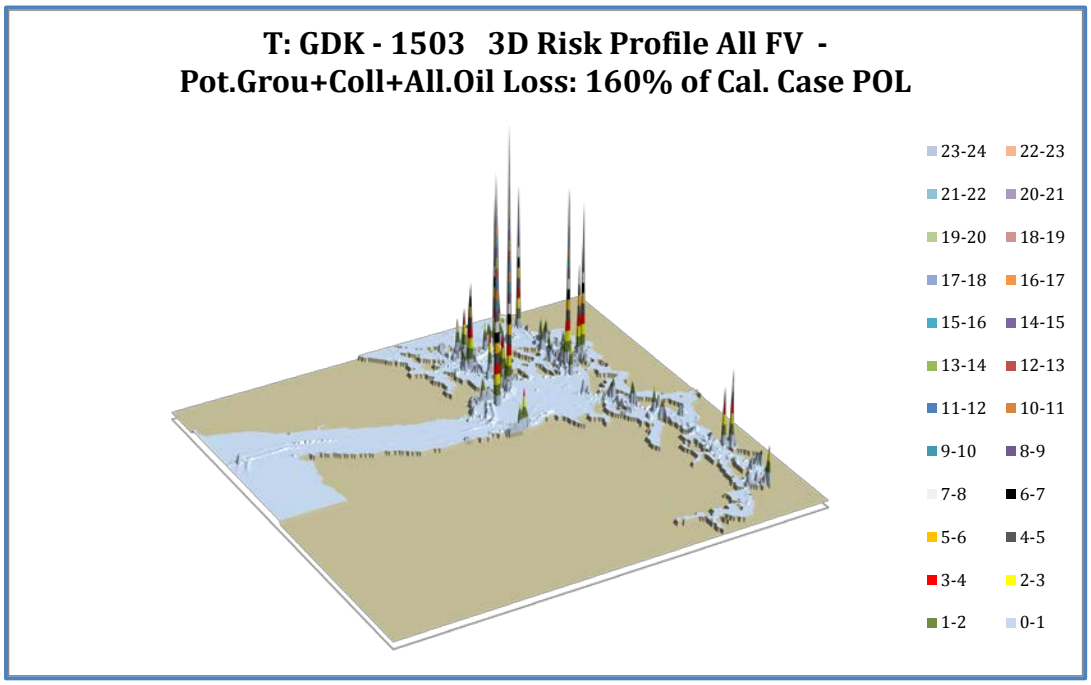
Vessel Traffic Risk Assessment 2015 (VTRA 2015):
Preventing Oil Spills from Large Ships and Barges

VTRA 2015 Addendum to VTRA 2010 QAPP



June 2016

Prepared by Author(s):

Dr. Johan Rene van Dorp
Professor Engineering Management and Systems Engineering (and of Decision Sciences)
George Washington University (GW)
Office Phone: (202) 994-6638
dorpjr@gwu.edu

Dr. Jason Merrick
Professor Statistical Sciences and Operations Research
Virginia Commonwealth University (VCU)
Office Phone: (804) 828 5865
jrmerric@vcu.edu

Prepared for:
Washington State Department of Ecology

Quality Assurance Project Plan Addendum

Vessel Traffic Risk Assessment 2015 (VTRA 2015):

Preventing Oil Spills from Large Ships and Barges

June 2016

Approved by:

Signature: _____ Date 6/28/2016

Johan Rene van Dorp, George Washington University

Signature: _____ Date 6/28/2016

Jason Merrick, Virginia Commonwealth University

Signature: _____ Date 7/19/2016

Brian Kirk, Contract Manager, Department of Ecology

Signature: _____ Date 7/19/2016

Scott Fergusson, Department of Ecology

Signature: _____ Date 6-28-16

William Kammin, QA Officer, Department of Ecology

Publication Information

Phase II of VTRA 2015 study has been funded wholly or in part by the United States Environmental Protection Agency (EPA) through their National Estuary Program, via grant agreement (#15-05354) with the Washington State Department of Ecology.

Each study conducted by EPA, or external parties funded by EPA, must have an approved Quality Assurance Project Plan (QAPP). The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. Such a plan was develop for the VTRA 2010 in February 2013. This attached report for the VTRA 2015 serves as an Addendum to the VTRA 2010 QAPP. To clarify the linkage between the VTRA 2015 QAPP Addendum and the original VTRA 2010 QAPP a comparison of their table of contents (TOC) of the main section of both is listed in Figure 1. One can observe from Figure 1 that the format of the TOC of both is the same, except that the VTRA 2015 QAPP Addendum does not contain a Section 6 containing the Summary of VTRA 2005 Methodology. For completeness, however, the VTRA 2010 QAPP is attached to the VTRA 2015 QAPP addendum as Appendix D.

VTRA 2010 QAPP TOC	VTRA 2015 QAPP ADDENDUM
Publication Information	Publication Information
Author and Contact Information	Author and Contact Information
Distribution List	Distribution List
List of Figures	List of Figures
1. Abstract	1. Abstract
2. Background	2. Background
3. Project Description	3. Project Description
4. Organization and Schedule	4. Organization and Schedule
5. Project Work Products	5. Project Work Products
6. Summary of 2005 VTRA Model Methodology	
Appendix: Glosaary and List of Acronymns	Appendix A: Glossary and List of Acronymns
	Appendix B: AIS Countline Data
	Appendix C: Available Accident Data
	Appendix D: VTRA 2010 QAPP

Figure 1. Comparison of VTRA 2010 QAPP TOC and VTRA 2015 QAPP Addendum TOC

After completing of the VTRA 2015 study/update to the VTRA 2010, the final report will be available upon request from the Washington State Department of Ecology and will also be posted on the Faculty page of Johan Rene van Dorp at:

https://www.seas.gwu.edu/~dorpjr/VTRA_2015/VTRA_2015_Project.html

This QAPP Addendum, Interim work products and deliverables are posted on the above site as well.

The contents of this document do not necessarily reflect the views and policies of the EPA, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Author and Contact Information

Dr. Johan Rene van Dorp
Professor Engineering Management and Systems Engineering (and of Decision Sciences)
George Washington University (GW)
Office Phone: (202) 994-6638
dorpjr@gwu.edu

Dr. Jason Merrick
Professor Statistical Sciences and Operations Research
Virginia Commonwealth University (VCU)
(804) 828 5865
jrmerric@vcu.edu

Distribution List

Brian Kirk, Marine Risk Management Lead
Spill Prevention Section
Spill Prevention, Preparedness, and Response Program
Washington Department of Ecology
Office Phone: 425-649-7292 Cell: 425-395-5800
bkir461@ecy.wa.gov

Scott Fergusson, Washington Department of Ecology

Sara Thompson, Washington Department of Ecology

Captain Stephen Moreno, Puget Sound Pilots

Tom Gries
NEP Quality Coordinator
Washington State Department of Ecology
300 Desmond Dr. SE
Lacey, WA 98503
tgri461@ecy.wa.gov

Table of Contents

List of Figures

1. Abstract

Several commercial projects have been proposed North of the Puget Sound and in Southern British Columbia over the next decade or more, potentially increasing the amount of oil being transported using tankers while adding many hundreds of other deep draft ship transits through the area.

The purpose of this VTRA 2015 project is to quantify the *potential difference between present and potential risks should these projects come to fruition*, and establish a technical basis for making *decisions on what risk management measures would be beneficial in managing the potential risk of an oil spill*. The objective of the VTRA 2015 project is to update the VTRA 2010 project analysis. As was the case with the VTRA 2010 project, the focus of the VTRA 2015 analysis is on evaluating changes between VTRA 2015 What-If Case(s) relative to a VTRA 2015 Base Case and the changes between the VTRA 2015 RMM Case(s) modeled on top of a combined VTRA 2015 What-if Case. The analysis results from this tool help to inform a risk management strategy to prevent these types of accidents. The GWU/VCU analysis VTRA approach has been well documented and peer-reviewed in the academic literature.

The Vessel Traffic Risk Assessment (VTRA) 2015 effort will utilize and leverage 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), the 2005 Vessel Traffic Risk Assessment (VTRA) funded by BP, the update of the VTRA 2005 model using Vessel Traffic Operational Support System (VTOSS) 2010 data funded by the Makah Indian Tribal Council and the VTRA 2010 project funded by the Puget Sound Partnership. The GW/VCU's VTRA analysis model evaluates vessel time exposure, oil time exposure, accident frequency and oil losses from pre-defined classes of focus vessels.

A body similar to the VTRA 2010 steering committee will serve as the VTRA 2015 Working Group in an advisory role through meetings typically following the Puget Sound Harbor Safety Committee meetings. The organizational chart and core members of the VTRA 2015 Working Group are listed in Figure 2.

VTRA 2015 Working Group

Chair:

- Captain Stephen Moreno, Puget Sound Pilots

Federal, State and Tribal Leads [representing]:

- Scott Fergusson (alternate Brian Kirk or Sara Thompson), Washington State Department of Ecology
- US Coast Guard Sector Puget Sound – CAPT Joe Raymond (alternate CDR Matt Edwards)
- US Coast Guard District 13 - R.E. McFarland
- Makah Tribal Council - Chad Bowechop (alternate Keith Ledford or Jon Neel)

Core Working Group Members:

- Puget Sound Pilots - Jostein Kalvoy
- American Waterways Operators – George Clark, Charles Costanzo
- Marine Exchange of Puget Sound – John Veentjer
- Pacific Merchant Shipping Association – Mike Moore
- Western States Petroleum Association – Frank Holmes
- Washington Association of Counties – Jamie Stephens
- Washington Public Ports Association – James Thompson
- Tesoro - Ed Irish, Rob McCaughey
- BP - Scott McCreery, Carl Obermeier
- Puget Sound Partnership – Todd Hass
- Mulno Cove Consulting – Lovel Pratt
- Puget Sound keeper – Chris Wilke
- Wave/Friends of the Earth – Fred Felleman
- Friends of the San Juans – Stephanie Buffum

Figure 2. Organizational Chart of the VTRA 2015 Working Group.

2. Background

The VTRA 2005 model was funded by BP and evaluated oil transportation risk of those Tankers, Articulated Tug Barges (ATB's) and Integrated Tug Barges (ITB's) that docked at the BP Cherry Point Terminal at one point during their journey through the VTRA Study Area depicted in Figure 3. The updating of the 2005 VTRA model to 2010 VTOSS data was funded under a contract between the Makah Indian Tribal Council and GW/VCU. By updating the VTRA 2005 model to a 2010 base year, the VTRA 2010 model more closely approximates present-day patterns in traffic because in the VTRA 2010 model all Maritime Traffic in the VTOSS 2010 data moved as it occurred during that year, whereas in the VTRA 2005 model only representative vessel routes were constructed. The VTRA 2010 model was developed using 2010 data from the federal Vessel Traffic Operational Support System (VTOSS) data, amongst other data sources. The 2010 year is the last full year of traffic data recorded for VTOSS.

Figure 3. VTRA Study Area.

The VTRA 2010 model was used to perform vessel traffic risk analysis for the VTRA 2010 focus vessel (FV) group of all Tankers, Articulated Tug Barges (ATB), Oil Barges, Chemical Carriers, Bulk Carriers, Container Ships and an Other Cargo Vessels. The VTRA 2010 Focus Vessel Group accounts for about 25% of the total vessel traffic in the VTRA model. As stated above, the VTRA 2005 FV group was limited to Tankers, ATB's and Integrated Tug Barge (ITB's) docking at the Cherry Point Terminal at some point during their voyage through the VTRA Study area (about 1% of the VTRA modelled traffic). The expansion of the VTRA Analysis from 1% of the VTRA modelled traffic to 25% of the VTRA modelled traffic was funded by the Puget Sound Partnership. The other 75% of the VTRA 2010 modelled traffic comprises of Interacting Vessels (IV's) that the FV group can collide with. Of course FV's can collide with other FV's. Both the potential oil loss from FV's and IV's are evaluated by the VTRA 2005 and VTRA 2010 models.

3. Project Description

To distinguish the study described herein from the previous VTRA 2005 and VTRA 2010 studies it will be labeled the VTRA 2015. The starting point for the VTRA 2015 model is the VTRA 2010 model. The overall methodology of the VTRA 2005, VTRA 2010 and VTRA 2015 models is the same, although in each projects improvements/updates have been or will be made. A summary of the VTRA 2005 methodology is included in the VTRA 2010 QAPP attached to this VTRA 2015 QAPP Addendum as Appendix D.

The VTRA 2005 model was calibrated to incident and accident data from the VTRA 2005 FV group (about 1% of VTRA modelled traffic). The incident and accident models for the VTRA 2010 model relied on an extrapolation technique from the VTRA 2005 FV group, to all other Tankers, ATB's for its incident and accident models (about 3% of the total modelled VTRA Traffic). That same extrapolation technique in the VTRA 2010 was applied to expand the VTRA analysis from Tankers and ATB's to other focus vessel classes, specifically: Oil Barges, Chemical Carriers, Bulk Carriers, Container Vessels and Other Cargo Vessels. Thus, the VTRA 2010 Focus Vessel group contains Tankers, ATB's, Chemical Carries, Oil Barges, Bulk Carriers, Container Vessels and Other Cargo Vessel. Of the VTRA 2010 FV group, the Tankers, ATB's, Oil Barges and Chemical Carrier combine to form the Tank Focus Vessel category. Of the VTRA 2010 FV group, the Bulk Carriers, Container Vessels and Other Cargo Vessels combine to form the Cargo Focus Vessel Category. The VTRA 2010 extrapolation technique (funded by the Puget Sound Partnership) is visually depicted in Figure 4 along the oil spill accident event chain modelled in the VTRA apporach.

The What-If Cases evaluated during the VTRA 2010 project were named:

- Case Q: Gateway: + 487 Bulkers + Bunker Support
- Case S: Delta Port: + 348 Bulkers, 67 Container Ships + Bunkering Support
- Case R: Kinder Morgan: + 348 Tankers + Bunkering Support

Their approximate locations relative to the VTRA Study area are depicted in Figure 3. In addition to these three separate What-If cases a combined What-If Case T was evaluated named:

a. Case T: GW - DP – KM: + 865 Bulkers, 67 Container Ships, 348 Tankers + Bunker Support

The combined What-If Case T added 1250 deep draft vessel arrivals to the VTRA 2010 Base Case. In comparison, the total number of deep draft arrivals entering the Strait of Juan de Fuca in 2010 equals about 4400. Thus, Case T constituted about a 30% increase in the

number of deep draft vessel arrivals entering the Strait of Juan de Fuca. In terms of Total Potential Oil Loss Case T in the VTRA 2010 evaluated about a 68% increase in potential Total Annual Oil Loss from the VTRA 2010 Base Case. For Cases Q, R and S a 12%, 36% and 4% increase in potential Total Annual Oil Loss was evaluated. In the VTRA 2010 model escorting for the VTRA 2010 Tank FV group was modelled as per the escorting requirement during that year for both the VTRA 2010 Base Case and the VTRA 2010 What-If Cases.

