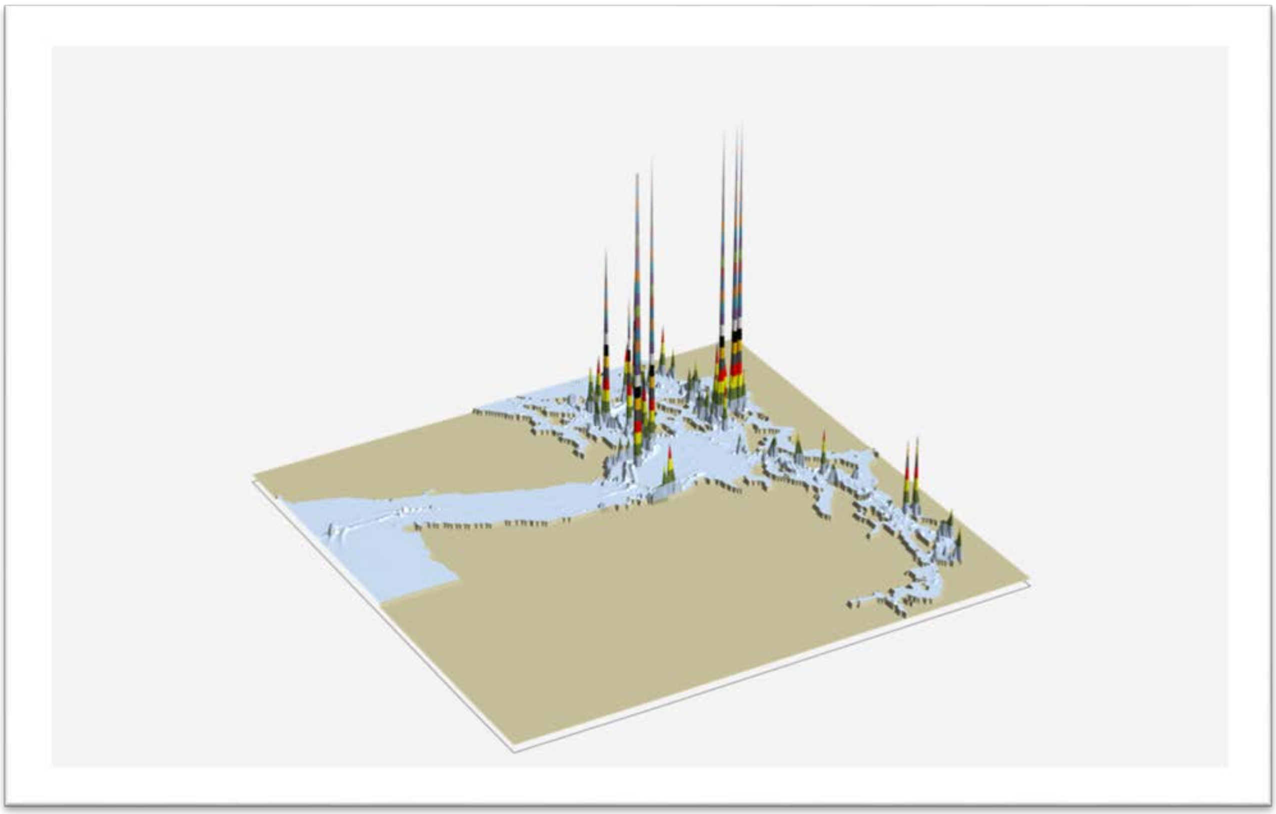
VTRA 2015 FINAL REPORT UPDATING THE VTRA 2010

A POTENTIAL Oil Loss Comparison of Scenario Analyses by four Spill Size Categories



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Washington State Department of Ecology

Final Report

Vessel Traffic Risk Assessment (VTRA):

A POTENTIAL Oil Loss Comparison of

Scenario Analyses by four Spill Size Categories

December, 2016

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This study was guided by a VTRA 2015 Working Group. The content of this document does not represent positions of the VTRA 2015 Working Group (or any of its members), or the Washington Department of Ecology.

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PREFACE

This report is submitted by Johan Rene van Dorp (George Washington University) and Jason R.W. Merrick (Virginia Commonwealth University), GW/VCU hereafter, on behalf of Washington State Department of Ecology. The content of the report describes a vessel traffic risk assessment (VTRA) conducted in 2016. The VTRA model has been updated during this VTRA study from the VTRA 2010 model using additional accident data from the period 1990 to 2015 and AIS passage line vessel count data from 2010 to 2015. To distinguish the study described herein from the previous VTRA studies (VTRA 2005 and VTRA 2010), it will be labeled VTRA 2015. Thus, the starting point for the VTRA 2015 study is the VTRA 2010 model with 2010 VTOSS data, as agreed upon in the scope of work between GW and Ecology.

This study has been funded by the Washington Department of Ecology through contract C1600131. Part I of the study utilized state funding from the Washington legislature; Part II of the study was funded by the United States Environmental Protection Agency under assistance agreement PC-00J90701 through the Washington Department of Fish and Wildlife. The VTRA 2010 study was funded by the Puget Sound Partnership. The update of the VTRA 2005 model to using VTOSS 2010 data was separately funded by the Makah Tribal Council. The VTRA 2005 Study was funded by BP. The VTRA 2005 study utilized the extensive technical work already completed by the George Washington (GW) University and Virginia Commonwealth University (VCU) in other funded maritime risk assessment (MRA) projects before that time. Specifically, The San Francisco Bay Exposure Assessment (2004), The Washington State Ferry Risk Assessment (1998) and The Prince William Sound Risk Assessment (1996).

The VTRA study area covers US/Canadian trans-boundary waters including: portions of the Washington outer coast, the Strait of Juan de Fuca and the approaches to and passages through the San Juan Islands, Puget Sound and Haro-Strait/Boundary Pass. The VTRA Study area is divided in 15 separate waterway zones outlined by the black border in Figure E-2 in the Executive Summary. One observes from Figure E-2 that the location of the Port of Vancouver, BC, falls outside the VTRA Study area boundary. The Strait of Juan de Fuca serves as the entrance to the VTRA Study area, for both US and CA port destinations, and is transited by approximately 8,300 deep draft vessels annually, including arrivals and departures, but excluding passenger vessel counts. Of these, about 5500 deep draft vessels travel to and from Canadian bound port destinations, i.e. including north and south bound transits, and about 3700 transit the entrance of the Puget Sound (at Admiralty Inlet), also including north and south bound transits.

The VTRA analysis tool evaluates the duration that vessels travel through the VTRA study area, referred to as vessel time exposure (VTE), by vessel type and the potential accident frequency and potential oil losses from a class of cargo focus vessels (bulk carrier, containerships and other cargo vessels) and a class of tank focus vessels (tankers, chemical carriers, articulated tug barges and oil barges). The inclusion of the-time-on-the-water element in the evaluation of exposure sets the VTRA methodology apart from count based approaches that focus on, for example, number of annual/monthly vessel transits, visits or calls. The value of a duration based approach versus a count based approach is that the former appropriately distinguishes between short and long transits in the evaluation of vessel traffic risk as well as differing vessel speeds. The VTRA Model methodology has been well documented and peer-reviewed in the academic literature and continuously improved over the course of the above maritime risk assessment projects. A reference list is provided at the end of this document.

A distinguishing feature of the VTRA 2015 study from the VTRA 2005 and VTRA 2010 Studies are evaluations of *estimated probabilities of at least one accident potentially occurring within a 10-year period per four potential oil loss categories*. Specifically, the following four POTENTIAL Oil Loss categories are being considered in the VTRA 2015 Study: (1) 0 m^3 – 1 m^3, (2) 1 m^3 – 1000 m^3, (3) 1000 m^3 – 2500 m^3, and (4) 2500 m^3 or more. These probability risk metrics relate directly to their estimated POTENTIAL accident frequencies per year and the length of the time period (i.e. a 10 year time period) over which these probabilities are estimated. Both the estimated probability of at least one accident per a period of time, on the one hand, and the POTENTIAL accident frequency per year, on the other hand, are considered absolute risk metrics. That being said, the evaluation of the probability risk metric demonstrate through the wording "probability" that however small the POTENTIAL accident frequency may be for a particular POTENTIAL Oil Loss category, a non-zero probability estimated using the VTRA 2015 Model supports that the occurrence of such a POTENTIAL event evaluated is not impossible and could in fact happen, however unlikely. The communication of such probability metrics per a specified period of time is advocated in [26]. That being said, the VTRA 2015 Study concentrates more on relative comparisons between risk metrics evaluated for different scenario analyses and less on the absolute values of their respective analysis results.

From the outset, this project has been guided by a VTRA 2015 Working Group. Meetings held with the VTRA 2015 Working Group provided GW/VCU a platform to obtain feedback from and access to the Washington State Department of Ecology, the United States Coast Guard, the Puget Sound Harbor Safety Committee, tribes, local governments, industry, non-profit groups in Washington State and British Columbia and other stakeholders in this maritime community. The VTRA 2010 and its update to utilizing VTOSS 2010 data were guided in a similar manner by an advisory committee of members drawn from this maritime/regulatory/tribal/stakeholder community. The sole purpose of this document and the analysis results described herein is to serve as an information source to this maritime/regulatory/tribal/stakeholder community.

E. EXECUTIVE SUMMARY

Vessels transiting the Salish Sea traverse waters bordering numerous communities en route to ports in both the US and Canada. The Salish Sea is a large (over 1000 square miles) and diverse water body physically characterized by passages that are broad and deep, as well as some narrow ones that are navigationally challenging with swift currents. In addition, it is a biologically rich ecosystem with significant natural resources these communities depend upon.

The purpose of this vessel traffic risk assessment (VTRA) is to evaluate the combined potential changes in risk in light of a number of potential maritime terminal developments in various stages of their permitting processes potentially coming to fruition, and to inform the State of Washington, the United States Coast Guard, the Puget Sound Harbor Safety Committee, tribes, local governments, industry, non-profit groups in Washington State and British Columbia and other stakeholders in this maritime community of these potential changes in risk. The combined evaluated risk changes serves as an information source to these stakeholders to assist them as to what actions could be taken to mitigate potential increases in oil spill risk from large commercial vessels in the VTRA Study Area, should all or some of these terminal projects come to fruition. However, this study was not designed to measure the effectiveness of risk mitigation measures already in place.

Planned maritime terminal projects were grouped in a manner to form What-If Scenarios. A VTRA 2015 Working Group (see, Figure E-1) selected the maritime terminal projects included in the What-If Scenarios. The inclusion of these terminal projects in these What-If Scenarios ought by no means to be interpreted to imply that these maritime terminal projects may come to fruition. Rather, the inclusion of these terminal projects in this VTRA 2015 study ought to be seen as being part of a safety culture being practiced in this maritime community over many years of which the formation of the Puget Sound Harbor Safety Committee back in 1997 and its bi-monthly held meetings since then is a prime example. Summarizing, this study was conducted because study sponsors (Ecology), involved tribes and stakeholders want to ensure that the combined potential risks of maritime development projects in various permitting stages are better understood, should some or all come to fruition, so informed decisions and recommendations could be made by them about potential additional risk mitigation measures (RMMs) that would add to the continuous improvement efforts of the past.

The VTRA methodology has been developed over the course of close to twenty years of work in various maritime risk assessment projects. Specifically, the Prince William Sound Risk Assessment (1996), The Washington State Ferry Risk Assessment (1998), The San Francisco Bay Exposure Assessment (2004), the Vessel Traffic Risk Assessment 2005 (VTRA 2005)[1] and the Vessel Traffic

[1] The VTRA 2005 analysis in [12] was limited to vessel traffic risk evaluation associated with Tankers, ATBs and ITBs docking at the Cherry Point terminal.

Risk Assessment 2010 (VTRA 2010). The VTRA analysis methodology has been well documented and peer-reviewed in the academic literature and continuously improved over the course of these maritime risk assessment projects. A reference list is provided at the end of this document.

VTRA 2015 Working Group

Chair:

- Captain Stephan Moreno[2], Puget Sound Pilots

Federal, State and Tribal Leads [representing]:

- Scott Ferguson (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/Friends of the San Juans – Lovel Pratt
- Puget Soundkeeper – Chris Wilke
- Wave/Friends of the Earth – Fred Felleman

Figure E-1. Organizational Chart of the VTRA 2015 Working Group.

The VTRA 2015 Study Area is defined by the black border in Figure E-2 covering US/Canadian trans-boundary waters including: portions of the Washington outer coast, the Strait of Juan de Fuca and the approaches to and passages through the San Juan Islands, Puget Sound and Haro-Strait/Boundary Pass. It is worthwhile to note that while Canadian bound traffic passes through the VTRA 2015 Study Area, the Port of Vancouver is located north of the VTRA 2015 Study Area boundary. The VTRA 2015 Study Area is divided in 15 separate waterway zones outlined in Figure E-2. The VTRA 2015 Study Area includes an International Maritime Organization (IMO) approved Traffic Separation Scheme (TSS) that governs vessel traffic in the system and its approaches. It is

[2] Captain Moreno served as chair from November 2015 through August 2016.

actively managed by a joint US - Canadian Cooperative Vessel Traffic Service (CVTS). At the western entrance to the Strait of Juan de Fuca, it includes the extent of Prince Rupert radar coverage via a radar unit on Mt. Ozzard; approximately 60 miles out to sea, and extends throughout the Puget Sound region north to Vancouver, British Columbia, and south to Tacoma, Washington and Olympia, Washington. Radar is supplemented by Automatic Identification System (AIS) transponders, radio communications and advance notices for arriving vessels.

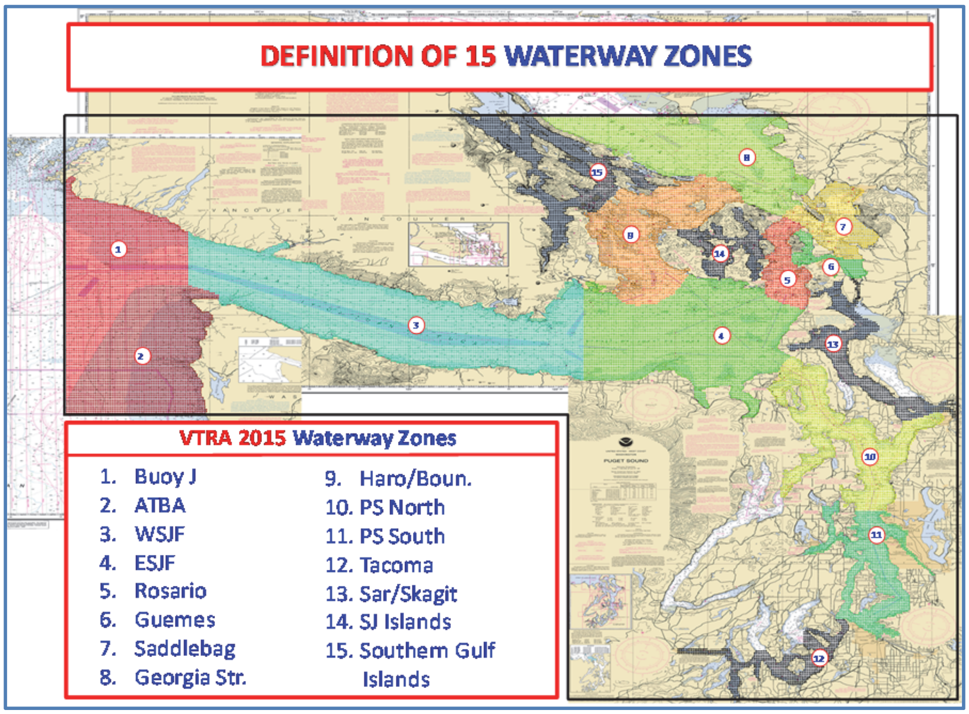

Figure E-2. Definition of 15 waterway zones and their descriptors in the VTRA 2010 Study Area.

For context, it is important to recognize that the VTRA Base Case 2015 Scenario analysis includes a series of risk mitigation measures. In addition to the previously mentioned IMO Traffic Separation Scheme and CVTS, vessels are subject to Port State Control and other vessel inspections regimes in both Canada and the United States to enforce international and federal standards. Pilotage is required in both the US and Canada and pilotage areas are comparable. Tug escorts for laden tankers are required and tugs are used to assist vessels into and out of the berths. Moreover, there are a number of risk mitigation measures that have been put in place internationally, federally and locally over the last several decades including double hulls for tankers, protectively located fuel tanks for non-tank vessels (still being phased in), a Puget Sound Harbor Safety Plan with Standards of Care, the implementation of AIS, a traffic procedure governing vessels transiting Turn Point at the boundary between Haro-Strait and Boundary Pass northeast of Victoria, BC, and a one-way zone regime in Rosario Strait. This list is not exhaustive.

Base Case Scenario Results

The Strait of Juan de Fuca serves as the entrance to these US and Canadian ports and facilities and is transited by approximately 8,300 deep draft vessels annually, including arrivals and departures. Of these transit entrances and departures, approximately nine cargo focus vessels (bulk carriers, container ships and other cargo vessels) enter and leave the Strait of Juan de Fuca daily totaling about 6500 transits annually. Similarly, approximately 1300 tank focus vessels (tankers, chemical carriers, articulated tug barges and oil barges) travel east and west annually (i.e. about 2 tank focus vessel per day enter and leave the Strait of Juan de Fuca in 2015).

Of these deep draft vessels transits, about 5500[3] deep draft vessels travel, including north and south bound transits, to the Port of Vancouver, British Columbia, and about 3700[4] transit the entrance of the Puget Sound (at Admiralty Inlet), also including north and south bound transits. Thus, in addition to the 8300 transits entering and leaving the Strait of Juan de Fuca, additional deep draft vessels transits occur internally as vessels shift locations. There are also tug and barge movements, ferry operations, fishing and recreational vessels throughout. For example, the US Coast Guard Vessel Traffic Service (VTS) alone handles approximately 230,000 transits annually with about 170,000 of those being Washington State Ferries meaning there are more than approximately 60,000 transits other than ferries handled by the USCG VTS. The Puget Sound Pilots assignments average at about 7,000 assignments annually which provide a good metric for how many deep draft vessel movements there are on the US side.

The VTRA 2015 analysis model evaluates the duration that vessels travel through the VTRA Study Area (referred to as Vessel Time Exposure, abbreviated VTE), by vessel type. The inclusion of the time-on-the-water element in the evaluation of exposure sets the VTRA 2015 methodology apart from other count based approaches that focus on, for example, number of annual/monthly vessel transits, visits or calls. The value of a duration-based approach versus a count-based approach is that the VTE approach appropriately distinguishes between short and long transits in the evaluation of vessel traffic risk as well as high and low vessel speeds. Figure E-3 and Figure E-4 are graphical depictions of VTE evaluated by the VTRA 2015 Model. Figure E-3 and Figure E-4 depict that of the total Base Case 2015 Scenario VTE, 24.2% (Figure E-3) is accounted for by focus vessels and 75.8% (Figure E-4) by non-focus vessels. Focus vessels are the vessels of primary interest in the VTRA 2015 study and are subdivided into tank focus vessels (tankers, chemical carriers, articulated tug barges and oil barges) and cargo focus vessels (bulk carriers, container ships and other cargo vessels). Non-focus vessels are represented in the VTRA 2015 as they can potentially collide with the focus vessel class or contribute to potential grounding of focus vessels (besides potential accidents amongst focus vessels themselves).

[3] This number excludes passenger vessel counts
[4] This number excludes passenger vessel counts

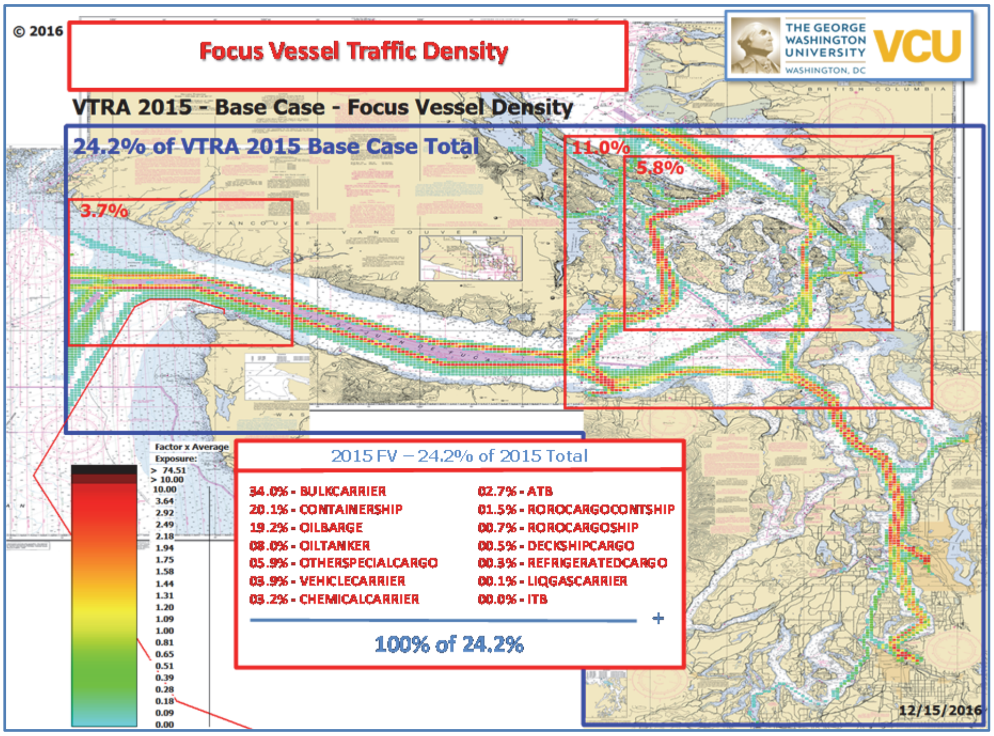

Figure E-3. 2D depiction of the traffic VTE for all focus vessels modeled in the Base Case 2015 Scenario.

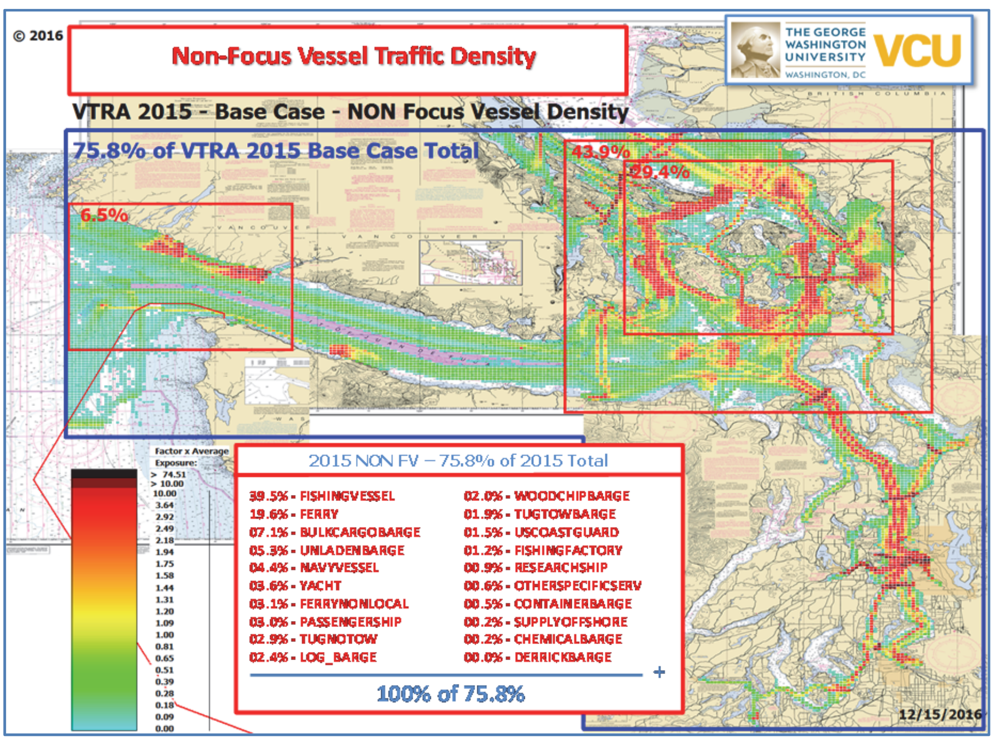

Figure E-4. 2D depiction of the traffic VTE for all non-focus vessel traffic modeled in the Base Case 2015 Scenario.

Totaling the VTE for tank focus vessels (oil barges – 19.2%, oil tanker – 8.0%, chemical carrier – 3.2%, ATB – 2.7%) we arrive at 33.1% in Figure E-3 of overall Base Case 2015 Scenario focus vessel VTE. Hence, about 19.2%/33.1% = 58.0% of the total tank focus vessel VTE is accounted for by oil barges that primarily travel within the VTRA Study Area in a north south direction and therefore many would not be captured as entrance counts to the Strait of Juan de Fuca. Totaling the VTE for cargo focus vessels in Figure E-3 we arrive at 66.9% of overall Base Case 2015 Scenario focus vessel VTE. Figure E-5 decomposes the VTE depicted in Figure E-3 into the VTE for cargo focus vessels @16.2% (Figure E-5A) of overall Base Case 2015 Scenario VTE and VTE for tank focus vessels @8.0% of overall Base Case 2015 Scenario VTE, together totaling the 24.2% of VTE depicted in Figure E-3.

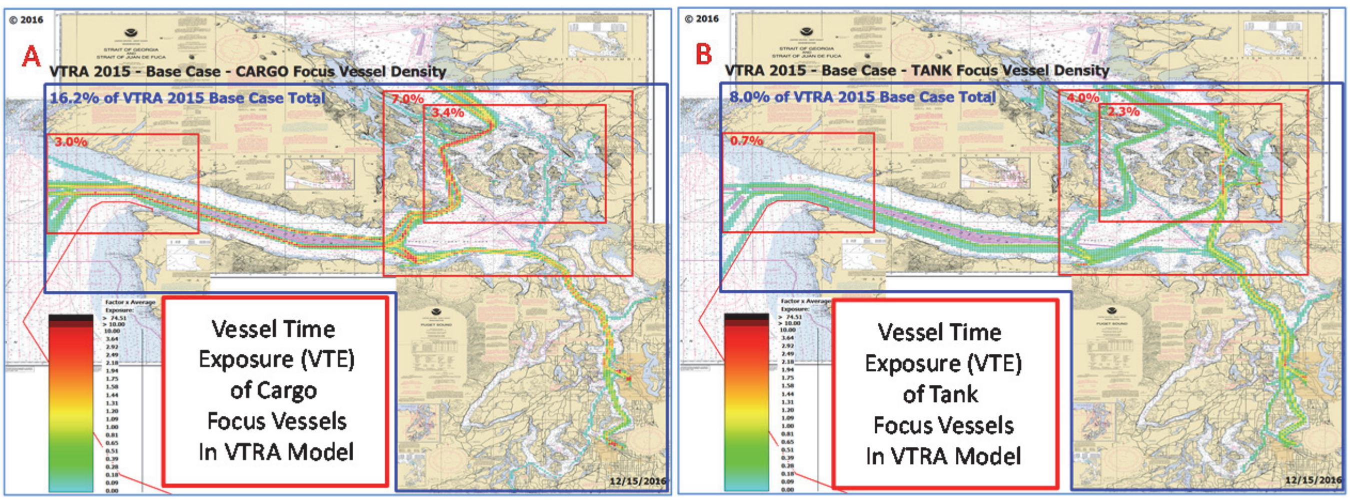

Figure E-5. 2D depiction of cargo focus vessel (A) and tank focus vessel (B) VTE components of Figure E-3 in the Base Case 2015 Scenario.

Analysis Observation 1: About 24.2% of the total modeled traffic time-on-the-water in the VTRA 2015 Model, called Vessel Time Exposure (VTE), is accounted for by focus vessels that are of primary interest within the VTRA 2015 Study. This 24.2% of Base Case 2015 Scenario VTE comprises of cargo focus vessels VTE (@16.2%) and tank focus vessels VTE (@8.0%). Thus, within the VTRA Study Area nearly a third of the total time that focus vessels are underway in the VTRA 2015 model is accounted for by focus vessels that carry oil products as cargo. The remaining about two thirds is attributed to focus vessels that carry other cargo (see Figure E-3 and Figure E-5).

Figure E-6 decomposes the VTE depicted for non-focus vessels modeled in the VTRA model depicted in Figure E-4 into four non-focus vessels VTE components being:

A. Fishing vessels and yachts (or recreational vessels) (@32.7% of Base Case 2015 Scenario VTE)
B. Ferry traffic (@17.2% of Base Case 2015 Scenario VTE)
C. Tug and tug tow barge traffic (excl. oil barges) (@17.0% of Base Case 2015 Scenario VTE)

D. Other non-focus vessel traffic (@8.9% of Base Case 2015 Scenario VTE)

When adding the 32.7%, 17.2%, 17.0% and 8.9% VTE's depicted in Figure E-6A, Figure E-6B, Figure E-6C and Figure E-6D one arrives at the 75.8% depicted in Figure E-4. While ferry traffic accounts for most of the transits handled by US Coast Guard Vessel Traffic Service (VTS) annually, one observes from Figure E-6B that their route length and location is relatively concentrated compared to the locations and distances that other non-focus vessels travel in the VTRA Study Area. Aside for vessel time exposure (VTE) accounting for those distances travelled and speed of the ferries in the VTRA Model, a large share of the VTE depicted in in Figure E-4 is accounted for by special events VTE depicted in Figure E-6A and that have been represented in the VTRA Model since the VTRA 2005 Study [12]. Special events in the VTRA Model involve movements of smaller vessels (less than 20 meters in length) that are not compelled to participate in the USCG VTS, such as whale watching activities, regatta events, and commercial and tribal (both Canadian and US) fishing openers. The darker regions in Figure E-6A depict the predominant locations of these special events in the VTRA model in terms of Base Case 2015 Scenario VTE.

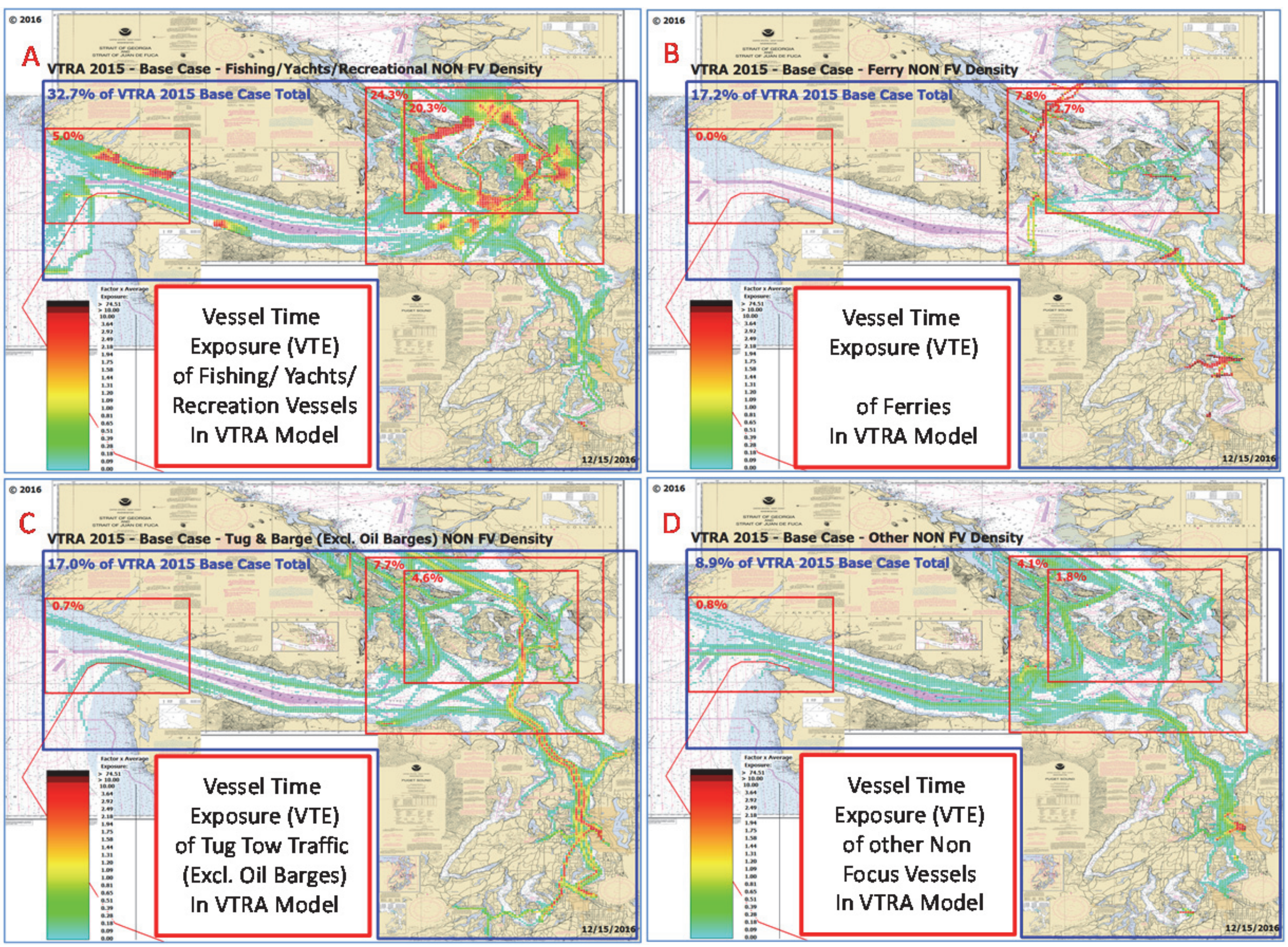

Figure E-6. 2D depiction of four Non-FV VTE Components of Figure E-4 in the Base Case 2015 Scenario.

Analysis Observation 2: About 75.8% of the total modeled traffic time on the water in the VTRA 2015 Model, called Vessel Time Exposure (VTE), is accounted for by non-focus vessel traffic that can potentially collide with focus-vessel traffic or contribute to potential grounding of focus vessels (See Figure E-4). This 75.8% of Base Case 2015 Scenario VTE comprises of movements of smaller vessels (less than 20 meters in length) VTE (@32.7%), ferries VTE (@17.2%), tug and tug-tow traffic (excl. oil barges) VTE (@17.0%) and other non-focus vessel VTE (@8.9%), see Figure E-6.

The VTRA 2015 analysis model represents the chain of events that could potentially lead to an oil spill and ends its evaluations with POTENTIAL volume of oil spilled in-the-water. Figure E-7 shows the accident causal chain.

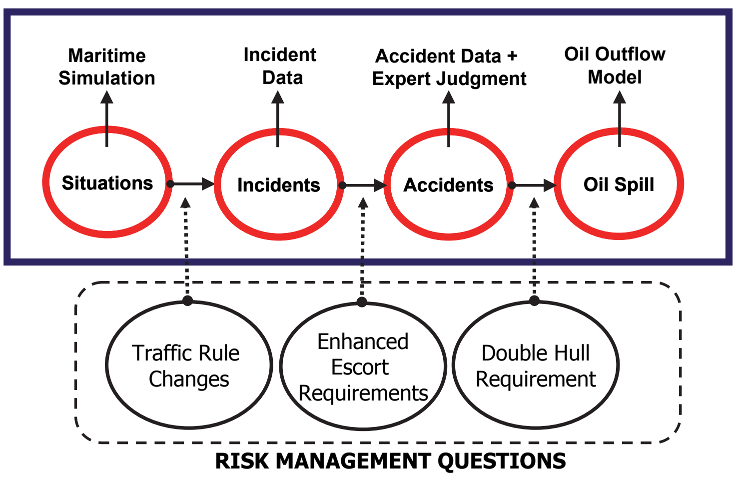

Figure E-7. A causal chain of events inter-connected by causal pathways. Risk management questions attempt to block these causal pathways.

A situation in which an accident could occur is called an accident exposure/situation. Maritime Transportation Systems (MTS) have accident exposures/situations simply from the movement of vessels within it. For each accident exposure, while the vessel is underway, incident and accident probability models are used to calculate the POTENTIAL Accident Frequency. This is not a prediction of an accident, but shows a relative propensity that an accident could occur in one situation versus another or the relative propensity for one type of accident versus another. The accident exposure and the potential accident frequency models are then combined with an oil outflow model to calculate potential oil loss. Throughout this report we shall use the terminology POTENTIAL to indicate that an accident exposure does not necessarily need to lead to an accident or oil loss, but may. As indicated by Figure E-7, the VTRA 2015 Analysis Tool does not evaluate the POTENTIAL fates and effects of a POTENTIAL Oil Loss beyond the POTENTIAL volume of oil spilled. That is, the VTRA Model's oil spill causal chain analysis ends with volume of POTENTIAL

Oil Loss in-the-water, should a POTENTIAL accident occur. The VTRA Oil Outflow model is described in [4] and modeled after the oil outflow model detailed in Special Report 259 [16] published by the Marine Board, Transportation Research Board of The National Academy of Sciences.

In terms of major oil spills over the past 25 years or so, defined as over 10,000 gallons ≈ 38 m^3 in the VTRA Study Area, the State of Washington and US Coast Guard records indicate one collision involving a fishing vessel and a cargo vessel spilling an estimated 361,000 gallons ≈ 1367 m^3 in 1991 near Cape Flattery and an oil barge grounding in 1994 near Anacortes on a transit from Vancouver, BC, resulting in an estimated 26,936 gallons ≈ 102 m^3 of diesel spilled. Even though this area has not experienced major oil spills in the past 20 years or so, the presence of tankers in an ever changing vessel traffic mix places the area at risk for large oil spills. While a previous GW/VCU analysis [3] of this area demonstrated significant risk reduction of oil transportation risk due to existing risk mitigation measures[5], the potential for large oil spills continues to be a prominent public concern heightened by proposed maritime terminal developments that are in various stages of their permitting processes.

Figure E-8 and Figure E-9 visualize graphically one of the VTRA 2015 analysis output formats in a manner that hopefully waterway users, regulators and the public can interpret. Figure E-8 and Figure E-9 are 3D visualizations of Base Case 2015 Scenario evaluated POTENTIAL Oil Loss within the VTRA Study Area and its geographic distribution. Figure E-8 depicts POTENTIAL Oil Loss for the Base Case 2015 Scenario (@100%), whereas Figure E-9 decomposes the POTENTIAL Oil Loss for the Base Case 2015 Scenario into POTENTIAL accidents with POTENTIAL Oil Loss in the following four categories:

A. 2500 m^3 or more POTENTIAL Oil Loss (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Loss (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Loss (@0% of Base Case POTENTIAL Oil Losses)

The ability to separate POTENTIAL accidents by POTENTIAL Oil Loss category is a distinguishing feature of the VTRA 2015 study as compared to the VTRA 2010 and the VTRA 2005 studies. One observes from the Figure E-9 that the largest contributor to overall Base Case 2015 Scenario evaluated POTENTIAL Oil Loss is the 1 m^3 to 1000 m^3 POTENTIAL Oil Loss category and the second largest is the 2500 m^3 or more of POTENTIAL Oil Loss Category.

[5] In [2] a 91.6% reduction in POTENTIAL oil loss was evaluated utilizing the VTRA 2005 model from all Tankers, Articulated Tug Barges (ATBs) and Integrated Tug Barges (ITBs) as a result of the implementation of the one-way zone regime in Rosario Strait, implementation of double hull tankers and the 2005 Escorting Regime.

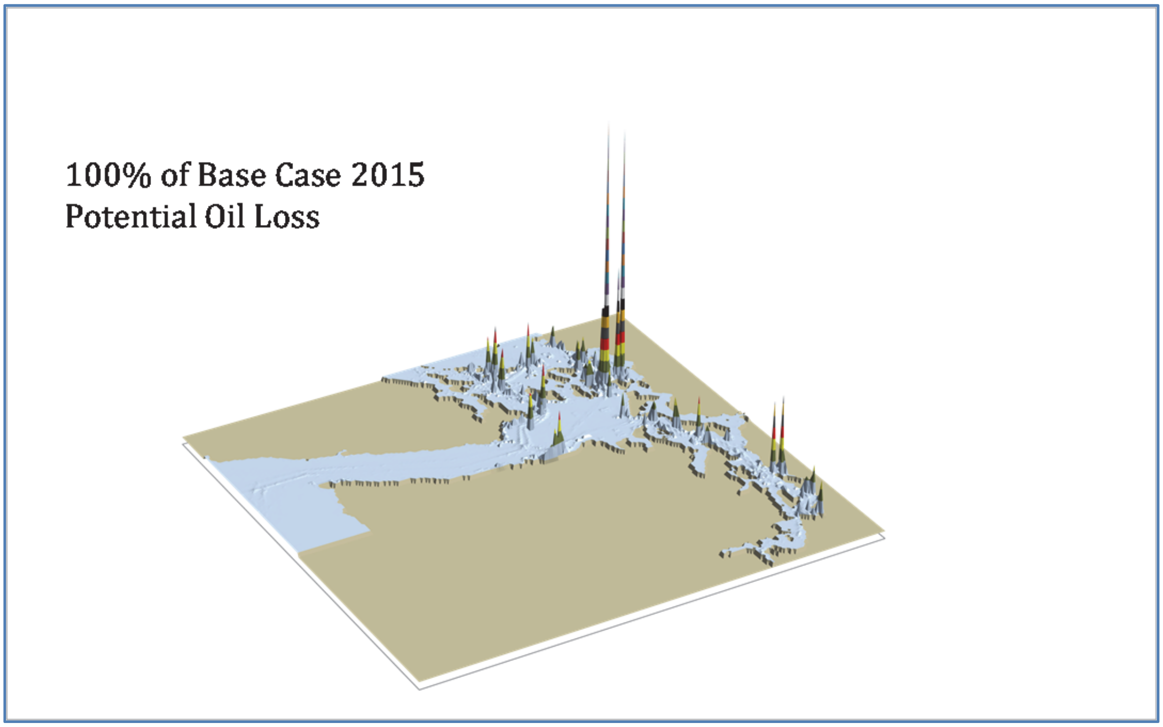

Figure E-8. 3D Geographic profile of Base Case 2015 Scenario POTENTIAL oil loss.

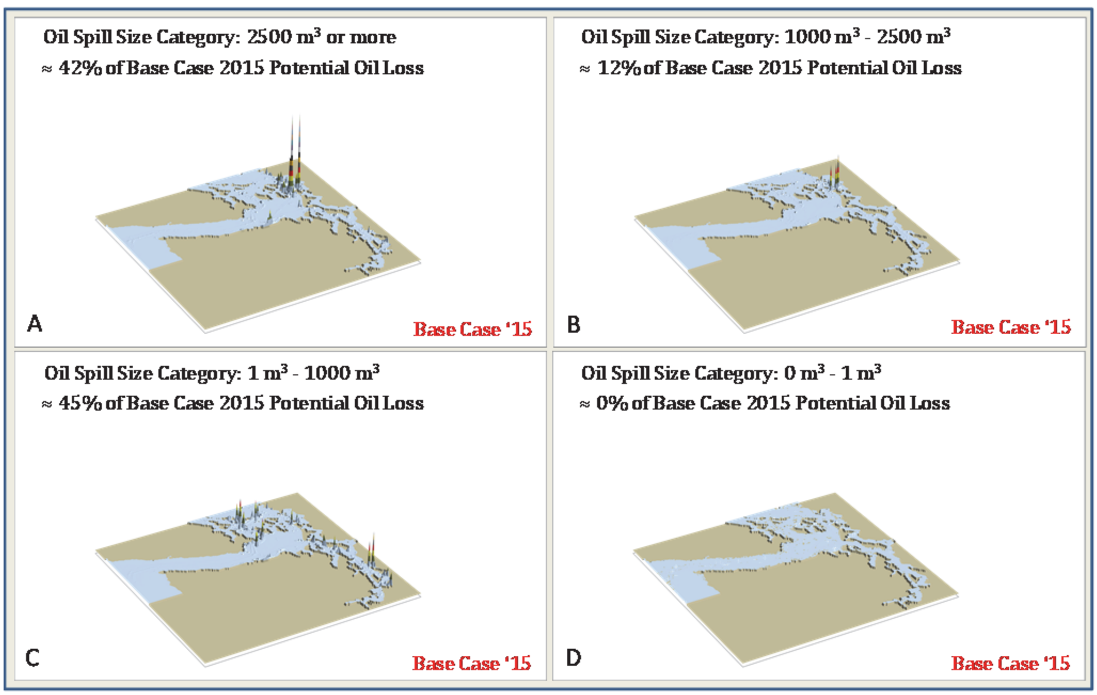

Figure E-9. Components of 3D Geographic profile of Base Case 2015 Scenario POTENTIAL oil loss.
A: 42% in Oil Spill Size Category of 2500 m^3 or more; B: 12% in Oil Spill Size Category of 1000 m^3 -2500 m^3;
C: 45% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 0% in Oil Spill Size Category of 0 m^3 -1 m^3.

Analysis Observation 3: Within the VTRA Study Area, the VTRA 2015 Model evaluates that the largest contributing POTENTIAL Oil Loss category is the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category @45% of Base Case 2015 Scenario POTENTIAL Oil Losses (see Figure E-8). The remainder is split between the 2500 m^3 or more of POTENTIAL Oil Loss Category (@42%), the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category (@12%) and the 0 m^3 – 1 m^3 POTENTIAL Oil Loss category (@0%).

In contrast, 98.2% of the POTENTIAL Accident Frequency evaluated by the VTRA 2015 model for the Base Case 2015 Scenario is accounted for by the 0 m^3 – 1 m^3 POTENTIAL Oil Loss category of which its contribution to Base Case 2015 Scenario POTENTIAL Oil Loss is about 0%. The remaining 1.79% of POTENTIAL Accident Frequency is split over the other three POTENTIAL Oil Loss categories above, with 1.76% in POTENTIAL Accident Frequency attributable to the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category. The Base Case Scenario accident frequency was calibrated separately to (1) the number of accidents available to the VTRA 2015 study over the time period 1995-2015 falling in the 0 m^3 – 1 m^3 oil loss category within the VTRA Study area and (2) two accidents available over the time period 1990-2015 falling in the 1 m^3 or more POTENTIAL Oil Loss category within the VTRA Study area, one involving a cargo focus vessel and the other involving a tank focus vessel. Overall the Base Case 2015 Scenario was calibrated to about 4.4 accidents per year evaluated using available accident data to the VTRA 2015 study from 1990 – 2015 and provided in Appendix B.

Analysis Observation 4: About 98.2% of the POTENTIAL Accident Frequency evaluated by the VTRA 2015 model in the Base Case 2015 Scenario is accounted for by the 0 m^3 – 1 m^3 category of which its contribution to Base Case 2015 Scenario POTENTIAL Oil Loss is about 0%. The remaining 1.8% of POTENTIAL Accident Frequency is split over the other three VTRA POTENTIAL Oil Loss categories 1 m^3 - 1000 m^3, 1000 m^3 -2500 m^3 and 2500 m^3 or more. Overall the Base Case 2015 Scenario was calibrated to about 4.4 accidents per year.

These percentages highlight the dichotomy and challenges for risk management of POTENTIAL Oil Loss, i.e. the objective of both (1) the prevention of accidents with lower POTENTIAL accident frequencies but higher POTENTIAL consequences and (2) the prevention of accidents with higher POTENTIAL accident frequencies but lesser POTENTIAL consequences. Needless to say, one's focus ought to be on the prevention of all POTENTIAL accidents. The information about their contribution to POTENTIAL consequences in terms of POTENTIAL Oil Loss categories, however, may be useful in the selection of a portfolio of risk mitigations that attempts to address all POTENTIAL Oil Loss categories.

What-If Scenario Results

Informed by Vessel Time Exposure (VTE), the VTRA 2015 analysis tool evaluates POTENTIAL Accident Frequency and POTENTIAL Oil Loss for tank focus vessels (tankers, chemical carriers, articulated tug barges and oil barges) and cargo focus vessels (bulk carriers, container ships and other cargo vessels). The Base Case 2015 Scenario analysis serves as a reference point to evaluate potential relative risk changes due to selected maritime terminal developments grouped in What-If Scenarios. Each What-If Scenario involves adding cargo focus vessels and tank focus vessels to the VTRA 2015 model. Subsequently, the model evaluates potential risk changes in terms of POTENTIAL Vessel Time Exposure, POTENTIAL Accident Frequency and POTENTIAL Oil Loss for the VTRA Study Area as a whole and by the fifteen VTRA waterway zones depicted in Figure E-2. Utilizing the VTRA 2015 Model, the following five What-If Scenarios were modeled in this study and evaluated for POTENTIAL risk increases from the Base Case 2015 Scenario:

(1) **US232:** A collection of terminal projects adding an estimated 232 focus vessels (32 tankers, 197 ATBs and 3 bulk carriers) to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 232 focus vessels travelling predominantly through US Waters.
(2) **KM348:** The Westridge Marine Terminal/Kinder Morgan pipeline expansion project adding an estimated 348 tankers to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 348 focus vessels travelling predominantly through Canadian (CA) Waters.
(3) **CA1020:** A collection of terminal projects adding an estimated 1020 focus vessels (629 bulk carriers, 368 container ships and 23 tankers) to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 1020 focus vessels travelling predominantly through Canadian (CA) Waters.
(4) **USKMCA1600:** The combination of US232, KM348 and CA1020 What-If Scenarios (632 bulk carriers, 368 container ships, 403 tankers and 197 ATBs) while these 1600 focus vessels travel through US and Canadian (CA) Waters.
(5) **USKMCALN2250:** The combination of the USKMCA1600 What-If Scenario (632 bulk carriers, 368 container ships, 403 tankers and 197 ATBs) with a collection of terminal projects adding an additional estimated 650 LNG vessels to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 2250 focus vessels travelling through US and Canadian (CA) Waters. **The VTRA 2015 Model, however, <u>does not</u> contain a model for the potential consequences of an accident with an LNG Tanker. Thus, LNG Tankers for the purposes of the VTRA 2015 study are <u>minimally modeled</u> for traffic impact as <u>cargo focus vessels</u> only. Hence, risk metrics evaluated for the USKMCALN2250 What-If Scenario ought to be considered <u>lower bounds of those risk metrics</u>.**

Bunkering support for the various terminal projects was also modeled in the VTRA 2015 What-If Scenarios. Specifically, 49, 17, 111, 177 and 207 oil barge bunker trips were added as part of the US232, KM348, CA1020, USKMCA1600 and USKMCALN2250 What-If Scenario definitions. Thus the number at the end of each What-If Scenario descriptor/name reflects the total number of focus vessels that are added to the Base Case 2015 Scenario while excluding from that number in the What-If Scenario name the number of bunkering support transits modeled for those What-If

Scenarios. Or, in other words, the total number of focus vessels added to the Base Case 2015 Scenario is higher than the ending number of the What-If Scenario name, since oil barges are part of the focus vessel group.

Four of the five above What-if Scenarios were compiled by the VTRA 2015 Working Group from their selected maritime development projects[6], specifically the US232, KM348, USKMCA1600 and USKMLN2250 What-If Scenarios above. The CA1020 What-If Scenario analysis is included in this report by GW/VCU since the US232, KM348 and the CA1020 What-If Scenarios together combine to form the USKMCA1600 What-If Scenario. It is worthwhile to note that there is about a 10-fold difference or more in the number of tankers and ATBs that are being added to Base Case 2015 Scenario for the US232 (32 tankers and 197 ATBs) and KM348 (348 tankers) What-if Scenarios, on the one hand, and the CA1020 What-If Scenarios (23 tankers), on the other hand. That being said, the CA1020 What-If Scenario adds about 997 cargo focus vessels, whereas the KM348 What-If Scenario adds no cargo focus vessels and the US233 scenario only adds 3 cargo focus vessels. Summarizing, the portfolio of focus vessels added to the Base Case 2015 Scenario for the What-if Scenario CA1020 is quite different from the portfolio of focus vessels added to the Base Case 2015 Scenario for the US232 and the KM348 What-If Scenarios. Moreover, the CA1020 What-If Scenario adds about 4.4 times (=1020/232) as many focus vessels as the US232 What-if Scenario, not including the added bunkering operations in this 4.4 factor, and about 2.9 times (=1020/348) as many focus vessels as the KM348 What-If Scenario, not including the added bunkering operations in this 2.9 factor.

Analysis Observation 5: There is about a 10-fold difference or more in the number of tankers and ATBs that are being added to Base Case 2015 Scenario for the US232 (32 tankers and 197 ATBs) and KM348 (348 tankers) What-if Scenarios, on the one hand, and the CA1020 What-If Scenarios (23 tankers), on the other hand. That being said, the CA1020 What-If Scenario adds about 997 cargo focus vessels to the Base Case 2015 Scenario, whereas the US232 scenario only adds 3 bulk carriers and the KM348 What-If Scenario adds no cargo focus vessels. The USKMCA1600 What-If Scenario combines the US232, KM348 and CA1020 What-If Scenarios.

Figure E-10 depicts POTENTIAL Oil Loss evaluated for the USKMCA1600 What-If Scenario (the combination of the above US232, KM348 and CA1020 What-If Scenarios). Similar figures as Figure E-10 are included for the other What-If Scenarios in the main body of this report.

Figure E-10 illustrates an estimated 1.85 relative increase in overall POTENTIAL Oil Loss compared to the Base Case 2015 Scenario without additional risk mitigation. This too demonstrates that the VTRA 2015 study concentrates more on relative comparisons between

[6] A list of maritime terminal projects is included in the main body of the report.

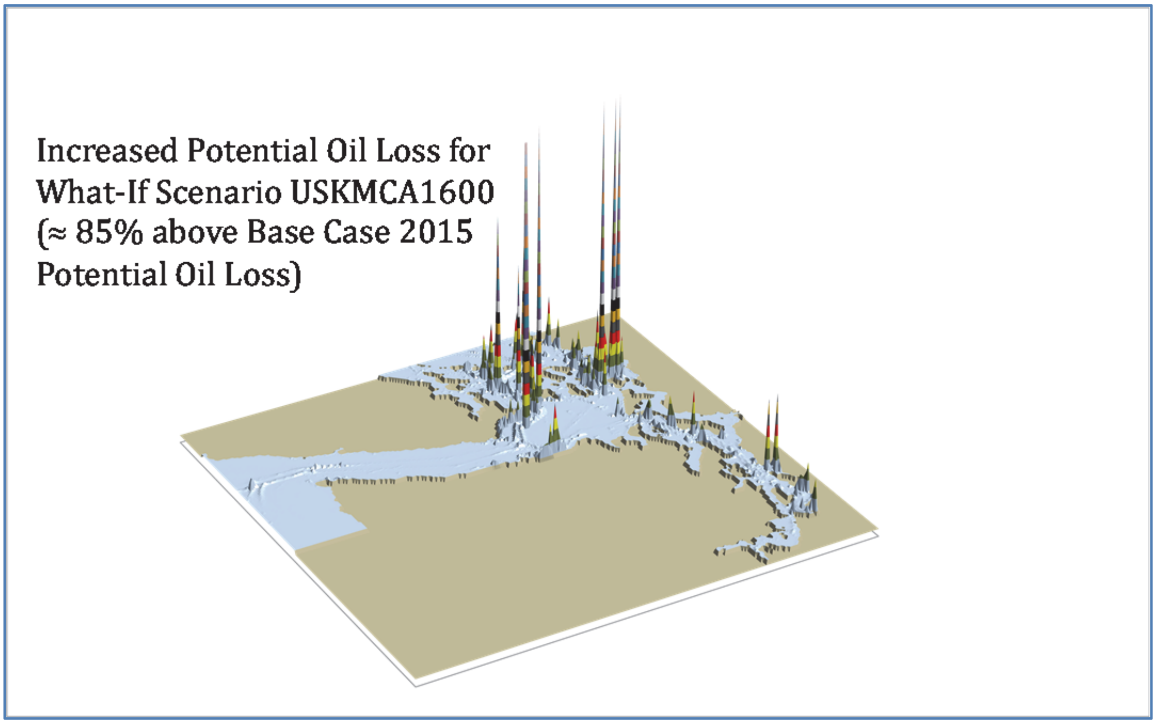

Figure E-10. 3D Geographic Profile of USKMCA1600 What-If Scenario POTENTIAL Oil Loss.

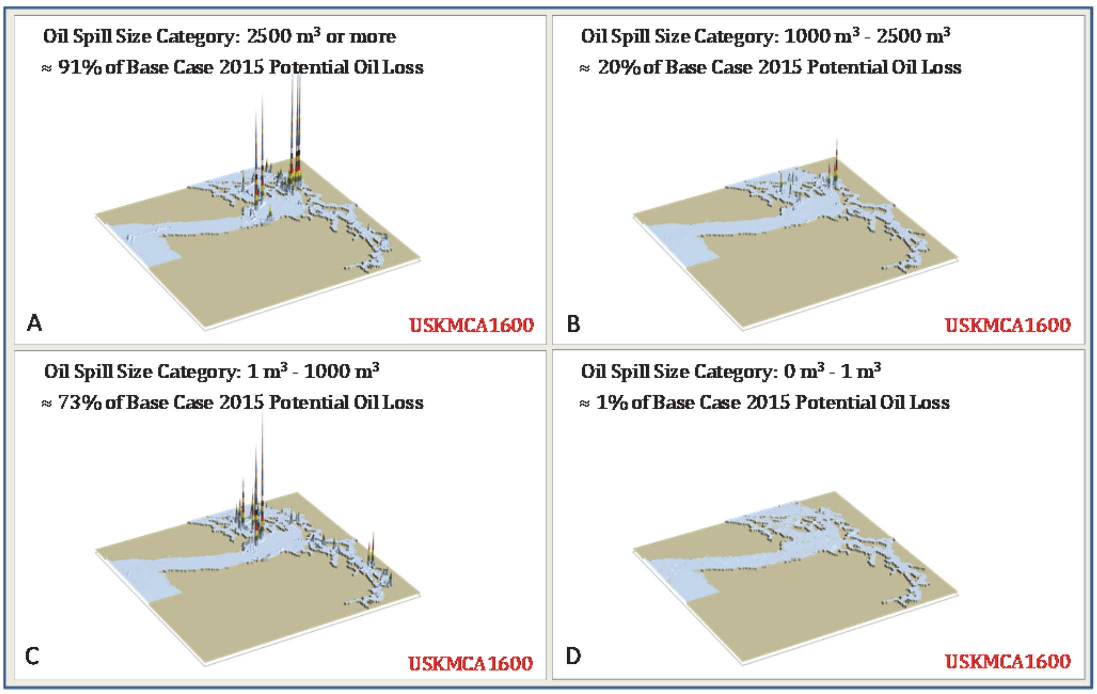

Figure E-11. Components of 3D Geographic Profile of What-If USKMCA1600 Scenario POTENTIAL Oil Loss. A: 91% in Oil Spill Size Category of 2500 m^3 or more; B: 20% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 73% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 1% in Oil Spill Size Category of 0 m^3 -1 m^3

What-If scenarios or between POTENTIAL Oil Loss categories and less on the absolute values of their respective analysis results. Figure E-11 decomposes the overall POTENTIAL Oil Loss for the combined What-If Scenario USKMCA1600 into POTENTIAL accidents across four POTENTIAL Oil Loss categories considered in the VTRA 2015 analysis model, i.e. those with:

A. 2500 m^3 or more POTENTIAL Oil Loss (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss (@21% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Loss (@73% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Loss (@1% of Base Case POTENTIAL Oil Losses)

Hence, in contrast to the Base Case 2015 Scenario analysis results, the 2500 m^3 or more POTENTIAL Oil Loss category is now the largest contributor to overall POTENTIAL Oil loss (@91%) increased by a multiplicative factor of 2.17 (= 91%/42%) and now the second largest contributor to overall POTENTIAL Oil Loss is the category 1 m^3 - 1000 m^3 (@73%) instead, increased by a multiplicative factor of 1.61 (= 73%/45%). These three different multiplicative factors, i.e. 1.85 for the Total POTENTIAL Oil Loss for the entire VTRA Study Area, 2.17 for the POTENTIAL Oil Loss Category 2500 m^3 or more and 1.61 for the POTENTIAL Oil loss category 1 m^3 - 1000 m^3, demonstrate that POTENTIAL Oil Loss risk does not increase uniformly (i.e. by the same relative factor) across the four POTENTIAL Oil Loss categories above, should all terminal projects in the USKMCA1600 Scenario come to fruition.

Analysis Observation 6: Should the maritime terminal projects in a What-If Scenario come to fruition POTENTIAL Oil Loss risk does not change by the same relative factor across the four POTENTIAL Oil Loss categories: 2500 m^3 or more, 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 or 0 m^3 – 1 m^3. While for the USKMCA1600 Scenario a relative factor 1.85 increase is evaluated in terms of Base Case 2015 Scenario POTENTIAL Oil Loss across the VTRA 2015 Study Area, relative factor increases 2.17, 1.61 and 1.56 were evaluated within the 2500 m^3 or more, the 1 m^3 - 1000 m^3 and the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss categories.

Figure E-12 depicts a by-waterway-zone comparison of POTENTIAL Oil Loss evaluated for the USKMCA1600 What-If Scenario to those evaluated for the Base Case 2015 Scenario. Similar to the POTENTIAL Oil Loss Categories themselves, one observes from Figure E-12 that POTENTIAL Oil Loss by-waterway-zone does not increase by the same relative factors across the fifteen waterway zones depicted in Figure E-2, should all terminal projects in the USKMCA1600 Scenario come to fruition. Figure E-12 shows that while system-wide POTENTIAL Oil Loss increases by about +85% (i.e. by about the evaluated relative factor 1.85 for the VTRA study area) in the USKMCA1600 What-If Scenario (green highlight in Figure E-12), larger relative factors are observed for the following specific waterway zones[7] (orange and red highlights in Figure E-12):

[7] See Figure E-2 for the geographical depiction of these waterway zones in the VTRA 2015 Model.

- Buoy J (× 4.09)
- Haro-Strait/Boundary Pass (× 3.53)
- East Strait of Juan de Fuca (× 2.64)
- West Strait of Juan de Fuca (× 2.08)
- Georgia Strait (× 1.83)
- Guemes (× 1.82)

Thus the waterway zones above experience a relative factor increase in POTENTIAL Oil Loss that is about the same or higher than the relative factor increase in POTENTIAL Oil Loss 1.85 for the entire VTRA Study Area, should all the terminal projects in the USKMCA1600 What-If Scenario come to fruition.

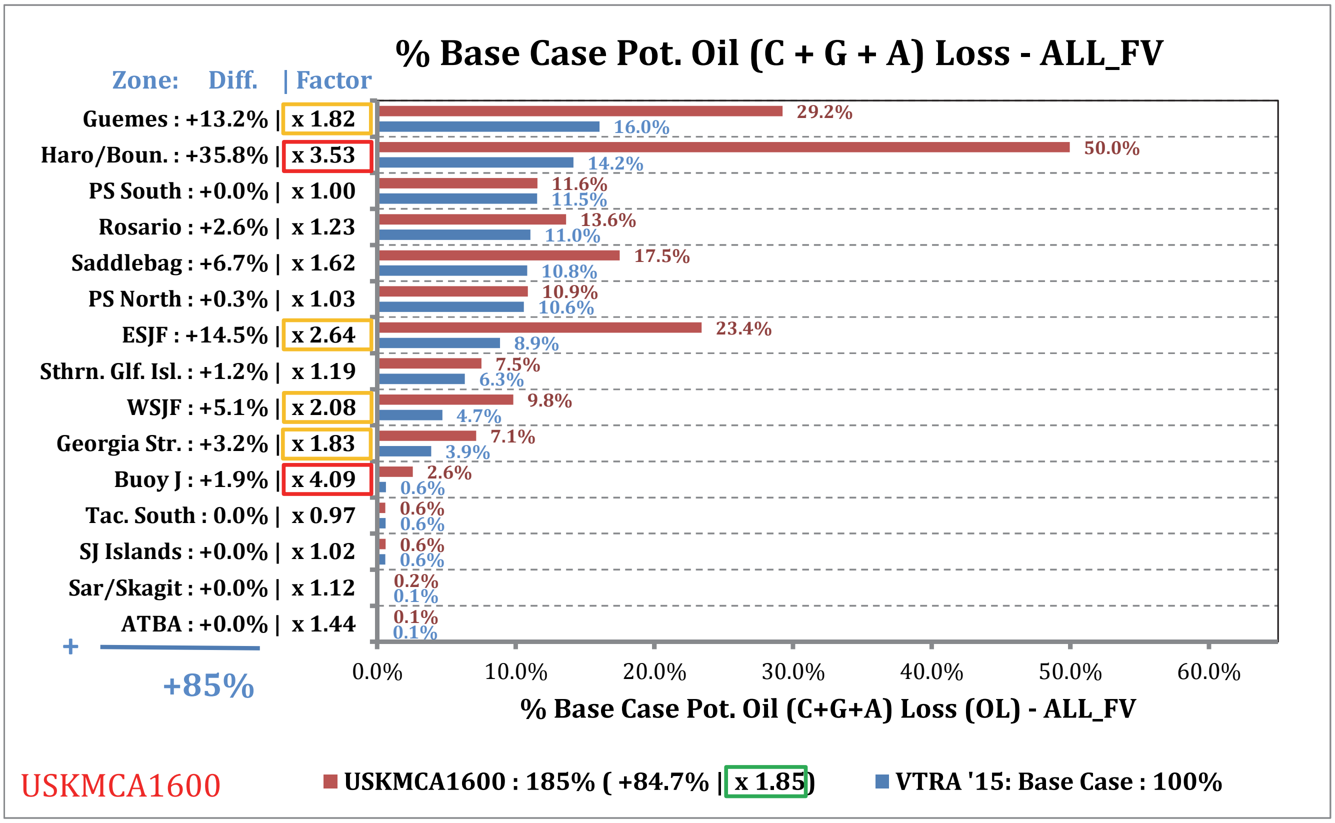

Figure E-12. Relative comparison of POTENTIAL Oil Loss by-waterway-zone. Blue bars show the percentage by waterway zone for the Base Case 2015 scenario, red bars show the percentage for What-If Scenario USKMCA1600 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

Analysis Observation 7: The Buoy J and Haro-Strait/Boundary Pass waterway zone specific increases in POTENTIAL Oil Loss was evaluated to be larger than a relative multiplier 3.5 (red highlights in Figure E-12), should all maritime terminal developments in the What-If Scenario USKMCA1600 come to fruition.

Similar to making a by-waterway-zone comparison in terms of overall POTENTIAL Oil Loss, such by-waterway-zone comparisons can also be made within a POTENTIAL Oil Loss Category. In the

VTRA 2015 study those by-waterway-zone comparisons are made in terms of what is called an absolute risk metric not utilized in the prior VTRA 2005 and VTRA 2010 studies, specifically *the estimated probability of one or more accidents potentially occurring over a 10-year period per potential oil loss category*. The evaluation of these probability risk metrics is also a distinguishing feature of the VTRA 2015 study compared to the VTRA 2010 and VTRA 2005 studies. These probability risk metrics relate directly to their evaluated POTENTIAL accident frequencies and the length of the time period over which these probabilities are estimated[8]. Both the probability of at least one accident per a period of time, on the one hand, and the POTENTIAL accident frequency per year, on the other hand, are considered absolute risk metrics. That being said, the evaluation of the probability risk metrics demonstrate through the wording "probability" that however small the POTENTIAL accident frequency may be for a particular POTENTIAL Oil Loss category, non-zero probabilities evaluated using the VTRA 2015 Model supports that the occurrence of these POTENTIAL events evaluated is not impossible and could in fact happen, however unlikely. The communication of such probability metrics per a specified period of time is advocated in [26]. As stated earlier, however, the VTRA 2015 Study concentrates more on relative comparisons between risk metrics evaluated for the five What-If scenarios and the Base Case 2015 Scenario and less on the absolute values of their respective analysis results.