As stated above, the starting point for the VTRA 2015 project was the VTRA 2010 Model. The VTRA 2015 project commenced with a recalibration of the VTRA 2010 model to additional accident data available to the project team from the period 1990 – 2015. The purpose of the recalibration is to be able to separately calibrate the VTRA accident model to the Tank FV Category and the Cargo FV Category to improve its accident probability model by not having to rely on the extrapolation technique from the VTRA 2010 model for the Cargo Focus Vessel Class depicted in Figure 4. The calibration of the VTRA 2015 model to this additional accident data for the VTRA 2015 project is depicted visually in Figure 5. The accident data available to GWU/VCU project team for this accident calibration is provided in Appendix C.

The recalibration of the VTRA 2010 Base Case to this accident data constitutes the VTRA 2015 Calibration Case. A full geographic profile analysis will be presented in the final report comparing the VTRA 2010 Base Case Analysis to the VTRA 2015 Calibration Case analysis to highlight the differences in VTRA model analysis results from the VTRA 2010 model to the VTRA 2015 model. Overall a reduction of 58.9% in potential Total Annual Potential Oil Loss was evaluated going from the VTRA 2010 Model to the VTRA 2015 Model both calibrated at the Oil Spill level of the accident event chain depicted in Figure 4 and Figure 5.

Next, a comparison will be presented in the VTRA 2015 final report of updated VTRA 2015 What-If Cases Q, R, S and T relative to the VTRA 2015 Calibration Case. That comparison in turn allows for a comparison between VTRA 2010 What-If Case Analyses for Case Q, R, S and T to the VTRA 2015 What-If Case Analyses for updated What-If Cases Q, R, S and T. The definition of the Updated VTRA 2015 What-If Case Q, R, S and T as compared to the VTRA 2010 What-If Case Q, R, S and T is presented in Figure 6. Please note that only the individual definition of Case S has changed and therefore also the definition of the updated Case T. The comparison of the updated What-If Case T relative to the VTRA 2015 Calibrations Case evaluated about a 61% increase in Total Potential Oil Loss (recall the 68% evaluated in the VTRA 2010 analysis). For the updated Cases Q, R and S a 12%, 36% and 4% increase in potential Total Annual Oil Loss was evaluated relative to the VTRA 2015 Calibration Case, respectively. Recall the respective 12%, 36% and 4% increases

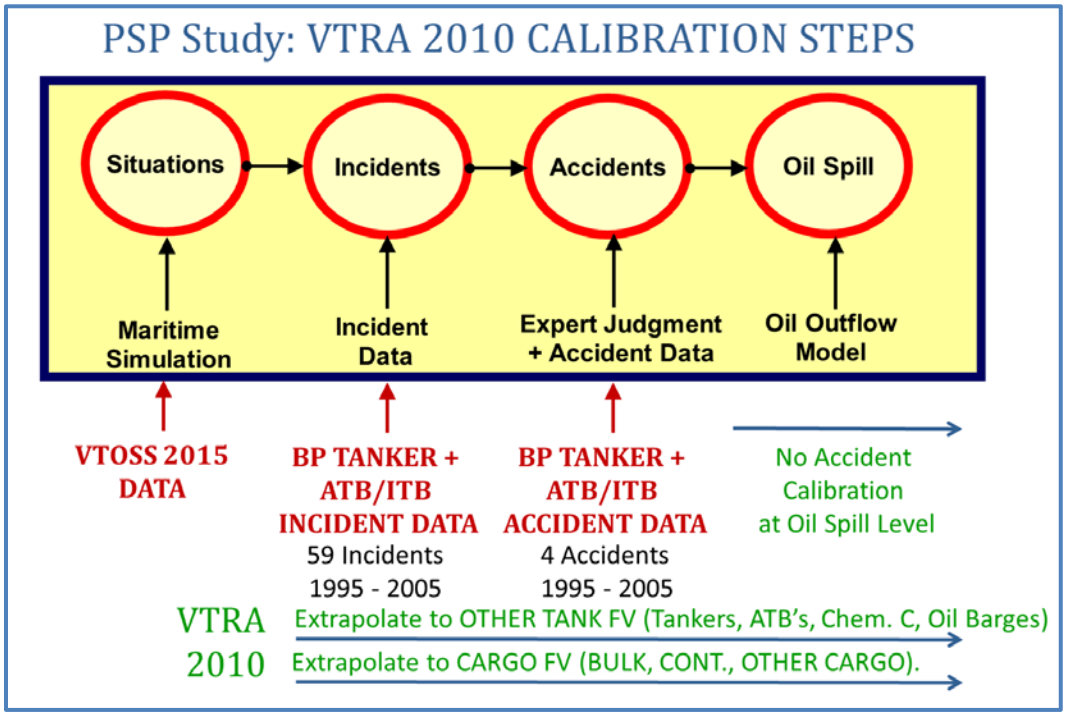


Figure 4. VTRA 2010 Oil Spill Accident Event Chain depicting the VTRA 2010 Extrapolation Technique.

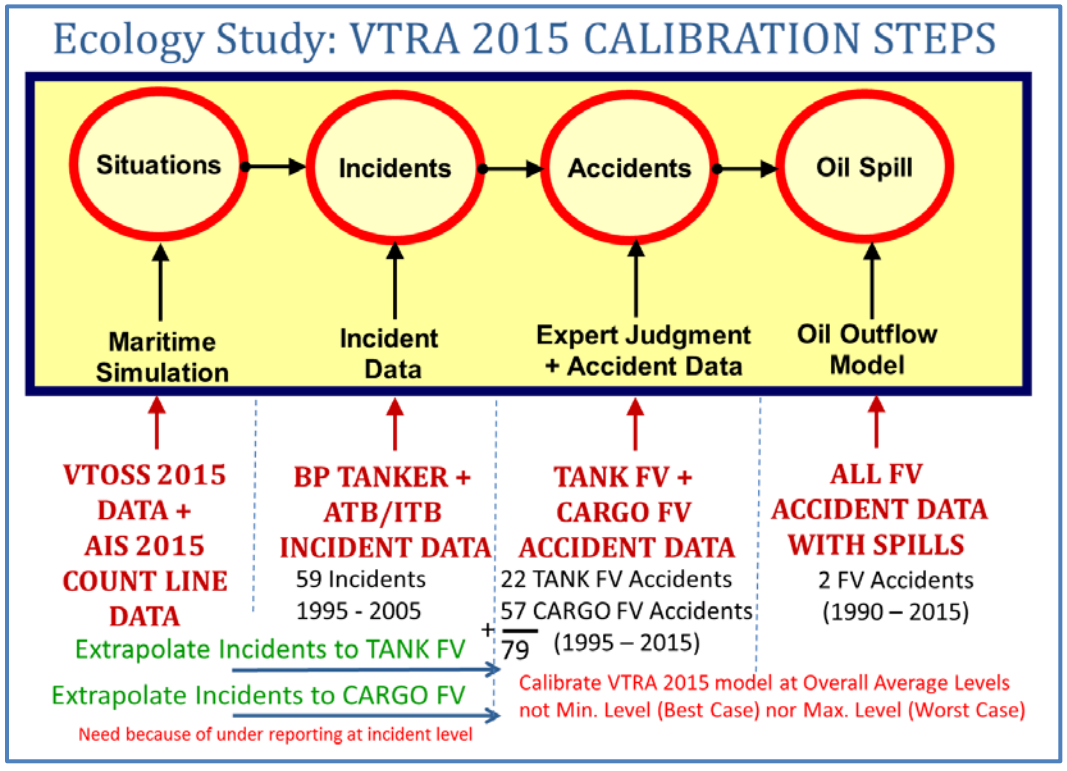


Figure 5. VTRA 2015 Accident Event Chain depicting the VTRA 2015 Calibration Approach.

CASE Q	VTRA 2010 Case Q	VTRA 2015 Updated Case Q
Bulk Carriers	487	487
Bunkering Support	229	229
SubTotal	716	716
CASE S	**VTRA 2010 Case S**	**VTRA 2015 Updated Case S**
Container Ships	67	368
Bulk Carriers	348	300
Bunkering Support	40	60
Subtotal	415	668
CASE R	**VTRA 2010 Case R**	**VTRA 2015 Updated Case R**
Tankers	348	348
Bunkering Support	21	21
Subtotal	369	369
CASE T	**VTRA 2010 Case T**	**VTRA 2015 Updated Case T**
Container Ships	67	368
Bulk Carriers	835	787
Tankers	348	348
Bunkering Support	290	310
Subtotal	1540	1813

Figure 6. VTRA 2010 What-If Case Definitions and their updated VTRA 2015 What-If Case Definitions

evaluated for Cases Q, R and S during the VTRA 2010 relative to the VTRA 2010 Base Case Analysis. This certainly demonstrates a level of robustness in the relative increases in terms of annual potential oil loss, despite two quite different modelling approaches depicted in Figure 4 and Figure 5.

In parallel to the construction of the VTRA 2015 Calibration Case, a longitudinal AIS crossing line analysis was conducted using 2010 – 2015 count line data for 10 AIS crossing lines was conducted. Using this count line data, and following the methodology described in Chapter 9 of the VTRA 2010 Final Report, a traffic stream analysis was conducted for the Cargo Focus Vessel and Tank Focus Vessel Categories over the years 2010 – 2015 and will be presented in the VTRA 2015 Final Report. The crossing line data utilized for this traffic stream analyses is provided in Appendix A. The traffic stream analysis concluded that some of the traffic streams have changed from 2010 to 2015. The VTRA 2015 Calibrated model will be augmented with Cargo FV and Tank FV traffic streams such that the VTRA model crossing line counts for the VTRA 2015 project more closely resemble the 2015 AIS crossing line counts for these two FV categories. This effort under Phase I is currently underway as this QAPP for Phase II of the VTRA 2015 project is written. The integration of the VTRA 2015 Calibration Case with the longitudinal AIS Count Line traffic stream analysis from 2010 – 2015 will constitute the VTRA 2015 Base Case Model.

Having established a VTRA 2015 Base Model, a baseline risk level for the VTRA 2015 project will be developed. While during the VTRA 2010 geographic profiles were generated for potential oil loss combining all potential spill sizes, the baseline risk level for the VTRA 2015 analysis will in addition separately generate geographic profiles by oil spill size within the following categories: (1) $1m^3$ – $1000m^3$, (2) $1000m^3$ – $2500m^3$, (3) larger than $2500m^3$. What-If projects will be added to the VTRA 2015 Base model by adding anticipated vessel traffic increases as a result of a select number of anticipated terminal project developments.

Under Phase I of the VTRA 2015 project, geographic profiles shall be generated for One Combined VTRA 2015 What-If Case (along the lines of the VTRA 2010 Case T) with anticipated potential projects added to the VTRA 2015 Base Model and these Combined What-IF Case geographic profiles shall be compared to their baseline geographic profile counter parts. Moreover, under Phase I of the VTRA 2015 project One risk mitigation measure (RMM's) portfolio case will be evaluated by modelling RMM's considered for potential implementation constituting this RMM portfolio. The RMM's to be considered are limited to those that can be meaningfully represented in the VTRA model. The RMM Case will modeled on top of the combined What-If case during Phase I of the VTRA 2015 project to evaluate potential risk reduction effectiveness to manage potential risk increases arising from this potential growth in vessel traffic associated with the added projects in the combined What-If Case. The RMM Portfolio Case effectiveness will be evaluated under Phase I by comparing RMM geographic profiles to their geographic profile counter parts of the combined VTRA 2015 What-If Case.

Under Phase II of the VTRA 2015 project, for which this QAPP is written, the combined VTRA 2015 What-If Case evaluated under Phase I will be separated into three What-If Cases that do not have to partition the combined VTRA 2015 What-If Case analyzed under Phase I. The geographic profiles of these three What-If Cases shall be compared to their VTRA 2015 baseline geographic profile counter parts. Likewise, under Phase II of the VTRA 2015 project the combined VTRA 2015 RMM portfolio case will be separated into three separate RMM Cases that do not have to partition the combined VTRA 2015 RMM portfolio case analyzed under Phase II. The effectiveness of these three RMM Case evaluated under Phase II will be compared relative to, in principle, the combined VTRA 2015 What-If Case, although another VTRA 2015 What-If Case developed under Phase II could be chosen for that relative comparison instead. Regardless no more than three RMM Case Relative comparisons will be evaluated under Phase II.

Project success can be gauged by the completion of the What-If Scenario(s) analyzed and Risk mitigation Scenario(s) analyzed and by the completion of a final report synthesizing the analysis results.

4. Organization and Schedule

The original proposed scope of work was written by J. Rene van Dorp (GW) and Jason Merrick (VCU) for the Washington State Department of Ecology to be shared with the former VTRA 2010 Steering Committee. It has been revised based on comments received from the former VTRA 2010 Steering Committee during an October 2015 meeting and a September 2015 meeting. The revised proposed scope of work consists of two Phases. Phase I consists of 5 main tasks of which only 4 could be completed within the time and budget anticipated. Phase II consist of 2 main task that could only be completed pending funding availability. Completion of tasks in Phase I and Phase II will follow the same collaborative analysis approach as the VTRA 2010 project involving the maritime stakeholder community. A body similar to the VTRA 2010 steering committee will serve as the VTRA 2015 work group in an advisory role through meetings typically following the Puget Sound Harbor Safety Committee meetings. The organizational structure if the VTRA 2015 Working Group is provided in Figure 2.

The numbering of the tasks for Phase I were as follows; Task 1-I, Task 2-I, Task 3-I, Task 4-I and Task 5-I and for Phase II the numbering of was: Task 3-II and Task 4-II. This numbering system was chosen to keep track of Task numbering over the different versions of this scope of work that were provided and over the two Phases. Task 1-I, 2-I, 3-I and 4-I were included in the first version. Task 5-I was added to the second version of this original proposed scope of work. Task 3-II and Task 4-II were added following the Department of Ecology announcement that an additional 65K may be available on top of the original budget 100K. Thus, Task 3-II and Task 4-II could only be executed if the indeed the availability of those funds materializes. The funding for Phase II has since then materialized and this QAPP, in principle, only applies to that Phase II funding. That being said, Task descriptions of Phase I are provided as context to the Task descriptions for Phase II.

During the Kick-Off meeting it was recommended by the VTRA 2015 working as per suggestion of the VTRA 2015 principle investigators to recalibrate the VTRA 2010 to available accident data to the GWU/VCU project team instead of performing Task 5-1, which involved a sensitivity analysis on Cargo FV incident rates using well sourced multipliers for the Tank FV incident rates to be provided by the VTRA 2015 Working Group (see Figure 2). The reason for the recalibration to additional accident data separately for Tank FV and Cargo FC, was the lack of well sourced document to arrive at those multipliers combined with an observed severe under reporting of incidents (i.e. propulsion failures, steering failures, navigational aid failures and human errors) as demonstrated during the VTRA 2005 for the period from 1995 – 2005.