These probability risk metrics per a specific period of time, as defined above, are also evaluated for the VTRA Study Area as a whole by POTENTIAL Oil Loss category. For the Base Case 2015 Scenario, a 0.50% probability is estimated for the POTENTIAL occurrence of at least one accident in the VTRA Study Area over a 10-year period within the POTENTIAL Oil Loss category 2500 m^3 or more. For the USKMCA1600 What-If Scenario this estimated probability increases to 1.35%, a relative factor 1.35%/0.50% ≈ 2.71 increase. Figure E-13 above demonstrates that while system-wide the estimated probability of at least one accident over a 10-year time period within the POTENTIAL Oil Loss category 2500 m^3 or more increases by this relative factor 2.71 (green highlight in Figure E-13) in the USKMCA1600 What-If Scenario, larger relative factors are observed for the following specific waterway zones (orange and red highlights in Figure E-13):

- Haro-Strait/Boundary Pass (× 11.19)
- Southern Gulf Islands (× 6.04)
- Buoy J (× 5.25)
- East Strait of Juan de Fuca (× 5.06)
- West Strait of Juan de Fuca (× 3.10)

[8] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f} \times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

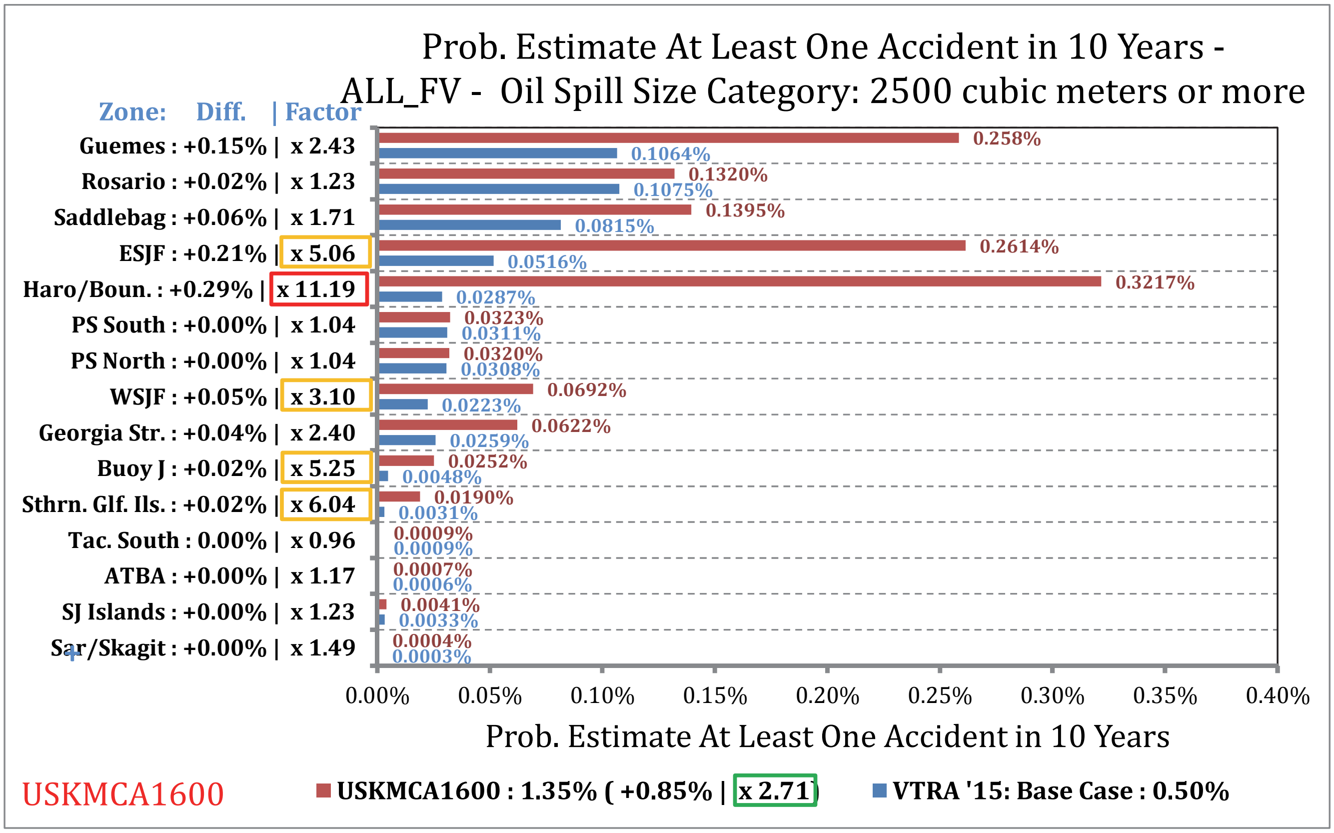

Figure E-13. Relative comparison of the probability of one or more accidents within 10-year period in the Oil Spill Size category 2500 m³ or more by waterway zone. Blue bars show these probabilities by waterway zone for the Base Case 2015 scenario, red bars show these probabilities for What-If Scenario USKMCA1600 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

Analysis Observation 8: The estimated probability of one or more accidents in the VTRA Study Area over a 10-year period within the POTENTIAL Oil loss category 2500 m³ or more increased from an estimated 0.50% for the Base Case 2015 Scenario to an estimated 1.35% for the USKMCA1600 What-if Scenario (i.e. an increase by a relative factor of 2.71, green highlight in Figure E-13). For the Haro-Strait/Boundary Pass waterway zone this and its estimated probability was evaluated to increase by a relative multiplier larger than a factor 11.0 (red highlight in Figure E-13) should all maritime terminal developments in the What-If Scenario USKMCA1600 come to fruition.

In Figure E-14 below, the by-waterway-zone comparison of the estimated probability of at least one accident within a 10-year time period in the POTENTIAL Oil Loss category 1000 m³ - 2500 m³ is provided. While the relative multiplier 1.56 (green highlight in Figure E-14) for this probability is smaller than the relative multiplier (2.71) for the 2500 m³ or more category in Figure E-13, the probability for an accident of this type over a 10-year period is estimated at 0.61% for the Base

Case 2015 Scenario. Recall from Figure E-11 that the 1000 m³ - 2500 m³ POTENTIAL Oil Loss category was estimated to contribute about 12% to the overall 2015 POTENTIAL Oil Loss evaluated for the Base Case 2015 Scenario. Figure E-14 demonstrates that while system-wide the estimated probability of one or more accidents over a 10-year period within the POTENTIAL Oil Loss category 1000 m³ - 2500 m³ increases by this relative factor 1.56 (green highlight in Figure E-14) in the USKMCA1600 What-If Scenario, larger relative factors are observed for the following specific waterway zones (orange and red highlights in Figure E-14) for this particular POTENTIAL Oil Loss category:

- Haro-Strait/Boundary Pass (× 4.05)
- Buoy J (× 2.06)
- West Strait of Juan de Fuca (× 2.04)

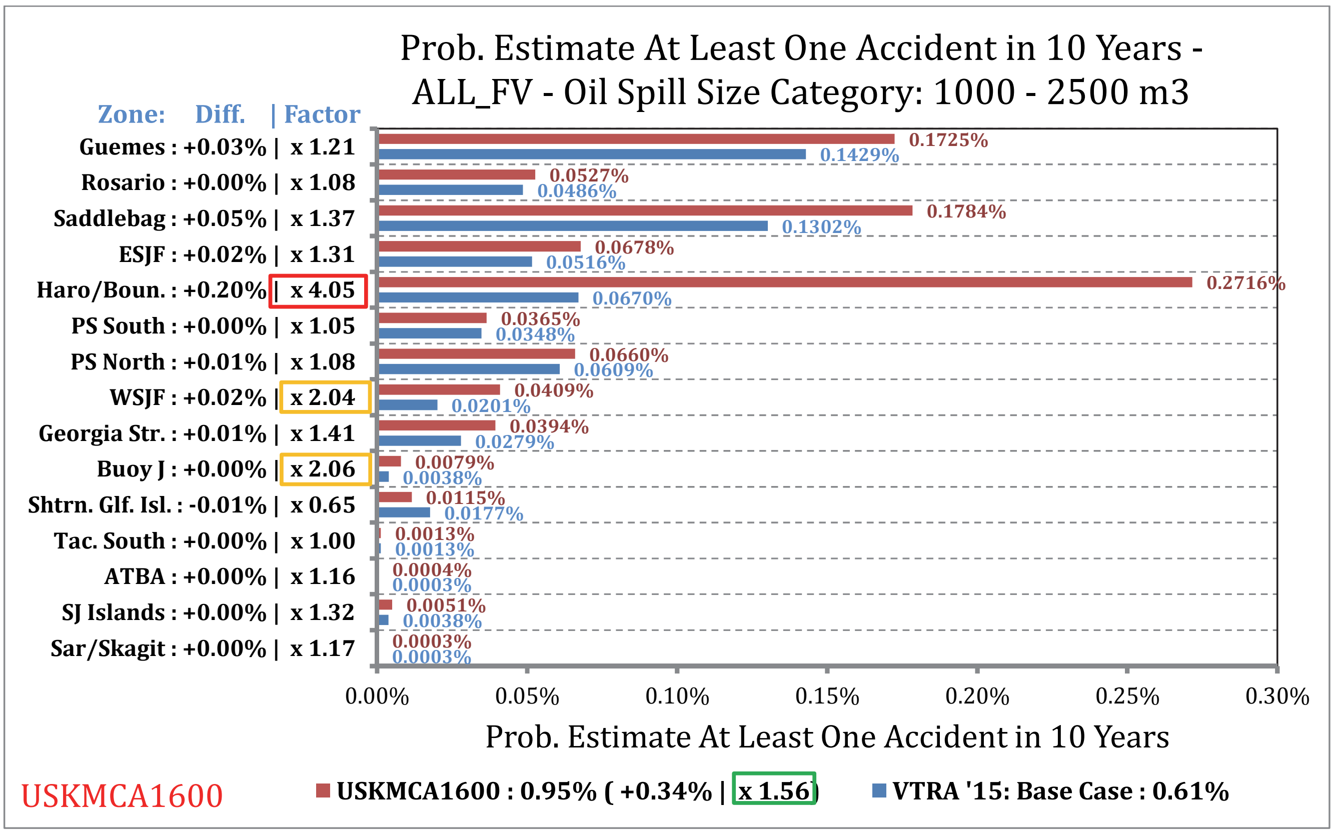

Figure E-14. Relative comparison of the probability of one or more accidents within 10-year period in the Oil Spill Size category 1000 m³ - 2500 m³ by waterway zone. Blue bars show these probabilities by waterway zone for the Base Case 2015 scenario, red bars show these probabilities for What-If Scenario USKMCA1600 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

Analysis Observation 9: The estimated probability of one or more accidents in the VTRA Study Area over 10-year period within the 1000 m³ - 2500 m³ POTENTIAL Oil Loss category increased from an estimated 0.61% for the Base Case 2015 Scenario to an estimated 0.96% for the USKMCA1600 What-if Scenario (i.e. an increase by a relative factor of 1.56). For the waterway zone Haro-Strait/Boundary Pass this and its estimated probability was evaluated to increase by a relative multiplier larger than 4.0 (red highlight in Figure E-14), should all maritime terminal developments in the What-If Scenario USKMCA1600 come to fruition.

In Figure E-15, the by-waterway-zone comparison of the probability of one or more accidents within a 10-year period in the 1 m³ - 1000 m³ POTENTIAL Oil Loss category is provided.

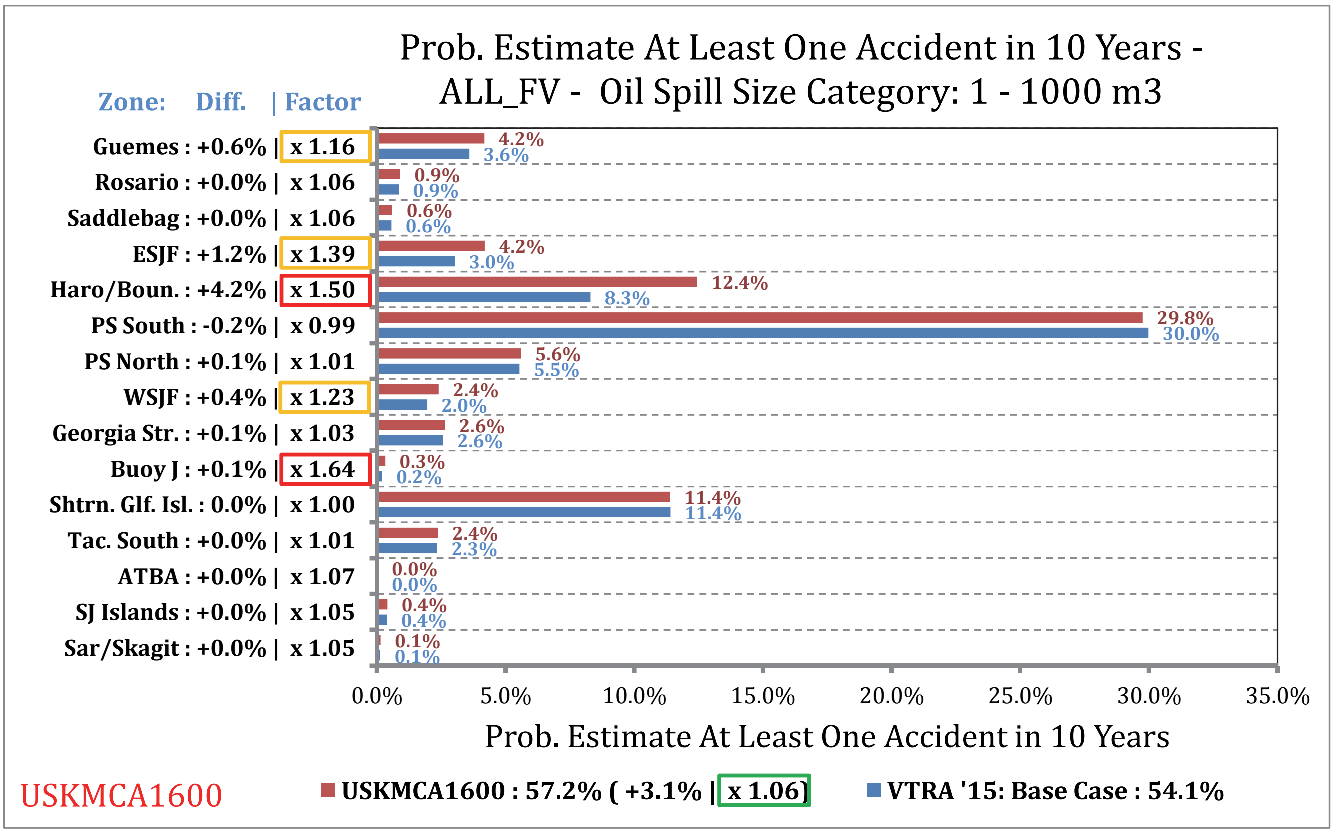

Figure E-15. Relative comparison of the probability of one or more accidents within a 10-year period in the Oil Spill Size category 1 m³ - 1000 m³ by waterway zone. Blue bars show these probabilities by waterway zone for the Base Case 2015 scenario, red bars show these probabilities for What-If Scenario USKMCA1600 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

While the relative multiplier 1.06 (green highlight in Figure E-15) for this probability is smaller than the relative multiplier (2.71) for the 2500 m³ or more category in Figure E-13, the probability for an accident of this type in the VTRA Study area over a 10-year period is estimated at 54.2% for the Base Case 2015 Scenario[9].

Recall from Figure E-11 that the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category was evaluated to contribute the most (45%) to overall POTENTIAL Oil Loss evaluated for the Base Case 2015 Scenario. Figure E-15 demonstrates that while system-wide the probability of one or more accidents over a 10-year period within the POTENTIAL Oil Loss category 1 m^3 – 1000 m^3 increases by this factor 1.06 (green highlight in Figure E-15) in the USKMCA1600 What-If Scenario, larger relative factors are observed for the following specific waterway zones (orange and red highlights in Figure E-15) for this particular POTENTIAL Oil Loss category:

- Buoy J (× 1.64)
- Haro-Strait/Boundary Pass (× 1.50)
- East Strait of Juan de Fuca (× 1.39)
- West Strait of Juan de Fuca (× 1.23)
- Guemes (× 1.16)

Analysis Observation 10: The estimated probability of one or more accidents in the VTRA Study Area over a 10-year period within the loss category 1 m^3 - 1000 m^3 increased from an estimated 54.2% for the Base Case 2015 Scenario to an estimated 57.2% for the USKMCA1600 What-if Scenario (i.e. an increase by a relative factor 1.06). For the Buoy J and Haro-Strait/Boundary Pass waterway zones this probability was evaluated to increase by about a relative factor 1.64 and 1.50 (red highlight in Figure E-15), respectively, should all maritime terminal developments in the What-If Scenario USKMCA1600 come to fruition.

Having explained that, should all the maritime terminal development projects in the USKMCA1600 What-If Scenario come to fruition, the relative risk factors neither change uniformly by-waterway-zone nor by POTENTIAL Oil Loss category, Figure E-16 summarizes the by VTRA Study Area wide relative factors for the five different What-If Scenarios evaluated and by the four different POTENTIAL Oil Loss categories. Specifically, Figure E-16 provides the relative multipliers by VTRA Study Area from the Base Case 2015 Scenario results for the probability of at least one accident occurring over a 10-year period by POTENTIAL Oil Loss category. For example, the factor 2.71 (green highlight in Figure E-13) is observed in Figure E-16 in the first row and the second column. Also, for example, the factor 1.06 (green highlight in Figure E-15) is observed in Figure E-16 in the third row and the second column. From Figure E-16 one observes across the five What-If Scenarios evaluated that the relative multipliers increase by oil spill size category within each What-If Scenario evaluated, except for the CA1020 What-If Scenario where the relative multipliers for the 1000 m^3 – 2500 m^3 and 2500 m^3 or more POTENTIAL Oil Loss categories are of about the same value.

[9] A probability of 50% is typically assigned to the probability of heads or tails in a coin toss experiment.

VTRA Study Area	USKMCALN2250	USKMCA1600	KM348	CA1020	US232
2500 m3 or More	2.80	2.71	1.95	1.10	1.60
1000 m3 - 2500 m3	1.58	1.56	1.37	1.11	1.09
1 m3 - 1000 m3	1.10	1.06	1.00	1.05	1.00
0 gallons - 264 gallons	1.00	1.00	1.00	1.00	1.00

Figure E-16. Relative multiplier comparison of the estimated probability of one or more accidents occurring within a 10-year period by POTENTIAL Oil Loss category over the VTRA Study Area for the five What-If Scenarios evaluated.

Moreover, from Figure E-16 one observes that the relative factor increase in the estimated probability of at least one accident occurring in the VTRA Study Area over a 10-year period is highest in the 1 m^3 – 1000 m^3 POTENTIAL Oil Loss category for the USKMCALN2250, USKMCA1600 and CA1020 What-If Scenarios with relative multipliers of 1.10, 1.06 and 1.05, respectively[10]. On the other hand, the relative multiplier for this estimated probability for the 2500 m^3 or more POTENTIAL Oil Loss category is lowest for the CA1020 What-If Scenario (1.10) compared to the other What-If Scenarios US232, KM348, USKMCA1600 and USKMCALN2250 with relative multipliers 1.60, 1.95, 2.71 and 2.80 in the top row of Figure E-16, respectively. A similar observation can be made for the CA1020 What-If Scenario for the 1000 m^3 – 2500 m^3 POTENTIAL Oil Loss category. In absorbing the relative multiplier results above for the VTRA Study area across the evaluated What-If Scenarios and by POTENTIAL Oil Loss category, it is important to recall the earlier discussion regarding the difference in nature of the portfolio of focus vessels added to the Base Case 2015 Scenario between, on the one hand, the CA1020 What-If Scenario and, on the other hand, the US232 and KM348 What-If Scenarios. At the same time, one needs to recall that the USKMCA1600 What-If Scenario is defined as the combination of the US232, KM348 and CA1020 What-If Scenarios.

Analysis Observation 11: The relative multipliers for the estimated probabilities of at least one accident occurring in the VTRA Study Area over a 10-year period by and large increase by oil spill size category within the five different What-If Scenarios evaluated. While the relative multiplier for the CA1020 What-If Scenario is amongst the highest for the 1 m^3 – 1000 m^3 POTENTIAL Oil Loss category, its relative multiplier is the lowest for the 2500 m^3 or more POTENTIAL Oil Loss category.

More detailed analysis results presentations for the evaluated What-If Scenarios in the VTRA 2015 study are posted at the following url:

https://www.seas.gwu.edu/~dorpjr/VTRA_2015/VTRA_2015_Presentations.html

[10] Recall that in the USKMLN2250 What-If Scenario the added LNG tankers are minimally modelled for traffic impact only in terms of consequences as cargo-focus vessels since the VTRA 2015 model does not contain a POTENTIAL consequence model for accidents with LNG tankers.

Risk Mitigation Measure Scenario Results

A series of risk mitigation measures were proposed over the course of the VTRA 2015 study either with involvement of the VTRA 2015 Working Group or by GW/VCU to help inform a risk management process should some of the maritime terminal development projects represented in the five What-If Scenarios USKMCALN2250, USKMCA1600, KM348, CA1020 or US232 come to fruition. However, the system-wide and the by-waterway-zone specific relative effectiveness of these risk mitigations measures were only evaluated relative to the USKMCA1600 What-If scenario. In other words, caution is in order in not interpreting these relative RMM effectiveness evaluations as being applicable to other What-If Scenarios, or the Base Case 2015 Scenario analysis for that matter. The manner of implementation of these risk mitigations measure in the VTRA 2015 model was as follows (in no specific order):

DH100-RMM: 100% Double hull fuel protection of cargo focus vessels (increased from 40% in the Base Case 2015 Scenario).

HM50-RMM: Reduce human error and mechanical failure on tugs (excluding oil barges) by 50%.

SE-RMM: Remove from the VTRA 2015 Simulation Model its special events, i.e. the modeled regatta, whale watching, and commercial and tribal fishing openers. Combined fishing vessels and yachts/recreational vessels account for about $(39.5\% + 3.6\%) \approx 43.1\%$ of the non-focus vessel traffic (see Figure E-4) in the VTRA 2015 model or $(43.1 \times 75.8\%) \approx 32.7\%$, i.e. about a third, of the VTRA Model traffic in terms of vessel time exposure (VTE). See also, Figure E-4 and Figure E-6A.

OAE-RMM: Continuously escort laden oil barges and ATBs east of Port Angeles (unthethered).

KME-RMM: Extend escorting of Kinder Morgan outbound laden tankers to Buoy J.

SRT-RMM: Station a rescue tug at Sidney, BC and model its coverage in the same manner as the coverage model that was developed for the Neah Bay rescue tug in the VTRA 2005.

125-RMM: Lift the 125 DWT limit on laden crude inbound tankers while reducing the number of crude inbound tanker transits to keep the volume of crude inbound tankers approximately the same.

17-RMM: Reduce the speed of container vessel to 17 knots throughout the VTRA 2015 Study Area, a speed restriction practiced south of Admiralty Inlet (i.e. the entrance to the Puget Sound) by container ships.

VBRT-RMM: Station a rescue tug at Victoria, BC, and Bedwell Harbor, BC, and model their coverage in the same manner as the coverage model that was developed for the Neah Bay rescue tug in the VTRA 2005.

The first three components DH100-RMM, HM50-RMM and SE-RMM are referred to in combination as the USCG-RMM Suite. DH100-RMM is currently being phased in by vessel owners to meet the requirements of the International Maritime Organization (IMO) Convention for the Prevention of Pollution from Ships, Annex I, Regulation 12A. The intent of the HM50-RMM is to conduct a maximum benefit type evaluation utilizing the VTRA 2015 model through the on-going implementation of 46CFR Subchapter M, which establishes safety regulations governing the inspections, standards, and safety management systems of towing vessels. The intent of including the SE-RMM is to conduct a maximum benefit type evaluation utilizing the VTRA 2015 model through increased carriage of AIS transponders by fishing and passenger vessels, changes to USCG VTS software that will allow VTS operators to display additional small vessel and recreational boat AIS data, and mandatory safety inspections for commercial fishing vessels. The effect of the SE-RMM implementation in the VTRA 2015 model evaluations is the removal of all POTENTIAL collisions in the VTRA analysis with special event vessels and the removal of the contributing effect that the presence of these special event vessels may have on other focus vessel accidents. By no means ought the implementation method of the HM50-RMM and the SE-RMM in the VTRA 2015 model, and their effectiveness evaluation, be interpreted as the manner in which the HM50-RMM and the SE-RMM are operationalized in practice.

To achieve risk reduction across the VTRA Study Area, we believe that the question "which risk mitigation measure should one implement?" is not the right question to ask, but rather it should be "which portfolio of risk mitigation measures should one implement?". Two of these trial portfolio scenario analyses were conducted utilizing the VTRA 2015 model. The first portfolio is referred to as the **5RMM** Scenario and combines the USCG RMM Suite (i.e. the DH100-RMM, HM50-RMM and the SE-RMM), with RMMs 2 through 5 (i.e. the OAE-RMM, KME-RMM, SRT-RMM and the 125-RMM). The second portfolio is referred to as the **3RMM** Scenario combining the DH100-RMM, 17-RMM and the VBRT-RMM. Four RMMs were evaluated individually: the OAE-RMM, SRT-RMM, KME-RMM and the 125-RMM. In summary, a total of six RMM Scenarios were evaluated during the VTRA 2015 Study of which two were portfolios of RMMs. The POTENTIAL effectiveness of these six RMM scenarios was evaluated in the VTRA 2015 model by implementing them on top of the USKMCA1600 What-If Scenario only. As such, these analyses solely reflect POTENTIAL effectiveness evaluation of these RMMs should all maritime development projects in the USKMCA1600 Scenario come to fruition and subsequently these RMMs have been adopted.

Similar to Figure E-16, Figure E-17 provides the relative multipliers by VTRA Study Area of the probability of one or more accidents occurring over a 10-year period by POTENTIAL Oil Loss category for the six evaluated RMM Scenarios (Columns 1 through 6) together with the relative multipliers for the USKMCA1600 What-If Scenario in the seventh column (see also the second column in Figure E-16).

VTRA Study Area	USKMCA1600 5RMM	USKMCA1600 3RMM	USKMCA1600 OAE-RMM	USKMCA1600 SRT-RMM	USKMCA1600 KME-RMM	USKMCA1600 125-RMM	USKMCA1600 NO RMM
2500 m3 or More	**2.28**	2.68	2.70	2.71	2.70	2.83	2.71
1000 m3 - 2500 m3	**1.04**	1.53	**1.38**	1.52	1.52	1.41	1.56
1 m3 - 1000 m3	**0.86**	**0.94**	1.03	1.06	1.06	1.05	1.06
0 m3 - 1 m3	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Figure E-17. Relative multiplier comparison of the probability of one or more accidents occurring within a 10 year period by Oil Spill Size Category over the VTRA Study Area for the six RMMs Scenarios evaluated and enacted upon the What-If Scenario USKMCA1600.

From Figure E-17 one observes that the relative multipliers evaluated for both RMM portfolios of these probabilities for the VTRA Study area are less than 1.0 in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (i.e. 0.86 for the 5RMM Scenario and 0.94 for the 3RMM Scenario indicated in a bold and underlined font in Figure E-17). This implies that a lesser POTENTIAL Oil Loss is observed in this particular POTENTIAL Oil Loss category than was evaluated for this POTENTIAL Oil Loss category in the Base Case 2015 Scenario. Recall, see Figure E-9, that the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category contributed the most (45%) to POTENTIAL Oil Loss in the Base Case 2015 Scenario analysis and second to most (73%), see Figure E-11, in the USKMCA1600 What-If Scenario.

Other notable reductions for the 5RMM Scenario are observed from Figure E-17 in both the 2500 m^3 or more POTENTIAL Oil Loss Category (going from a relative multiplier 2.71 in the USKMCA1600 What-If Scenario to a relative multiplier of 2.28 in the 5RMM Scenario enacted upon the USKMCA1600 What-If Scenario, i.e. a relative multiplier reduction of $2.27/2.28 \approx 0.84$) and the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category (going from a relative multiplier 1.56 in the USKMCA1600 What-If Scenario to a relative multiplier of 1.04 in the 5RMM Scenario enacted upon the USKMCA1600 What-If Scenario, i.e. a relative multiplier reduction of $1.04/1.56 \approx 0.67$). Both observations are indicated in Figure E-11 in a bold only font, as is the cell in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category for the OAE-RMM Scenario which shares with these two cells a relative multiplier less than 0.90 from their USKMCA1600 What-If Scenario evaluated levels. Similar reductions, on the other hand, in the 2500 m^3 or more POTENTIAL Oil Loss Category and the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category are not observed from Figure E-11 for the 3RMM Scenario. That being said, it is important to note that the 5RMM Portfolio Scenario makes maximum benefit type assumptions with respect to its components HM50-RMM and SE-RMM, whereas the 3RMM Portfolio Scenario and the OAE-RMM Scenario do not contain these two components and therefore do not make these maximum benefit type assumptions for their effectiveness evaluation.

Analysis Observation 12: The relative multipliers for the probabilities of at least one accident occurring in the VTRA Study Area over a 10-year period in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category are less than 1.0 for the 5RMM Portfolio Scenario (with a relative multiplier 0.86) and the 3RMM Portfolio Scenario (with a relative multiplier 0.94)

enacted on the USKMCA1600 What-If Scenario, implying a lesser POTENTIAL Oil Loss evaluated for these two portfolio RMM Scenarios than evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss category. Other notable reductions are observed from Figure E-17 for the 5RMM Scenario in the 2500 m^3 or more POTENTIAL Oil Loss Category and for the 5RMM Scenario and OAE-RMM Scenario in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category.

Figure E-18 provides the by-waterway-zone relative multipliers of the probability of at least one accident occurring over a 10-year period within the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category for the six evaluated RMM Scenarios (Columns 1 through 6) and the relative multipliers for the USKMCA1600 What-If Scenario in the seventh column (see also the seventh column in Figure E-17 for VTRA Study Area wide relative factors). As mentioned previously, VTRA study wide effects are not distributed uniformly across the VTRA Study Area (i.e. not with the same relative multipliers across the fifteen different waterway zones).

One must realize in evaluating the VTRA 2015 RMM analysis results in Figure E-18 that risk does not necessarily disappear when mitigated, but tends to migrate in these analysis results as demonstrated by some waterway zones experiencing increases in risk from the USKMCA1600 Scenario, whereas other waterway zones see risk reductions. This is in large part a result of a maritime transportation system being dynamic, where a small traffic perturbation can precipitate traffic behavior changes later in time and elsewhere in the VTRA 2015 Model. Such migrations are preferably avoided in a sound risk management strategy, but some risk migration may be inevitable. In addition, the VTRA 2015 maritime simulation model contains some random elements in terms of its traffic simulation for what are termed “special events” representing movements in the VTRA model of smaller vessels (less than 20 meters in length). These special events represented in the VTRA model are modeled whale watching activities, regattas, tribal fishing openers (US and Canadian), and commercial fishing openers[11]. As a result of these random elements, some small risk changes in the evaluated RMM Scenarios (and the What-If Scenarios) are a result of these random elements changing their behavior from scenario simulation run to scenario simulation run.

With the caveat above, however, one observes from Figure E-18 relative multipliers less than 1.0 for the probability of at least one accident occurring within a 10-year period for twelve out of the fifteen waterway zones (the exceptions being the Buoy J, East Strait of Juan de Fuca and ATBA waterway zones) for the 5RMM Scenario in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category. Similarly, relative multipliers less than 1.0 are observed for these probabilities for seven out of the fifteen waterway zones for the 3RMM Scenario and six out of the fifteen waterway zones for the

[11] Combined fishing vessels and yachts (or recreational vessels) account for about 43% of the non-focus vessel traffic modeled in the VTRA 2015 model which is equivalent to a about a third of the overall modeled traffic in the VTRA Model. See also, Figure E-4 and Figure E-6A.

OAE-RMM Scenario. That being said, it is important to note that 5RMM Portfolio Scenario makes maximum benefit type assumptions with respect to its components HM50-RMM and SE-RMM, whereas the 3RMM Portfolio Scenario and the OAE-RMM Scenario do not contain these two components and therefore do not makes these maximum benefit type assumptions for their effectiveness evaluation.

1 m3 - 1000 m3	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600
	5RMM	3RMM	OAE-RMM	SRT-RMM	KME-RMM	125-RMM	NO RMM
Haro/Boun.	**0.92**	**1.29**	1.50	1.46	1.50	1.51	1.50
Sthrn. Glf. Ils.	**0.64**	**0.68**	**0.87**	0.97	1.01	1.01	1.00
Buoy J	**1.11**	**1.16**	1.64	1.62	1.62	1.60	1.64
ESJF	**1.22**	**1.27**	1.36	1.38	1.38	1.36	1.39
WSJF	**0.99**	**0.93**	1.24	1.23	1.23	1.20	1.23
Guemes	**0.66**	1.13	**0.79**	1.21	1.21	**1.09**	1.16
Georgia Str.	**0.82**	0.99	1.06	1.09	1.09	0.99	1.03
Saddlebag	**0.74**	1.03	**0.94**	1.09	1.09	**0.99**	1.06
Sar/Skagit	**0.93**	**0.84**	1.13	1.07	1.07	1.15	1.05
SJ Islands	**0.99**	1.03	1.04	1.06	1.13	1.04	1.05
Rosario	**0.56**	1.14	**0.82**	1.12	1.12	1.12	1.06
ATBA	1.02	1.02	1.04	1.08	1.07	1.05	1.07
PS North	**0.85**	**0.82**	0.96	1.01	1.01	1.01	1.01
PS South	**0.83**	**0.85**	1.00	0.99	0.99	0.99	0.99
Tac. South	**0.80**	0.99	**0.84**	0.99	0.99	0.98	1.01

Figure E-18. Relative multiplier comparison by waterway zone of the probability of at least one accident occurring within a 10 year period for the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category for the six RMM Scenarios evaluated and enacted upon the What-If Scenario USKMCA1600.