The period for accident data calibration of the VTRA 2015 model was expanded to 1990 – 2015 to allow for accident calibration at both the accident level and the oil spill level of the oil spill accident event chain in Figure 5. The new Task of recalibration to available accident data to the GW/VCU project team is termed Task "5-I" to indicate it replaces Task 5-I despite it being one of the first tasks that had to be executed to construct the VTRA 2015 Calibration Case described in Section 3 of this QAPP. The change to a Task "5-1" also required a separation of the original Task 1 – I into a Task 1 – IA and a Task 1 – IB. Likewise a separation of the original Task 2-1 into a Task 2-IA and Task 2-1B was required. Finally Task 3-II is also separated into Task 3-IIA and Task 3-IIB. Task 3-IIA includes a sub task to write this QAPP. This sub-task was added to the original proposal necessitated by the source of funding for Phase II[1]. The updated project schedule with these tasks at the time that this QAPP is written is provided in Figure 6.

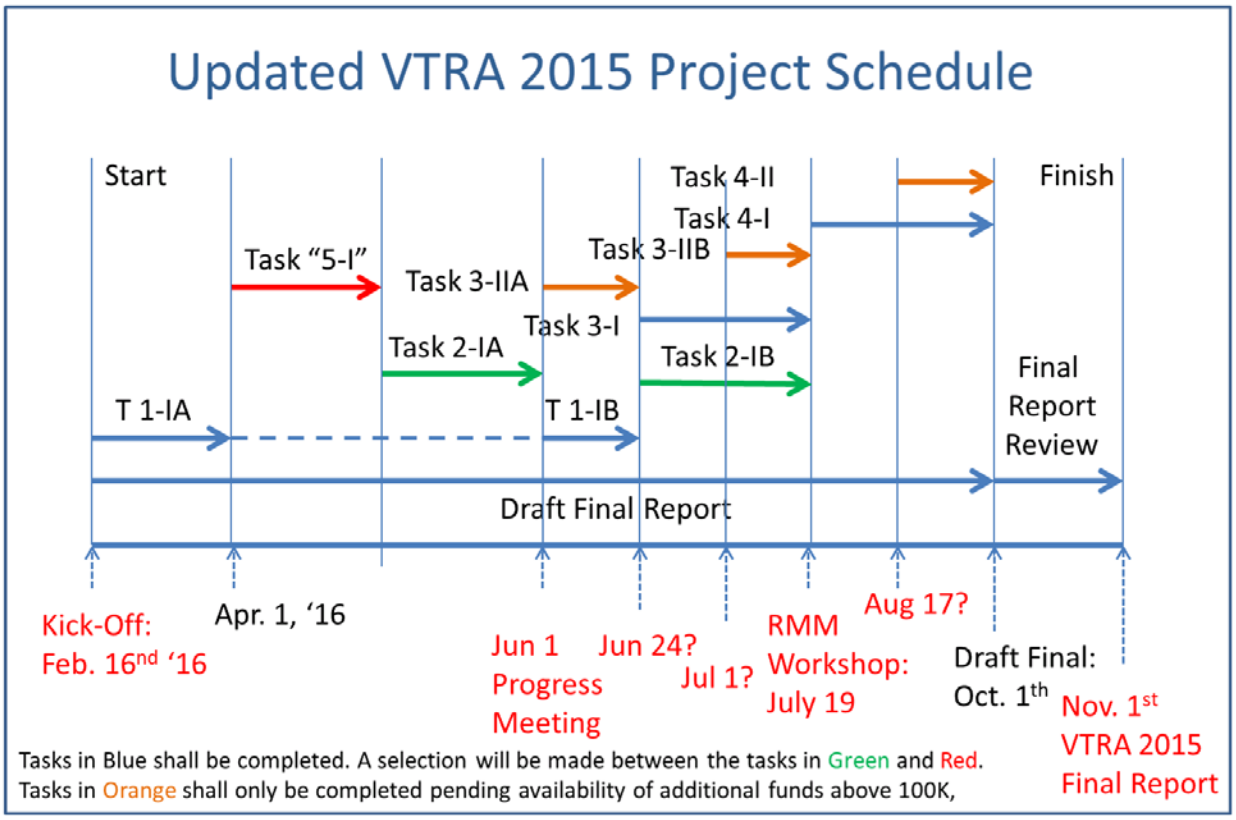


Figure 7. Updated VTRA 2015 Phase I and Phase II Schedule at the time QAPP is written for Phase II

Task 1-I (now Task 1-1A and Task 1-1B), 3-I and 4-I from the original version of this proposed Scope of Work are selected for completion. A selection was to be made by the

[1] Since the funding source for Phase II was not known at the time the proposed scope of work, the production of TASK 3A was not budgeted for in the original proposed budget.

VTRA 2015 Steering Committee, whether Task 2-I (from the original version of the Scope of Work) or Task 5-I (added after the first version) will be completed, since funding to execute both Tasks was not available. Despite this lack of funds GW/VCU executed both Tasks "5-1" and Task 2-1 to sufficiently inform the VTRA 2015 Working Group during the June 2 VTRA 2015 Work Group meeting on changes to the VTRA 2015 model analysis relative to the VTRA 2010 model analysis for What-If Cases Q, R, S and T as a result of the execution of Task "5-1". The development of the VTRA 2015 Calibration Case falls under Task "5-1".

Task 1-IA involves the traffic stream analysis using longitudinal AIS crossing line date from 2010 – 2015. Task 1-1B involves the development of the VTRA 2015 base case by integrating the traffic stream analysis from Task 1-A with the VTRA 2015 Calibration Case constructed under Task "5-1"; Task 2-IA revisits/updates the VTRA 2010 What-If Case Q, R, S and T and compares their analysis relative to the VTRA 2015 Calibration Case; Task 2-IB compares the VTRA 2015 Base constructed under Task 1-IB relative to the VTRA 2015 Calibration Case constructed under Task "5-1". Task 3-I defines a new VTRA 2015 Combined What-if Case, in consultation with the VTRA 2015 Working Group (see Figure 2) where additional anticipated projects will be added to the VTRA 2010 Case T to form this Combined VTRA 2015 What-If Case. During the June 2nd meeting with VTRA 2015 Working Group it was decided to remove Case Q from further consideration in this new VTRA 2015 Combined What-If Case.

Task 3-II will be completed since additional funds for Phase II have become available. Task 3-II will evaluate three Phase II What-If Cases individually, defined in consultation with the VTRA 2015 Working Group, that do not have to partition the combined Phase I VTRA 2015 What-if Case. These three individual Phase II What-If Cases will be added to the VTRA 2015 Base Case constructed under Task 2-1B. Task 4-I deals with the development of a new Phase I Risk Mitigation Measure (RMM) Case in which a portfolio of RMM's will be evaluated. This portfolio will contain VTRA 2010 RMM's and additional RMM's selected in consultation with the VTRA 2015 Working Group. A condition for including an additional RMM to the Phase I RMM Case is that such an RMM can be meaningfully represented in the VTRA 2015 model. Task 4-II will be completed since additional funds for Phase II have become available. Task 4 - II will evaluate prioritized individual Phase II RMM's Cases that do not have to partition the Task 4-I RMM portfolio case. These Phase II RMM Cases will in principle be evaluated relative to the combined VTRA 2015 What-If case, unless the VTRA 2015 Working Group prefers another relative comparison to one of the other Phase II What-If Cases.

A total of three meetings were envisioned throughout the project: a kick-off meeting, a progress meeting and a final meeting. A kick-off meeting was held on March 2nd and a Progress meeting was held on June 2nd. A final RMM workshop meeting is tentatively scheduled for July 19th pending sufficient progress of Task 2-IB (the construction of the VTRA 2015 Base Case) and sufficient progress on Task 3-IB (the relative comparison of the combined Phase I VTRA 2015 What-If Case to the VTRA 2015 Base Case). At this point the earliest date for the commencement of Task 3-II is July 1st, although that is a very optimistic estimate. Task 4-II's anticipated start date is August 17th (see the update VTRA 2015 Project Schedule in Figure 7).

All case analyses shall be compared using geographic profiles by oil spill sizes 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More. The generation of these geographic profiles by oil spill size is particularly informative for the consideration of additional potential risk mitigation measures under Task 4 - I. Geographic profiles by oil spill size were not available during the VTRA 2010 project and are an added work product to the VTRA 2015 project analysus. In addition to the generation of the geographic profiles by Oil Spill Sizes 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More, a by waterway zone comparison will be conducted for the 15 VTRA 2010 waterway zones in terms of these oil spill size categories. The definition of VTRA 2015 waterway zones is provided in Figure 8. These waterway zones are the same as those used in the VTRA 2010 although the waterway zone "Island Trust" was renamed to "Southern Gulf Islands. Below Tasks 1-IA, Task 1-IB, 2-IA, Task 2-1B, Task 3-I, Task 3-II, Task 4-I, Task 4-II and Task "5-I" are described in more detail through the description of sub-tasks.

Task 1-IA: Longitudinal Traffic Stream Analysis using AIS Crossing Line Data

a. Perform a crossing line analysis of 2010 - 2015 AIS data for crossing lines: WSJF, Admiralty Inlet, Entrances Haro-Strait/Bound Pass, Entrances Rosario Strait, Saddle Bags and Point Roberts. The crossing line analysis will "tease out" the various traffic streams by cargo focus vessel and tank focus vessel category to evaluate changes in traffic volume over these traffic streams over that time period. The crossing line counts were provided to GW/VCU for the years 2010 through 2015 at no charge and are listed in Appendix B.

Task "5-I": Development of VTRA '15 Calibration Case

a. Using the Accident Data provided in Appendix C of this QAPP recalibrate the VTRA model such that the oil spill accident event chain in Figure 5 evaluates the same Average Number of Accidents per year observed in this dataset at the accident level and the oil spill level of this event chain. More detail has been provided in the interim work product: VTRA 2015 Model Callibration. The case referred to as a result of this recalibration is termed the VTRA 2015 Calibration Case.

b. Use the model developed under Task "5-1".a to perform a relative comparison analysis by generating for the VTRA 2015 Calibration Case using geographic profiles by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – 1000 m3. These VTRA 2015 Calibration geographic profiles will be compared to their counterparts of the VTRA 2010 Base Case.

c. Use the model developed under Task "5-1".a to compare the VTRA 2015 Calibration Case results to the VTRA 2010 Base Case Results by the 15 VTRA waterway zones and by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More.

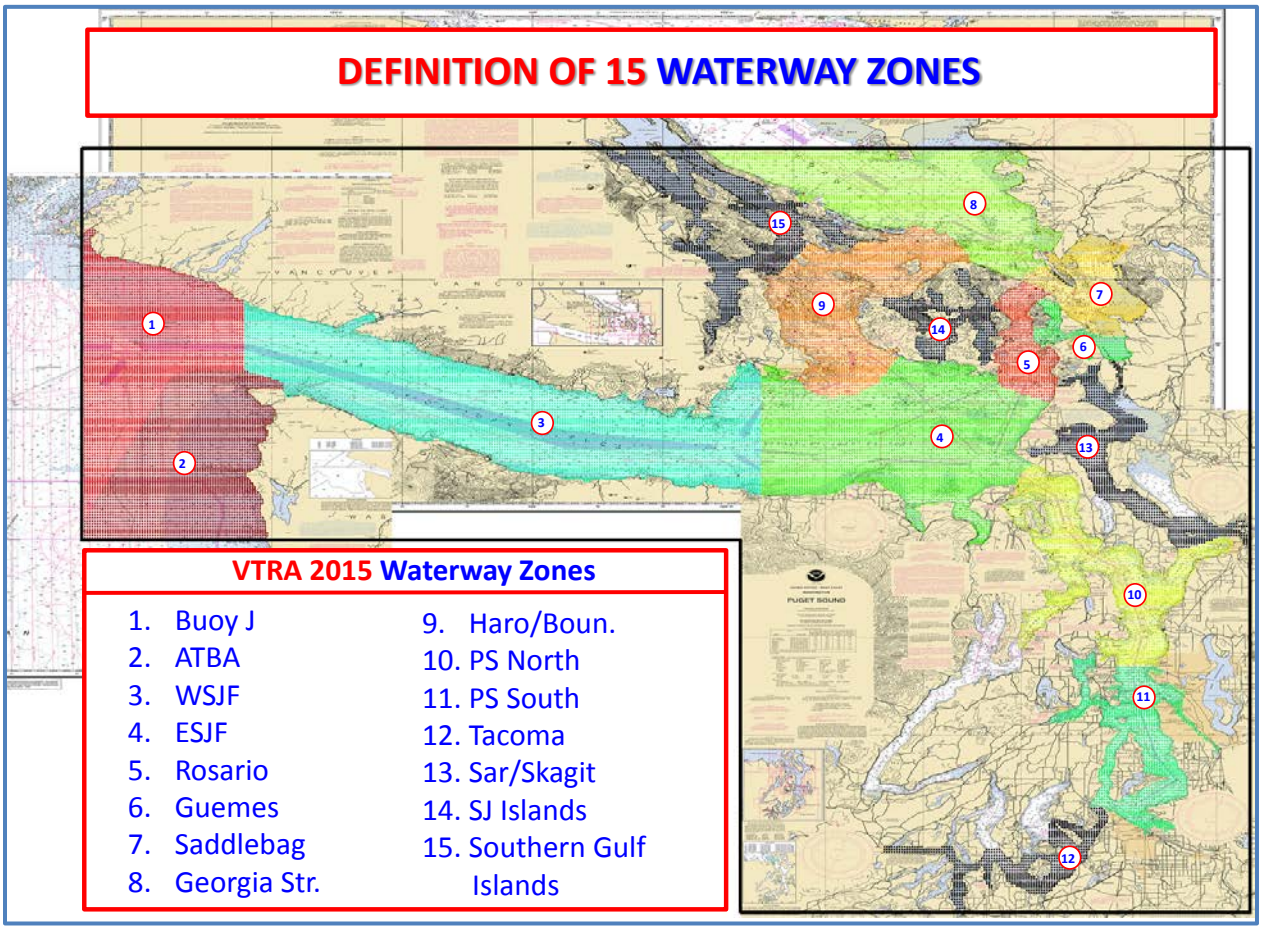


Figure 8. Definition of VTRA 2015 Waterway Zones

Task 2-IA: Revisit VTRA '10 What-if Cases and Compare to VTRA '15 Calibration Case

a. Revisit the VTRA 2010 definition of What-If Cases Q, R, S and T and update their definitions if necessary in collaboration with the VTRA 2015 working group. The updated VTRA 2015 definitions of Cases Q, R, S and T are provided in Figure 6.

b. Use the model developed under Task "5-1".a and the What-If Case definitions revisited under Task 2-1A.a to generate geographic profiles by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More. Compare the Case Q, R, S and T results to the VTRA 2015 Calibration Case in terms of these geographic profiles.

c. Use the model developed under Task "5-1".a and the What-If Case definitions revisited under Task 2-1A.a to compare Case Q, R, S, and T results to the VTRA 2015 Calibration Case Results by the 15 VTRA waterway zones and by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More.