Analysis Observation 13-A: For the 5RMM, 3RMM and OAE-RMM Scenarios, enacted on the USKMCA1600 What-If Scenario, relative multipliers with a value less than 1.0 are observed from Figure E-18 for the probabilities of at least one accident occurring within a 10-year period for the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category for respectively, twelve, seven and six out of the fifteen waterway zones in the VTRA Study Area (implying a lesser POTENTIAL Oil loss than evaluated for the Base Case 2015 Scenario in these waterway zones for this POTENTIAL Oil Loss category than the USKMCA1600 What-If Scenario).

Other notable by-waterway-zone risk reductions in Figure E-18, although not reduced to below Base Case 2015 Scenario levels, is the reduction for the 5RMM Scenario in the relative multiplier for the Buoy J waterway zone (going from a relative multiplier 1.64 evaluated for the USKMCA1600 What-If Scenario to a relative multiplier 1.11 in the 5RMM Scenario enacted upon the USKMCA1600 What-If Scenario, i.e. a relative multiplier reduction of $1.11/1.64 \approx 0.68$) and the reduction for the 3RMM Scenario in the relative multiplier for the Buoy J waterway zone (going from a relative multiplier 1.64 evaluated for the USKMCA1600 What-If Scenario to a relative multiplier 1.16 in the 3RMM Scenario enacted upon the USKMCA1600 What-If Scenario, i.e. a relative multiplier reduction of $1.11/1.64 \approx 0.71$).

Overall, across all six RMM Scenarios relative multipliers reductions are observed in terms of the probability of at least one accident over a 10-year period in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category from their USKMCA1600 What-If Scenario probabilities in 63 out of their 90 by-waterway-zone cells (i.e. 6 RMM Scenarios × 15 Waterway Zones) in Figure E-18, with 29 out of these 63 cells having a relative multiplier less than 0.95 for their USKMCA1600 What-If Scenario estimated probability levels (indicated in a bold font in Figure E-18), and with 25 out of these 29 having a relative multiplier less than 0.90 for their USKMCA1600 What-If Scenario estimated probabilities (indicated in a bold and underlined font in Figure E-18). That being said, 55 out of the 90 relative multipliers in Figure E-18 are larger than one, implying larger than Base Case 2015 Scenario analysis results for these probabilities in these waterway zones, should all the terminal projects in the USKMCA1600 Scenario come to fruition, despite the six RMM Scenarios evaluated in the VTRA 2015 Study.

Analysis Observation 13-B: Overall, across all six RMM Scenarios relative multipliers less than 0.95 are evaluated for the probability of at least one accident occurring over a 10-year period in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category <u>from their USKMCA1600 What-If Scenario estimated probability levels</u> in 29 out of 90 by-waterway-zone cells (i.e. 6 RMM Scenarios × 15 Waterway Zones) in Figure E-18. These 29 cells are indicated in a bold font (underlined or not) in Figure E-18. That being said, 55 out of the 90 relative multipliers in Figure E-18 are larger than one, implying larger than Base Case 2015 Scenario analysis results for these probabilities in these waterway zones, should all the terminal projects in the USKMCA1600 Scenario come to fruition, despite the six RMM Scenarios evaluated and enacted upon the USKMCA1600 Scenario.

Figure E-19 provides the by-waterway-zone relative multipliers of the probability of at least one accident occurring over a 10-year period within the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category for the six evaluated RMM Scenarios (Columns 1 through 6) and the relative multipliers for the USKMCA1600 What-If Scenario in the seventh column (see also the seventh column in Figure E-17 for VTRA Study Area wide relative factors). One immediately observes from Figure E-19 relative multipliers from the Base Case 2015 Scenario for the Haro/Boundary Pass waterway zone of larger than 3.0, regardless of the six RMM Scenarios evaluated. Furthermore, one observes relative multipliers of about 1.5 to 2.5 for the waterway zones Buoy J and West Strait of Juan de Fuca and relative multipliers larger than 1.0 for the East Strait of Juan de Fuca waterway zone for this 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category. Overall, 61 out of the 90 relative multipliers in Figure E-19 are larger than one, implying larger than Base Case 2015 Scenario analysis results for these probabilities in these waterway zones, should all the terminal projects in the USKMCA1600 Scenario come to fruition, despite the six RMM Scenarios evaluated in the VTRA 2015 Study.

1000 m3 - 2500 m3	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600
	5RMM	3RMM	OAE-RMM	SRT-RMM	KME-RMM	125-RMM	NO RMM
Haro/Boun.	3.26	3.81	4.09	3.98	4.06	4.00	4.05
Sthrn. Glf. Ils.	0.57	0.38	0.59	0.63	0.65	0.66	0.65
Buoy J	2.46	1.81	2.46	2.10	1.93	2.17	2.06
ESJF	1.14	1.25	1.24	1.31	1.31	1.28	1.31
WSJF	1.58	1.89	1.91	2.05	1.85	1.96	2.04
Guemes	0.78	1.45	1.05	1.17	1.17	1.24	1.21
Georgia Str.	0.81	1.25	1.09	1.41	1.41	1.29	1.41
Saddlebag	0.55	1.32	1.19	1.30	1.34	0.83	1.37
Sar/Skagit	0.59	0.97	1.14	1.20	1.17	1.21	1.17
SJ Islands	0.89	0.43	0.92	1.36	1.31	1.03	1.32
Rosario	0.48	1.09	0.62	1.02	1.07	0.90	1.08
ATBA	1.16	0.98	1.02	1.19	1.16	0.98	1.16
PS North	0.71	0.92	0.79	1.08	1.08	1.05	1.08
PS South	0.78	1.09	0.92	1.05	1.05	0.97	1.05
Tac. South	0.86	0.86	0.88	1.00	1.00	1.02	1.00

Figure E-19. Relative multiplier comparison by waterway zone of the probability of one or more accidents occurring within a 10 year period for the 1000 m³ - 2500 m³ POTENTIAL Oil Loss Category for the six RMM Scenarios evaluated and enacted upon the What-If Scenario USKMCA1600.

Analysis Observation 14-A: Most of the relative multipliers, 61 out of 90 (i.e. 6 RMM Scenarios × 15 Waterway Zones), in Figure E-19 for the probability of at least one accident over a 10-year period in the 1000 m³ - 2500 m³ POTENTIAL Oil Loss category are larger than 1.0 across the fifteen waterway zones in the VTRA Study Area, implying larger than Base Case 2015 Scenario analysis results for these probabilities. In fact, the analysis results in Figure E-19 demonstrate relative multipliers larger than 3.0 in this POTENTIAL Oil Loss category for the Haro-Strait/Boundary Pass waterway zone and multipliers ranging from 1.5 to 2.5 for the Buoy J and West Strait of Juan de Fuca waterway zones, despite the six RMM Scenarios evaluated and enacted upon the USKMCA1600 What-If Scenario.

This does not mean that the six RMM Scenarios evaluated in Figure E-19 do not show risk reduction in this 1000 m³ - 2500 m³ POTENTIAL Oil Loss Category from the USKMCA1600 Scenario. In fact, the 5RMM Scenario shows relative multipliers of these probabilities of less than 1.0 in ten of the fifteen waterway zones, implying a lesser probability in Figure E-19 for at least one accident occurring in a 10-year period in these waterway zones in the 1000 m³ - 2500 m³ POTENTIAL Oil Loss category than evaluated for the Base Case 2015 Scenario. Similarly, relative multipliers less than 1.0 are observed for these probabilities for six out of the fifteen waterway zones for the 3RMM Scenario and the OAE-RMM Scenario. That being said, it is important to note that 5RMM Portfolio Scenario makes maximum benefit type assumptions with respect to its components HM50-RMM and SE-RMM, whereas the 3RMM Portfolio Scenario and the OAE-RMM Scenario do not contain these two components and therefore do not makes these maximum benefit type assumptions for their effectiveness evaluation.

Other by-waterway-zone risk reductions are observed in Figure E-19, although not reduced to below Base Case 2015 Scenario levels. For example, one observes a reduction for the KME-RMM

Scenario in the relative multiplier for the West Strait of Juan de Fuca waterway zone going from a relative multiplier 2.06 evaluated for the USKMCA1600 What-If Scenario to a relative multiplier 1.85 in the KME-RMM Scenario enacted upon the USKMCA1600 What-If Scenario (i.e. a relative multiplier reduction of $1.85/2.06 \approx 0.91$), and a reduction for the KME-RMM Scenario in the relative multiplier for the Buoy J waterway zone going from a relative multiplier 2.06 evaluated for the USKMCA1600 What-If Scenario to a relative multiplier 1.93 in the KME-RMM Scenario enacted upon the USKMCA1600 What-If Scenario (i.e. a relative multiplier reduction of $1.93/2.06 \approx 0.94$).

Overall, across all six RMM Scenarios relative multipliers reductions are observed in terms of the probability of at least one accident over a 10-year period in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category from their USKMCA1600 What-If Scenario probabilities in 66 out of a total of their 90 by-waterway-zone cells in Figure E-19, with 45 out of these 66 having a relative multiplier less than 0.95 for their USKMCA1600 What-If Scenario estimated probabilities (indicated in a bold font in Figure E-19), and 35 out of these 66 having a relative multiplier less than 0.90 for their USKMCA1600 What-If Scenario estimated probabilities (indicated in a bold and underlined font in Figure E-19).

Analysis Observation 14-B: **Overall, across all six RMM Scenarios relative multipliers less than 0.95 are evaluated for the probability of at least one accident occurring over a 10-year period in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category <u>from their USKMCA1600 What-If Scenario estimated probability levels</u> in 45 out of 90 by-waterway-zone cells (i.e. 6 RMM Scenarios $\times$ 15 Waterway Zones) in Figure E-19. These 45 cells are indicated in a bold font (underlined or not) in Figure E-19.**

Figure E-20 provides the by-waterway-zone relative multipliers of the probability of at least one accident occurring over a 10-year period within the 2500 m^3 or more POTENTIAL Oil Loss category for the six evaluated RMM Scenarios (Columns 1 through 6) and the relative multipliers for the USKMCA1600 What-If Scenario in the seventh column (see also the second column in Figure E-16). One immediately observes from Figure E-20 relative multipliers larger than 9.0 from the Base Case 2015 Scenario for the Haro/Boundary Pass waterway zone, regardless of the six RMM Scenarios evaluated. Furthermore, one observes relative multipliers of about 4.5 to 6 for the waterway zones Buoy J, East Strait of Juan de Fuca and relative multipliers of about 2 to 4 for the Guemes and Georgia Strait waterway zones for this 2500 m^3 or more POTENTIAL Oil Loss Category. Overall, 78 out of the 90 relative multipliers in Figure E-20 are larger than one, implying larger than Base Case 2015 Scenario analysis results for these probabilities in these waterway zones, should all the terminal projects in the USKMCA1600 Scenario come to fruition, despite the six RMM Scenarios evaluated in the VTRA 2015 Study.

2500 m3 or More	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600	USKMCA1600
	5RMM	3RMM	OAE-RMM	SRT-RMM	KME-RMM	125-RMM	NO RMM
Haro/Boun.	**9.84**	**10.53**	11.37	11.00	11.19	11.08	11.19
Sthrn. Glf. Ils.	**5.49**	**1.88**	6.39	5.82	6.04	6.76	6.04
Buoy J	**4.89**	5.24	5.35	5.23	**4.88**	6.03	5.25
ESJF	**4.78**	4.92	4.96	5.07	5.01	4.97	5.06
WSJF	**2.89**	**2.89**	**2.83**	3.14	3.05	3.23	3.10
Guemes	**2.10**	2.67	2.65	2.42	2.42	2.72	2.43
Georgia Str.	**1.43**	**2.27**	**2.07**	2.40	2.40	**2.17**	2.40
Saddlebag	**1.29**	1.76	1.63	1.73	1.71	2.26	1.71
Sar/Skagit	**0.44**	1.43	1.51	1.49	1.49	1.49	1.49
SJ Islands	1.22	1.56	2.08	1.23	1.23	1.41	1.23
Rosario	**0.75**	1.24	**1.10**	1.23	1.23	1.17	1.23
ATBA	**1.00**	1.21	1.26	1.16	1.17	1.21	1.17
PS North	**0.89**	**0.92**	**0.98**	1.04	1.04	1.01	1.04
PS South	**0.79**	1.02	1.02	1.03	1.04	**0.91**	1.04
Tac. South	**0.88**	1.07	**0.82**	0.96	0.96	**0.76**	0.96

Figure E-20. Relative multiplier comparison by waterway zone of the probability of one or more accidents occurring within a 10 year period for the 2500 m³ or more POTENTIAL Oil Loss Category for the six RMM Scenarios evaluated and enacted upon the What-If Scenario USKMCA1600.

Analysis Observation 15-A: Most of the relative multipliers, 78 out of 90 (i.e. 6 RMM Scenarios × 15 Waterway Zones), in Figure E-20 for the probability of at least one accident over a 10-year period in the 2500 m³ or more POTENTIAL Oil Loss category are larger than 1.0 across the fifteen waterway zones in the VTRA Study Area, implying larger than Base Case 2015 Scenario analysis results for these probabilities in the USKMCA1600 What-If Scenario. In fact, the analysis results in Figure E-20 demonstrate relative multipliers larger than 9.0 in this POTENTIAL Oil Loss category for the Haro-Strait/Boundary Pass waterway zone and multipliers ranging from 4.5 to 6.0 for the Buoy J, East Strait of Juan de Fuca and Southern Gulf Islands waterway zones, despite the six RMM Scenarios evaluated and enacted upon the USKMCA1600 What-If Scenario.

This does not mean that the six RMM Scenarios evaluated do not show risk reduction in this 2500 m³ or more POTENTIAL Oil Loss Category from the USKMCA1600 Scenario. In fact, in Figure E-20 in five of the fifteen waterway zones, the 5RMM Scenario shows relative multipliers with a value less than 1.0 of these probabilities, implying a lesser probability for one or more accidents occurring in a 10-year period in these waterway zones in the 2500 m³ or more POTENTIAL Oil Loss category than evaluated for the Base Case 2015 Scenario. Other notable by-waterway-zone risk reductions in Figure E-20, although not reduced to below Base Case 2015 Scenario levels, are the reduction for the 3RMM Scenario in the relative multiplier for the Southern Gulf Islands waterway zone (going from a relative multiplier 6.04 evaluated for the USKMCA1600 What-If Scenario to a relative multiplier 1.88 in the 3RMM Scenario enacted upon the USKMCA1600 What-If Scenario, i.e. a relative multiplier reduction of 1.88/6.04 ≈ 0.31) and the reduction for the 5RMM Scenario in the relative multiplier for the Georgia Strait waterway zone (going from a relative multiplier 2.40 evaluated for the USKMCA1600 What-If Scenario to a relative multiplier

1.43 in the 5RMM Scenario enacted upon the USKMCA1600 What-If Scenario, i.e. a relative multiplier reduction of 1.43/2.40 ≈ 0.59). That being said, it is important to note that 5RMM Portfolio Scenario makes maximum benefit type assumptions with respect to its components HM50-RMM and SE-RMM, whereas the 3RMM Portfolio Scenario does not contain these two components and therefore does not makes these maximum benefit type assumptions for their effectiveness evaluation.

Overall, across all six RMM Scenarios relative multipliers reductions are observed in terms of the probability of at least one accident occurring within a 10-year period in the 2500 m^3 or more POTENTIAL Oil Loss Category from their USKMCA1600 What-If Scenario estimated probabilities in 51 of their 90 by-waterway-zone cells in Figure E-20, with 28 out of these 51 having a relative multiplier less than 0.95 for their USKMCA1600 What-If Scenario estimated probabilities (indicated in a bold font in Figure E-20), and with 16 out of these 28 having a relative multiplier less than 0.90 for their USKMCA1600 What-If Scenario estimate probabilities (indicated in a bold and underlined font in Figure E-20).

Analysis Observation 15-B: **Overall, across all six RMM Scenarios relative multipliers less than 0.95 are evaluated for the probability of at least one accident occurring over a 10-year period in the 2500 m^3 or more POTENTIAL Oil Loss Category <u>from their USKMCA1600 What-If Scenario estimated probability levels</u> in 28 out of 90 by-waterway-zone cells (i.e. 6 RMM Scenarios × 15 Waterway Zones) in Figure E-20. These 28 cells are indicated in a bold font (underlined or not) in Figure E-20.**

The combined effect of the RMM analysis observations described above for the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category, the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category and the 2500 m^3 or more POTENTIAL Oil Loss category for the VTRA Study Area overall are depicted in Figure E-21.

VTRA Study Area	USKMCA1600 5RMM	USKMCA1600 3RMM	USKMCA1600 OAE-RMM	USKMCA1600 SRT-RMM	USKMCA1600 KME-RMM	USKMCA1600 125-RMM	USKMCA1600 NO RMM	2015 BASE CASE NO RMM
2500 m3 or More	83%	91%	92%	92%	91%	106%	91%	42%
1000 m3 - 2500 m3	**13%**	20%	**18%**	20%	20%	**18%**	20%	12%
1 m3 - 1000 m3	**<u>35%</u>**	**<u>37%</u>**	71%	71%	73%	72%	73%	45%
0 m3 - 1 m3	**<u>0.12%</u>**	0.61%	**<u>0.45%</u>**	0.62%	0.62%	0.56%	0.54%	0.46%
All Categories	131%	149%	181%	183%	184%	197%	185%	100%

Figure E-21. Percent POTENTIAL OIL Loss comparison measured in terms of Base Case 2015 percentage POTENTIAL Oil Loss for the Base Case 2015 Scenario, the USKMCA1600 What-If Scenario and the six RMMs Scenarios evaluated and enacted upon the What-If Scenario USKMCA1600

Figure E-21 provides the contribution in POTENTIAL Oil Loss, measured in terms of percentages of Base Case 2015 POTENTIAL Oil Loss, for the six RMM Scenarios evaluated, the USKMCA1600 What-If Scenario and the Base Case 2015 Scenario. Recall from Figure E-9, that the 2500 m^3 or more POTENTIAL Oil Loss category contributed second most (@42%) to POTENTIAL Oil Loss in the Base Case 2015 Scenario analysis and most (@91%), see Figure E-11, in the USKMCA1600 What-If Scenario analysis. These percentages are observed in the first row and the seventh and eighth columns of Figure E-21. Recall from Figure E-9, that the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category contributed most (@45%) to POTENTIAL Oil Loss in the Base Case 2015 Scenario analysis and second most (@73%), see Figure E-11, in the USKMCA1600 What-If Scenario analysis. These latter percentages are observed in the third row and the seventh and eight column of Figure E-21.

When comparing the percent POTENTIAL Oil Loss evaluation in the 7th column (i.e. the USKMCA1600 What-If Scenario analysis) and the 8th column (the Base Case 2015 Scenario analysis) with the percent contributions in Columns 1 through 6 for the six RMM Scenarios, one observes that increases in POTENTIAL Oil Loss are observed across all POTENTIAL Oil Loss categories from the Base Case 2015 Scenario, despite the six RMM Scenarios evaluated and enacted on top of the USKMCA1600 What-If Scenario, with the exception of the percent POTENTIAL Oil Loss evaluations for the 5RMM Scenario and the 3RMM Scenario in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category and the percent POTENTIAL Oil Loss evaluations for the 5RMM Scenario and OAE-RMM Scenario in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category (indicated in a bold and underlined font in Figure E-21). That being said, it is important to note that the 5RMM Portfolio Scenario analysis makes maximum benefit type assumptions with respect to its components HM50-RMM and SE-RMM, whereas the 3RMM Portfolio Scenario and the OAE-RMM Scenario analyses do not contain these two components and therefore do not makes these maximum benefit type assumptions for their effectiveness evaluation.

Analysis Observation 16: Should all the terminal projects in the USKMCA1600 Scenario come to fruition and either the 5RMM Portfolio Scenario or the 3RMM Portfolio Scenario be enacted thereafter, the RMM Scenario POTENTIAL Oil Loss results show a reduction below the Base Case 2015 Scenario analysis results for the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category in Figure E-21. The same applies to the POTENTIAL Oil Loss for the 5RMM Portfolio Scenario and the OAE-RMM Scenario in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss Category. These four cells are indicated by a bold and underlined font in Figure E-21. Relative multiplier decreases of less than 0.90 are observed in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category for the 5RMM Portfolio Scenario, and the OAE-RMM, 125-RMM Scenarios <u>from their USKMCA1600 What-If Scenario estimated levels</u> (these three cells being indicated in a bold only font in Figure E-21).

A worthwhile observation from Figure E-21 is that the 5RMM Scenario is the only RMM Scenario that achieves a nearly 8% reduction in the 2500 m^3 or more POTENTIAL Oil Loss in category from the USKMCA1600 What-If Scenario (going from 91% to 83%), while containing within it the 125-RMM component that has shown to increase close to 15% in POTENTIAL Oil Loss in this 2500 m^3 or more POTENTIAL Oil Loss category (when this 125-RMM Scenario was evaluated individually as an RMM-Scenario enacted upon the USKMCA1600 Scenario). On the other hand, the 125-RMM Scenario analysis does show a relative multiplier decrease of close to 18%/20% ≈ 0.90 (in evaluated POTENTIAL Oil loss in the 1000 m^3 - 2500 m^3 category), as does the OAE-RMM Scenario analyses. Moreover, the 5RMM Scenario also shows a relative multiplier decrease of close to 13%/20% ≈ 0.65 (in evaluated POTENTIAL Oil loss in the 1000 m^3 - 2500 m^3 category). All three observations above are indicated in a bold only font in Figure E-21). In other words, no conclusion can be drawn as to the specific increased percentage of effectiveness of a 4RMM type scenario analysis in terms of VTRA Study area wide POTENTIAL Oil Loss with the 125-RMM removed from 5RMM Scenario without conducting such a 4RMM Scenario portfolio RMM analysis (which has not been conducted under this VTRA 2015 study).

The last row in Figure E-21 provides the POTENTIAL Oil Loss measured in terms of overall Base Case 2015 Scenario evaluated POTENTIAL Oil Loss (note the 100% POTENTIAL Oil loss in the eighth column and fifth row in Figure E-21). One observes from this last row that should all the maritime development projects in the USKMCA1600 Scenario come to fruition, neither of the six RMM Scenarios that were evaluated using the VTRA 2015 model reduce POTENTIAL Oil Loss to below Base Case 2015 Scenario levels. Hence, should all the maritime development projects in the USKMCA1600 Scenario come to fruition it would be prudent to consider additional risk mitigation measures beyond the ones evaluated via the six RMM Scenarios enacted upon the USKMCA1600 What-If Scenario in this VTRA 2015 Study.

Analysis Observation 17: **Overall, the six RMM Scenarios evaluated show VTRA Study area wide POTENTIAL Oil Loss increases ranging from 131% to 185% following their POTENTIAL enactment on the USKMCA1600 What-If Scenario. Hence, were the USKMCA1600 scenario come to effect, it would be prudent to consider implementation of risk mitigation measures beyond the six RMM Scenarios evaluated in the VTRA 2015 study to counter those POTENTIAL risk increases.**

That being said, comparing the individual evaluated VTRA area study wide POTENTIAL Oil Losses for the KME-RMM, SRT-RMM and OAE-RMM Scenarios evaluated at 184%, 183% and 181%, respectively (see the last row of Figure E-21) with, one the one hand, the overall POTENTIAL Oil Loss evaluated for the USKMCA1600 What-If Scenario (@185%) and, on the other hand, the overall POTENTIAL Oil Loss evaluated for the 5RMM Scenario (@131%), there is no doubt that the combined effect of DH100-RMM, HM50-RMM and SE-RMM contributes the most to the evaluated risk reduction in evaluated VTRA Study Area wide POTENTIAL Oil Loss for the 5RMM Portfolio analysis. The largest part of that risk reduction is achieved in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (decreasing from 73% to 35%), where the 3RMM Portfolio evaluates a similar risk reduction in POTENTIAL Oil Loss (going from 73% to 37%)[12] in that particular POTENTIAL Oil Loss category. However, as mentioned previously, the 5RMM Scenario analysis does make maximum benefit type assumptions for its effectiveness analysis via its components HM50-RMM and SE-RMM, which are not components of the 3RRM Portfolio Scenario.

Closing Comments

By providing What-If Scenario and RMM Scenario analyses by waterway zone and by POTENTIAL Oil Loss category similar to the ones provided in this Executive Summary, an information source is provided to help answer difficult and location specific risk management questions in the event some or all of the maritime terminal projects considered in the VTRA 2015 study come to fruition.

In light of the analysis observations in this VTRA 2015 study, while considering a longer-term view of risk management in the VTRA Study Area, we close with the observation that there still is a serious need for an electronic data source that is cross-border (US and Canadian waters) where the vessel type is consistently defined and verified beyond cargo focus vessel or tank focus vessel classifications. VTOSS was and AIS is such cross-boundary data source that could serve this purpose. However, without AIS refining the classification of vessel type to the level that was customary in the VTOSS data, it will become increasingly difficult to further update the VTRA 2015 model solely using AIS data. While it may be possible to link vessel identifiers recorded in AIS data to databases to further refine AIS vessel type classification, the recording of four to five different vessel types in AIS compared to the 26 different vessel types in the decommissioned VTOSS data is a step in the opposite direction from a risk modeling perspective. That being said, there is no doubt that with more and more vessels participating in AIS, dynamic risk modeling, similar to the VTRA 2015 model, can become more representative of actual experienced risk levels.

Moreover, with the same eye towards risk management analysis it would be equally beneficial if AIS datasets capture cargo or at a minimum cargo levels (laden, un-laden, 50% laden, etc.) and a cargo type. In particular, we would like to specifically call out the need for the electronic recording at a much greater consistency of the barge type and cargo content of tug-tows. Not only would studies like these benefit from the availability of such a data source, but the immediacy of having such information available could also benefit first responders responding to a spill scenario both from a response and a safety to the first responder perspective.

Summarizing, we advocate an integrated systems approach towards answering risk management questions (i.e. combining the POTENTIAL impact of multiple maritime projects coming to fruition while combining the POTENTIAL effectiveness of a portfolio of RMMs) as opposed to the individual evaluation of these components, to not miss POTENTIAL synergistic effect that could be

[12] It is important to note here too that the 125-RMM does show a risk reduction in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category when evaluated individually and not a risk increase as was observed in the 2500 m^3 or more POTENTIAL Oil Loss category

missed by avoiding such combinations. Ultimately, we believe that the strength of the VTRA 2015 analysis lies in this systems view, but equally important is the evaluation of relative POTENTIAL risk changes of What-If Scenarios and RMM scenarios within a single common framework. No doubt, the risk communication process amongst stakeholders that took place following the collaborative analysis approach in conducting these analyses during the VTRA 2005, VTRA 2010 and this VTRA 2015 study is at least as important.

Table Contents

Table of Figures

1. INTRODUCTION

Washington State shares the Salish Sea with the province of British Columbia. A large number of ships and barges operate in these shared waters, placing the area at risk for major oil spills. While a recent study [2] demonstrated significant risk reduction of oil transportation risk due to existing risk mitigation measures[1], the potential for large spills continues to be a prominent 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 and Salish Sea waters. Public concern for protecting the environment stemming from potential maritime economic developments was the catalyst for this study funded by the Washington State Department of Ecology.

The VTRA model is predominantly based on Vessel Traffic Operational Support System (VTOSS) 2010 data augmented with traffic stream increases and decreases since then by cargo focus vessel and tank focus vessel. These traffic streams increases or decreases from 2010 were gleaned from a longitudinal AIS passage line vessel count data analysis conducted on such data from 2010 to 2015. In addition, the VTRA Model was recalibrated utilizing cargo focus vessel and tank focus vessel accident data from the period 1990 – 2015 available to the VTRA 2015 Study. The start of this data period coincides with the enactment of the Oil Pollution Act (OPA) '90. Because of the augmentation of the VTOSS 2010 data from the VTRA 2010 Study with 2015 cargo focus vessel and tank focus vessel traffic streams and the utilization of cargo focus vessel and tank focus vessel accident data from 1990-2015 this study will be referred to as the VTRA 2015 study hereafter. The analysis conducted with this updated VTRA model will serve as a Base Case 2015 Scenario Analysis in the VTRA 2015 Study.

The VTRA 2015 Study Area is defined by the black border in Figure E-2 covering US/Canadian trans-boundary waters including: portions of the Washington outer coast, the Strait of Juan de Fuca and the approaches to and passages through the San Juan Islands, Puget Sound and Haro-Strait/Boundary Pass. It is worthwhile to note that while Canadian bound traffic passes through the VTRA 2015 Study Area, the Port of Vancouver is located north of the VTRA 2015 Study Area boundary. The VTRA 2015 Study Area is divided in 15 separate waterway zones outlined in Figure E-2. The VTRA area includes an International Maritime Organization (IMO) approved Traffic Separation Scheme (TSS) that governs vessel traffic in the system and its approaches. It is actively managed by a joint US - Canadian Cooperative Vessel Traffic Service (CVTS). At the western entrance to the Strait of Juan de Fuca, it includes the extent of Prince Rupert radar coverage via a radar unit on Mt. Ozzard; approximately 60 miles out to sea, and extends throughout the Puget Sound region north to Vancouver, British Columbia, and south to Tacoma, Washington and

[1] In [3] a 91.6% reduction in POTENTIAL oil loss was evaluated from all Tankers, Articulated Tug Barges (ATBs) and Integrated Tug Barges (ITBs) utilizing the VTRA 2005 model as a result of the implementation of the one-way zone regime in Rosario Strait, double hull tankers and the 2005 escorting regime.

Olympia, Washington. Radar is supplemented by Automatic Identification System (AIS) transponders, radio communications and advance notices for arriving vessels.

For context it is important to recognize that the Base Case 2015 VTRA Scenario analysis includes a series of risk mitigation measures. In addition to the previously mentioned IMO Traffic Separation Scheme and CVTS, vessels are subject to Port State Control and other vessel inspections regimes in both Canada and the United States to enforce international and federal standards. Pilotage is required in both the US and Canada and pilotage areas are comparable. Tug escorts for laden tankers are required and tugs are used to assist vessels into and out of the berths. Moreover, there are a number of risk mitigation measures that have been put in place internationally, federally and locally over the last several decades including double hulls for tankers, protectively located fuel tanks for non-tank vessels (still being phased in), a Puget Sound Harbor Safety Plan with Standards of Care, the implementation of AIS, a traffic procedure governing vessels transiting Turn Point at the boundary between Haro-Strait and Boundary Pass northeast of Victoria, Canada and a one-way zone regime in Rosario Strait. This list is not exhaustive. This study was not designed to measure the effectiveness of risk mitigation measures already in place. However, through the calibration process of accident data available to the VTRA 2015 Study from 1990 – 2015, risk mitigation measures implemented over this time frame are implicitly taken into account, combined with vessel traffic changes that have occurred over that time frame, in the Base Case 2015 Scenario Analysis results.

The VTRA 2015 utilizes the extensive technical work already completed by the George Washington (GW) University and Virginia Commonwealth University (VCU) under prior maritime risk assessment 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)[2] and the Vessel Traffic Risk Assessment 2010 (VTRA 2010). In summary, the VTRA Model has been developed over the course of about twenty years of work in maritime risk assessment, has been peer reviewed by the National Research Council and experts in the field of expert elicitation design and analysis, and has been improved thanks to a grant from the National Science Foundation and interactions with stakeholders over the course of the above maritime risk assessment projects. A reference list is provided at the end of this document. We will suffice with a summary of the VTRA methodology below, but encourage readers to consult the references related to the prior maritime risk assessment studies above.

[2] The VTRA 2005 was limited to vessel traffic risk evaluation associated with tankers, ATBs and ITBSs docking at the Cherry Point terminal.

Summary Description of VTRA Methodology

As previously stated, the VTRA 2015 Study Area is defined by the black border in Figure E-2 and Figure 1-1 below covering US/Canadian trans-boundary waters including: portions of the Washington outer coast, the Strait of Juan de Fuca and the approaches to and passages through the San Juan Islands, Puget Sound and Haro-Strait/Boundary Pass. It is worthwhile to note that while Canadian bound traffic passes through the VTRA 2015 Study Area, the Port of Vancouver is located north of the VTRA 2015 Study Area boundary. The VTRA 2015 Study Area is divided in 15 separate waterway zones outlined in Figure E-2 as well.

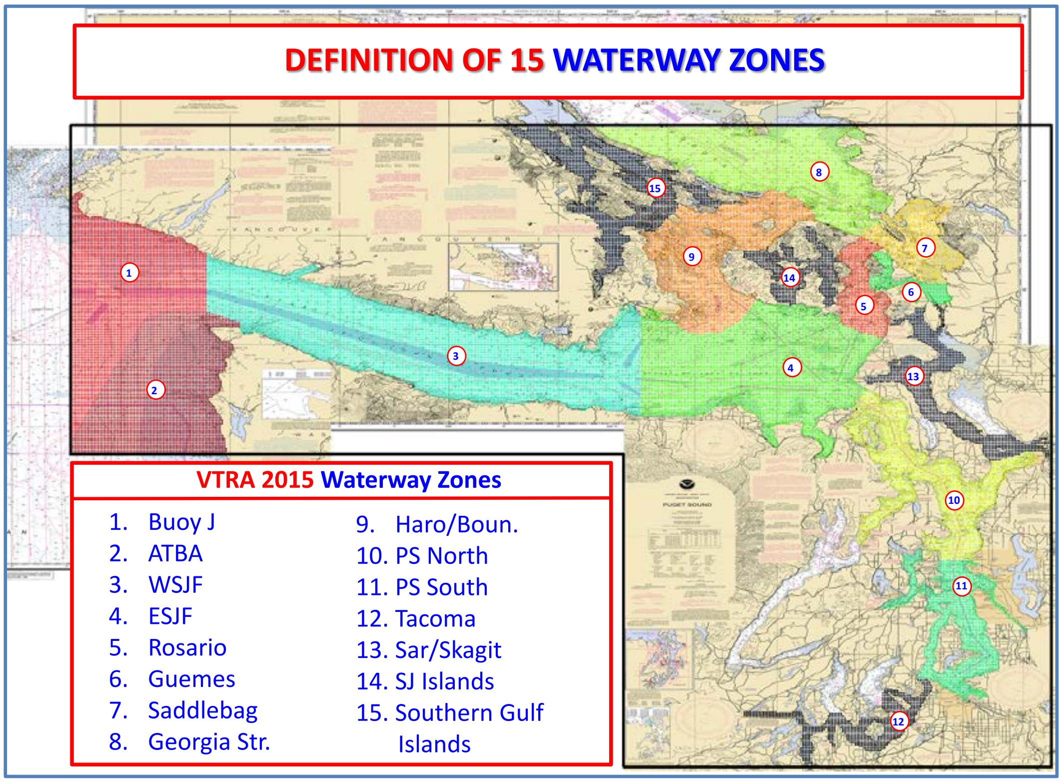

Figure 1-1. Definition of 15 waterway zones and their descriptors in the VTRA 2010 Study Area.