Task 1-IB: Development of VTRA '15 Base Case

a. Use the analysis results of Task 1-IA.a to "rebalance" the focus vessel traffic in the VTRA 2010 analysis model such that rebalancing will result in VTRA model annual crossing line counts that are more representative of observed 2015 AIS crossing line counts by Cargo Focus Vessel and Tank Focus Vessel.

Task 2-IB: Compare VTRA '15 Base Case to the VTRA 2015 Calibration Case

a. Use the model developed under Task 1-IB.a to develop a VTRA 2015 Base Case analysis by generating geographic profiles by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More. Compare the VTRA 2015 Base Case Analysis to the VTRA 2015 Calibration Case Analysis developed under Task "5-1" in terms of these geographic profiles.

b. Use the model developed under Task 1-IB.a to compare the VTRA 2015 Base Case results to the VTRA 2015 Calibration Case Results developed under Task "5-1" by the 15 VTRA waterway zones and by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More.

Task 3-I: Definition of Phase I VTRA '15 What-if Case and compare to VTRA 2015 Base Case

a. With the VTRA 2015 working group, collaboratively define a new Combined VTRA 2015 What-If Case using the VTRA 2010 Focus Vessel categories reflecting additional planned projects that have come to light following the VTRA 2010 completion. Add the additional potential traffic to the What-If Case T from Task 2-1A.a while removing VTRA 2010 What-If Case Q. This case will be designated the VTRA 2015 What-If Case U.

b. Use the model developed under Task 1-IB.a and the What-If Case U defined under Task 3-I.a to generate geographic profiles by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – 1000 m3 for Case U. Compare the What-If Case U results to the VTRA 2015 Base Case Analysis in terms of these geographic profiles.

c. Use the model developed under Task 1-IB.a and the What-If Case U defined under Task 3-I.aa to compare What-If Case U results to the VTRA 2015 Base Case Results developed under Task 1-IB.a by the 15 VTRA waterway zones and by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More.

Task 3-IIA: Write the VTRA '15 QAPP Addendum and define Phase II What-If Cases

a. Write the VTRA 2015 Quality Assurance Plan Addendum required by the funding source for Phase II funding.

b. With the VTRA 2015 Working Group, separate What-If Case U defined under Task 3-1.a into three individual What-If Cases to be analyzed under Phase II using the VTRA 2010 Focus Vessel categories. These Phase II What-If Cases do not have to partition Phase I What-If Case U.

Task 3-IIB: Compare VTRA '15 Phase II What-if Cases to VTRA 2015 Base Case

a. For each Phase II What-If Case defined under Task 3-II.b add them individually to the VTRA 2015 Base Case defined under Task 1-IB.a

b. Use the model developed under Task 1-IB.a and the individual What-If Cases defined under Task 3-II.b to generate geographic profiles by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – 1000 m3 for these What-If cases. Compare the Phase II What-If Cases results to the VTRA 2015 Base Case Analysis in terms of these geographic profiles.

c. Use the model developed under Task 1-IB.a and the individual Phase II What-If Cases defined under Task 3-II.b to compare What-If Cases results to the VTRA 2015 Base Case Results by the 15 VTRA waterway zones and by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More.

Task 4-I: Definition of Phase I VTRA '15 RMM Case and compare to VTRA 2015 Base Case

a. With the VTRA 2015 working group, collaboratively define a new RMM Case using the VTRA 2010 Focus Vessel categories reflecting a portfolio of RMM's selected from VTRA 2010 RMM's, existing RMMs that have been introduced since 2010, and potentially other RMM's to be defined based on insights gleaned from the results under Task 2-IA and Task 3-1.

b. Use the model developed under Task 1-IB.a to perform an analysis combining the RMM Case defined under Task 4-I.a with Phase I What-If Case U defined under Task 3-1.a. Designating this as the U-RMM Case, generate for this case geographic profiles by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – 1000 m3. Compare these U-RMM results to the Phase I What-if Case U geographic profile results generated under Task 3-Ib.

c. Use the model developed under Task 1-IB.a and the U-RMM Case defined under Task 4-I.b to compare the U-RMM Case results for the 15 VTRA waterway zones and by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More to the Phase I What-If Case U by waterway zone results generated under Task 3-Ic.

Task 4-II: Definition of VTRA '15 RMM Case and compare to VTRA 2015 Base Case

a. With the VTRA 2015 working group, separate the Phase I U-RMM Case into three individual Phase II RMM Cases. These three Phase II RMM Cases do not have to partition the Phase I U-RMM Case defined under Task 4-I.a by adding them in principle to Phase I Case U or one of the Phase II What-If Cases, but not both, using the VTRA 2010 Focus Vessel categories.

b. Use the model developed under Task 1-IB.a and the individual RMM Cases defined under Task 4-II.a to generate geographic profiles by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – 1000 m3 for these RMM cases. Compare the RMM Cases results to the Phase I What-If Case U, or the Phase II What-If Case of choice under Task 4-II.a, in terms of these geographic profiles.

c. Use the model developed under Task 1-IB.a and the RMM Cases defined under Task 4-I.Ia to compare RMM Case results to the Phase I What-If Case U, or the Phase II What-If Case of choice under Task 4-II.a, by the 15 VTRA waterway zones and by Oil Spill Size Categories: 1m3 – 1000 m3, 1000m3 – 2500 m3, 2500m3 – More.

5. Project Work Products

The primary work products are (i) presentations detailing Case to Case relative comparisons as described by the Tasks above in Section 4, (ii) this VTRA 2015 Quality Assurance Project Plan Addendum, (iii) the draft VTRA 2015 Final Report and (iv) the VTRA 2015 final report. A draft outline of the VTRA 2015 final report is provided in Figure 9. The interim work product presentations shall utilize the generated geographic risk profiles to facilitate stakeholder understanding and will synthesize/summarize analytical results. Interim presentations, this VTRA 2015 QAPP addendum, the VTRA 2015 draft final report and VTRA 2015 final report shall be posted on the Faculty of Johan Rene van Dorp at:

https://www.seas.gwu.edu/~dorpjr/VTRA_2015/VTRA_2015_Project.html

1. EXECUTIVE SUMMARY

2. PROJECT DESCRIPTION

3. SUMMARY OF METHODOLOGY

4. RECALLIBRATING THE VTRA 2010 MODEL
   - 4.1. Comparison of VTRA 2015 Calibration Case to the VTRA 2010 Base Case

5. THE 2015 BASELINE ANALYSIS
   - 5.1. Longitudinal Analysis of AIS Counting Lines
   - 5.2. Comparison of VTRA 2015 Base Case to the VTRA 2015 Calibration Case
   - 5.3. VTRA 2015 Base Case Analysis Results

6. WHAT-IF CASE ANALYSES
   - 6.1. Comparison of Combined Phase I What-If Case to the VTRA 2015 Base Case
   - 6.2. Comparison of Phase II What-If Cases to the VTRA 2015 Base Case

7. RISK MITIGATION CASE ANALYSES
   - 7.1. Comparison of Phase I RMM Portfolio Case to the Combined Phase I What-If Case
   - 7.2. Comparison of Phase II RMM Case to the Combined Phase I What-If Case or another Phase II What-If Case.

8. CONCLUSION AND RECOMMENDATIONS

9. REFERENCES

Figure 9. Draft outline of 2015 VTRA Final Report for PHASE I, II.

References

[1] J.R. van Dorp and J.R.W. Merrick (2014). "PSP VTRA 2010 Final Report", https://www.seas.gwu.edu/~dorpjr/tab4/publications_VTRA_Update_Reports.html

[2] J.R. van Dorp and J.R.W. Merrick (2013). "Makah VTRA 2010 Model Update Final Report, https://www.seas.gwu.edu/~dorpjr/tab4/publications_VTRA_Update_Reports.html

[3] J. R. van Dorp and J. R.W. Merrick (2009). "On a risk management analysis of oil spill risk using maritime transportation system simulation", *Annals of Operations Research*, published online before print December 12, 2010, DOI: 10.1007/s10479-009-0678-1. (http://www.springerlink.com/content/w168111018754401/)

[4] G. van de Wiel and J. R. van Dorp (2009). "An oil outflow model for tanker collisions and groundings", *Annals of Operations Research*, published online before print November 25, 2010, DOI: 10.1007/s10479-009-0674-5. (http://www.springerlink.com/content/d7432xmg431v42q7/)

[5] J.R. van Dorp, J.R.W. Merrick (2009), "A Response to Seven Additional Questions Related to the VTRA Project", completed May, 2009. http://www.seas.gwu.edu/~dorpjr/tab4/publications_technical.html

[6] J.R. van Dorp, J.R.W. Merrick, J.R. Harrald, M. Gabowksi (2009), "VTRA Final Report Addendum: A response to 23 comments from the Corps", completed January 2009. http://www.seas.gwu.edu/~dorpjr/tab4/publications_technical.html

[7] J.R. van Dorp, J.R.W. Merrick, J.R. Harrald, M. Gabowksi (2008) "Assessment of Oil Spill Risk due to Potential Increased Vessel Traffic at Cherry Point, Washington " Final Report – Completed August 2008. http://www.seas.gwu.edu/~dorpjr/tab4/publications_technical.html

[8] P. Szwed, J. Rene van Dorp, J.R.W.Merrick, T.A. Mazzuchi and A. Singh (2006). "A Bayesian Paired Comparison Approach for Relative Accident Probability Assessment with Covariate Information", *European Journal of Operations Research*, Vol. 169 (1), pp. 157-177.

[9] Merrick, J. R. W. and J. R. van Dorp (2006). "Speaking the Truth in Maritime Risk Assessment". *Risk Analysis*, Vol. 26 (1), pp. 223 - 237.

[10] J.R.W.Merrick, J. Rene van Dorp, V. Dinesh (2004). "Assessing Uncertainty in Simulation Based Maritime Risk Assessment". *Risk Analysis*, Vo. 25 (3), pp. 731-743.

[11] J.R.W. Merrick, J.R. van Dorp, J.P. Blackford, G.L. Shaw, T.A. Mazzuchi and J.R. Harrald (2003). "A Traffic Density Analysis of Proposed Ferry Service Expansion in San Francisco Bay Using a Maritime Simulation Model", *Reliability Engineering and System Safety*, Vol. 81 (2): pp. 119-132.

[12] J.R.W. Merrick, J. R. van Dorp, T. Mazzuchi, J. Harrald, J. Spahn and M. Grabowski (2002). "The Prince William Sound Risk Assessment". *Interfaces*, Vol. 32 (6): pp.25-40.

[13] J.R. van Dorp J.R.W. Merrick , J.R. Harrald, T.A. Mazzuchi, and M. Grabowski (2001). "A Risk Management procedure for the Washington State Ferries", *Journal of Risk Analysis*, Vol. 21 (1): pp. 127-142.

[14] National Research Council (2001). Environmental Performance of Tanker Designs in Collision and Grounding, Special Report 259, Marine Board, Transportation Research Board, The National Academies.

[15] M. Grabowski, J.R.W. Merrick , J.R. Harrald, T.A. Mazzuchi, and J.R. van Dorp (2000). "Risk Modeling in Distributed, Large Scale Systems", *IEEE Transactions on Systems, Man, Cybernetics – PART A: Systems and Humans*, Vol. 30 (6): pp. 651-660.

[16] J.R. van Dorp J.R.W. Merrick , J.R. Harrald, T.A. Mazzuchi, M. Grabowski, and J.E Spahn (2000). "A Systems approach to managing oil transportation risk in Prince William Sound", *Systems Engineering*, Vol 3: pp. 128-142.

[17] George J. Busenberg (1999). "Collaborative and adversarial analysis in environmental policy", *Policy Sciences,* Vol. 32, pp. 1-11.

[18] J.R. Harrald, T.A. Mazzuchi, J. E. Spahn, J.R. van Dorp J.R.W. Merrick, S. Shrestha, M. Grabowski (1998). "Using System Simulation to Model the Impact of Human Error in a Maritime Risk Assessment". *Safety Science*, Vol. 30, pp. 235-247.

[19] National Research Council (1998), Review of Prince William Sound Risk Assessment. Review of the Prince William Sound, Alaska, Risk Assessment Study Committee on Risk Assessment and Management of Marine Systems, Marine Board, ISBN: 0-309-55835-2, 78 pages.

Appendix A: 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.
- 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.
- GWU – George Washington University is the prime subgrant awardee.
- VCU – Virginia Commonwealth University is a sub-awardee to GWU.
- GW/VCU – The technical team composed of GWU 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 GWU/VCU over the course of this study.
- QAPP – Quality Assurance Project Plan
- USCG – US Coast Guard Sector Seattle, District 13.
- VTOSS – Vessel Traffic Operational Support System
- VTRA – Vessel Traffic Risk Assessment
- VTS – Vessel Traffic Service is thereal-time marine traffic monitoring system used by the USCG, similar to air traffic control for aircraft.