The VTRA 2015 analysis model represents the chain of events that could potentially lead to an oil spill and ends its evaluations with POTENTIAL volume of oil spilled. Figure E-7 shows the accident causal chain. A situation in which an accident could occur is called an accident exposure/situation. Maritime Transportation Systems (MTS) have accident exposures/situations simply from the movement of vessels within it. The VTRA analysis model evaluates the duration that vessels travel through the VTRA study area (referred to as Vessel Time Exposure, abbreviated VTE), by vessel type. The inclusion of the time on-the-water element in the evaluation of exposure sets the VTRA methodology apart from count based approaches that focus on, for example, number of annual/monthly vessel transits, visits or calls. The value of a duration-based approach versus a count-based approach is that the VTE approach appropriately distinguishes between short and long transits in the evaluation of vessel traffic risk as well as high and low vessel speeds.

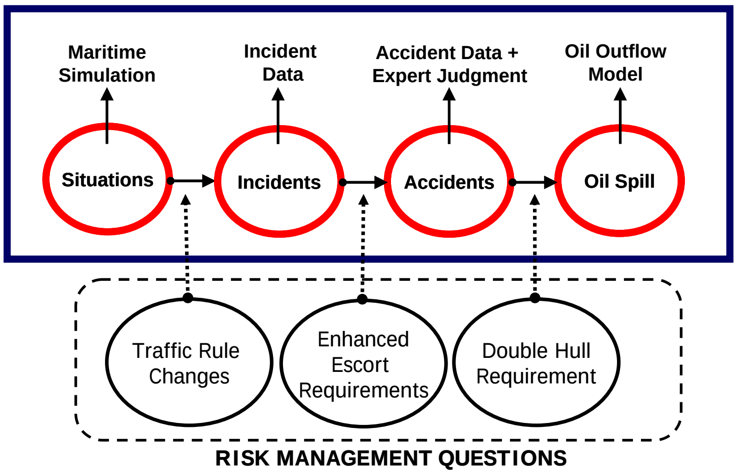

Figure 1-2. A causal chain of events inter-connected by causal pathways. Risk management questions attempt to block these causal pathways.

For each accident exposure, while the vessel is underway, incident and accident probability models are used to calculate the POTENTIAL Accident Frequency. This is not a prediction of an accident, but shows a relative propensity that an accident could occur in one situation versus another or the relative propensity for one type of accident versus another. The accident exposure and the POTENTIAL Accident Frequency models are then combined with an oil outflow model to calculate POTENTIAL Oil Loss. Throughout this report we shall use the terminology POTENTIAL to indicate that an accident exposure does not necessarily need to lead to an accident or oil loss, but may. As such, while the VTRA model is calibrated to accident data available to the VTRA 2015 Study from 1990 – 2015, the distribution of the POTENTIAL Oil Loss evaluation using the VTRA Model across the VTRA Study area and its study zones ought not be interpreted as a historical reflection of oil loss distribution represented by that historical accident data.

As indicated by Figure E-7, the VTRA 2015 Analysis Tool does not evaluate the POTENTIAL fates and effects of a POTENTIAL Oil Loss beyond the POTENTIAL volume of oil spilled. That is, the VTRA Model's oil spill causal chain analysis ends with volume of POTENTIAL Oil Loss in the water should a POTENTIAL accident occur. The VTRA Oil Outflow model is described in [4] and modeled after the oil outflow model detailed in Special Report 259 [16] published by the Marine Board, Transportation Research Board of The National Academy of Sciences.

Thankfully, to calibrate the VTRA 2015 model to the number of accidents of focus vessels utilizing available accident data to the VTRA Study from 1990-2015 with an oil loss size above 1 m^3, the only two accidents that fall in that oil loss category in the VTRA Study Area are the Tenyo Maru

(1991) and Barge 101 (1994) spills. In other words, over the past 20 years or so, no accidents have occurred within the VTRA Study Area with a spill size over 1 m^3. That does not mean, however, that their POTENTIAL occurrence or the POTENTIAL occurrence of larger POTENTIAL oil spills than have been observed over the past 25 years or so, and the risk mitigation thereof, ought not to be studied in an attempt to prevent such events from happening.

All models are abstractions of reality, however, through the need for a set of simplifying assumptions. For instance, we only included a limited set of factors in our expert judgment questionnaires, otherwise we would have had to ask hundreds of questions and the experts would have grown tired and not have given useful, consistent information after a while. This also limits the level of granularity to which we can break down the factors. For instance, we must group similar types of vessels to reduce the number of categories, which is especially applicable to the AIS passage line vessel count data from 2010-2015 and we cannot model locations down to the seconds of the longitude and latitude coordinates. Essentially, as within any analysis model, one must make assumptions. However, every attempt was made to test assumptions with experts and stakeholders. That being said, the famous quote by George Box [1] "*All models are wrong, but some are useful*" is also applicable to the VTRA model. We trust that the analysis described herein falls in the *useful category*. Ultimately that decision, however, belongs to the eyes of the beholder and is not ours to make.

Regardless, the analysis presented herein solely serves as an information source where various What-If Scenarios and RMM Scenarios are evaluated within a single analysis framework to inform a potential future risk management process amongst the State of Washington, the United States Coast Guard, the Puget Sound Harbor Safety Committee, tribes, local governments, industry, non-profit groups in Washington State and British Columbia and other stakeholders in this maritime community should maritime terminal projects represented in the What-If Scenarios evaluated come to fruition. As such we shall solely making pertinent analysis observations in this VTRA 2015 Study based on its analysis results and refrain from making recommendations or findings. The updating of the VTRA 2010 Study to the VTRA 2015 Study followed a collaborative analysis approach involving guidance from the tribal and Puget Sound stakeholder community and some cross-boundary Canadian stakeholders through the VTRA 2015 Working Group (see Figure E-1) and three scheduled meetings with the study authors:

"*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[2] ."*

Other meetings of the VTRA 2015 Working Group were held without the study authors over the study's time frame.

The general topics of the three meetings with the study authors were a Kick-Off Meeting (held in March 2016), a What-If Scenario Workshop Meeting (held in June 2016) and a Risk Mitigation Measure (RMM) Work Shop meeting (held in August 2016). The general thrust during the Kick-Off meeting was focused on guidance pertaining to the direction of the VTRA 2015 update. In particular, it was during that meeting that, through the guidance of the VTRA 2015 Working Group, it was decided to recalibrate the VTRA Model to additional accident data from 1990-2015 consisting of available accident data to the VTRA 2015 study from both cargo focus vessels and tank focus vessels. The available accident data to recalibrate the VTRA Model is provided in Appendix B.

During the What-If Scenario Workshop the VTRA 2015 Working Group selected the maritime terminal development projects, in various stage of their permitting processed, to be included in What-If Scenarios analyses. The inclusion of these maritime terminal development projects in the What-If Scenarios analyzed ought by no means to be interpreted as to imply that these terminal projects may come to fruition. Rather, the inclusion of these maritime terminal development projects in the VTRA 2015 study ought to be seen as being part of a safety culture being practiced in this maritime community over many years of which the formation of the Puget Sound Harbor Safety Committee back in 1997 and its bi-monthly meetings held since then is a prime example.

During the RMM Scenario Workshop the VTRA 2015 Working Group was involved in the selection of potential risk mitigation measures to be studied, partially gleaned from What-If Scenario analysis results, in an effort to evaluate, using the VTRA model, if such risk mitigation measures would have the POTENTIAL to counter the POTENTIAL risk increases should some or all or the terminal projects represented in the What-If Scenarios come to fruition. In the same vain, the definition of six Risk Mitigation Measure (RMM) Scenarios in this study ought by no means to be interpreted to be an exhaustive list of RMMs that could be considered to counter POTENTIAL risk increases as a result of maritime development project POTENTIALLY coming to fruition. Outside of the six RMM Scenarios evaluated this document does not provide any guidance as to what those other RMMs might be, beyond the RMM Scenarios that were analyzed.

A detailed summary of the VTRA 2010 update from the VTRA 2005 Study is provided in [21] with references to peer-reviewed publications and technical reports and will not be repeated in this VTRA 2015 Final Report. The items below summarize the improvements made to 2005 VTRA methodology while updating the GW/VCU VTRA analysis model using the VTOSS 2010 efforts over the course of both the Makah [20] and PSP funded efforts [21]:

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

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

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

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

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

Organization of VTRA 2015 Report

In Section 2 of this report, the updating of the VTRA 2010 model to the VTRA 2015 model is described. It must be said, however, that in particular the recalibration of the VTRA Model to available additional accident data to the VTRA 2015 Study from 1990 – 2015 from oil barges and cargo focus vessels, rather than relying on the extrapolation techniques utilized during the VTRA 2010 from accident data for tankers, ATBs and ITBs from the VTRA 2005 Study, causes all of the analysis results from the VTRA 2010 Study to be obsolete. In addition, we describe in Section 2, the results of a longitudinal AIS passage line vessel count data analysis by cargo focus vessel, tank focus vessel (excluding ATBs and Oil Barges) and ATBs using AIS passage line vessel count data from 2010-2015. That analysis is utilized in Section 2 to augment the VTRA 2010 modeled traffic with traffic stream changes from 2010 – 2015 gleaned from this longitudinal AIS passage line vessel count data analysis. The implementation of these traffic streams increases and decreases to the VTRA 2010 simulation model is described in a separate section in Section 2. Section 2 is closed with a summary description of the Base Case 2015 Scenario analysis results that serve as a benchmark in the VTRA 2015 Study to compare against analysis results of What-If Scenarios and RMM Scenarios. Analysis results will be described by decomposing POTENTIAL Accidents into four different POTENTIAL Oil Loss categories: 0 m^3 - 1 m^3 , 1 m^3 - 1000 m^3, 1000 m^3 -2500 m^3 and 2500 m^3 or more.

A distinguishing feature of the VTRA 2015 study from the VTRA 2005 and VTRA 2010 Studies are evaluations of *estimated probabilities of at least one accident potentially occurring within a 10-year period per the four potential oil loss categories above*. These probability risk metrics relate directly to their estimated POTENTIAL accident frequencies per year and the length of the time period (i.e. a 10 year time period) over which these probabilities are estimated. Both the estimated probability of at least one accident per a period of time, on the one hand, and the POTENTIAL accident frequency per year, on the other hand, are considered absolute risk metrics. That being said, the evaluation of the probability risk metric demonstrate through the wording "probability" that however small the POTENTIAL accident frequency may be for a particular POTENTIAL Oil Loss category, a non-zero probability estimated using the VTRA 2015 Model supports that the occurrence of such a POTENTIAL event evaluated is not impossible and could in fact happen, however unlikely. The communication of such probability metrics per a specified period of time is advocated in [26]. That being said, the VTRA 2015 Study concentrates more on relative comparisons between risk metrics evaluated for different scenario analyses and less on the absolute values of their respective analysis results.

In Section 3, we provide a description of the What-Scenarios evaluated during the VTRA 2015 study in terms of the maritime terminal projects included and the manner in which they are represented in the VTRA 2015 What-If Scenario Analyses. Subsequently we present/summarize the analysis results by What-If Scenario. In Section 4, we provide a description of the RMM-Scenarios evaluated during the VTRA 2015 study and the manner in which they are represented in the VTRA 2015 Model. Subsequently we present/summarize the analysis results by RMM Scenario. In Section 5, a cursory look is provided at a hypothetical crude export scenario analysis (only from a VTRA study wide POTENTIAL Oil Loss perspective) by increasing outbound crude oil movement by volumetric capacity of outbound crude oil tankers in the Base Case 2015 Scenario, while not increasing the number of tankers transits in the VTRA Model. Only a cursory look is provided as such a crude export scenario is, unlike the various maritime development projects represented in the What-If Scenarios, not being planned, to the best of our knowledge. Finally, a conclusion section summarizes the VTRA 2015 Analysis observations.

2. UPDATING THE VTRA 2010 MODEL TO THE VTRA 2015 MODEL

The overall methodology of the VTRA 2005, VTRA 2010 and VTRA 2015 models is the same and is documented in [3] and [4], although in each project improvements/updates have been made. See [12], [13] and [14] for a series of reports describing the VTRA 2005. The updates from the VTRA 2005 Model to the VTRA 2010 Model were summarized in the introduction and are described in more detail in [20] and [21].

The starting point for the VTRA 2015 model is the VTRA 2010 model. In this chapter, the specific updates to the VTRA 2010 model are described leading to the VTRA 2015 model. The VTRA analysis based on the VTRA 2015 model shall serve as a Base Case 2015 Scenario analysis to compare potential changes in risk as a result of maritime terminal developments included in five What-If Scenarios analyses. Throughout the VTRA 2015 we concentrate more on relative comparisons across POTENTIAL Oil Loss categories and What-If Scenarios evaluated in terms of Base Case 2015 analysis metrics, and less on the absolute values of the analysis metrics in these scenario analyses. The same applies to the RMM Scenario Analyses where in these scenarios one or more risk mitigation measures are modeled and their POTENTIAL effectiveness evaluations too are measured relative in terms of Base Case 2015 analysis metrics.

Calibrating the oil accident event chain from Incidents onward to additional accident data

The VTRA 2005 model was calibrated to incident and accident data from the VTRA 2005 focus vessel group[1] (about 1% of VTRA modelled traffic at that time). The incident and accident models for the VTRA 2010 model relied on an extrapolation technique from the VTRA 2005 focus vessel group, to all other Tankers, ATBs for its incident and accident models (about 3% of the total modelled VTRA Traffic). That same extrapolation technique was applied in the VTRA 2010 to expand the VTRA analysis from tankers and ATBs 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, ATBs, chemical carriers, oil barges, bulk carriers, container cessels and other cargo vessels. Of the VTRA 2010 focus vessel group, the tankers, ATBs, oil barges and Chemical Carriers combine to form the tank focus vessel category. Of the VTRA 2010 focus vessel 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 (PSP), is visually depicted in Figure 2-1 along the oil spill accident event chain modelled in the VTRA approach. As stated previously, the starting point for the VTRA 2015 project was the VTRA 2010 Model.

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[1] Tankers, Articulate Tug Barges (ATBs) and Integrated Tug Barges (ITBs) visiting the Cherry Point dock during their journey through the VTRA Study Area.

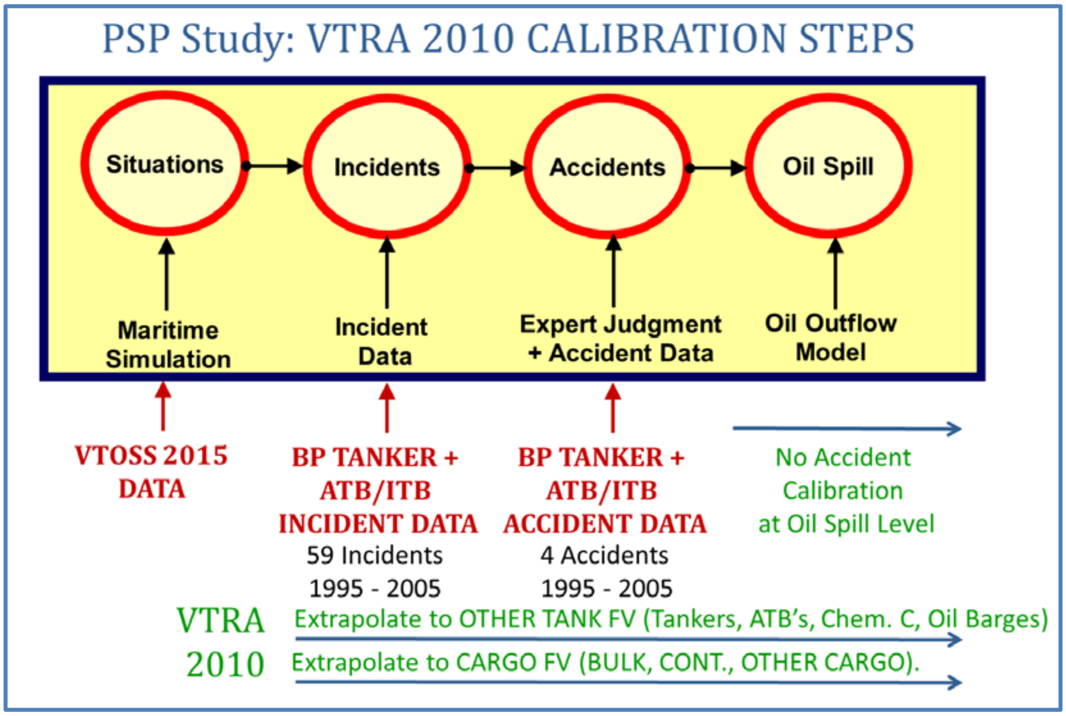

Figure 2-1. VTRA 2010 Oil Spill Accident Event Chain depicting the VTRA 2010 Extrapolation Technique.

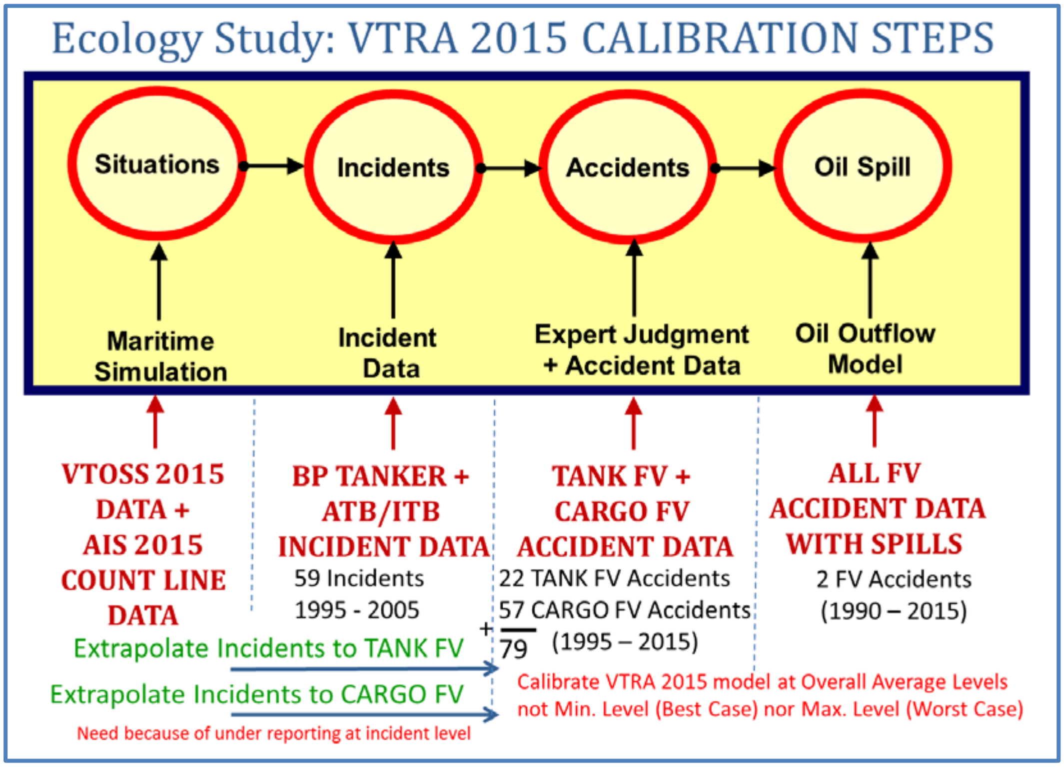

Figure 2-2. VTRA 2015 Accident Event Chain depicting the VTRA 2015 Calibration Approach.

The VTRA 2015 project commenced with a recalibration of the VTRA 2010 model to additional accident data available to the VTRA 2015 Study from the period 1990 – 2015. The purpose of the recalibration is to be able to separately calibrate the VTRA accident model to the tank focus vessel category and the cargo focus vessel 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 2-1. The calibration of the VTRA 2015 model to this additional accident data for the VTRA 2015 project is depicted visually in Figure 2-2. The accident data available to the GWU/VCU project team for this accident calibration process of the VTRA Model is provided in Appendix B.

By calibrating the VTRA 2015 model to a total of 81 accidents provided in Appendix B involving both cargo focus vessels and tank focus vessels (about 25% of modelled VTRA Traffic), as opposed to the 4 accidents in the VTRA 2010 model combined with an extrapolation technique, the analysis conducted with the VTRA 2015 model is more reflective of vessel traffic risk in the VTRA study area than the VTRA 2010 model. The VTRA 2010 model relied on 4 accidents for accident calibration involving only BP Tankers and ATBs/ITBs (about 1% of traffic modeled in the VTRA simulation model). To model the risk of other tankers, ATBs/ITBs, oil barges and cargo focus vessels, the VTRA 2010 model used an extrapolation technique from BP Tankers and ATB/ITBs to the broader set of focus vessels. While the 81 accidents used in the VTRA 2015 model may sound like a lot compared to the 4 accidents used in the VTRA 2005 and VTRA 2010 models, it is a factor of about 20 more (i.e. 81/4), whereas the focus vessel traffic in the VTRA 2015 model is about a factor 25 higher (25%/1%) than the focus vessel traffic in the VTRA 2005 model. The 81 calibration accidents for the VTRA 2015 model were gathered from a variety of data sources, collectively spanning 26 years, although some data sources only covered 12 years or 21 years of accident data. This is accounted for in the VTRA 2015 model calibration process by evaluating the average number of accidents per year from each data source and merging that information, since the VTRA 2015 model is a Maritime Transportation System (MTS) simulation for a one-year period.

The accident data utilized and available to the VTRA 2015 Study to achieve that calibration contains 81 accidents provided in Appendix B. These 81 accidents were divided into two categories: (1) accidents within the spill size category of 0 m^3 – 1 m^3 and (2) accidents within the spill size category 1 m^3 and above. The accident data used to calibrate the first category (0 m^3 – 1 m^3) contains 79 accidents obtained from the following datasets:

a. 21 years (1995 – 2015) of data for tank focus vessels (excluding oil barges) and cargo focus vessels in US Waters of the VTRA study Area collected during the VTRA 2005 and supplement by the USCG for the time period (2010 – 2015)
b. 12 years (2001 – 2012) of data for oil barges in US Waters of the VTRA Study Area.

c. 12 years (2004 – 2015) of tank focus vessel and cargo focus vessel data in Canadian waters of the VTRA study Area.

The accident data to calibrate the second category (1 m^3 or more) contains 2 accidents obtained from the following dataset:

d. 26 years (1990 to 2015) of accident data for tank focus vessels and cargo focus vessels with a spill size above 1 m^3 in the VTRA Study Area

With respect to the last data set, it is important to note that of the total VTRA model traffic about 75% is non-focus vessel traffic (that includes traffic of smaller vessels, smaller than 20 meters in length and not compelled to participate in the USCG VTS, in the VTRA model represented by regattas, whale watching activities and fishing vessels of tribal, Canadian or US, and commercial fishing openers). Focus vessels in the VTRA 2010 and VTRA 2015 (about 25% of the VTRA model traffic) can collide with both non-focus vessels and focus vessels. The Tenyo Maru Oil Spill in this 1 m^3 or more dataset (d) above involved the collision of a non-focus vessel (Tenyo Maru) with a cargo focus vessel (Tuo Hai) that are with tank focus vessels of primary interest in the VTRA 2015 Study[2]. The Barge 101 oil spill in this 1 m^3 or more dataset involved an oil barge. Neither of these two accidents were used for calibration purposes in the VTRA 2005 model at that time, since they were not part of VTRA 2005 focus vessel traffic[3] (about 1% of VTRA Model traffic at that time). Through the extrapolation technique used in the VTRA 2010 model, these two data points were also not used in the VTRA 2010 study. Since these two accidents, however, do involve focus vessels in the VTRA 2015 model (which improves on the VTRA 2010 by not relying on this previously discussed extrapolation technique) these two accident data points have been used in the calibration procedure of the VTRA 2015 model. The same reasoning applies to using other accident data for VTRA 2015 model calibration in the 0 m^3 – 1 m^3 spill category involving those focus vessels that were not part of the VTRA 2005 focus vessel group.

To explain further, both the collision of a cargo focus vessel and a fishing vessel and the powered grounding of an oil barge resulting in oil spill above 1 m^3 are potential accidents that are within the realm of possibilities today. While the Barge 101 spill, evaluated at estimated 26,936 gallons ≈ 102 m^3 oil loss [27], involved a single hull barge at the time, spills from double hull barges through powered grounding are accidents that could occur in the current environment. Moreover, a recent journal publication [23] states that: "*The results indicate that double hull design on average reduces the size of oils spill by 20% and 62% in tank barge and tanker ships accidents, respectively*". Thus, when applying the on average 20% spill reduction quoted from [23] to the ≈ 102 m^3 of the Barge 101 spill, the Precautionary Principle [22] to data selection for risk analysis/risk management prescribes that the Barge 101 spill ought to be used in the VTRA 2015 model calibration process of

[2] The VTRA Oil Outflow model takes in its analysis the POTENTIAL Oil Loss from two vessels involved in a POTENTIAL collision into account in its evaluations, even if one of those vessels falls in the non-focus vessel category.

[3] The focus vessel traffic in the VTRA 2005 were tankers, ATBs and ITBs visiting the Cherry Point terminal.

POTENTIAL accidents with a POTENTIAL Oil Loss above 1 m^3, despite the Barge 101 being a single hull barge and despite other publications perhaps attributing a larger benefit to double hull barge protection. The start of the time period of the data source (d) above to calibrate the VTRA 2015 model for POTENTIAL accidents with spill above 1 m^3 coincides with the year that the Oil Pollution Act (OPA), 1990 [24] was enacted. Hence, the inclusion of the collision in 1991 of a cargo focus vessel (Tuo Hai) with a non-focus vessel (Tenyo Maru), resulting in a spill above 1 m^3 in the the VTRA Study area, in the calibration process of the VTRA 2015 model for the 1 m^3 or above POTENTIAL Oil Loss category. Thankfully, to calibrate the VTRA 2015 model for POTENTIAL accidents of focus vessels since 1990 with a POTENTIAL Oil Loss above 1 m^3, the only two accidents that fall in that category in the VTRA Study Area are the Tenyo Maru (1991) and Barge 101 (1994) spills. It is important to note that here the Base Case 2015 Scenario number of accidents per year calibration occurred (1) by the number of accidents available to the VTRA 2015 Study in the 0 m^3 – 1 m^3 oil loss category in the VTRA Study Area over the time period 1995 – 2015 and (2) by the number of accidents available to the VTRA 2015 Study in the 1 m^3 or above oil loss category in the VTRA Study Area over the time period 1990 - 2015, and not by the volume of oil spilled in these accidents. The VTRA Oil Outflow model is described in [4] and is modeled after the oil outflow model detailed in Special Report 259 [16] published by the Marine Board, Transportation Research Board of The National Academy of Sciences.

With respect to the VTRA 2015 model accounting for potential accident rate reduction over time, it is important to note that using the longer time window 1990 – 2015 for the VTRA 2015 model for data sources, rather than the shorter time window 1995 – 2005 used in the VTRA 2005, has the effect of reducing the average number of potential accidents per year for VTRA 2015 model calibration procedure. This is exemplified in Figure 2-3 by combining the datasets (a – c) above for the 0 m^3 – 1 m^3 oil loss category spanning the period 1995-2015. Both in Figure 2-3A and Figure 2-3B one observes for the tank focus vessel category a downward trend towards the year 2015 in terms of the combined running average number of collisions and groundings (Figure 2-3A) and the running average number of allisions per year (Figure 2-3B) for the 0 m^3 – 1 m^3 oil loss category. In Figure 2-4A and Figure 2-4B one observes for the cargo focus vessel category a downward trend towards the year 2015 in terms of the combined running average number of collisions and groundings (Figure 2-4A) and the running average number of allisions per year (Figure 2-4B) for the 0 m^3 – 1 m^3 oil loss category. Finally, in Figure 2-5 one observes for all focus vessels combined a downward trend towards the year 2015 in terms of the combined running average number of accidents per year for the 1 m^3 or more oil loss category. Thus the VTRA 2015 model calibration procedure accounts for a reduction of potential number accidents per year over time up to the year 2015. In other words, through the calibration process of accident data available to the VTRA 2015 Study from 1990 – 2015, risk mitigation measures implemented over this time frame, and since the Oil Pollution Act (OPA), 1990 [24] was enacted, are implicitly taken

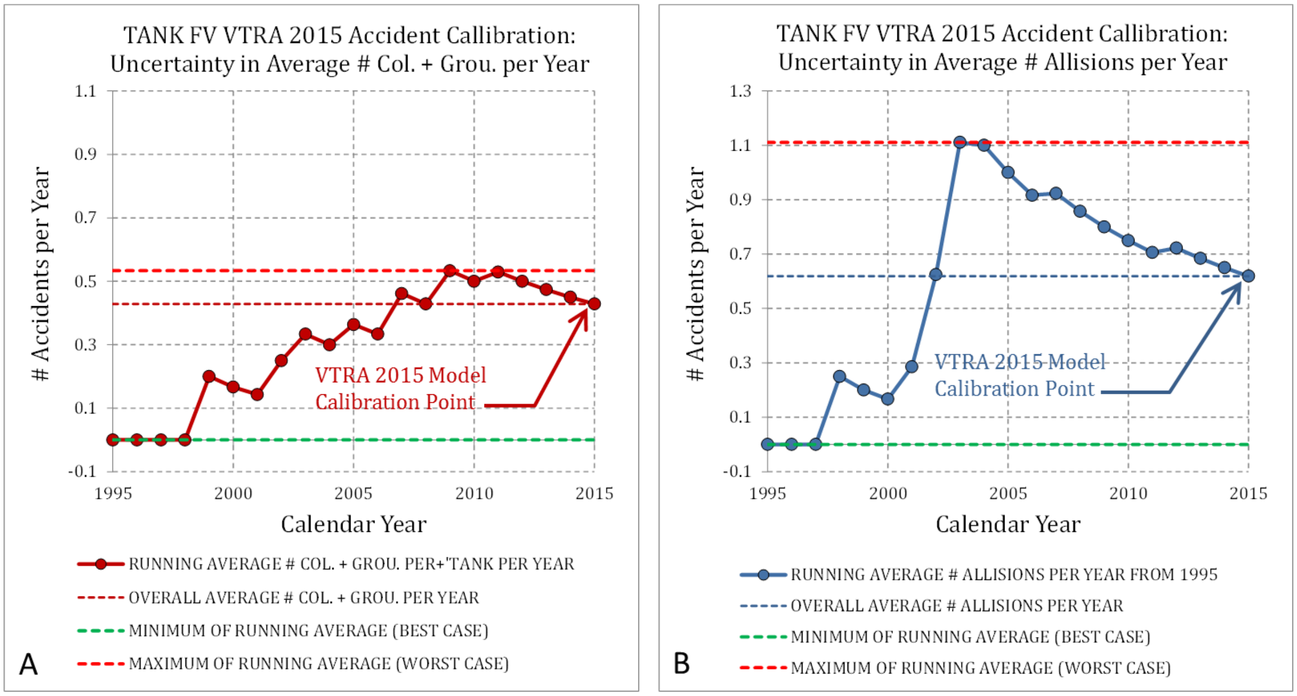

Figure 2-3. Running average evaluation of accident data from 1995 – 2015 in the oil loss category 0 m³ – 1 m³ for tank focus vessels in the VTRA 2015 calibration dataset.

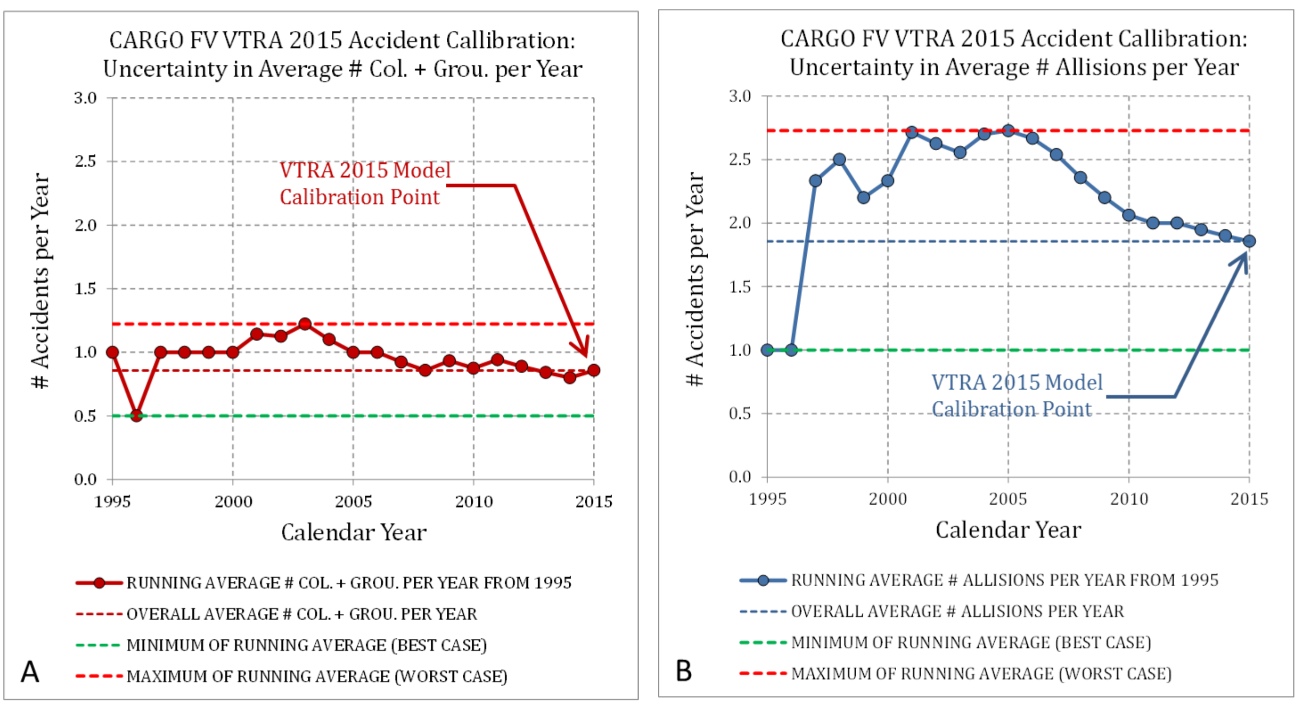

Figure 2-4. Running average evaluation of accident data from 1995 – 2015 in the oil loss category 0 m³ – 1 m³ for cargo focus vessels in the VTRA 2015 calibration dataset.

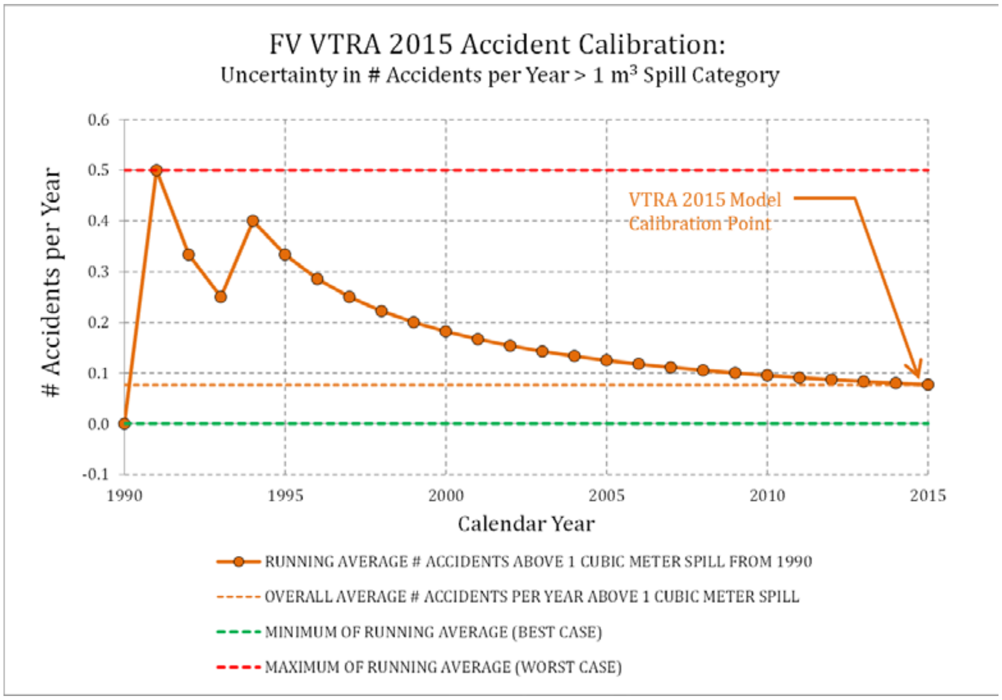

Figure 2-5. Running average evaluation of accident data from 1990 – 2015 in the oil loss category above 1 m³ for all focus vessels combined in the VTRA 2015 calibration dataset.

into account, combined with vessel traffic changes that have occurred over that time frame, in the Base Case 2015 Scenario Analysis results.

The average number of accidents per year evaluated at the end of the year 2015 depicted in Figure 2-3, Figure 2-4 and Figure 2-5, using the 81 accident data points provided in Appendix B, are the average accident number of accidents per year that the VTRA 2015 model is calibrated to. First, the POTENTIAL number of accidents per year is evaluated by merging the (a) through (c) dataset above while accounting for the different time periods of these data sets. This is further explained in Figure 2-6 for the 79 accidents in the 0 m³ – 1 m³ oil loss category. The top left and right tables in Figure 2-6 combined sum to a total of 79 accidents separated by cargo focus vessel, tank focus vessel (excl. oil barges) and oil barges, and by US waters and Canadian (CA) waters in the VTRA study area. The middle left and right tables in Figure 2-6 provide the length of the data periods for these data sets separated by cargo focus vessel, tank focus vessel (excl. oil barges) and oil barges, and by US waters and CA waters in the VTRA study area. The bottom left and right tables in Figure 2-6 next evaluates the average number of accident per year separated by cargo focus vessel, tank focus vessel (excl. oil barges) and oil barges, and by US waters and CA waters in the VTRA study area. The bottom table next merges the average number of accidents per year for the US and CA waters, but still separated by cargo focus vessel, tank focus vessel (excl. oil barges) and oil barges. One observes overall an evaluated average number of accidents per year of about 4.3 in Figure 2-6 for the oil loss category 0 m³ – 1 m³ in the VTRA study area. The nine accident frequencies values in the bottom table of Figure 2-6 by accident type and by cargo focus vessels, tank focus vessels (excl. oil barges) and oil barges, are the accident frequency calibration points for the VTRA 2015 Model accident calibration procedure for the 0 m³ – 1 m³ POTENTIAL Oil Loss category.

VTRA 2015 Model Accident Calibration of the 0 m³ – 1 m³ Spill Category
Source: VTRA Data from 1995 - 2015

US	NUMBER OF ACCIDENTS IN 0 - 1 m^3		
	ALLISION	GROUNDING	COLLISION
CARGO FV	36	6	8
TANK FV (Excl. Oil Barge)	5	1	1
OIL BARGE	8	1	6

CA	NUMBER OF ACCIDENTS IN 0 - 1 m^3		
	ALLISION	GROUNDING	COLLISION
CARGO FV	2	4	1
TANK FV (Excl. Oil Barge)	0	0	0
OIL BARGE	0	0	0

US	NUMBER OF DATABASE YEARS		
	ALLISION	GROUNDING	COLLISION
CARGO FV	21	21	21
TANK FV (Excl. Oil Barge)	21	18	21
OIL BARGE	15	15	15

CA	NUMBER OF DATABASE YEARS		
	ALLISION	GROUNDING	COLLISION
CARGO FV	12	12	12
TANK FV (Excl. Oil Barge)	12	12	12
OIL BARGE	12	12	12

US	NUMBER OF ACCIDENTS IN 0 - 1 m^3 PER YEAR		
	ALLISION	GROUNDING	COLLISION
CARGO FV	1.714	0.286	0.381
TANK FV (Excl. Oil Barge)	0.238	0.056	0.048
OIL BARGE	0.533	0.067	0.400

CA	NUMBER OF ACCIDENTS IN 0 - 1 m^3 PER YEAR		
	ALLISION	GROUNDING	COLLISION
CARGO FV	0.167	0.333	0.083
TANK FV (Excl. Oil Barge)	0.000	0.000	0.000
OIL BARGE	0.000	0.000	0.000

additive

US + CA	NUMBER OF ACCIDENTS IN 0 - 1 m^3 PER YEAR			
	ALLISION	GROUNDING	COLLISION	TOTAL
CARGO FV	1.881	0.619	0.464	2.964
TANK FV (Excl. Oil Barge)	0.238	0.056	0.048	0.341
OIL BARGE	0.533	0.067	0.400	1.000
TOTAL	2.652	0.741	0.912	4.306

additive

Figure 2-6. Accident frequency calibration points for cargo focus vessels, tank focus vessels (excl. oil barges) and oil barges utilizing the VTRA 2015 calibration dataset in Appendix B for the 0 m³ – 1 m³ oil loss category

To arrive at an overall average number of accidents per year, regardless of oil loss category, one needs to merge the datasets for the 0 m³ – 1 m³ oil loss category with the dataset for the 1 m³ or more oil loss category (i.e. the Barge 101 and the Tenyo Maru Spille) while accounting for the length of the time of the data periods of these datasets. This is further explained in Figure 2-7. Note in in Figure 2-7 one arrives at an estimated average of $4.306 \times 26 = 111.94$ number of accidents over a 26 year period in the 0 m³ – 1 m³ POTENTIAL Oil Loss Category of (and not just the 79 accidents in the VTRA 2015 accident calibration dataset in this category provided in Appendix B). Combining that information with the 2 accidents in the 1 m³ or more POTENTIAL Oil Loss Category observed over a 26 year period (totaling 113.94), one arrives at an average number of accidents per year of about 4.4, regardless of oil loss category. Overall, one observes from the analysis in Figure 2-7 that 98.2% of the accidents in the VTRA 2015 accident data calibration procedure fall in the 0 m³ – 1 m³ POTENTIAL Oil Loss category and 1.8% fall in the Potential Oil Loss category 1 m³ and above.

VTRA 2015 Model Accident Calibration of the
0 m³ – 1 m³ Spill and the 1 m3 or more Spill Category
Source: VTRA Data from 1990 - 2015

US + CA	NUMBER OF ACCIDENTS		TOTAL
	0 - 1 m3	1 m3 or More	
ALL FOCUS VESSELS	111.94	2	113.94

??? Why not 79

US + CA	NUMBER OF DATABASE YEARS		TOTAL
	0 - 1 m3	1 m3 or More	
ALL FOCUS VESSELS	26	26	26

US + CA	NUMBER OF ACCIDENT PER YEAR		TOTAL
	0 - 1 m3	1 m3 or More	
ALL FOCUS VESSELS	4.31	0.08	4.38

US + CA	NUMBER OF ACCIDENT PER YEAR		TOTAL
	0 - 1 m3	1 m3 or More	
ALL FOCUS VESSELS	98.2%	1.8%	100%

1. Recall 4.306 Per Year in 0 m³ – 1 m³ Cat.
2. and 4.306 x 26 years = 111.94

Figure 2-7. Accident frequency calibration points for all focus vessels by the 0 m³ – 1 m³ oil loss category and the 1 m³ or more oil loss category.

It is important to note that these accident calibration frequencies in Figure 2-6 and the calibration percentages in Figure 2-7 are evaluated using solely accident data applicable to the VTRA Study area and not using worldwide maritime accident data statistics (or other accident data outside the VTRA Study area, but in a closer vicinity).

Conducting a longitudinal AIS passage line vessel count data analysis from 2010 to 2015

The Puget Sound Marine Exchange collects vessel movements in the study area using Automated Identification System (AIS) data and has the capability to count the number of vessels crossing a specified line, called a passage line, in a given year. A longitudinal AIS passage line vessel count line data analysis was conducted using 2010 to 2015 passage line vessel count data for 10 AIS passage lines. The 10 passage lines that were utilized for the AIS passage line analysis are depicted in Figure 2-8 together with six departure/destination zones defined by these passage lines. Following the methodology described in Chapter 9 of the VTRA 2010 Final Report, a traffic stream analysis was conducted for the VTRA 2015 over the years 2010 to 2015, whereas during the VTRA 2010 such an analysis was conducted for the years 2008 – 2012 using only three passage lines,

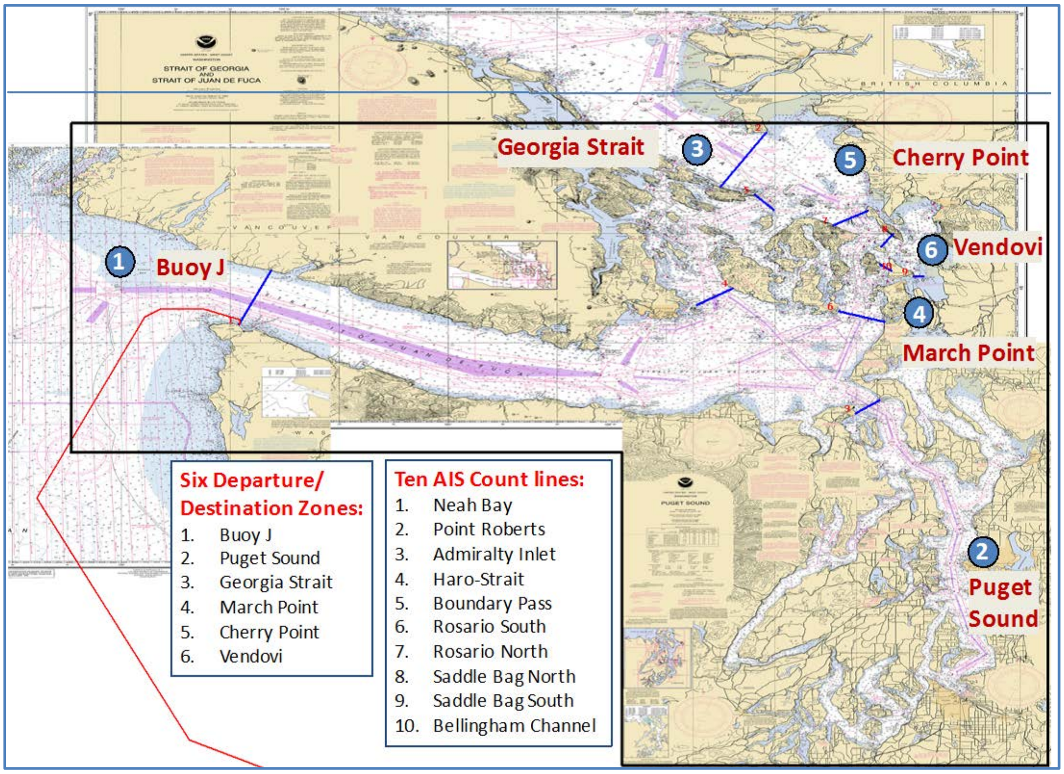

Figure 2-8. AIS Passage Lines Provided by the Puget Sound Marine Exchange.

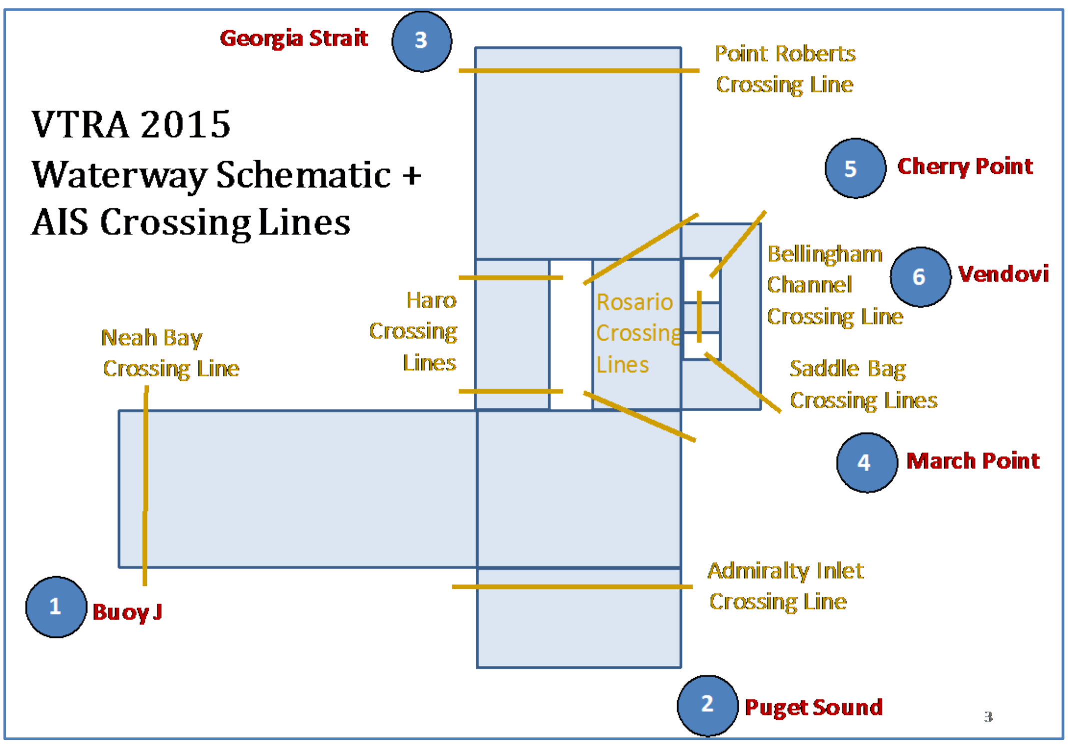

Figure 2-9. Waterway Schematic of VTRA Study area with the 10 AIS Passage Lines.

one at the entrance of the Strait of Juan de Fuca, one at the entrance of Georgia Strait and one at the entrance of the Puget Sound (Admiralty Inlet). The passage line vessel count data utilized in the VTRA 2015 study for the traffic stream analyses is provided in Appendix C.

Figure 2-9 above shows a simplified schematic of the ten AIS passage lines and six departure/ destination zones identified in Figure 2-8 and Figure 2-9 as Buoy J (1), Puget Sound (2), Georgia Strait (3), March Point (4), Cherry Point (5) and Vendovi (6). Next, utilizing this indexing of thedeparture/destination zones one can introduce, for example, the variable x_{12} to represent the annual traffic flow/stream from Buoy J (1) to the Puget Sound (2) and x_{21} to represent the annual traffic flow from the Puget Sound (2) to Buoy J (1), etc. In other words, the variable x_{ij} represents the annual traffic flow from departure zone (i) to destination zone (j). The sum of the variables x_{ij} that share, for example, the first index $i = 1$ represents the total annual in-flow of vessels entering the VTRA study area at Buoy J (or the entrance of the Strait of Juan de Fuca). The use of six different departure/destination zones in a longitudinal AIS passage vessel count line data analysis is another distinguishing feature of the VTRA 2015 from the VTRA 2010 where only three departure/destination zones were considered, specifically the Buoy J (1), the Puget Sound (2) and the Georgia Strait (3) departure/destination zones.

The schematic in Figure 2-9 is therefore also a more complex version of the one used in the VTRA 2010 for a longitudinal AIS passage line vessel count data analysis from 2008 to 2012 therein. That higher level of complexity also requires a higher level of complexity in the variable definition for the VTRA 2015 traffic stream analysis. To that end, an additional index, in letter format, is used to distinguish those vessels travelling from, for example, Cherry Point (5) to March Point (4) using a Rosario Strait route, on the one hand, from those vessels travelling from Cherry Point (5) to March Point (4) using a Saddlebag route, on the other hand. The former variable is denoted x_{45R} and the latter variable is denoted x_{45S}. The complete set of variable definitions used in the AIS Traffic stream analysis for the time period 2010 to 2015 is depicted in Figure 2-10.

Considering the destinations (2), (3), (4), (5) and (6) as "closed" it follows that traffic that arrives at Buoy J, must leave at Buoy J[4]. These types of considerations allow one to formulate what are called "balance equations". The set of departure/destination zone balance equations formulated for the AIS passage line vessel count analysis from 2010 to 2015 using the six departure/ destination zones is depicted in Figure 2-11. In addition to departure/destination zone balance equations depicted in Figure 2-11, balance equations are formulated for each individual passage line as well. Figure 2-12 shows the set of balance equations formulated for the Neah Bay passage line. Similar equations were formulated for the other 9 passage lines in a similar manner.

[4] It is assumed here that focus vessel traffic that travels from Buoy J to the Georgia Strait does not leave through the Northern Passage.

Variable Definition:

$x_{ij} \equiv$ # of vessels traveling from Departure Zone i to Destination Zone j

$x_{ijH} \equiv$ # of vessels traveling from Dep. Zone i to Dest. Zone j **through Haro - Strait**

$x_{ijR} \equiv$ # of vessels traveling from Dep. Zone i to Dest. Zone j **through Rosario**

$x_{ijS} \equiv$ # of vessels traveling from Dep. Zone i to Dest. Zone j **through Saddle Bag**

$x_{ijB} \equiv$ # of vessels traveling from Dep. Zone i to Dest. Zone j **through Belling. Channel**

Figure 2-10. Variable definition for AIS Passage line count analysis from 2010 to 2015.

Buoy J Balance Equation:

$$x_{12} + x_{13} + x_{14} + x_{15R} + x_{15H} + x_{16B} + x_{16S} = x_{21} + x_{31} + x_{41} + x_{51R} + x_{51H} + x_{61B} + x_{61S}$$

Puget Sound Balance Equation:

$$x_{21} + x_{23H} + x_{23R} + x_{24} + x_{25} + x_{26B} + x_{26S} = x_{12} + x_{32H} + x_{32R} + x_{42} + x_{32H} + x_{52} + x_{62B} + x_{62S}$$

Georgia Strait Balance Equation:

$$x_{31} + x_{32H} + x_{32R} + x_{34S} + x_{34R} + x_{35} + x_{36} = x_{13} + x_{23H} + x_{23R} + x_{43S} + x_{43R} + x_{53} + x_{63}$$

March Point Balance Equation:

$$x_{41} + x_{42} + x_{43S} + x_{43R} + x_{45S} + x_{45R} + x_{46S} + x_{46R} = x_{14} + x_{24} + x_{34S} + x_{34R} + x_{54S} + x_{54R} + x_{64S} + x_{64R}$$

Cherry Point Balance Equation:

$$x_{51H} + x_{51R} + x_{52} + x_{53} + x_{54S} + x_{54R} + x_{56} = x_{15R} + x_{15H} + x_{25} + x_{35} + x_{45S} + x_{45R} + x_{65}$$

Vendovi Balance Equation:

$$x_{61B} + x_{61S} + x_{62B} + x_{62S} + x_{63} + x_{64S} + x_{64R} + x_{65} = x_{16B} + x_{16S} + x_{26B} + x_{26S} + x_{36} + x_{46S} + x_{46R} + x_{56}$$

Figure 2-11. Departure/destination zone balance equations at the core of AIS 2010-2015 traffic stream analysis.

Neah Bay Crossing Line Equations:

$$N-WB = x_{12}+x_{13}+x_{14}+x_{15R}+x_{15H}+x_{16B}+x_{16S}$$
$$N-EB = x_{21}+x_{31}+x_{41}+x_{51R}+x_{51H}+x_{61B}+x_{61S}$$

Figure 2-12. Example balance equations for the Neah Bay passage line vessel counts travelling west bound and east bound.

It is important to note that the passage line vessel counts in Appendix C contain counting discrepancies/errors. For example, in 2010 there is a difference of about 200 between cargo focus vessels entering and leaving the Strait of Juan de Fuca at the Neah Bay passage line. Similar discrepancies are observed at the other passage lines counts throughout the years 2010 to 2015. As a result of these counting differences one can solve for a set of values for the variables depicted in Figure 2-10 from the complete set of balance equations that closely matches the passage line vessel count data provided in Appendix C, but not exactly. Solutions were separately obtained to a set of balance equations for cargo focus vessels, tank focus vessels (excluding ATBs) and ATBs. Although ATBs are not a separate counting category in AIS passage line vessel count data, ATB passage line counts were separated from the tank focus vessel category, with the assistance of the Puget Sound Marine Exchange using separate ATB vessel identifiers.

Figure 2-13 summarizes the results of the longitudinal AIS passage line vessel count data analysis from 2010 to 2015. From Figure 2-13A one observes that from the year 2010 to the year 2015 cargo focus vessels departures increased from the Georgia Strait departure zone, which implies also an increase in arrivals to the Georgia Strait destination zone from the other departure/ destination zones. From Figure 2-13B, one observes that from the year 2010 to the year 2015 tank focus vessels (excluding ATBs) departures both increased and decreased from the six different departure zones. While increases are observed for the departure zones Vendovi and March Point, decreases are observed in number of tank focus vessels (excluding ATBs) from the departure zones Buoy J, Puget Sound, George Strait and Cherry Point.

From Figure 2-13C one observes that from the year 2010 to the year 2015 ATB departures increased from all six departure zones. Finally, Figure 2-13D combines the information provided in Figure 2-13A, B and C and evaluates the overall changes from the six departure zones by all focus vessels combined. From Figure 2-13D one observes for all focus vessel combined, traffic increases from the year 2010 to the year 2015. It should be noted, however, that fluctuations up and down are observed in the AIS passage line vessel count data analysis solutions that were solved using the complete set of balance equations for the years 2011 through 2014. That being said, the differences between the 2010 year and the 2015 year were used to augment the VTRA 2010 model with traffic stream increases as defined by the variables in Figure 2-10 by cargo focus vessels, tanks focus vessels (excluding ATBs) and ATBs.

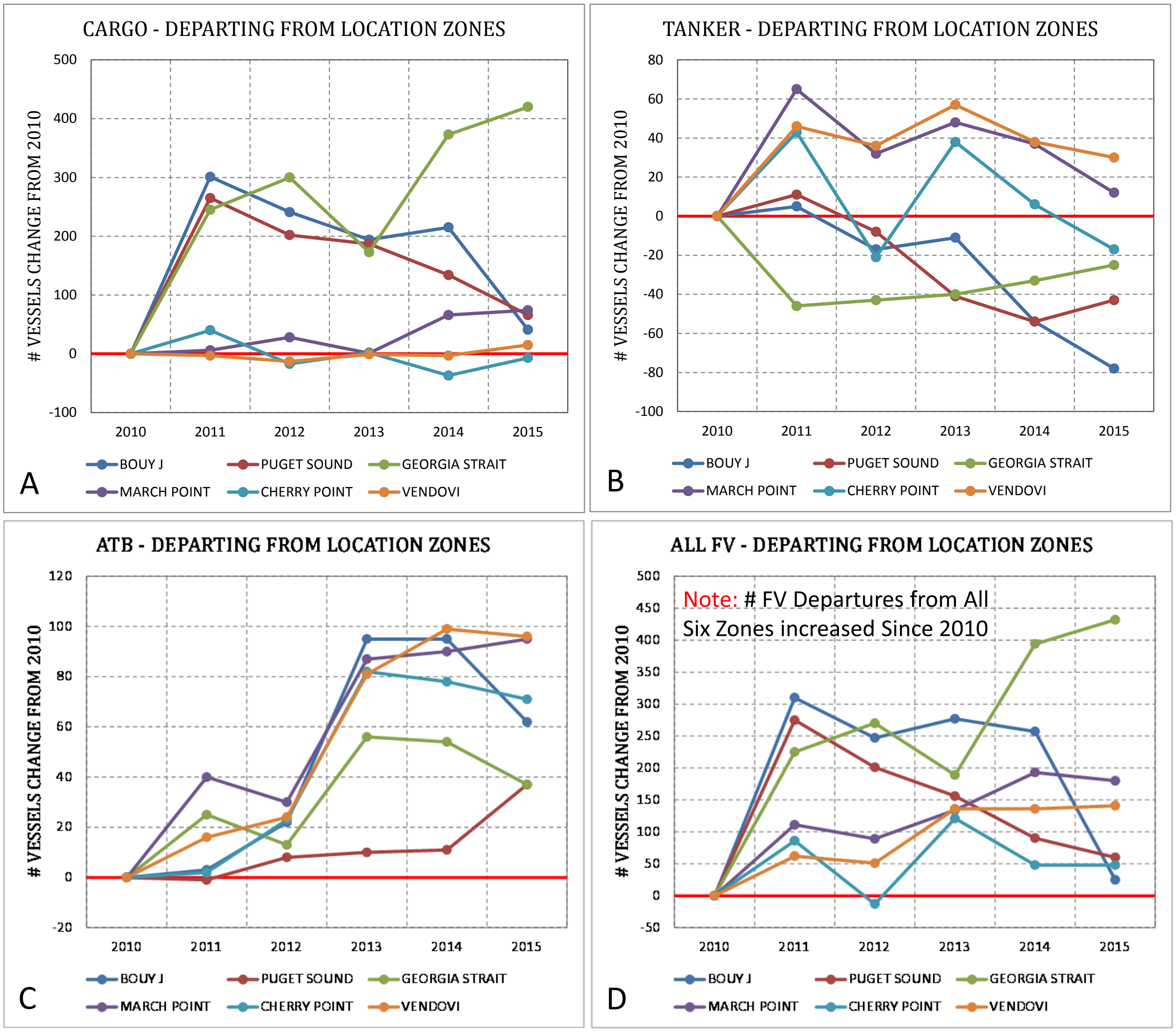

Figure 2-13. Summary of AIS passage line vessel count data analysis by departing zone.
A: Cargo Focus Vessels, B: Tank Focus Vessels (Excl. ATBs), C: ATBs, D: All Focus Vessels combined.

Adding cargo focus vessel and tank focus vessel traffic streams to the VTRA model

To arrive at Base Case 2015 Scenario simulation model, the VTRA 2010 Model was augmented using the preceding traffic stream analysis. Only those traffic streams were modeled in the VTRA 2015 model where the vessel count along a traffic stream exceeded the average passage line vessel count data error observed over the years 2010 to 2015 at the three passage lines entering the Strait of Juan de Fuca, the Puget Sound and Georgia Strait. The average annual passage line vessel count errors were evaluated at 99, 12 and 5 for cargo focus vessels, tank focus vessels (excluding ATBs) and ATBs, respectively.

Figure 2-14A depicts the modeled traffic stream changes for cargo focus vessels, whereas Figure 2-14B depicts the modeled traffic stream changes for tank focus vessels (excluding ATBs). Observe from Figure 2-14 that both traffic stream increases and decreases are depicted. To decrease a traffic stream, the VTRA 2010 base case simulation model was run and all transits were detected of a given vessel type along a specific route. This allowed for the determination of the rate at which to cancel transits along each route. For example, suppose there were 100 transits along a given route in the VTRA simulation model and one needed to remove 10 transits. one could then remove every 10th transit and achieve the targeted traffic stream reduction. Figure 2-15A depicts the modeled traffic stream changes for ATBs departing from Departure Zones 1, 2 and 3, Figure 2-15B depicts the modeled traffic stream changes for ATBs departing from Departure zone 4 and Figure 2-15C depicts the modeled traffic stream changes for ATBs departing from Departure zone 6.

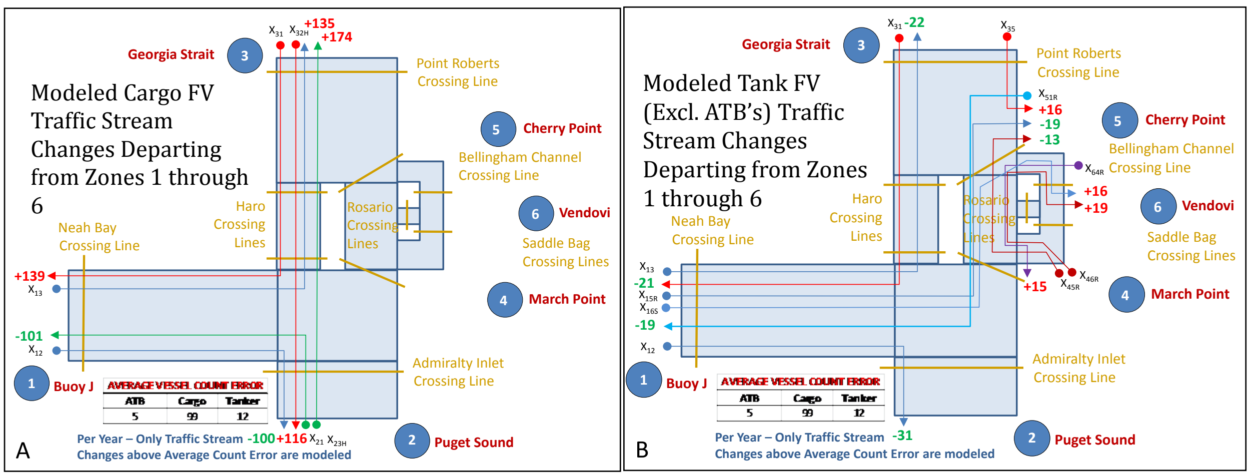

Figure 2-14. Annual Traffic Stream changes modeled for Cargo Focus Vessels and Tanks Focus Vessels (Excl. ATBs) in the VTRA 2015 Model from the VTRA 2010 Model. A: Cargo Focus Vessel changes, B: Tank Focus Vessels (Excl. ATBs) changes.

In the VTRA 2010 model, what-if focus vessel transits were added on a deterministic and scheduled pattern. As another arbitrary example, suppose one wished to add 36 transits in a year. One could then add a transit every 10 days and achieve this increase in annual transits per year in a particular traffic stream. An artifact of that modeling approach of using equidistant arrival times is that a "bunching up" of arrivals could occur in the VTRA 2010 simply due to this deterministic modeling approach towards scheduling of additional vessel arrivals to the VTRA 2010 model.