Appendix B. AIS Count Line Data

2010 CROSSING LINE COUNTS

SJDF

	East	West	Grand Total
ATB	72	66	138
Cargo	3204	2996	6200
Passenger	265	229	494
Tanker	599	557	1156
Grand Total	4140	3848	7988

ADMIRALTY INLET

	North	South	Grand Total
ATB	23	20	43
Cargo	1696	1627	3323
Passenger	852	849	1701
Tanker	75	73	148
Grand Total	2646	2569	5215

POINT ROBERTS

	East	West	Grand Total
ATB	29	32	61
Cargo	2212	2271	4483
Passenger	100	129	229
Tanker	244	243	487
Grand Total	2585	2675	5260

BOUNDARY PASS

	North	South	Grand Total
ATB	3	3	6
Cargo	2342	2145	4487
Passenger	99	76	175
Tanker	265	252	517
Grand Total	2709	2476	5185

HARO STRAIT

	North	South	Grand Total
ATB	3	3	6
Cargo	2180	2310	4490
Passenger	137	118	255
Tanker	246	271	517
Grand Total	2566	2702	5268

BELLINGHAM CHANNEL

	North	South	Grand Total
ATB	10	4	14
Cargo	22	48	70
Passenger	43	47	90
Tanker	23	3	26
Grand Total	98	102	200

ROSARIO SOUTH

	North	South	Grand Total
ATB	79	78	157
Cargo	66	71	137
Passenger	45	56	101
Tanker	311	320	631
Grand Total	501	525	1026

ROSARIO NORTH

	North	South	Grand Total
ATB	75	81	156
Cargo	53	57	110
Passenger	57	64	121
Tanker	252	270	522
Grand Total	437	472	909

SADDLEBAGS NORTH

	North	South	Grand Total
ATB	31	46	77
Cargo	20	4	24
Passenger	52	79	131
Tanker	90	61	151
Grand Total	193	190	383

SADDLEBAGS SOUTH

	North	South	Grand Total
ATB	38	36	74
Cargo	12	15	27
Passenger	1	3	4
Tanker	5	55	60
Grand Total	56	109	165

2011 CROSSING LINE COUNTS

SJDF

	East	West	Grand Total
ATB	74	66	140
Cargo	3507	3331	6838
Passenger	218	183	401
Tanker	605	578	1183
Grand Total	4404	4158	8562

ADMIRALTY INLET

	North	South	Grand Total
ATB	21	22	43
Cargo	1963	1844	3807
Passenger	931	1017	1948
Tanker	88	85	173
Grand Total	3003	2968	5971

POINT ROBERTS

	East	West	Grand Total
ATB	53	56	109
Cargo	2495	2532	5027
Passenger	150	160	310
Tanker	198	189	387
Grand Total	2896	2937	5833

BOUNDARY PASS

	North	South	Grand Total
ATB	3	4	7
Cargo	2658	2460	5118
Passenger	102	70	172
Tanker	199	200	399
Grand Total	2962	2734	5696

HARO STRAIT

	North	South	Grand Total
ATB	3	4	7
Cargo	2452	2681	5133
Passenger	131	112	243
Tanker	186	212	398
Grand Total	2772	3009	5781

BELLINGHAM CHANNEL

	North	South	Grand Total
ATB	10	5	15
Cargo	9	26	35
Passenger	66	53	119
Tanker	21	5	26
Grand Total	106	89	195

ROSARIO SOUTH

	North	South	Grand Total
ATB	79	83	162
Cargo	70	65	135
Passenger	46	54	100
Tanker	398	400	798
Grand Total	593	602	1195

ROSARIO NORTH

	North	South	Grand Total
ATB	89	96	185
Cargo	54	50	104
Passenger	95	83	178
Tanker	305	330	635
Grand Total	543	559	1102

SADDLEBAGS NORTH

	North	South	Grand Total
ATB	56	69	125
Cargo	15	3	18
Passenger	99	132	231
Tanker	145	91	236
Grand Total	315	295	610

SADDLEBAGS SOUTH

	North	South	Grand Total
ATB	73	70	143
Cargo	1	2	3
Passenger	50	49	99
Tanker	26	99	125
Grand Total	150	220	370

2012 CROSSING LINE COUNTS

SJDF

	East	West	Grand Total
ATB	94	84	178
Cargo	3444	3222	6666
Passenger	240	237	477
Tanker	586	558	1144
Grand Total	4364	4101	8465

ADMIRALTY INLET

	North	South	Grand Total
ATB	32	30	62
Cargo	1898	1789	3687
Passenger	912	976	1888
Tanker	69	68	137
Grand Total	2911	2863	5774

POINT ROBERTS

	East	West	Grand Total
ATB	46	44	90
Cargo	2560	2598	5158
Passenger	142	143	285
Tanker	201	198	399
Grand Total	2949	2983	5932

BOUNDARY PASS

	North	South	Grand Total
ATB	2	6	8
Cargo	2612	2418	5030
Passenger	64	60	124
Tanker	198	195	393
Grand Total	2876	2679	5555

HARO STRAIT

	North	South	Grand Total
ATB	3	6	9
Cargo	2434	2606	5040
Passenger	79	79	158
Tanker	182	212	394
Grand Total	2698	2903	5601

BELLINGHAM CHANNEL

	North	South	Grand Total
ATB	22	5	27
Cargo	9	16	25
Passenger	42	54	96
Tanker	18	5	23
Grand Total	91	80	171

ROSARIO SOUTH

	North	South	Grand Total
ATB	106	102	208
Cargo	73	64	137
Passenger	35	52	87
Tanker	366	358	724
Grand Total	580	576	1156

ROSARIO NORTH

	North	South	Grand Total
ATB	106	110	216
Cargo	47	49	96
Passenger	102	93	195
Tanker	257	262	519
Grand Total	512	514	1026

SADDLEBAGS NORTH

	North	South	Grand Total
ATB	52	68	120
Cargo	10	1	11
Passenger	89	144	233
Tanker	116	84	200
Grand Total	267	297	564

SADDLEBAGS SOUTH

	North	South	Grand Total
ATB	46	51	97
Cargo	1		1
Passenger	23	21	44
Tanker	26	69	95
Grand Total	96	141	237

2013 CROSSING LINE COUNTS

SJDF

	East	West	Grand Total
ATB	168	156	324
Cargo	3396	3219	6615
Passenger	203	184	387
Tanker	592	570	1162
Grand Total	4359	4129	8488

ADMIRALTY INLET

	North	South	Grand Total
ATB	34	33	67
Cargo	1883	1775	3658
Passenger	865	893	1758
Tanker	37	36	73
Grand Total	2819	2737	5556

POINT ROBERTS

	East	West	Grand Total
ATB	88	80	168
Cargo	2399	2450	4849
Passenger	124	111	235
Tanker	194	204	398
Grand Total	2805	2845	5650

BOUNDARY PASS

	North	South	Grand Total
ATB	3	6	9
Cargo	2555	2468	5023
Passenger	59	63	122
Tanker	213	221	434
Grand Total	2830	2758	5588

HARO STRAIT

	North	South	Grand Total
ATB	3	6	9
Cargo	2426	2624	5050
Passenger	67	62	129
Tanker	202	233	435
Grand Total	2698	2925	5623

BELLINGHAM CHANNEL

	North	South	Grand Total
ATB	50	13	63
Cargo	12	16	28
Passenger	38	52	90
Tanker	25	6	31
Grand Total	125	87	212

ROSARIO SOUTH

	North	South	Grand Total
ATB	182	177	359
Cargo	73	63	136
Passenger	53	56	109
Tanker	349	336	685
Grand Total	657	632	1289

ROSARIO NORTH

	North	South	Grand Total
ATB	192	210	402
Cargo	48	44	92
Passenger	98	80	178
Tanker	285	310	595
Grand Total	623	644	1267

SADDLEBAGS NORTH

	North	South	Grand Total
ATB	102	134	236
Cargo	10	4	14
Passenger	98	146	244
Tanker	154	109	263
Grand Total	364	393	757

SADDLEBAGS SOUTH

	North	South	Grand Total
ATB	64	72	136
Cargo	2	2	4
Passenger	8	14	22
Tanker	21	90	111
Grand Total	95	178	273

2014 CROSSING LINE COUNTS

SJDF

	East	West	Grand Total
ATB	168	154	322
Cargo	3419	3245	6664
Passenger	210	190	400
Tanker	544	511	1055
Grand Total	4341	4100	8441

ADMIRALTY INLET

	North	South	Grand Total
ATB	33	33	66
Cargo	1830	1761	3591
Passenger	936	965	1901
Tanker	23	21	44
Grand Total	2822	2780	5602

POINT ROBERTS

	East	West	Grand Total
ATB	85	77	162
Cargo	2639	2675	5314
Passenger	131	162	293
Tanker	205	211	416
Grand Total	3060	3125	6185

BOUNDARY PASS

	North	South	Grand Total
ATB	6	11	17
Cargo	2676	2510	5186
Passenger	78	60	138
Tanker	212	206	418
Grand Total	2972	2787	5759

HARO STRAIT

	North	South	Grand Total
ATB	5	13	18
Cargo	2500	2647	5147
Passenger	143	125	268
Tanker	204	215	419
Grand Total	2852	3000	5852

BELLINGHAM CHANNEL

	North	South	Grand Total
ATB	48	20	68
Cargo	11	16	27
Passenger	51	53	104
Tanker	29	2	31
Grand Total	139	91	230

ROSARIO SOUTH

	North	South	Grand Total
ATB	176	172	348
Cargo	71	62	133
Passenger	79	77	156
Tanker	311	328	639
Grand Total	637	639	1276

ROSARIO NORTH

	North	South	Grand Total
ATB	196	206	402
Cargo	51	45	96
Passenger	103	111	214
Tanker	263	282	545
Grand Total	613	644	1257

SADDLEBAGS NORTH

	North	South	Grand Total
ATB	119	154	273
Cargo	8	2	10
Passenger	127	145	272
Tanker	116	104	220
Grand Total	370	405	775

SADDLEBAGS SOUTH

	North	South	Grand Total
ATB	76	62	138
Cargo	13	15	28
Passenger	12	21	33
Tanker	36	75	111
Grand Total	137	173	310

2015 CROSSING LINE COUNTS

SJDF

	East	West	Grand Total
ATB	134	125	259
Cargo	3365	3185	6550
Passenger	253	232	485
Tanker	521	513	1034
Grand Total	4273	4055	8328

ADMIRALTY INLET

	North	South	Grand Total
ATB	61	57	118
Cargo	1800	1702	3502
Passenger	1132	1288	2420
Tanker	33	27	60
Grand Total	3026	3074	6100

POINT ROBERTS

	East	West	Grand Total
ATB	67	71	138
Cargo	2528	2596	5124
Passenger	145	197	342
Tanker	215	219	434
Grand Total	2955	3083	6038

BOUNDARY PASS

	North	South	Grand Total
ATB	5	2	7
Cargo	2655	2368	5023
Passenger	117	87	204
Tanker	222	208	430
Grand Total	2999	2665	5664

HARO STRAIT

	North	South	Grand Total
ATB	2	5	7
Cargo	2366	2658	5024
Passenger	145	157	302
Tanker	205	226	431
Grand Total	2718	3046	5764

BELLINGHAM CHANNEL

	North	South	Grand Total
ATB	47	22	69
Cargo	14	19	33
Passenger	48	49	97
Tanker	20	4	24
Grand Total	129	94	223

ROSARIO SOUTH

	North	South	Grand Total
ATB	154	166	320
Cargo	70	69	139
Passenger	113	111	224
Tanker	284	287	571
Grand Total	621	633	1254

ROSARIO NORTH

	North	South	Grand Total
ATB	176	197	373
Cargo	43	42	85
Passenger	111	145	256
Tanker	223	247	470
Grand Total	553	631	1184

SADDLEBAGS NORTH

	North	South	Grand Total
ATB	119	149	268
Cargo	13	3	16
Passenger	125	87	212
Tanker	122	86	208
Grand Total	379	325	704

SADDLEBAGS SOUTH

	North	South	Grand Total
ATB	86	76	162
Cargo	6	11	17
Passenger	36	51	87
Tanker	28	69	97
Grand Total	156	207	363

VESSEL TRAFFIC RISK ASSESSMENT (VTRA 2015)
1990 – 2015 Data for Model Calibration

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC
VCU

Record	Data	Accident Type	Latitude	Longitude	Vessel Type	FV Type	Waterway	Vessel Name
1	4/13/1995	ALLISION	N47360	W122190	FREIGHTER	CARGO FV	US	EASTERN WIND
2	9/3/1995	COLLISION	N47243	W122216	FREIGHTER	CARGO FV	US	SEALAND INNOVATOR
3	9/11/1996	ALLISION	N47394	W122224	BULK CARRIER	CARGO FV	US	MOKUHANA
4	1/12/1997	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	ETERNAL MARINER
5	3/27/1997	GROUNDING	NULL	NULL	BULK CARRIER	CARGO FV	US	SEA TRIDENT
6	3/30/1997	GROUNDING	NULL	NULL	FREIGHTER	CARGO FV	US	SKAUGRAN
7	5/30/1997	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	VERNAL STAR
8	8/26/1997	GROUNDING	NULL	NULL	FREIGHTER	CARGO FV	US	KRASKINO
9	10/23/1997	ALLISION	N47360	W122190	BULK CARRIER	CARGO FV	US	THALASSINI NIKI
10	10/30/1997	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	NORTHERN LIGHTS
11	1/24/1998	ALLISION	NULL	NULL	TANKER	TANK FV	US	OVERSEAS ARCTIC
12	6/14/1998	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	SEA HAPPINESS
13	7/7/1998	ALLISION	N47325	W122200	BULK CARRIER	CARGO FV	US	FIVI
14	9/5/1998	GROUNDING	47.16	-122.73	FREIGHTER	CARGO FV	US	MONCHEGORSK
15	10/26/1998	ALLISION	N48070	W122450	FREIGHTER	CARGO FV	US	GLENDYNE
16	8/17/1999	GROUNDING	N47304	W122249	FREIGHTER	CARGO FV	US	COASTAL SEA
17	12/5/1999	GROUNDING	W122344	38947.00	ITB	TANK FV	US	ITB NEW YORK
18	12/23/1999	ALLISION	N47590	W122130	FREIGHTER	CARGO FV	US	SEA AMELITA
19	1/14/2000	ALLISION	48.26	123.56	BULK CARRIER	CARGO FV	US	CYNTHIA HARMONY
20	6/7/2000	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	HYUNDAI LIBERTY
21	7/29/2000	ALLISION	N48124	W123277	FREIGHTER	CARGO FV	US	MERKER RIVER
22	9/6/2000	COLLISION	N48274	W125418	FREIGHTER	CARGO FV	US	SELENDANG KASA
23	1/23/2001	ALLISION	N47342	W122211	FREIGHTER	CARGO FV	US	NORTON
24	2/11/2001	COLLISION	47:16:45	122:26:00	FREIGHTER	CARGO FV	US	GLYFADA
25	2/11/2001	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	HYUNDAI LIBERTY
26	4/29/2001	ALLISION	NULL	NULL	CONTAINER	CARGO FV	US	MARUBA TRADER
27	6/2/2001	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	T.L.I. ATSAH
28	7/6/2001	COLLISION	48.27	-125.06	FREIGHTER	CARGO FV	US	HORIZON NAVIGATOR
29	8/6/2001	ALLISION	48.17	124.90	CONTAINER	CARGO FV	US	CSX NAVIGATOR
30	12/14/2001	ALLISION	48.83	122.72	TANKER	TANK FV	US	LEYTE SPIRIT
31	1/11/2002	ALLISION	N 47° 39' 12.00"	W 122° 22' 42.00"	FREIGHTER	CARGO FV	US	COASTAL NOMAD
32	1/19/2002	COLLISION	48.41	122.78	TANKER	TANK FV	US	ALLEGIANCE
33	2/11/2002	ALLISION	N 48° 07' 50.00"	W 123° 27' 12.00"	TANKER	TANK FV	US	BLUE RIDGE
34	5/4/2002	COLLISION	47:27	122:24	FREIGHTER	CARGO FV	US	MEDEA
35	6/23/2002	ALLISION	47.54	-122.33	TANK BARGE	OIL BARGE	US	NATHAN 114
36	7/17/2002	ALLISION	47.27	-122.40	TANK BARGE	OIL BARGE	US	FOSS 185 P2
37	12/6/2002	ALLISION	48.86	122.76	BULK CARRIER	CARGO FV	US	ALMA
38	2/27/2003	ALLISION	47.59	-122.34	TANK BARGE	OIL BARGE	US	FOSS 248 P2
39	4/5/2003	COLLISION	N 47° 19' 24.00"	W 122° 27' 27.00"	FREIGHTER	CARGO FV	US	MEDEA
40	4/17/2003	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	TEAL ARROW