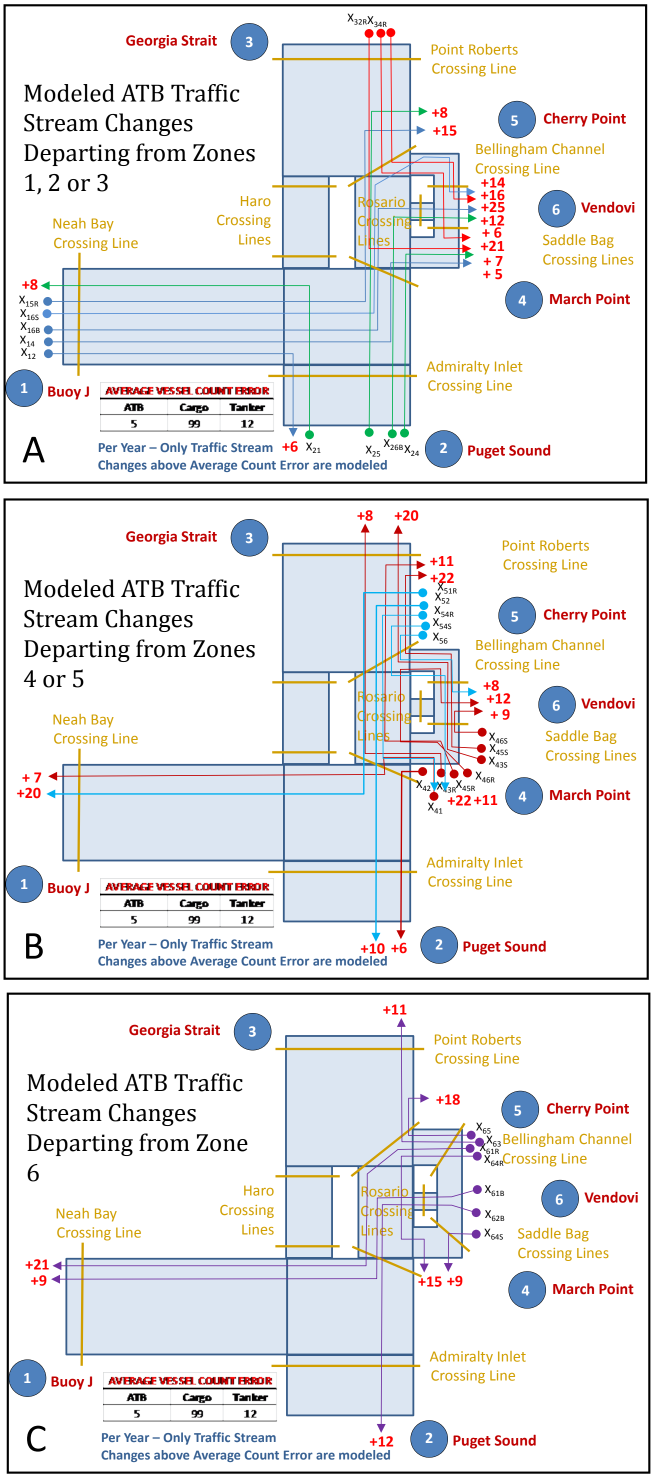

Figure 2-15. Annual Traffic Stream changes modeled for ATBs in the VTRA 2015 Model from the VTRA 2010 Model. A: Traffic stream changes from departure zones 1, 2 and 3, B: Traffic stream changes from departure zones 4 and 5, Traffic stream changes from departure zone 6.

The arrival process that was modeled in the VTRA 2015 analysis is another distinguishing feature between the VTRA 2010 model and the VTRA 2015 model. Whereas in the VTRA 2010 arrivals were modeled equidistant in time ensuring a certain number of focus vessels arriving per year, the arrival pattern in the VTRA 2015 model are modeled at random arrival times.

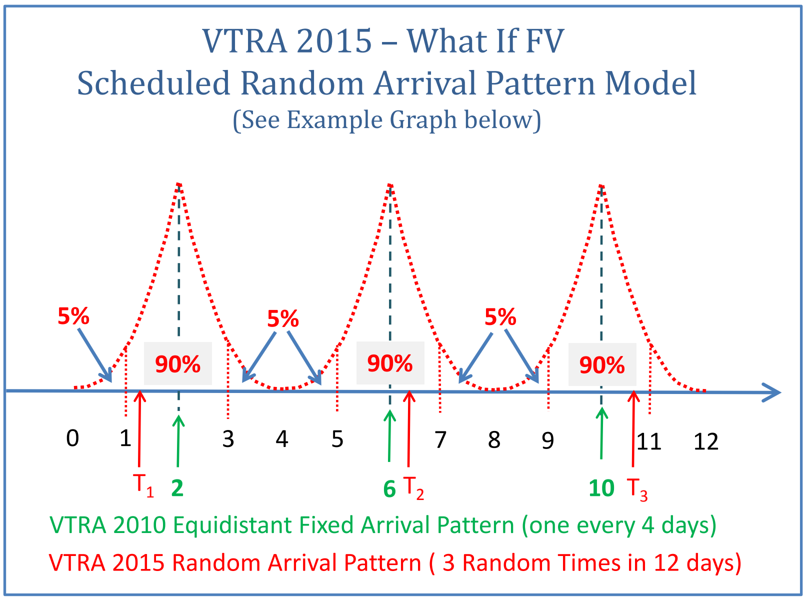

Figure 2-16. Scheduled random arrival pattern for added traffic streams.

The difference between the VTRA 2010 arrival process and the VTRA 2015 random arrival process is graphically exemplified in Figure 2-16 above. The example depicted in Figure 2-16 provides with green arrows a hypothetical equidistant arrival process of one arrival every four days, which is the arrival process modelled in the VTRA 2010 while ensuring a number of arriving focus vessels per year, whereas the red arrows in Figure 2-16 exemplifies three randomly selected times T_1, T_2 and T_3 over the same 12 day period depicted in Figure 2-16. This random arrival process is referred to as a *scheduled random arrival process* as the most likely values of these random arrival times are set at the fixed scheduled arrival times process of the VTRA 2010 model, as depicted in Figure 2-16, but with a 90% probability of these random arrivals occurring over half the distance in time between equidistant consecutive most likely arrival times, while symmetrically distributed to the left and right of these most likely values. In Figure 2-16, for example, there is a 90% probability of a random arrival in the time periods [1,3], [5,7], [9,11], whereas the most likely arrival times are depicted at 4, 6 and 10 in Figure 2-16 at the midpoints of these three time periods, respectively. This chosen random arrival process for increasing focus vessel traffic streams is called a *scheduled random arrival process* since it too assures a certain number of focus vessels arrival per year, but also because these selected random arrival times of these focus vessels are set fixed from simulation run to simulation run for the added traffic streams depicted in Figure 2-14 and Figure 2-15. In other words, changes evaluated or differences observed in risk metric results between scenario evaluations are not a result of these randomly selected, but fixed, arrival times for the added traffic stream changes in Figure 2-14 and Figure 2-15. In simulation lingo the use of this technique is called a *variance reduction technique* [25].

Integrating the recalibrated VTRA model with the added traffic streams

The recalibration of the VTRA model to additional accident data from 1990 – 2015 and the traffic stream analysis using AIS passage line vessel count data from 2010 to 2015 occurred in parallel during the VTRA 2015 study[5]. Following the longitudinal traffic stream analysis utilizing the AIS passage line vessel count data, the VTRA model was augmented utilizing the results from the traffic stream analysis in the preceding section. A comparison was conducted between an analysis conducted using the VTRA model following recalibration to the additional accident data and an analysis conducted using this recalibrated VTRA model augmented with the results from traffic stream analysis[6]. While an increase in POTENTIAL Oil Loss was observed from the first scenario analysis to the second scenario analysis, which can be explained by the addition of the traffic streams in Figure 2-14 and Figure 2-15, the POTENTIAL number of accidents per year between these two analyses remained at the calibrated level of about 4.4 accidents per year, where in each of these analyses 98.2% of these accidents fell in the 0 m^3 – 1 m^3 POTENTIAL Oil Loss category and the remainder fell in the 1 m^3 or more POTENTIAL Oil Loss category. While recognizing the presence of AIS passage line vessel count errors as described in the preceding sections, the latter model is therefore referred to as the VTRA 2015 model, herein, and was utilized to perform a Base Case 2015 Scenario analysis to relatively compare against What-If Scenario analyses and RMM Scenario analyses.

Base Case 2015 Scenario analysis results

Figure 2-17 and Figure 2-18 visualize graphically one of the VTRA 2015 analysis output formats in a manner that hopefully waterway users, regulators, tribes and the public can interpret. Recall from the re-calibration section of the VTRA model that approximately 4.4 accidents per year were evaluated overall, of which about 98.2% fell in the oil loss category 0 m^3 – 1 m^3. In other words, 98.2% of the POTENTIAL Accident Frequency in the Base Case 2015 Scenario analysis accounts for close to 0% of the overall POTENTIAL Oil Loss evaluated for the Base Case 2015 Scenario. The 2D geographic profile/distribution of this 98.2% POTENTIAL Accident Frequency evaluated for

[5] The VTRA 2015 project was originally envisioned to start at the beginning of December 2015, but due to contracting delays the kick-off meeting was held at the beginning of March 2016.
[6] A detailed presentation of this comparison is available at:
https://www.seas.gwu.edu/~dorpjr/VTRA_2015/VTRA_2015_Presentations.html

the Base Case 2015 Scenario is depicted in Figure 2-19. From Figure 2-19, one observes that within the 0 m³ – 1 m³ POTENTIAL Oil Loss category the VTRA 2015 model evaluates an average POTENTIAL spill size of 2.3 gallons (or 0.01 m³) per accident. In other words, these POTENTIAL accidents in the 0 m³ – 1 m³ POTENTIAL Oil Loss category do contribute some to the overall evaluated POTENTIAL Oil loss for the Base Case 2015 Scenario analysis, but combined it amounts to close to 0% of the overall evaluated POTENTIAL Oil Loss in the Base Case 2015 analysis. Moreover, one observes from Figure 2-19 about a 100% chance (or probability) of an accident of this type occurring within a 10 year period. That is essentially equivalent to saying that accidents of this type, i.e. within the POTENTIAL Oil Loss Category 0 m³ – 1 m³, will very likely happen within a 10-year period.

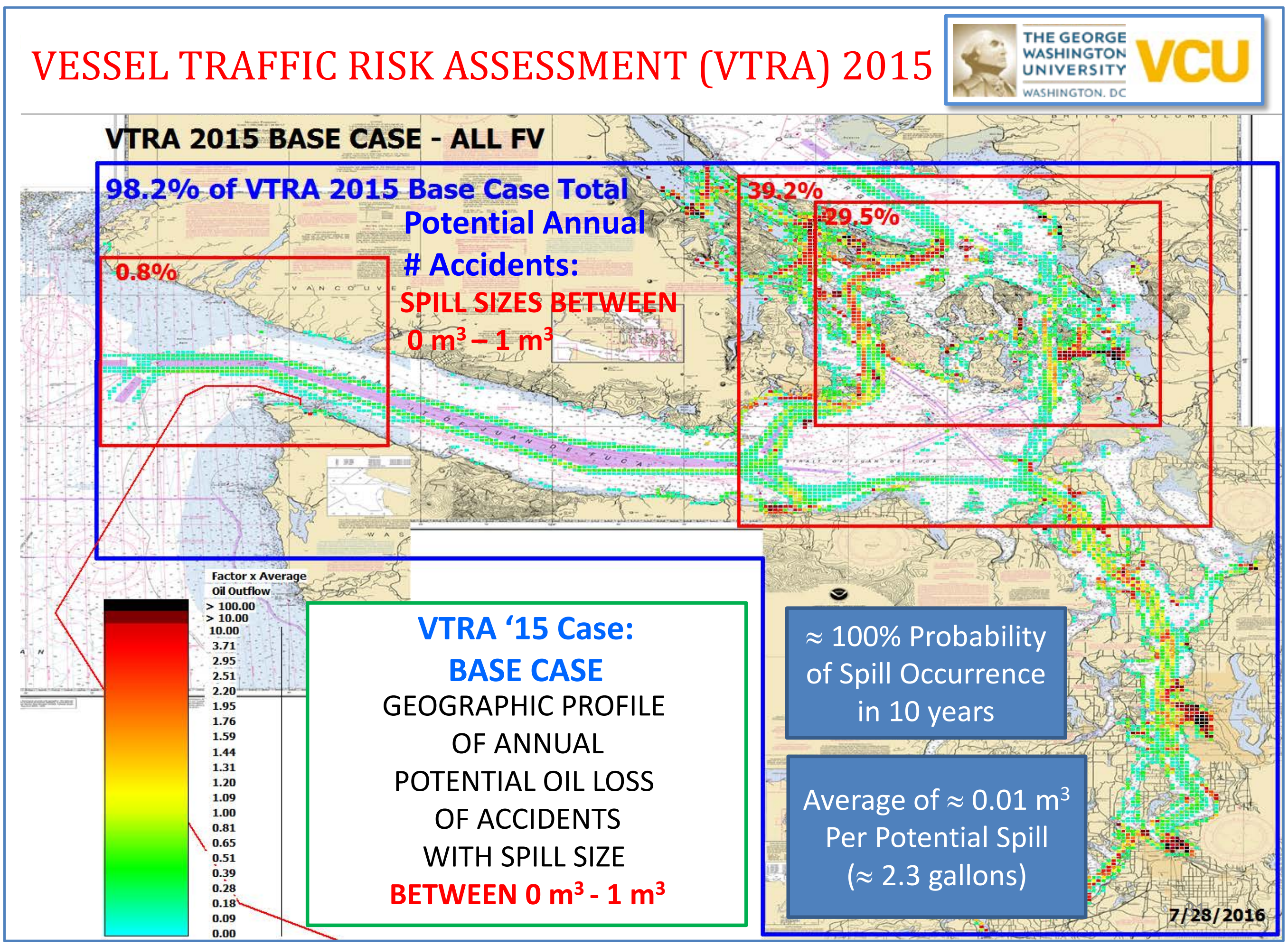

Figure 2-17. 2D Geographic profile 98.2% of POTENTIAL Accident Frequency contribution to about 0% of Base Case 2015 POTENTIAL Oil Loss with an average POTENTIAL Spill Size of 2.3 gallons per accident.

Analogously, 1.8% of the POTENTIAL Accident Frequency in the Base Case 2015 Scenario accounts for nearly 100% of the overall POTENTIAL Oil Loss evaluated for the Base Case 2015 Scenario analysis. This remaining 1.8% of POTENTIAL accident frequency is split over the remaining three POTENTIAL oil loss categories above, with about 1.76% of that 1.8% in POTENTIAL accident frequency attributable to the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category. Figure 2-17 and Figure 2-18 are 3D visualizations of POTENTIAL oil losses evaluated by the VTRA 2015 model within the VTRA Study Area and their geographic distribution across all POTENTIAL accident frequencies. Figure 2-17 depicts POTENTIAL oil losses for the Base Case 2015 Scenario (@100%), whereas Figure 2-18 decomposes the POTENTIAL oil losses for the Base Case 2015 Scenario by POTENTIAL accidents with POTENTIAL oil losses in the following four categories:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These numbers highlight the dichotomy and challenges for risk management of POTENTIAL oil losses, i.e. the objective of both (1) the prevention of accidents with lower POTENTIAL accident frequencies but higher POTENTIAL consequences and (2) the prevention of accidents with higher POTENTIAL accident frequencies but lesser POTENTIAL consequences. Needless to say, one's focus ought to be on the prevention of all POTENTIAL accidents. The information about their distribution across the four POTENTIAL Oil Loss Categories above, however, may be useful in the selection of a portfolio of risk mitigation measures (RMMs) that attempts to address all POTENTIAL oil loss categories. The ability to separate POTENTIAL Accidents by POTENTIAL Oil Loss category is a distinguishing feature of the VTRA 2015 study as compared to the VTRA 2010 and the VTRA 2005 studies. One observes from Figure 2-18 that the largest contributor to overall POTENTIAL Oil Loss evaluated for the Base Case 2015 Scenario analysis is the 1 m^3 to 1000 m^3 POTENTIAL Oil Loss category @ about 45%. The second largest is the 2500 m^3 or more of POTENTIAL Oil Loss Category @ about 42%, and the 1000 m^3 to 2500 m^3 POTENTIAL Oil Loss category comes third @ about 12%.

In Figure 2-20 some of the risk metrics mentioned above are summarized for the Base Case 2015 Scenario analysis. In the first row, the % POTENTIAL Oil Loss by spill category is provided. In the second row the % POTENTIAL Accident Frequency by spill category is presented. The third row contains an additional risk metric by POTENTIAL Oil Loss category, i.e. the evaluated average POTENTIAL Spill Size measured in m^3. Thus one observes from that third row an average POTENTIAL Spill size of 6,798 m^3, 1619 m^3, 46.9 m^3 and 0.01m^3 for the POTENTIAL Oil Loss categories 2500 m^3 or more, 1000 m^3 to 2500 m^3, 1 m^3 to 1000 m^3 and 0 m^3 to 1 m^3, respectively, for the Base Case 2015 Scenario analysis. It is important to note that in the 1 m^3 to 1000 m^3 POTENTIAL Oil Loss Category the evaluated average POTENTIAL spill size per accident of 46.9 m^3

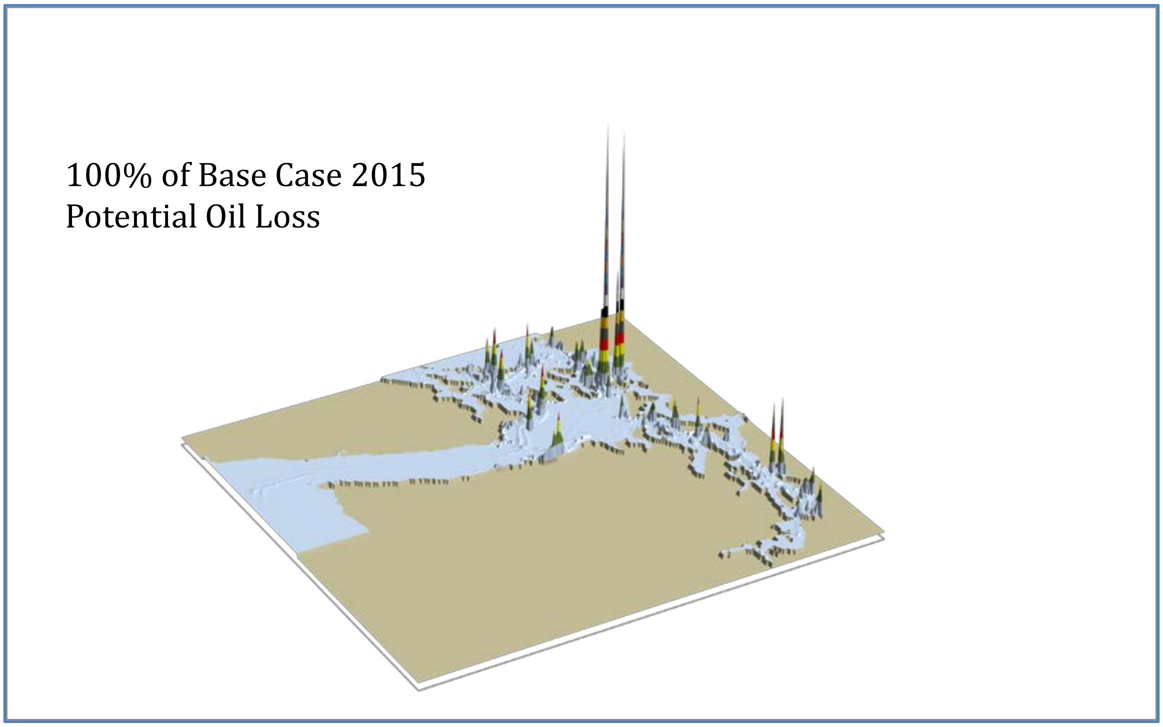

Figure 2-18. 3D Geographic profile of Base Case 2015 POTENTIAL oil loss.

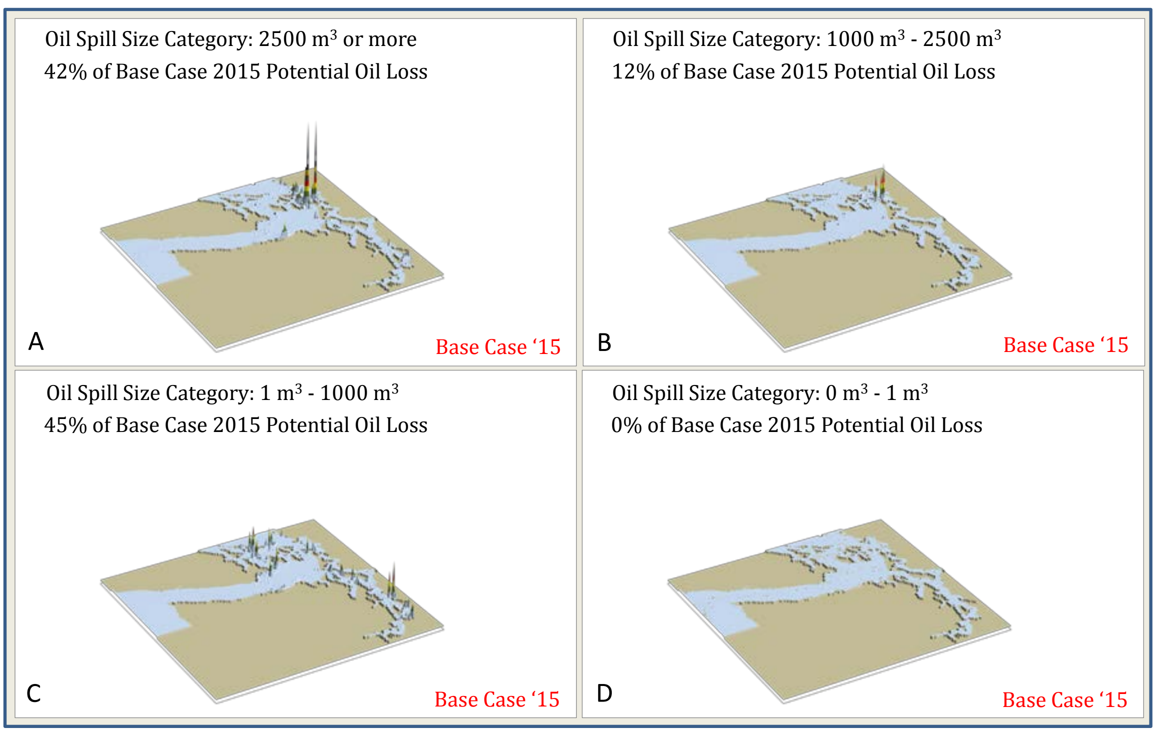

Figure 2-19. Components of 3D Geographic profile of Base Case 2015 POTENTIAL oil loss.
A: 42% in Oil Spill Size Category of 2500 m^3 or more; B: 12% in Oil Spill Size Category of 1000 m^3 -2500 m^3;
C: 45% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 0% in Oil Spill Size Category of 0 m^3 -1 m^3

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%

Figure 2-20. VTRA 2015 summary of risk metrics for the Base Case 2015 analysis

is closer to the lower bound of that category, whereas in the 1000 m^3 to 2500 m^3 the average POTENTIAL Spill Size per accident is closer to the midpoint of that POTENTIAL Oil Loss Category.

Finally, in the fourth, fifth and sixth row of Figure 2-20 estimated probabilities are provided for the occurrence of at least one accident (by POTENTIAL Oil Loss category) in a 1, 10 and 25 year period, respectively. These probability risk metrics relate directly to their evaluated POTENTIAL accident frequencies per year and the length of the time period over which these probabilities are estimated[7]. Observe from each column that the probability of at least one accident over a specified time period naturally increases with the length of that time period. For example, focusing on the third column, while a 7.5% probability is evaluated for at least one accident in the POTENTIAL Oil Loss category 1 m^3 to 1000 m^3 in a 1-year period, a 54.2% probability is evaluated for that probability in a 10-year period and an 85.8% probability in a 25-year period. Similar probability estimates by length of time period are provided for the 2500 m^3 or more, 1000 m^3 to 2500 m^3 and the 0 m^3 to 1 m^3 POTENTIAL Oil Loss categories in the first, second and fourth column of Figure 2-20, respectively. The risk metrics in Figure 2-20 shall be used to compare against the results of VTRA study area wide What-If Scenario analysis results and RMM Scenario analysis results.

In Figure 2-21 the overall POTENTIAL Oil Loss evaluated for the Base Case 2015 analysis is distributed over the fifteen waterway zones depicted in Figure E-2 in the VTRA Study Area. One observes from Figure 2-21 that the Guemes and Haro-Strait/Boundary Pass waterway zones rank first and second in terms overall of POTENTIAL Oil Loss and the Puget Sound South, Rosario, Saddlebag and Puget Sound North fall in a grouping thereafter.

[7] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f} \times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

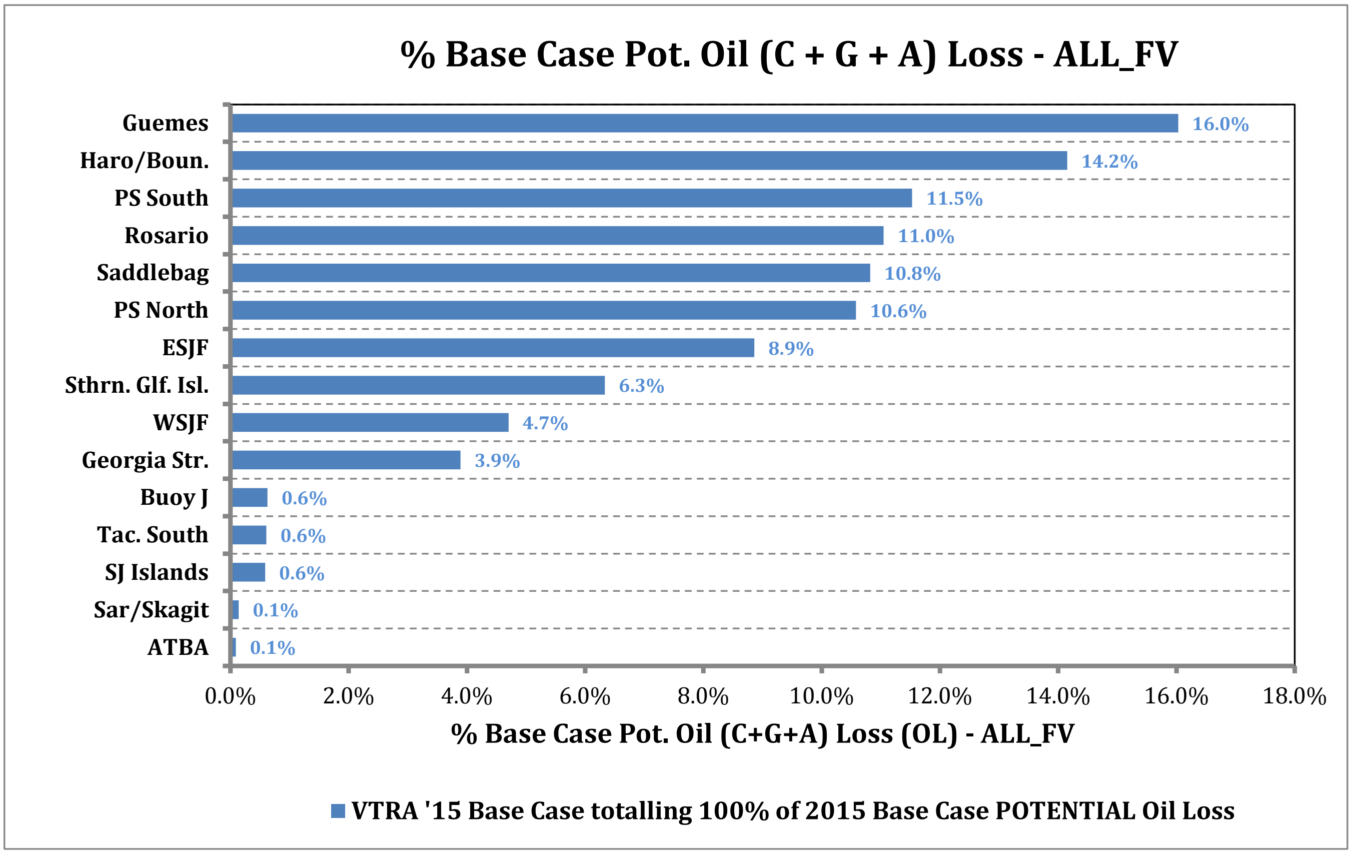

Figure 2-21. Percent overall POTENTIAL Oil Loss by waterway zone for Base Case 2015

In Figure 2-22 estimated probabilities are provided per POTENTIAL Oil Loss category for the occurrence of at least one accident in a 10-year period by-waterway-zone. Starting with Figure 2-22C, the 1 m^3 to 1000 m^3 POTENTIAL Oil Loss category with an estimated 54.2% probability ofat least one accident in the VTRA Study Area in a 10-year period, one observes that the Puget Sound South, Southern Gulf Islands, and Haro-Strait Boundary Pass waterway zones rank number 1, 2 and 3, respectively. Continuing with Figure 2-22B, the 1000 m^3 to 2500 m^3 POTENTIAL Oil Loss category with an estimated 0.61% probability of at least one accident in the VTRA Study Area over a 10-year period, one observes that the Guemes, Saddlebag, and Haro-Strait/Boundary Pass waterway zones rank number 1, 2 and 3, respectively. Closing with Figure 2-22A, the 2500 m^3 or more POTENTIAL Oil Loss category with an estimated 0.50% probability of at least one accident in the VTRA Study area over a 10-year period, one observes that the Rosario, Guemes, and Saddlebag waterway zones rank number 1, 2 and 3. Thus, for example, the observation that Haro-Strait/Boundary Pass waterway zone ranks third in both Figure 2-22B and Figure 2-22C explains in part the second ranking in Figure 2-21. Similarly, the observation that the Guemes waterway zone ranks first in Figure 2-22B and a close second in Figure 2-22A explains in part that the Guemes waterway zone ranks first in Figure 2-21 for overall evaluated POTENTIAL Oil Loss in the

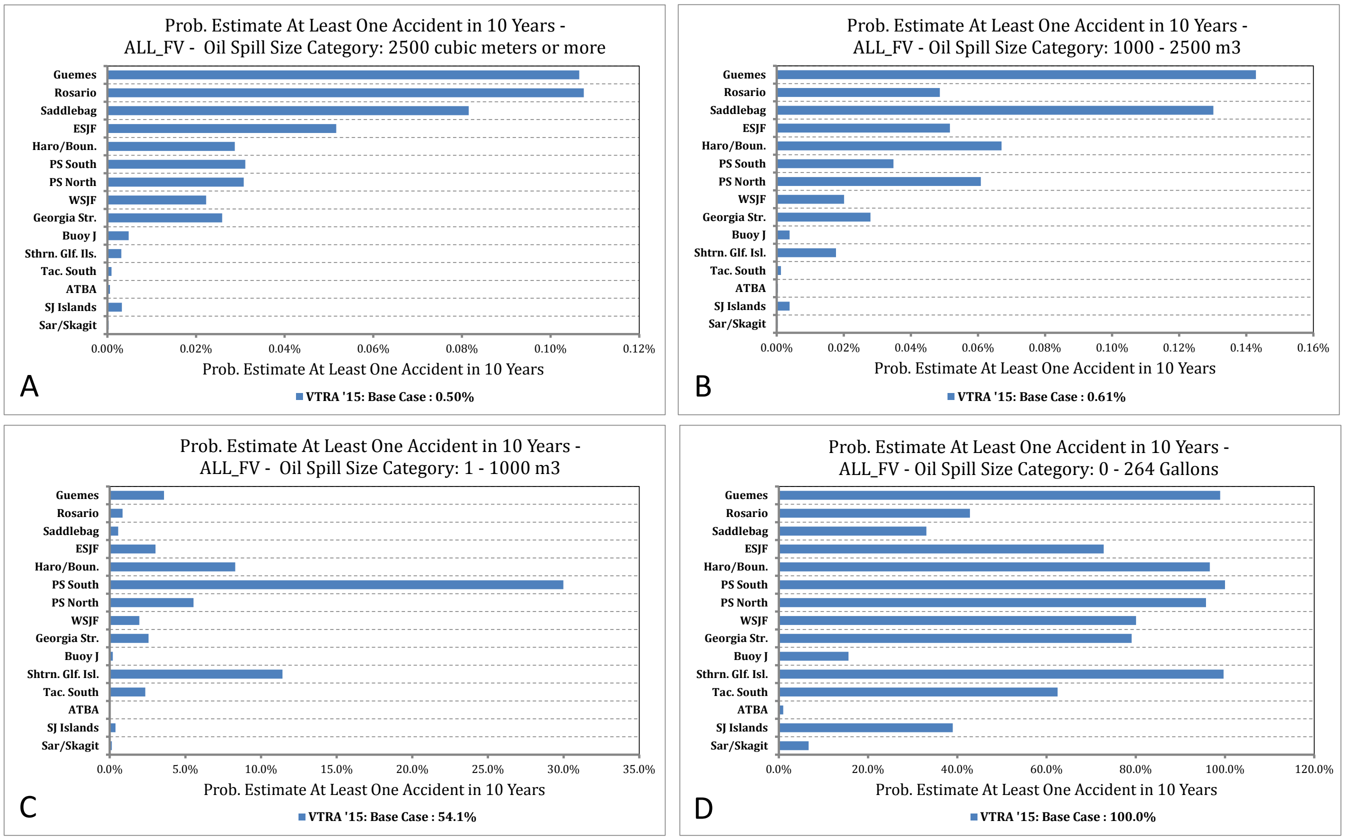

Figure 2-22. Probability estimates of at least one accident in a 10 year period by waterway zone and by POTENTIAL Oil Loss category for the Base Case 2015 Year. A: 2500 m^3 or more B: 1000 m^3 – 2500 m^3 C: 1 m^3-1000 m^3 D: 0 m^3 – 1 m^3

3. WHAT-IF SCENARIO DESCRIPTION AND ANALYSIS RESULTS

The purpose of this vessel traffic risk assessment (VTRA) is to evaluate the combined POTENTIAL changes in risk in light of a number of maritime terminal development projects, in various stages of their permitting processes, potentially coming to fruition and to inform the State of Washington, the United States Coast Guard, the Puget Sound Harbor Safety Committee, tribes, local governments, industry, non-profit groups in Washington State and British Columbia and other stakeholders in this maritime community. Vessel traffic collision and grounding risks are evaluated for tank focus vessels (oil tankers, chemical carriers, oil barges and articulated tug barges) and cargo focus vessels (bulk carriers, container ships and other cargo vessels) combined in the VTRA 2015 Study in terms of overall POTENTIAL accident frequency and in terms of overall POTENTIAL Oil Losses by VTRA study area and by fifteen waterway zones. Planned maritime terminal development projects were grouped in a manner further described in this chapter to form five What-If Scenarios. Each What-If Focus Scenario involved adding cargo focus vessels and tanks focus vessels to a maritime risk simulation model (The VTRA 2015 Model) representing the Base Case 2015 Scenario. Subsequently, the VTRA model evaluates POTENTIAL risk changes in terms of POTENTIAL Exposure, POTENTIAL Accident Frequency and POTENTIAL Oil Loss for the VTRA Study Area as a whole and by 15 VTRA waterway zones depicted in Figure E-2. The following five What-If Scenarios were modeled in this study and evaluated for potential risk increases from the Base Case 2015 Scenario:

(1) **US232:** A collection of terminal projects adding an estimated 232 focus vessels (32 tankers, 197 ATBs and 2 bulk carriers) to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 232 vessels travelling predominantly through US Waters.