Record	Data	Accident Type	Latitude	Longitude	Vessel Type	FV Type	Waterway	Vessel Name
41	5/21/2003	ALLISION	47.28	-122.41	TANK BARGE	OIL BARGE	US	SCT 282
42	5/27/2003	ALLISION	47.58	-122.33	TANK BARGE	OIL BARGE	US	NAVY OIL BARGE
43	6/3/2003	ALLISION	47.57	-122.35	TANK BARGE	OIL BARGE	US	BARGE 255
44	10/11/2003	COLLISION	48.32	-125.03	TANK BARGE	OIL BARGE	US	DOTTIE
45	11/20/2003	ALLISION	47.58	122.36	CONTAINER	CARGO FV	US	CAP REINGA
46	12/18/2003	ALLISION	47.57	-122.35	TANK BARGE	OIL BARGE	US	NORTON
47	12/28/2003	COLLISION	48.22	-123.50	FREIGHTER	CARGO FV	US	NORSUL VITORIA
48	5/13/2004	ALLISION	47.98	122.22	FREIGHTER	CARGO FV	US	CAPE CAVO
49	9/16/2004	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	WADI ALRAYAN
50	11/12/2004	ALLISION	48.86	122.76	TANKER	TANK FV	US	GULF SCANDIC
51	11/22/2004	ALLISION	48.22	-123.53	FREIGHTER	CARGO FV	US	WILLI SALAMON
52	11/25/2004	ALLISION	48.43	-123.43	BULK CARRIER	CARGO FV	CA	THRASYVOULOS V.
53	2/14/2005	COLLISION	48.92	-122.92	TANK BARGE	OIL BARGE	US	PB 20
54	5/9/2005	ALLISION	N48°06'00.00"	W122°46'30.00"	FREIGHTER	CARGO FV	US	ROSE
55	9/10/2005	ALLISION	NULL	NULL	FREIGHTER	CARGO FV	US	APL ENGLAND
56	9/25/2005	ALLISION	NULL	NULL	BULK CARRIER	CARGO FV	US	OAK HARBOUR
57	4/13/2006	GROUNDING	28.75	114.00	FREIGHTER	CARGO FV	US	
58	6/23/2006	ALLISION	47.27	-122.55	FREIGHTER	CARGO FV	US	SWAN
59	6/27/2006	ALLISION	47.29	-122.45	FREIGHTER	CARGO FV	US	APHRODITE
60	3/2/2007	COLLISION	48.52	-122.59	TANK BARGE	OIL BARGE	US	SHAUNA KAY
61	4/14/2007	ALLISION	48.52	-122.62	TANK BARGE	OIL BARGE	US	BARGE 255
62	10/18/2007	ALLISION	47.79	-122.42	FREIGHTER	CARGO FV	US	NURTEN ANA
63	12/18/2007	GROUNDING	47.63	122.39	TANK BARGE	OIL BARGE	US	
64	7/29/2009	COLLISION	49.29	-123.09	TANK BARGE	OIL BARGE	US	
65	11/10/2009	COLLISION	47.50	-122.43	FREIGHTER	CARGO FV	US	HORIZON ANCHORAGE
66	11/18/2009	GROUNDING	48.82	-123.29	BULK CARRIER	CARGO FV	CA	HEBEI LION
67	12/16/2009	COLLISION	49.12	-123.20	TANK BARGE	OIL BARGE	US	
68	3/9/2011	COLLISION	47.59	-122.37	TANK BARGE	OIL BARGE	US	DAVID 120
69	4/16/2011	GROUNDING	48.88	-123.63	BULK CARRIER	CARGO FV	CA	SELANDIA
70	8/19/2011	COLLISION	48.52	-124.63	CONTAINER	CARGO FV	CA	COSCO SHENZEN
71	10/4/2011	ALLISION	47.26	-122.36	FREIGHTER	CARGO FV	US	
72	1/25/2012	ALLISION	33.73	-118.17	TANKER	TANK FV	US	
73	7/26/2012	ALLISION	47.55	-122.34	FREIGHTER	CARGO FV	US	
74	12/7/2012	ALLISION	49.01	-123.15	CONTAINER	CARGO FV	CA	CAPE APRICOT
75	11/2/2013	ALLISION	47.26	-122.39	FREIGHTER	CARGO FV	US	
76	8/29/2014	ALLISION	47.28	-122.41	FREIGHTER	CARGO FV	US	
77	6/22/2015	GROUNDING	48.75	-123.08	BULK CARRIER	CARGO FV	CA	ANDROMEDA
78	9/1/2015	ALLISION	47.55	-122.34	FREIGHTER	CARGO FV	US	
79	11/26/2015	GROUNDING	48.75	-123.09	FREIGHTER	CARGO FV	CA	STAR LYGRA

4 VTRA 2005/2010 Accident Calibration Records in 0 - 1 m3

+ 1991 Tenyo Maru Collision in > 1 m3 Spill Category

+ 75 Additional VTRA 2015 Accident Calibration Records in 0 – 1 m3

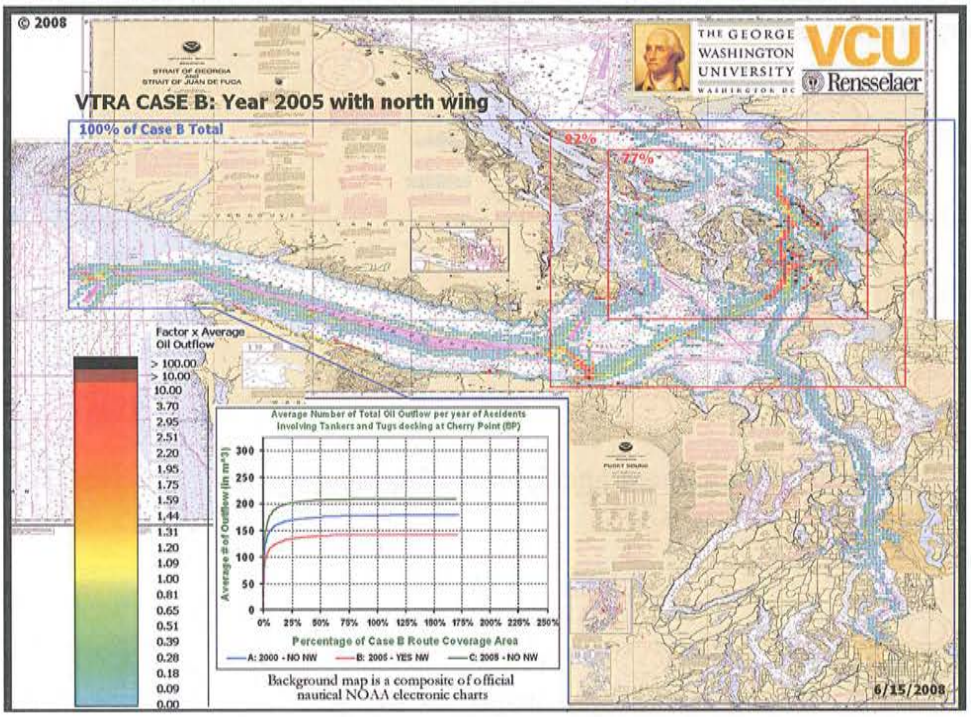
+ 1994 Barge 101 Grounding in > 1 m3 Spill Category

Appendix D. VTRA 2010 QAPP

Vessel Traffic Risk Assessment (VTRA):

Preventing Oil Spills from Large Ships and Barges In Northern Puget Sound & Strait of Juan De Fuca

Quality Assurance Project Plan



February 2013

Prepared by:
Dr. Todd Hass, Washington State Puget Sound Partnership
Dr. Johan Rene Van Dorp, George Washington University
Dr. Jason Merrick, Virginia Commonwealth University

Prepared for:
Washington State Puget Sound Partnership

Publication Information

This study has been funded wholly or in part by the United States Environmental Protection Agency (EPA) through their National Estuary Program, via a grant agreement (#2013-028) with the Puget Sound Partnership (PSP).

Each study conducted by EPA, or external parties funded by EPA, must have an approved Quality Assurance Project Plan (QAPP). The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completing this study, the final report will be available upon request from the PSP.

The contents of this document do not necessarily reflect the views and policies of the EPA, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Author and Contact Information

Dr. Todd Hass
VTRA Contract Manager
Washington State Puget Sound Partnership (PSP)
(360) 280-1588
todd.hass@psp.wa.gov

Dr. Johan Rene Van Dorp
Professor Engineering Management and Systems Engineering
George Washington University (GW)
(202) 994-6638
dorpjr@gwu.edu

Dr. Jason Merrick
Professor Statistical Sciences and Operations Research
Virginia Commonwealth University (VCU)
(804) 828 5865
jrmerric@vcu.edu

Jon Neel, Washington State Department of Ecology, (360) 480-5696
jnee461@ecy.wa.gov

Chip Boothe, Washington State Department of Ecology, (360) 407-7465,
cboo461@ecy.wa.gov

Quality Assurance Project Plan

Vessel Traffic Risk Assessment (VTRA):

Preventing Oil Spills from Large Ships and Barges In Northern Puget Sound & Strait of Juan De Fuca

February 2013

Approved by:

Signature: _____ Date 2/21/13
Johan Rene Van Dorp, George Washington University

Signature: _____ Date 2/21/13
Jason Merrick, Virginia Commonwealth University

Signature: _____ Date 2/21/13
Alana Knaster, Deputy Director of Operations, Puget Sound Partnership

Signature: _____ Date 2/21/13
Todd Hass, Contract Manager, Puget Sound Partnership

Signature: _____ Date 2/15/13
William Kammin, QA Officer, Department of Ecology

Distribution List

Authors and Contract Manager
Chip Boothe, Jon Neel, and Tom Gries , Washington Department of Ecology
Robert McFarland, United States Coast Guard District 13
Kiley Ross, United States Coast Guard Sector Seattle
John Veentjer, Puget Sound Harbor Safety Committee
Chad Bowechop, Makah Nation

Table of Contents

List of Figures

1. Abstract

Several commercial projects have been proposed for northern Puget Sound and southern British Columbia over the next decade, potentially increasing the amount of oil being transported and adding many hundreds of deep draft ship transits through the area. The purpose of this VTRA is to quantify the *relative difference between present and future risks*, and establish a well-accepted technical basis for making *decisions on what risk management measures would be beneficial in managing the risk of potential spills currently and in the future.*

This effort will utilize and leverage 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), the 2005 Vessel Traffic Risk Assessment (VTRA) funded by BP and most recently the update of that model funded by the Makah Indian Tribal Council. The 2005 VTRA analysis tool was developed using 2005 data from the federal Vessel Traffic Operational Support System (VTOSS) data, amongst other data sources. GW/VCU's VTRA analysis tool evaluates exposure, accident frequency and oil losses from pre-defined classes of focus vessels. The analysis results from this tool are useful to help inform a risk management strategy to prevent these accidents. The GWU/VCU analysis VTRA approach has been well documented and peer-reviewed in the academic literature.

The 2010 year is the last full year of traffic data recorded for VTOSS. The updating of the 2005 VTRA model to 2010 VTOSS data is funded under a separate contract between the Makah Indian Tribal Council and GWU/ VCU. Updating under the Makah grant of the 2005 VTRA model to a 2010 base year will more closely approximate the present-day patterns in traffic compared to those exhibited in the modeled scenarios in future projects. Included under the Makah grant is a 2010 vessel traffic analysis for the 2005 VTRA focus vessel group of all oil tankers, Articulated Tug Barges (ATB) and Integrated Tug Barges (ITB), expanded from those just docking at the BP Cherry Point terminal.

To distinguish the study described herein from the previous 2005 VTRA study it will be labeled the 2010 VTRA. The starting point for the 2010 VTRA analysis is the updated 2005 VTRA model with 2010 VTOSS data as agreed upon in the scope of work between GWU and the PSP. The 2010 VTRA will commence with establishing a baseline risk level for a pre-defined (enlarged from VTRA 2005) group of focus vessels for the year 2010 to include in addition: bulk carriers, container vessels and oil barges. Future scenarios will be run adding anticipated vessel traffic increases as a result of select future anticipated developments. Risk mitigation scenarios will be developed to attempt to manage potential risk increases arising from potential growth in vessel traffic associated with these future scenarios. Project success can be gauged by the completion of the number of future scenarios analyzed, risk mitigation scenarios analyzed and by the completion of a final report synthesizing the analysis results.

2. Background

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

The purpose of the 2010 VTRA is to inform the State of Washington and the United States Coast Guard on what potential actions should be taken to mitigate any increase in oil spill risk from large commercial vessel oil spills in the northern Puget Sound and the Strait of Juan de Fuca areas. This study area is expected to experience significant changes in deep draft vessel traffic during the next decade. The 2010 VTRA is also intended to inform federal agencies, tribes, local governments, industry and non-profit groups in Washington State and British Columbia on potential risk management options and facilitate their input into achieving consensus risk management decisions regarding vessel operations in the study area

The development of the 2010 VTRA is expected to proceed in several phases following the collaborative analysis approach [1] involving coordination with a Puget Sound Advisory group/steering committee of stakeholders to be selected early on in the 2010 VTRA by the PSP.

"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 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. These represent only a very small percentage (~1%) of all vessel traffic in the region. Accident types included in the 2005 VTRA were collisions, powered groundings, drift grounding and allisions. Vessels that can collide with FVs in the 2005 VTRA are

termed Interacting Vessels (IVs). The 2010 year is the last full year of traffic data recorded for VTOSS.

The starting point for the 2010 VTRA analysis is the updated 2005 VTRA model with 2010 VTOSS data to establish a 2010 base case scenario to more closely approximate the present-day patterns in traffic compared to those exhibited in the modeled scenarios in future projects. This base case 2010 VTRA scenario update will allow an expansion of the analysis to include other focus vessels—like the non-BP tank vessels (another 2% of traffic overall), other classes of deep draft vessels (e.g., container ships, bulk cargo vessels, tugs towing oil barges, etc.) and allow for the 2010 VTRA to incorporate more current (or more accurate/realistic) estimates of anticipated traffic levels and routes than used in the 2005 VTRA.

3. Project Description

The development of the 2010 VTRA will proceed in several phases. The first phase will determine a short list (likely two or three) of future projects, to include the proposed Gateway terminal, for future scenario definition for the 2005 updated VTRA model. Based on the types of ships projected to call on those future projects, the 2010 VTRA will determine a set of focus vessels (FVs) in the analyses. At this point, GW/VCU and PSP Advisory group will determine jointly the estimated number of transits, likely routes, and other parameters from recently published project descriptions and stakeholder engagement efforts with the corresponding maritime industries and specific commercial projects. This data collected is the only data gathering effort under this grant. Collected data will serve as the input data for the definition of a number of future traffic scenarios to be jointly defined in cooperation with the PSP and engaged stakeholders This step, consequently, enlarges the class of focus vessels (FVs) from the 2005 VTRA to include potentially: Oil Tankers, ATB's, ITB's, Oil Barges, Bulk Carriers and Container vessels. This is a preliminary list as enlarging the class of FVs markedly increases the computational complexity —stretching potentially the limits of the updated 2005 VTRA analysis model.

The main factor in evaluating a need to modify the updated 2005 VTRA analysis model is determined by observed computation times and computer memory capacity limitation when expanding the 2005 VTRA analysis using 2010 VTOSS Traffic data for the larger focus vessel group. Simulation and subsequent analysis runs using the 2005 VTRA model took approximately 8 hours for the 2005 focus vessel group. Enlarging the focus vessel group will likely require a separation of the analysis per focus vessel due to file size limitations of VTRA model recorded accident scenarios, potentially increasing calculation times by a factor two or more. Should computational complexity explode beyond reasonable calculation limits, a reduction of the focus vessel group may be required, but such decisions shall be made in cooperation with the PSP advisory group.

Based on the stakeholder vetted future scenario inputs, the VTRA analyses are expected to show changes in the region's risk profile—both system-wide and in specific geographic sub-regions (e.g., Western Strait of Juan de Fuca, Rosario Strait, etc.). An example of a geographic risk profile developed during the 2005 VTRA is displayed in Figure 1. Those changes will be conveyed to the PSP advisory group, who will use those results to suggest the most meaningful potential intervention measures to be modeled. Because: (1) the Puget Sound Harbor Safety Committee and US Coast Guard have agreed to use the GW/VCU VTRA as a common "language" by which they discuss and manage system-wide maritime traffic risk, and (2) there is strong stakeholder participation and transparency in the process – the researchers and the principal agencies involved (PSP, Ecology, USCG) expect that the results of this study will be embraced widely and used to modify regional Best Management Practices/Standards of Care and make regulatory improvements to improve maritime safety.

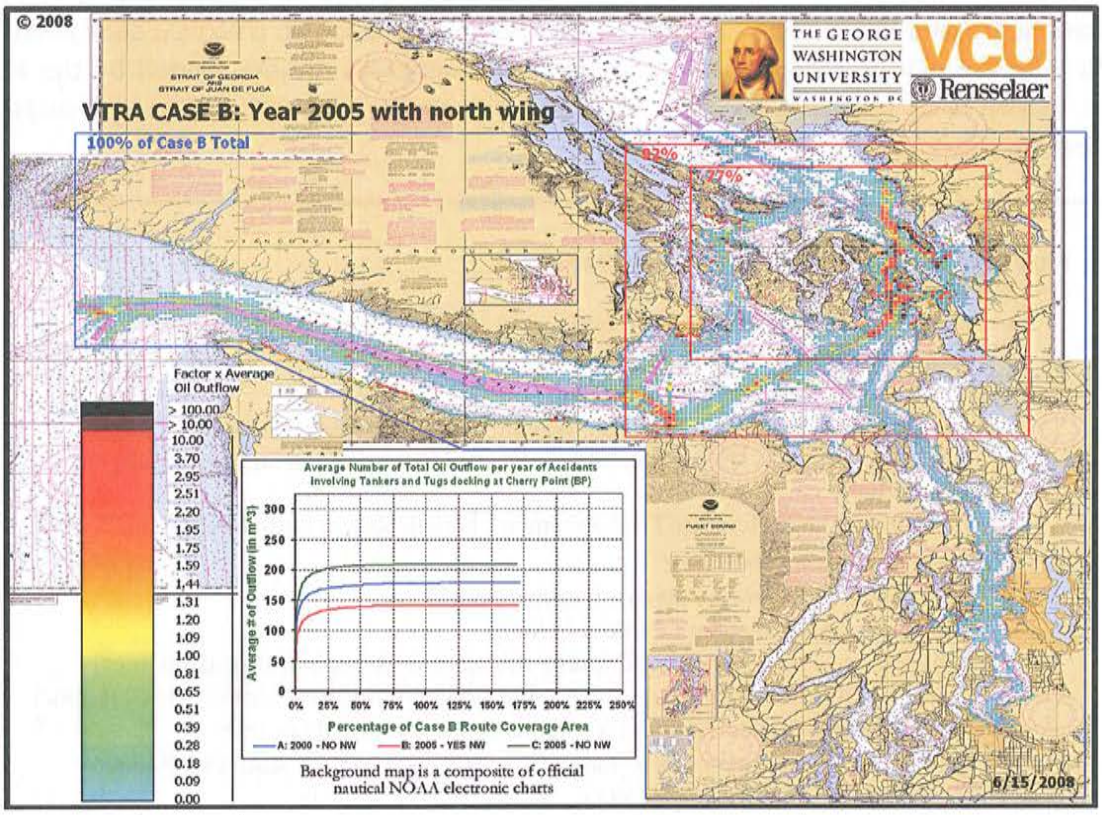


Figure 1. Example geographic profile of oil spill risk (*from 2005 VTRA*).

4. Organization and Schedule

The overall project to complete the 2010 VTRA and develop a Risk Management Strategy (RMS) is expected to proceed in five PHASES. The first PHASE involves a stakeholder process led by the Puget Sound Partnership and the Washington State Department of Ecology; supported by the US Coast Guard and Puget Sound Harbor Safety Committee in which GW/VCU shall participate. This first PHASE will be completed in parallel with a separate project funded by the MAKAH TRIBAL COUNCIL to update GW/VCU's VTRA analysis tool by GW/VCU. Figure 2 displays an organization chart of the PSP advisory group.

Puget Sound Partnership VTRA Advisory Group

Co-Chairs:

- Todd Hass, Puget Sound Partnership
- John Veentjer, Puget Sound Harbor Safety Committee

Federal, State and Tribal Leads [representing]:

- Chip Boothe (alternate John Neel), Washington State (Department of Ecology)
- Kiley Ross and R.E. McFarland, US Coast Guard [Sector Puget Sound and District 13, respectively
- Chad Bowechop (alternate Fred Felleman), Makah Nation [native American Tribes]

Core Steering Committee Members:

- Mark Homeyer, Crowley Marine [tug and barge]
- Del Mackenzie, Puget Sound Pilots [pilots]
- Mike Moore, Pacific Mechant Shipping Association [shipping/steamship lines]
- Vince O'Halloran, Washington State Labor Council (alternate Lori Provinci) [Labor]
- Mike Doherty, Clallam County [Washington Association of Counties
- Jess Shaw, Polar Tankers(alternate Frank Holems, Western State Petroleum Association) [petroleum industry]

Figure 2. Organizational Chart of PSP Advisory Group.

The second PHASE under this grant will firstly establish a 2010 VTRA base case scenario for the enlarged focus vessel group. The Phase II analysis for the enlarged focus vessel group can only commence with the completion of the MAKAH contract with GWU/VCU (anticipated by the end of February '13).

It is expected that the second and third PHASE will be led by the PSP Advisory Group with strong technical support from GW/VCU using this updated VTRA analysis tool. Pending additional funding, the fourth PHASE GW/VCU will provide technical support to a regional expert panel for the formulation of an RMS and the fifth implementation PHASE will be largely independent of the university consortium's work. This GW/VCU grant is to provide funding for GW/VCU cost and expenses for phases I-III only. Figure 3 provides an approximate timeline for the completion of Phases I-III.

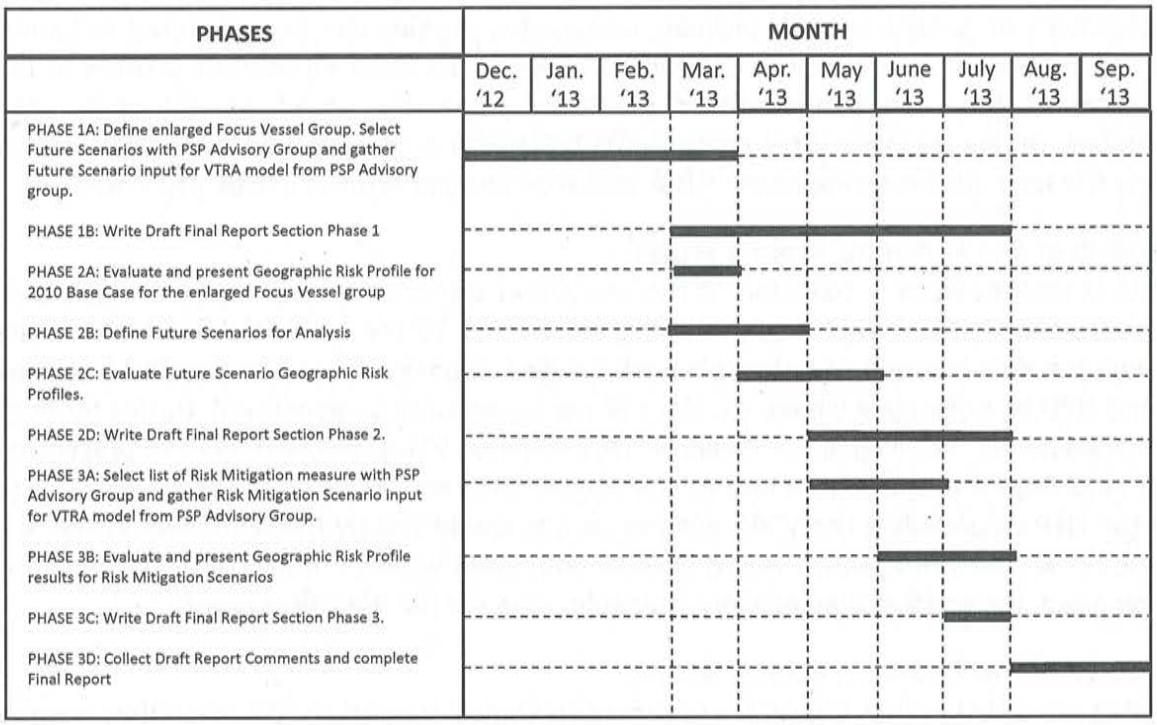


Figure 3. Approximate Timeline for PHASE I, II and III.

The PSP Advisory Group will meet/advise GWU/VCU in their development of the 2010 VTRA through meetings every two months to coincide with the meeting schedule of the PSHSC in 2013 (Every two months, first Wednesday in the month, first meeting in February 2013). During these meetings GW/VCU shall prepare progress presentations. GW/VCU will also be available via video conference for interim monthly with the PSP advisory group. Below a more detailed description of the different phases is provided.

PHASE I of the Technical Project Scope:

GWU/VCU met with a preliminary PSP Advisory group in October of 2012 and met with an established PSP advisory group in December 2012. During October 2012, December 2012 and February 2013 meetings, GW/VCU was available for consultation to facilitate the definition of future scenarios to be analyzed by GW/VCU during PHASE II and reported on analysis progress under the Makah contract with GWU/VCU. PSP will lead the effort to define the future scenarios during Phase I. To allow for their representation in the 2010 VTRA, questions need to be answered during PHASE I for future traffic scenarios involving number of vessels visiting other terminals in the area that are expected to increase vessel traffic and their anticipated vessel routes. This necessitates the close coordination with the PSP advisory group.

PHASE II of the Technical Project Scope:

GW/VCU will develop a 2010 baseline risk analysis scenario using the FV classes defined under PHASE 1. GW/VCU will implement the future traffic scenarios in their VTRA Analysis tool as

defined under PHASE I and compare risk to the 2010 baseline risk scenario through the development of geographic risk profiles. Geographic profiles will be generated in terms of accident frequency and combined oil outflow volume. Separate oil outflow profiles in terms persistent oil (PO) and non-persistent (NPO) by originating vessel, i.e. FV or IV can be generated. During the April 2013 meeting GW/VCU shall present the baseline VTRA scenario. During the June 2013 meeting future VTRA scenarios analysis results shall be presented.

PHASE III of the Technical Project Scope:

GW/VCU shall evaluate a selection of risk mitigation scenarios in their VTRA Analysis tool as defined under PHASE I and PHASE II and compare risk to the 2010 baseline VTRA scenario through the development of geographic risk profiles. Separate oil outflow profiles in terms of PO and NPO by originating vessel, i.e. FV or IV are expected to be generated. During the August 2013 stakeholder meeting(s), risk levels of risk mitigation VTRA scenarios shall be presented. A draft Final Report is anticipated mid to late August 2013 for review to the PSP Advisory Group and the NEP QC detailing the VTRA analysis results conducted by GW/VCU over PHASE II and PHASE III. A final VTRA project report shall be submitted within a month after final comments are received, but no later than 60 days after submission of the draft final report.

PHASE IV of the Technical Project Scope:

Pending available funding, GW/VCU will provide technical support to PSP when they convene a regional expert panel in developing a Risk Management Strategy (RMS) being informed by the PHASE III final report. This phase seeks to support and inform the existing regional model of continuous improvement in maritime safety—especially as articulated in the PSHSC's Harbor Safety Plan—endorsed by the US Coast Guard Captain of the Port.

5. Project Work Products

The primary written work product to be developed is a final report that details:

(1) A historical vessel trend analysis;
(2) A description of the development and assumptions of future projection scenarios GW/VCU were asked to conduct under PHASE II; and
(3) A description of the development and assumptions of risk mitigation scenarios GWU/VCU were asked to evaluate under PHASE III; and
(4) A detailed description of 2010 FV traffic baseline risk for an extended FV class; and
(5) A comparison of PHASE II future traffic scenario risk levels to the 2010 baseline risk; and
(6) The effect of PHASE III risk mitigation scenarios on PHASE II future traffic scenarios.

A draft outline of the final report is provided in Figure 4.

1. EXECUTIVE SUMMARY
2. PROJECT DESCRIPTION
3. SUMMARY OF METHODOLOGY
4. THE 2010 BASELINE ANALYSIS
   4.1. Selection of focus vessel class
   4.2. Baseline geographic profile results
5. FUTURE SCENARIO ANALYSIS
   5.1. Selection and definition of future scenarios
   5.2. Future scenario geographic focus results
6. RISK MITIGATION SCENARIOS
   6.1. Selection and definition or risk mitigation scenarios
   6.2. Risk mitigation geographic profile focus results
7. CONCLUSION AND RECOMMENDATIONS
8. REFERENCES
9. APPENDICES
   9.1. Baseline individual focus vessel geographic profile results
   9.2. Future scenario focus vessel geographic profile results
   9.3. Risk mitigation focus vessel geographic profile results.

Figure 4. Draft outline of 2010 VTRA Final Report for PHASE I, II and III.

Presentations shall utilize the generated geographic risk profiles to facilitate stakeholder understanding and will synthesize/summarize analytical results. Interim presentations, the draft final report and final report shall be posted on Professor van Dorp's faculty page as agreed upon between the PSP and GWU/VCU.

6. 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 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 Fig .5). 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 been 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]. 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 model was most recently used during the 2005 VTRA [11-13] and has been updated to 2010 traffic for the Makah Tribal Council. Thus, all data and model assumptions are pre-existing before this contract and have been peer-reviewed [2-13]. The following is a brief description of this modeling approach.

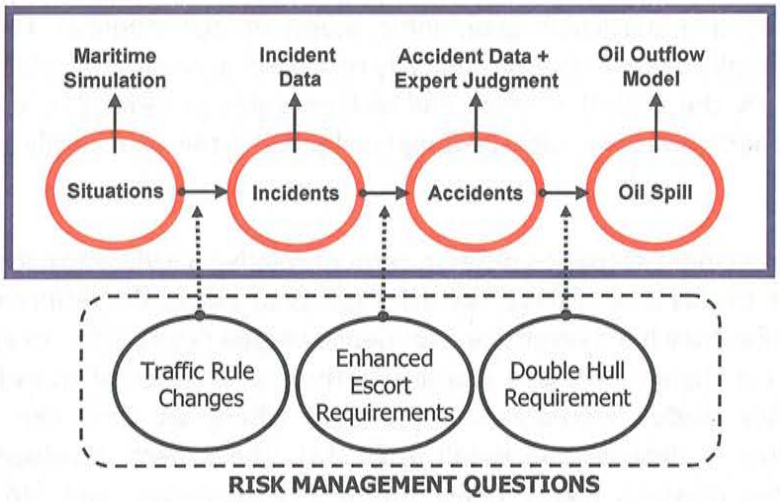


Figure 5. Causal chain of events interconnected by causal pathways. Risk management questions attempt to block these causal pathways.

Situations

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 VTOSS data) and simulates the movement of smaller fishing vessels, whale watchers, and organized regatta events. The environmental factors modeled include wind, fog, and current replayed hourly (using data sources publicly available from the National Climatic Data Center). Every minute over this calendar year, the simulation counts situations 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 an analysis scenario (for example the base case and various part or future traffic scenarios).

Incidents

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

Accidents

The accident types included in this study are collisions between two vessels, groundings (both powered and drift), and allisions. 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 affects the chances of an accident; accidents are rare (typically, less than ten accidents

were observed within a particular geographic scope of our studies)! The VTRA model is calibrated to historically observed 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 scenarios differ in term 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 3 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 during the 2010 VTRA and expert judgment elicitation results from the 2005 VTRA shall be used for the 2010 as agreed upon in the Scope of Work between GWU and the PSP.

Situation 1	TANKER DESCRIPTION	Situation 2
Strait of Juan de Fuca East	**Location**	-
Inbound	**Direction**	-
Laden	**Cargo**	-
1 Escort	**Escorts**	-
Untethered	**Tethering**	-
	INTERACTING VESSEL	
Shallow Draft Pass. Vessel	**Vessel Type**	-
Crossing the Bow	**Traffic Scenario**	-
Less than 1 mile	**Traffic Proximity**	-
	WATERWAY CONDITIONS	
More than 0.5 mile Visibility	**Visibility**	-
Along Vessel	**Wind Direction**	-
Less than 10 knots	**Wind 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 6. Example question during 2005 VTRA of a paired comparison questionnaire of situations for tanker collision accident attribute parameter assessment given all incidents.

Oil Spill

An oil outflow model [3] for collision and grounding accidents explicitly links input variables such as hull design (single or double, see Figure 5), displacement and speed, striking vessel displacement and speed, and the interaction angle of both vessels to output variables (see Figure 6): longitudinal and transversal damage extents of the tanker. Overlaying these damage extents on the vessel's design (see Figure 5) yields an oil outflow volume totaling the capacity of the damaged tank compartments. A similar model was developed for grounding accidents during the VTRA 2005. 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].

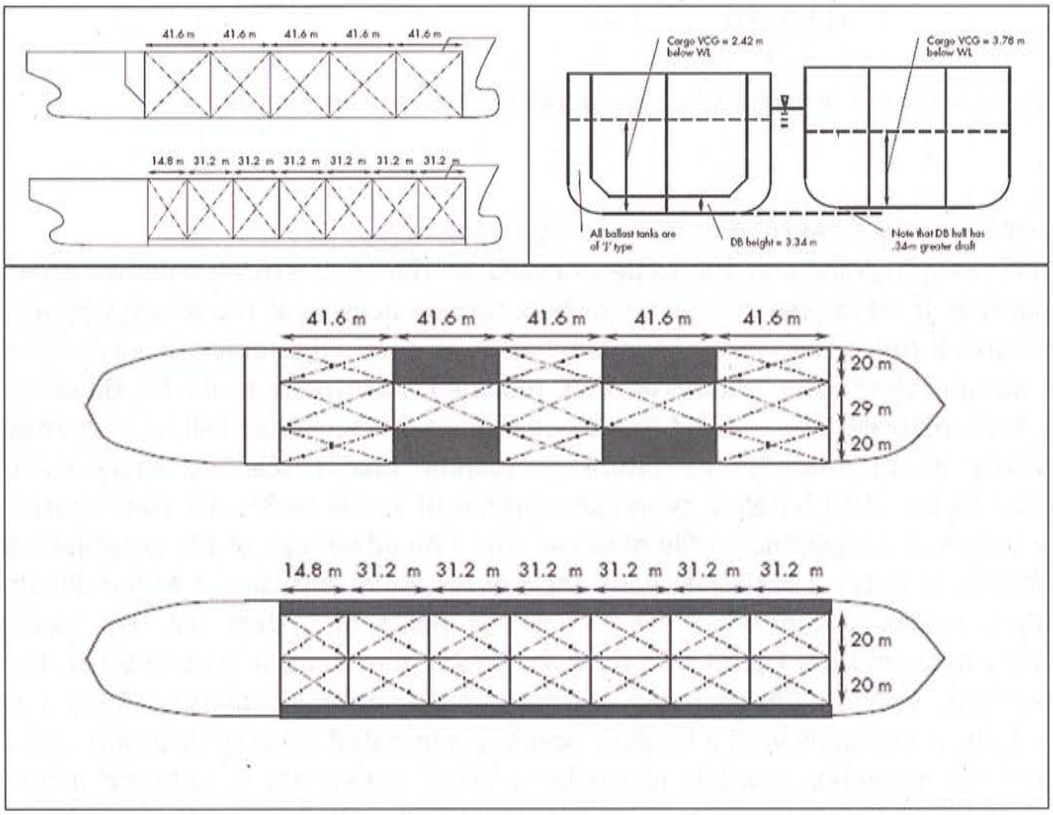


Figure 7. Single hull and double hull 150.000 DWT tanker designs used in 2005 VTRA taken from the National Research Council SR259 report [15].

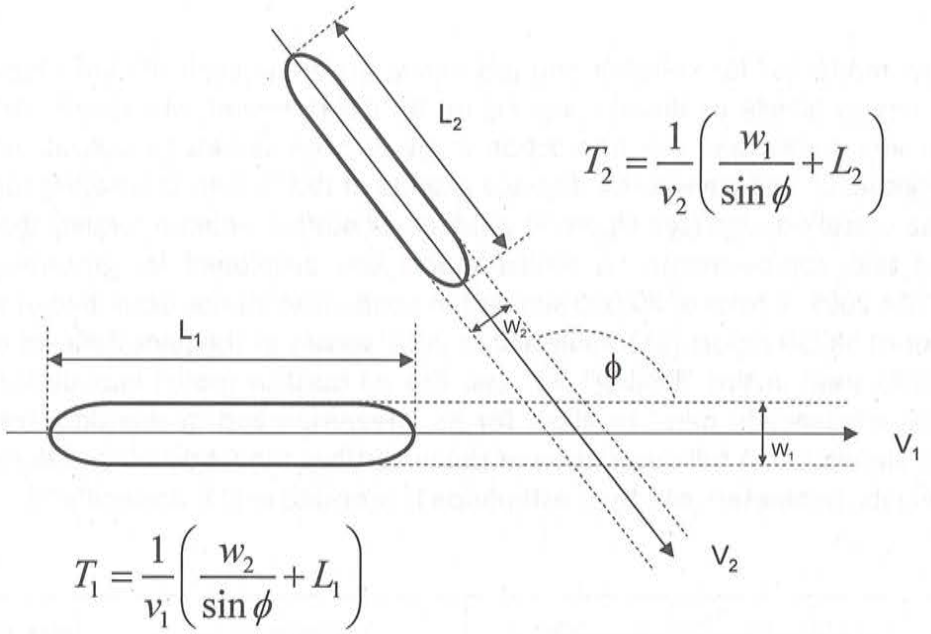


Figure 8. A schematic of a striking ship-struck ship probability model used in the 2005 VTRA.

Format of Scenario Analysis Results and Comparisons

A potential risk mitigation scenario to be analyzed for the 2010 VTRA is whether from a vessel risk perspective it makes sense to allow for bulk carriers docking at the future 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. Other vessel traffic risk mitigations scenarios will be suggested by the PSP advisory group informed by future geographic profile scenario analyses and their comparison to the 2010 baseline geographic profile of vessel traffic risk (see Figure 1 for an example of such a geographic profile of vessel risk). An advantage of the geographical profile display format in Figure 1 is that it allows for a direct visual assessment of the distribution of the analysis results and provides for an understanding of system risk. For example, we immediately observe from Figure 1 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 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 rectangles in Figure 1 allows for a more quantitative evaluation of system risk and its changes from a baseline scenario to future and risk mitigation scenario analysis results.

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 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.

References

[1] George J. Busenberg (1999). "Collaborative and adversarial analysis in environmental policy", *Policy Sciences,* Vol. 32, pp. 1-11.

[2] J. R. van Dorp and J. R.W. Merrick (2009). "On a risk management analysis of oil spill risk using maritime transportation system simulation", *Annals of Operations Research*, published online before print December 12, 2010, DOI: 10.1007/s10479-009-0678-1. (http://www.springerlink.com/content/w168111018754401/)

[3] G. van de Wiel and J. R. van Dorp (2009). "An oil outflow model for tanker collisions and groundings", *Annals of Operations Research*, published online before print November 25, 2010, DOI: 10.1007/s10479-009-0674-5. (http://www.springerlink.com/content/d7432xmg431v42q7/)

[4] National Research Council (1998), Review of Prince William Sound Risk Assessment. Review of the Prince William Sound, Alaska, Risk Assessment Study Committee on Risk Assessment and Management of Marine Systems, Marine Board, ISBN: 0-309-55835-2, 78 pages.

[5] J.R.W. Merrick, J. R. van Dorp, T. Mazzuchi, J. Harrald, J. Spahn and M. Grabowski (2002). "The Prince William Sound Risk Assessment". *Interfaces*, Vol. 32 (6): pp.25-40.

[6] J.R. van Dorp J.R.W. Merrick , J.R. Harrald, T.A. Mazzuchi, M. Grabowski, and J.E Spahn (2000). "A Systems approach to managing oil transportation risk in Prince William Sound", *Systems Engineering*, Vol 3: pp. 128-142.

[7] M. Grabowski, J.R.W. Merrick , J.R. Harrald, T.A. Mazzuchi, and J.R. van Dorp (2000). "Risk Modeling in Distributed, Large Scale Systems", *IEEE Transactions on Systems, Man, Cybernetics – PART A: Systems and Humans*, Vol. 30 (6): pp. 651-660.

[8] J.R. Harrald, T.A. Mazzuchi, J. E. Spahn, J.R. van Dorp J.R.W. Merrick, S. Shrestha, M. Grabowski (1998). "Using System Simulation to Model the Impact of Human Error in a Maritime Risk Assessment". *Safety Science*, Vol. 30, pp. 235-247.

[9] J.R. van Dorp J.R.W. Merrick , J.R. Harrald, T.A. Mazzuchi, and M. Grabowski (2001). "A Risk Management procedure for the Washington State Ferries", *Journal of Risk Analysis*, Vol. 21 (1): pp. 127-142.

[10] J.R.W. Merrick, J.R. van Dorp, J.P. Blackford, G.L. Shaw, T.A. Mazzuchi and J.R. Harrald (2003). "A Traffic Density Analysis of Proposed Ferry Service Expansion in San Francisco Bay Using a Maritime Simulation Model", *Reliability Engineering and System Safety*, Vol. 81 (2): pp. 119-132.

[11] J.R. van Dorp, J.R.W. Merrick, J.R. Harrald, M. Gabowksi (2008) "Assessment of Oil Spill Risk due to Potential Increased Vessel Traffic at Cherry Point, Washington " Final Report – Completed August 2008. http://www.seas.gwu.edu/~dorpjr/tab4/publications_technical.html

[12] J.R. van Dorp, J.R.W. Merrick, J.R. Harrald, M. Gabowksi (2009), "VTRA Final Report Addendum: A response to 23 comments from the Corps", completed January 2009. http://www.seas.gwu.edu/~dorpjr/tab4/publications_technical.html

[13] J.R. van Dorp, J.R.W. Merrick (2009), "A Response to Seven Additional Questions Related to the VTRA Project", completed May, 2009. http://www.seas.gwu.edu/~dorpjr/tab4/publications_technical.html

[14] P. Szwed, J. Rene van Dorp, J.R.W.Merrick, T.A. Mazzuchi and A. Singh (2006). "A Bayesian Paired Comparison Approach for Relative Accident Probability Assessment with Covariate Information", *European Journal of Operations Research*, Vol. 169 (1), pp. 157-177.

[15] National Research Council (2001). Environmental Performance of Tanker Designs in Collision and Grounding, Special Report 259, Marine Board, Transportation Research Board, The National Academies.

[16] Merrick, J. R. W. and J. R. van Dorp (2006). "Speaking the Truth in Maritime Risk Assessment". *Risk Analysis*, Vol. 26 (1), pp. 223 - 237.

[17] J.R.W.Merrick, J. Rene van Dorp, V. Dinesh (2004). "Assessing Uncertainty in Simulation Based Maritime Risk Assessment". *Risk Analysis*, Vo. 25 (3), pp. 731-743.

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.
- FV – Focus Vessel.
- GWU – George Washington University is the prime subgrant awardee.
- VCU – Virginia Commonwealth University is a sub-awardee to GWU.
- GW/VCU – The technical team composed of GWU and VCU.
- ITB – Integrated Tug Barge.
- IV – Interacting Vessel.
- MTS – Maritime Transportation System.
- NEP QC – National Estuary Program Quality Coordinator
- NGO – Non-Governmental Organization.
- NPO – Non-Persistent Oil
- 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 GWU/VCU over the course of this study.
- QAPP – Quality Assurance Project Plan
- Study Area – The Washington waters of Puget Sound east of Cape Flattery, north of Admiralty Inlet and west of Deception Pass, and their approaches.
- 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.