(2) **KM348:** The Westridge Marine Terminal/Kinder Morgan pipeline expansion project adding an estimated 348 tankers to the VTRA 2015 modeled Base Case 2015 Scenario traffic.

(3) **CA1020:** A collection of terminal projects adding an estimated 1020 focus vessels (629 bulk carriers, 368 container ships and 23 tankers) to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 1020 vessels travelling predominantly through Canadian (CA) Waters.

(4) **USKMCA1600:** The combination of US232, KM348 and CA1020 What-If Scenarios (632 bulk carriers, 368 container ships, 403 tankers and 197 ATBs) while these 1600 focus vessels travel through US and Canadian (CA) Waters.

(5) **USKMCALN2250:** The combination of USKMCA1600 with a collection of terminal projects adding an additional estimated 650 LNG vessels to the VTRA 2015 modeled Base Case 2015 Scenario traffic while predominantly travelling through Canadian Waters. **The VTRA 2015 Model, however, <u>does not</u> contain a model for the potential consequences of an accident with an LNG Tanker. Thus, LNG Tankers for the purposes of the VTRA 2015**

study are minimally modeled for traffic impact as cargo focus vessels only. Hence, risk metrics evaluated for the USKMCALN2250 What-If Scenario ought to be considered lower bounds of those risk metrics.

Bunkering support for the various terminal projects was also modeled in the VTRA 2015 What-If Scenarios. Specifically, 49, 17, 111, 177 and 207 bunker trips were added as part of the US232, KM348, CA1020, USKMCA1600 and USKMCALN2250 What-If Scenario descriptions, respectively. Thus the number at the end of each What-If Scenario descriptor reflects the total number of focus vessels that are added to the Base Case Scenario, while excluding from that number the bunkering support numbers for those What-If Scenarios. In other words, the total number of focus vessels, since oil barges are part of the focus vessel group, is higher than the ending number of the What-If Scenario descriptors above.

Four of the five above What-if Scenarios were compiled by the VTRA 2015 Working Group from their selected maritime development projects, specifically the US232, KM348, USKMCA1600 and USKMLN2250 What-If Scenarios above. The CA1020 What-If Scenario analysis is included in this report by GW/VCU since the US232, KM348 and the CA1020 What-If Scenarios together combine to form the USKMCA1600 What-If Scenario. It is worthwhile to note that there is about a 10-fold difference or more in the number of tankers and ATBs that are being added to the US232 (32 tankers and 197 ATBs) and KM348 (348 tankers) What-if Scenarios on the one hand and the CA1020 What-If Scenarios (23 tankers) on the other hand. That being said, the CA1020 What-If Scenario adds about 997 cargo focus vessels; whereas the KM348 What-If Scenario adds no cargo focus vessels and the US233 scenario only adds 2 bulk carriers. Summarizing, the portfolio of focus vessels added to the 2015 Base Scenario for the What-if Scenario CA1020 is quite different from the portfolio of focus vessels added to the Base Case 2015 Scenario for the US232 and the KM348 What-If Scenarios. Moreover, the CA1020 What-If Scenario adds about 4.4 times (=1020/232) as many focus vessels as the US232 What-if Scenario, not including the added bunkering operations in this 4.4 factor, and about 2.9 times (=1020/348) as many focus vessels as the KM348 What-If Scenario, not including the added bunkering operations in this 2.9 factor.

The combined evaluated POTENTIAL risk changes serve as an information source to these stakeholders as to what the POTENTIAL risk changes might be, should some or all of the terminal projects represented in the four What-If Scenario come to fruition, rather than individually evaluated POTENTIAL risk changes by terminal project[1]. Evaluated risk changes are evaluated by the combined focus vessel group in the VTRA 2015 Study in terms of percent changes or relative multipliers from the Base Case 2015 Scenario combined analysis results and therefore are not

[1] The exception being the KM348 What-If Scenario which deals only with the Westridge Marine Terminal/Kinder Morgan pipeline expansion project.

evaluated as percent changes or relative multipliers applicable to an individual analysis obtained, were one to have focused on a particular focus vessel member type within that focus vessel group (which may be more typical when evaluating relative POTENTIAL risk changes when focusing on an individual maritime terminal project potentially coming to fruition). The combined evaluated POTENTIAL risk changes for the What-If Scenarios above are decomposed by POTENTIAL Oil Loss changes for POTENTIAL accidents with POTENTIAL Oil Loss in the following four categories::

A. 2500 m^3 or more of POTENTIAL Oil Losses
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses

The information about POTENTIAL risk changes in terms of overall POTENTIAL Oil Loss and their distribution across the four POTENTIAL Oil Loss Categories above, should some or all of the terminal projects represented in the five What-If Scenarios come to fruition, may serve as a useful information source in the selection of a portfolio of risk mitigation measures that attempts to address a particular or all POTENTIAL oil loss categories.

Description of the four What-If Scenarios and their ingredient terminal development projects

A VTRA 2015 Working Group (see, Figure E-1) selected the maritime terminal development projects to be included in the above five What-If Scenarios. The maritime terminal projects that are represented within these What-If Scenarios are:

1. Vancouver Airport Fuel Consortium Project (12 Tankers, 36 ATBs)
2. Tacoma Anacortes Upgrade (18 Tankers, 42 ATBs)
3. Westway Project (119 ATBs)
4. Columbia River Bunkering (3 Bulk Carriers, 2 Tankers)
5. Westridge Marine Terminal/Kinder Morgan pipeline expansion project (348 Tankers)
6. Pacific Coast Terminal Expansion (23 Tankers, 44 Bulk Carriers)
7. Global Holdings Grain Export (200 Bulk Carriers)
8. Vitara Pacific Elevators Project (85 Bulk Carriers)
9. Centerm (65 Container Ships)
10. Other BC Expansion Projects (300 Bulk Carriers, 303 Container Ships) updated from the VTRA 2010 What-If Case S which included Deltaport, Westshore, Neptune, Fraser Surrey Docks/Texada and Richardson Grain expansion projects.
11. Discovery LNG Project (366 LNG vessels modeled as cargo vessels for traffic impact only)
12. Island Gas LNG Project (122 LNG vessels modeled as cargo vessels for traffic impact only)
13. Westpac LNG Project (122 LNG vessels modeled as cargo vessels for traffic impact only)
14. Woodfibre LNG Project (40 LNG vessels modeled as cargo vessels traffic impact only)

The specific number of focus vessels to be added should a POTENTIAL maritime terminal project coming to fruition, was provided by the VTRA 2015 Working Group. The grouping of maritime terminal projects into five What-If Scenarios and the number of cargo focus vessels, tank focus vessels and bunkering support to be added to the Base Case 2015 Scenario model, are depicted in Figure 3-1. Four of the five What-if Scenarios were compiled from the selected maritime development projecta BOVE by the VTRA 2015 Working Group, specifically the US232, KM348, USKMCA1600 and USKMLN2250 What-If Scenarios. The CA1020 What-If Scenario was added by GW/VCU in this report since the US232, KM348 and the CA1020 What-If Scenario combine to form the USKMCA1600 Scenario. While the Vancouver Airport Fuel Consortium (VAPFC) is included in the description of US232 What-If Scenario, the VAPFC What-If focus vessels are Canadian bound travelling predominantly through US waters.

A What-If Scenario : US232

ANACORTES TO VANCOUVER	TOTAL
Tankers (VAFC)	12
ATB (VAFC)	36
OIL BARGE Bunkering Support	0
BUOY J TO ANACORTES	**TOTAL**
Tankers (TAU Xylene)	18
ATB (TAU Xylene)	42
OIL BARGE Bunkering Support (ANAC - PORT ANGELES)	2
OIL BARGE Bunkering Support (SEATTLE TO ANAC)	6
BUOY J TO ANACORTES	**TOTAL**
ATB (WW) - BUOY J to BP	42
ATB (WW) - BUOY J to FERNDALE	19
ATB (WW) - BUOY J to ANACORTES	50
ATB (WW) - BUOY J to TACOMA	8
OIL BARGE Bunkering Support (SEATTLE TO ANAC)	37
OIL BARGE Bunkering Support (SEATTLE to TACOMA)	3
BUOY J TO PORT ANGELES	**TOTAL**
Bulk Carriers (CRB)	3
Tankers (CRB)	2
OIL BARGE Bunkering Support (ANAC to PORT ANGELES)	2
	VTRA 2015
TOTAL WHATIF - US PROJECTS (without Bunkering)	232
TOTAL BUNKERING SUPPORT - US PROJECTS	50
TOTAL WHAT-IF FOCUS VESSELS	282

VAPFC = Vancouver Airport Fuel Consortium

TAU = Tacoma Anacortes Upgrade

WW = Westway

CRB = Columbia River Bunkering

B What-If Scenario : KM348

CASE KM 348	TOTAL
Tankers (WRT)	348
Bunkering Support (WRT)	17
TOTAL WHAT-IF FOCUS VESSELS	365

KM = Kinder Morgan
WRT = Westridge Terminal

C What-If Scenario : CA1020

BUOY J TO VANCOUVER VIA HARO/BOUNDARY PASS	TOTAL
Tankers (PCT - Canola)	23
Bulk Carriers (G3 + PCT + VPE + OBC)	586
Container Ships (Centerm)	65
OIL BARGE Bunkering Support (CHPT To Vancouver)	54
BUOY J TO DELTA PORT VIA HARO/BOUNDARY PASS	**TOTAL**
Bulk Carriers (Case DP)	43
Container Ships (Case DP)	303
OIL BARGE Bunkering Support (CHPT To Vancouver)	57
	VTRA 2015
TOTAL CARGO FV WHATIF - CA PROJECTS (without Bunkering)	997
TOTAL TANK FV WHATIF - CA PROJECTS (without Bunkering)	23
TOTAL FV WHATIF - CA PROJECTS (without Bunkering)	1020
TOTAL BUNKERING SUPPORT - CA PROJECTS	111
TOTAL WHAT-IF FOCUS VESSELS	1131

PCT = Pacific Coast Terminal

G3 = Global Holdings Grain Export

VPE = Vitara Pacific Elevators

OBC = Other British Columbia Project (Updated from VTRA 2010 Case S)

DP = Delta Port

D What-If Scenario : USKMCA1600

	VTRA 2015
TOTAL WHATIF - CA PROJECTS (without Bunkering)	1020
TOTAL WHATIF - KM (without Bunkering)	348
TOTAL WHATIF - US PROJECTS (without Bunkering)	232
SUBTOTAL WHAT-IF (without Bunkering)	1600
TOTAL BUNKERING SUPPORT - CA PROJECTS	111
TOTAL BUNKERING SUPPORT - KM	17
TOTAL BUNKERING SUPPORT - US PROJECTS	49
SUBTOTAL Bunkering Support	177
TOTAL WHAT-IF FOCUS VESSELS	1777

E What-If Scenario : USKMCALN2250

BUOY J TO VANCOUVER VIA HARO/BOUNDARY PASS	TOTAL
LNG (D) - Modeled as Cargo FV	366
LNG (IG) - Modeled as Cargo FV	122
LNG (WP) - Modeled as Cargo FV	122
LNG (WF) - Modeled as Cargo FV	40
OIL BARGE Bunkering Support (CHPT To Vancouver)	29
	VTRA 2015
TOTAL WHATIF - LNG PROJECTS (without Bunkering)	650
TOTAL WHATIF - CA PROJECTS (without Bunkering)	1020
TOTAL WHATIF - KM (without Bunkering)	348
TOTAL WHATIF - US PROJECTS (without Bunkering)	232
SUBTOTAL WHAT-IF (without Bunkering)	2250
TOTAL BUNKERING SUPPORT - LNG PROJECTS	29
TOTAL BUNKERING SUPPORT - CA PROJECTS	111
TOTAL BUNKERING SUPPORT - KM	17
TOTAL BUNKERING SUPPORT - US PROJECTS	50
SUBTOTAL Bunkering Support	207
TOTAL WHAT-IF FOCUS VESSELS	2457

D = Discovery

IG = Island Gas

WP = WestPac

WF = WoodFibre

Figure 3-1.Terminal projects included in the four What-If Scenarios with bunkering support. A: US232, B: KM348, C: CA1020, D: USKMCA1600, E: USKMCALN2250.

The inclusion of the terminal projects above in the five What-If Scenarios above ought by no means to be interpreted as to imply that these terminal projects may come to fruition. Rather, the inclusion of these terminal projects in the VTRA 2015 study ought to be seen as being part of a

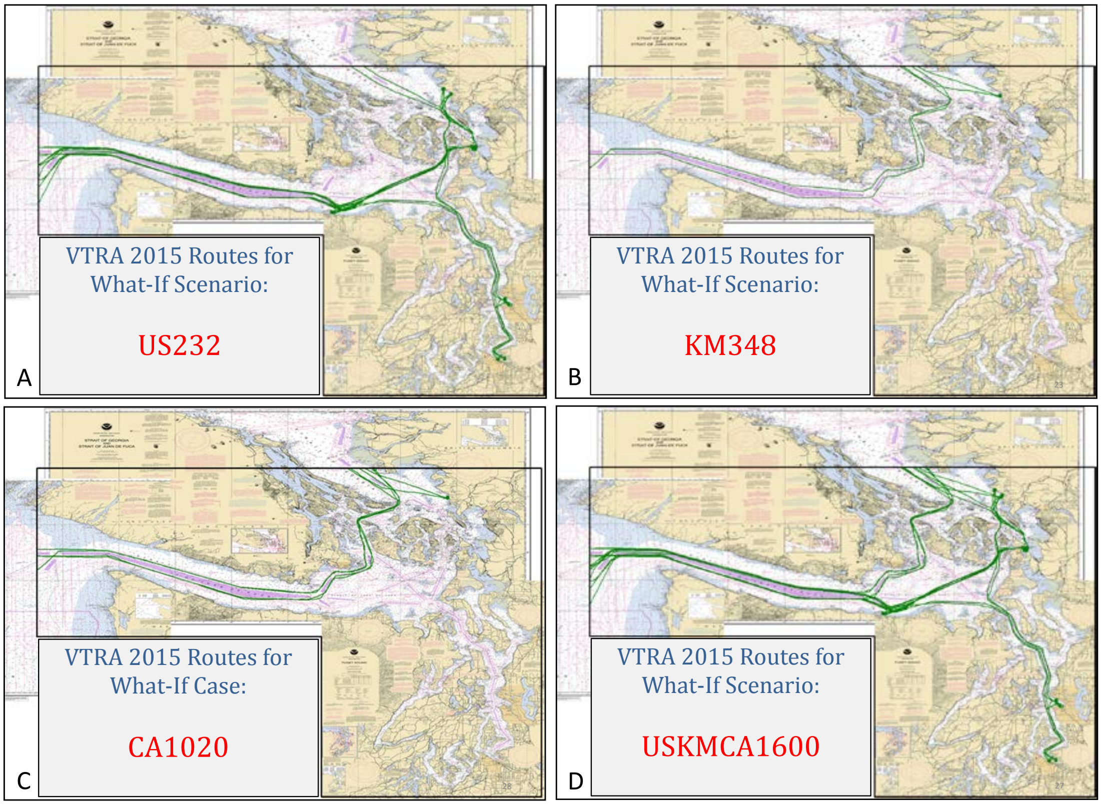

Figure 3-2. Modeled focus vessel routes for the Four What-If Scenario with bunkering support. A: US232, B: KM348, C: USKMCA1600, D: USKMCALN2250.

safety culture being practiced in this maritime community over many years of which the formation of the Puget Sound Harbor Safety Committee back in 1997 and its bi-monthly held meetings since then is a prime example.

The specific routes for the US232, KM348, CA1020 and USKMCA1600 What-If Scenarios modeled in the VTRA 2015 model are depicted in Figure 3-2 above. The routes for the USKMCALN2250 What-If Scenario are the same as those modeled for the USKMCA1600 What-If Scenario. The routes for the five What-If Scenarios were selected from existing focus vessel routes available in the VTRA 2010 Model and with the guidance of the VTRA 2015 working group. The descriptor for a What-If Scenario is also chosen to reflect the predominant location of these focus vessel routes. For example, comparing Figure 3-2A with Figure 3-2C one observe that the focus vessels in the US232 What-If Scenario travel predominantly through US waters, whereas the focus vessels in the CA1020 What-If Scenario travel predominantly though Canadian waters. Laden assumptions for tank focus vessels associated with these terminal projects were the same as those for tank focus vessels represented in the VTRA 2010 analysis (see, [21]), with the exception of the Westway project where ATBs are assumed to be laden inbound and un-laden outbound.

The arrival process that was modeled in the VTRA 2015 analysis for the five modeled What-If Scenario is another distinguishing feature between the VTRA 2010 model and the VTRA 2015 model. Whereas in the VTRA 2010 arrivals were modeled equidistant in time ensuring a certain number of focus vessels arriving per year, the arrival pattern in the VTRA 2015 model are modeled at random arrival times. The difference between the VTRA 2010 arrival process and the VTRA 2015 random arrival process is graphically depicted in Figure 2-16.

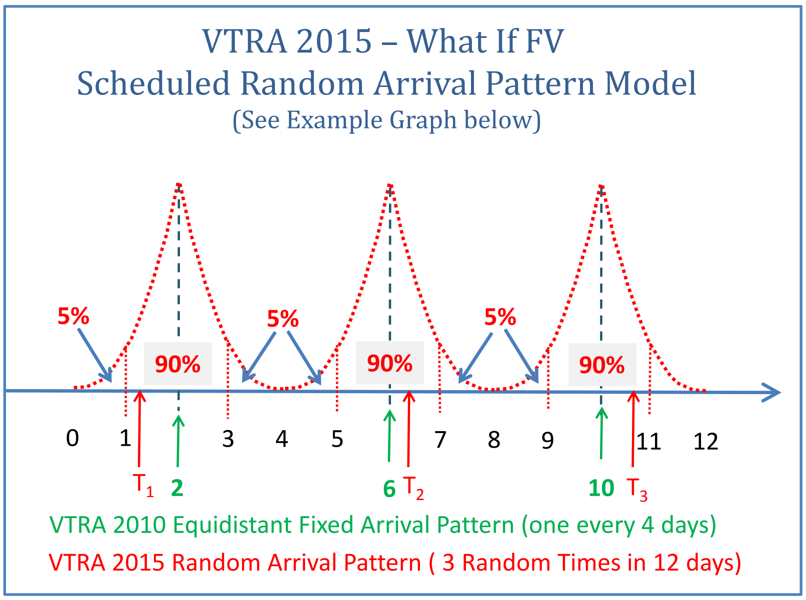

Figure 3-3. Scheduled random arrival pattern for What-If focus vessels in the VTRA 2015 model.

The example depicted in Figure 2-16 provides with green arrows a hypothetical equidistant arrival process of one arrival every four days, which is the arrival process modeled in the VTRA 2010 while ensuring a number of focus vessels per year, whereas the red arrows in Figure 2-16 exemplifies three randomly selected times T_1, T_2 and T_3 over the same 12-day period depicted in Figure 2-16. This random arrival process is referred to as a *scheduled random arrival process* as the most likely values of these random arrival times are set at the fixed scheduled arrival times process of the VTRA 2010 model, as depicted in Figure 2-16, but with a 90% probability of these random arrivals occurring over half the distance in time between equidistant consecutive most likely arrival times while being symmetrically distributed to the left and right of these most likely values. In Figure 2-16, for example, there is a 90% probability of a random arrival in the time periods [1,3], [5,7] and [9,11], whereas the most likely arrival times are depicted at times 4, 6 and 10 in Figure 2-16 at the midpoints of these three time periods, respectively. This choses random arrival process for focus vessels is called a *scheduled random arrival process* since it assures a certain number of focus vessel arrivals per year, but also because these selected random arrival times of What-If focus vessels are set fixed from simulation run to simulation run. In other words, changes evaluated or differences observed in risk metric results between What-If Scenarios that contain a particular maritime terminal project in both, are not a result of these randomly selected, but fixed, arrival times for such a terminal project. In simulation lingo the use of this technique is called a *variance reduction technique* [25].

US232 analysis results

Below the US232 What-If Scenario analysis results are evaluated for potential risk increases from the Base Case 2015 Scenario[2]. A summary description of the US232 What-if Scenario is:

US232: A collection of terminal projects adding an estimated 232 focus vessels (32 tankers, 197 ATBs and 2 bulk carriers) to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 232 focus vessel vessels travelling predominantly through US Waters.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL accident frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was evaluated as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 3-4 one observes that overall for the US232 What-If Scenario about a +32% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area. Figure 3-5 shows that the distribution of this about 132% of POTENTIAL Oil Loss was evaluated for the US232 What-If Scenario as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@72% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@13% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@46% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 132% of POTENTIAL Oil Loss per year for the US232 What-If Scenario (in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the Base Case 2015 Scenario, one observes that of the +32% POTENTIAL Oil Loss increase about +30% is accounted for by the 2500 m^3 or more POTENTIAL

[2] Bunkering support for the various terminal projects was also modeled in the VTRA 2015 What-If Scenarios. Specifically, 49 bunker trips were added as part of the US232 What-If Scenario description.

Oil Loss Category and the close to +2% remainder by the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss and the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss categories.

Figure 3-6 presents the relative increases of the total POTENTIAL Oil Loss evaluated for the US232 Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.32 (green highlight in Figure 3-6) for the VTRA 2015 Study Area as a whole for the US232 What-If Scenario. From Figure 3-6 one observes that the largest relative increase is evaluated by the VTRA 2015 Model in the Guemes waterway zone with a relative multiplicative factor of about 2.07 (red highlight in Figure 3-6) in terms of POTENTIAL Oil loss. Thus, one observes that while overall a relative factor increase is observed of about 1.32 for the VTRA 2015 study area combined, these relative factors can be higher or lower within a particular waterway zone within the VTRA 2015 study area. In other words, the POTENTIAL Oil Loss evaluated in the Base Case 2015 Scenario increases within the Guemes waterway zone by about a relative multiplicative factor of 2.07 in the US232 What-If Scenario. The other waterway zones that experience a higher POTENTIAL Oil loss relative factor increase for the US232 What-If Scenario than the VTRA Study Area are the waterway zones Saddlebag, Buoy J, Rosario and Georgia Strait with relative factors of about 1.59, 1.44, 1.39 and 1.38 (yellow highlights in Figure 3-6), respectively.

Figure 3-7 presents the relative increases of the total POTENTIAL Accident Frequency evaluated for the US232 Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.04 (green highlight in Figure 3-6) for the VTRA 2015 Study Area combined for the US232 What-If Scenario. Thus overall, the VTRA 2015 Model evaluated about $1.04 \times 4.4 \approx 4.6$ number of accidents per year of which now about 102% (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) fall in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category. From Figure 3-7 one observes that the largest relative increase is evaluated by the VTRA 2015 Model in the Guemes and Rosario waterway zones with a relative factor of about 1.22 and 1.11 (red highlights in Figure 3-7), respectively, in terms of POTENTIAL Accident Frequency. Thus, one observes that while overall a relative factor increase is observed of 1.04 for the VTRA 2015 study area as a whole, these relative factors can be higher or lower within a particular waterway zone in the VTRA study area. In other words, the POTENTIAL Accident Frequency evaluated in the Base Case 2015 Scenario increases within the Guemes waterway zone and Rosario Waterway zones by about a factor 1.20 and 1.11, respectively in the US232 What-If Scenario analysis. The other waterway zones that experience a higher POTENTIAL Accident Frequency relative factor increase for the US232 What-If Scenario than the VTRA Study Area, are the waterway zones Saddlebag, Buoy J and Saragota Skagit with relative factors of about 1.08, 1.08, and 1.06 (yellow highlights in Figure 3-7), respectively.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) over a 10-year period. Thus, for example, Figure 3-8 shows an estimated probability[3] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area, of about 0.80%[4]. Recall from Figure 3-5A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 72% (in terms of Base Case 2015 Scenario percentages) of the overall POTENTIAL Oil Loss evaluated for the US232 What-If Scenario (@ ≈ 132%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 0.80% (up by a multiplicative factor of 1.60, green highlight in Figure 3-8, from the same probability evaluated for the Base Case 2015 Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 72% of the overall POTENTIAL Oil Loss (up by a factor 1.7 from POTENTIAL Oil loss evaluated for 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the US232 What-If Scenario (which was evaluated at about 132% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to more than half of the POTENTIAL Oil Loss evaluated for the US232 What-If Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 3-8 for the US232 What-If Scenario, one observes a relative factor increase 2.59 (red highlight in Figure 3-8) for the Guemes waterway zone for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period for this particular waterway zone. Other waterway zones that experience about the same or higher relative factors for these probabilities as compared to the VTRA Study area, are the waterway zones Buoy J, Saddlebag and Georgia Strait with relative factors 1.76, 1.74 and 1.59, respectively.

Similar observations can be made from Figure 3-9, Figure 3-10 and Figure 3-11 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3, respectively. While about 0% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the US232 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-11 at about 100%. In other words, it is estimated that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will likely happen within the VTRA Study Area within a 10-year period. While about a 13% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (up by close to +1% from the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the US232

[3] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f}\times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[4] A 1% probability equals to a probability of 1 in 100.

What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-9 at about 0.66%. Finally, while about a 46% POTENTIAL Oil Loss contribution is evaluated for 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (about the same percentage as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the US232 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-10 at about 54.2% (about the same percentage as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category).

As was the case for Figure 3-8, red highlights shows the largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-9, Figure 3-10 and Figure 3-11. Yellow highlights shows the next largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-9, Figure 3-10 and Figure 3-11. Figure 3-12, Figure 3-13, Figure 3-14 and Figure 3-15 provide estimated average spill size per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the US232 What-if Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 3-9, Figure 3-10 and Figure 3-11 in the manner it was described above for Figure 3-8, but also the summary table for the US232 What-If Scenario comparison to the Base Case 2015 Scenario in Appendix D. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 0.80% for the US232 What-If Scenario, a value of 0.08% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 1.98% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

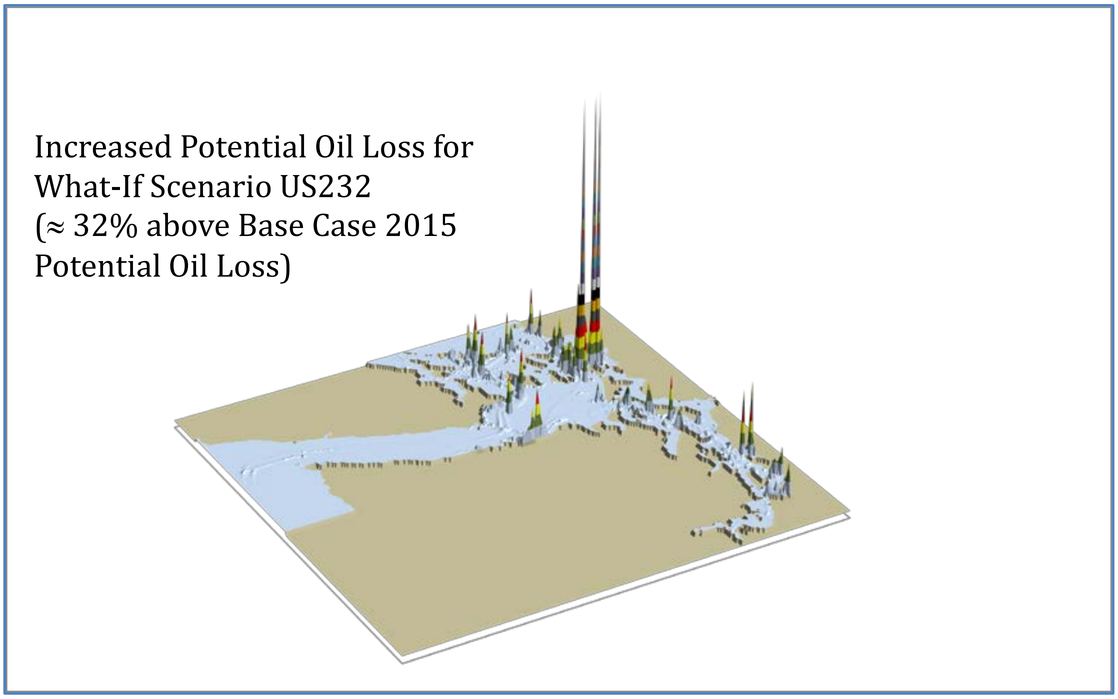

Figure 3-4. 3D Geographic profile of POTENTIAL oil loss for What-If Scenario US232 .

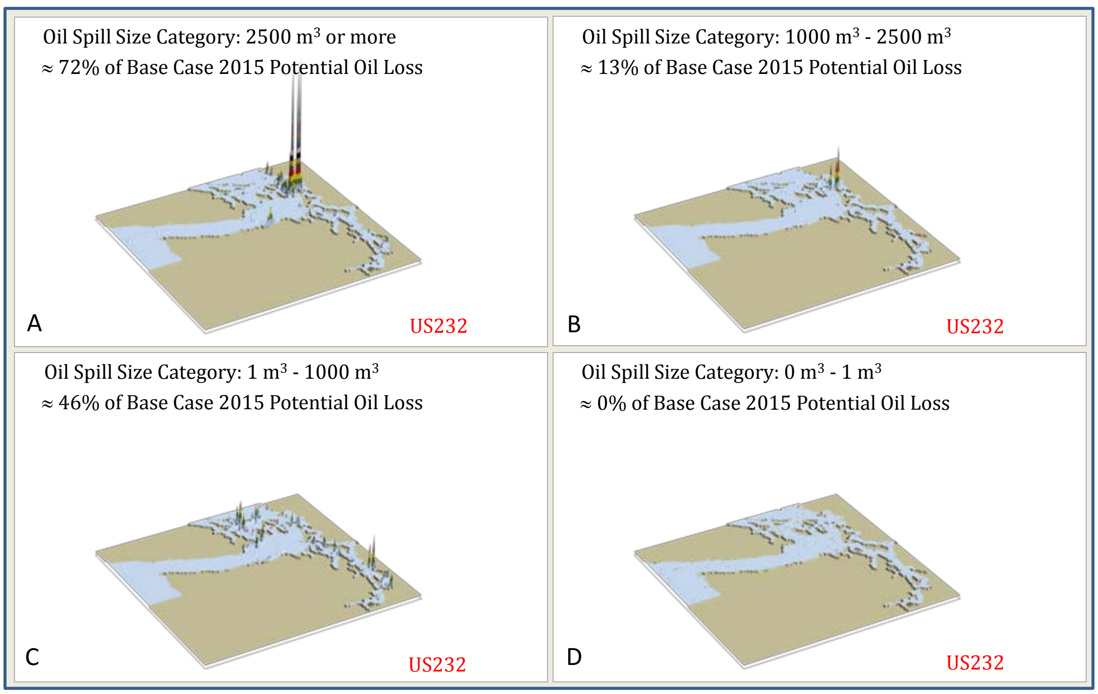

Figure 3-5. Components of 3D Geographic profile of US232 What-If Scenario POTENTIAL oil loss. A: 72% in Oil Spill Size Category of 2500 m^3 or more; B: 13% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 46% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 0% in Oil Spill Size Category of 0 m^3 -1 m^3

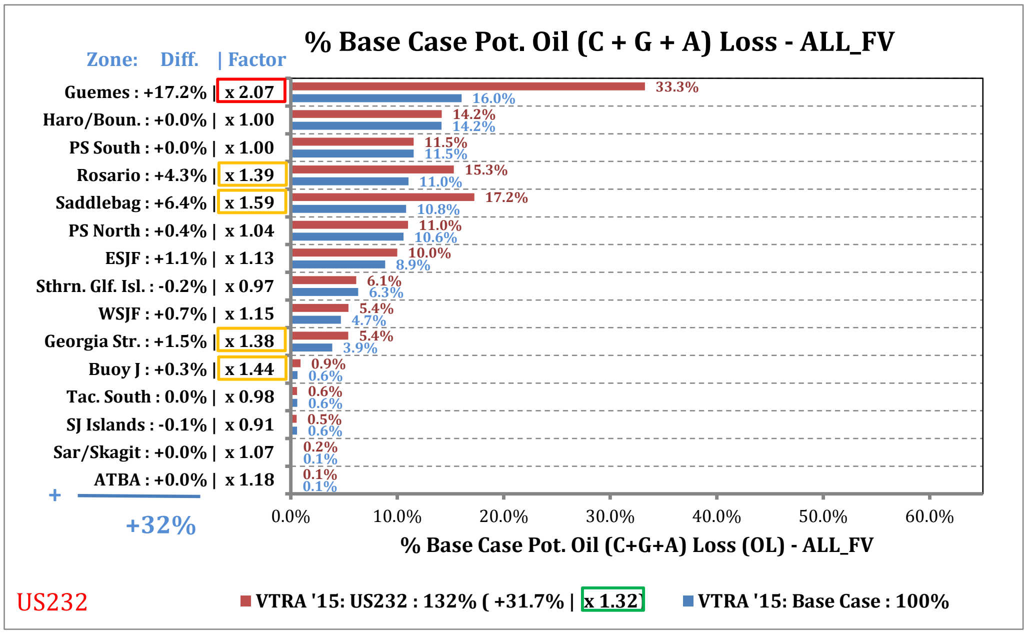

Figure 3-6. Relative comparison of POTENTIAL Oil Loss by waterway zone. Blue bars show the percentages by waterway zone for the Base Case 2015 Scenario, red bars show the percentages for What-If Scenario US232 both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

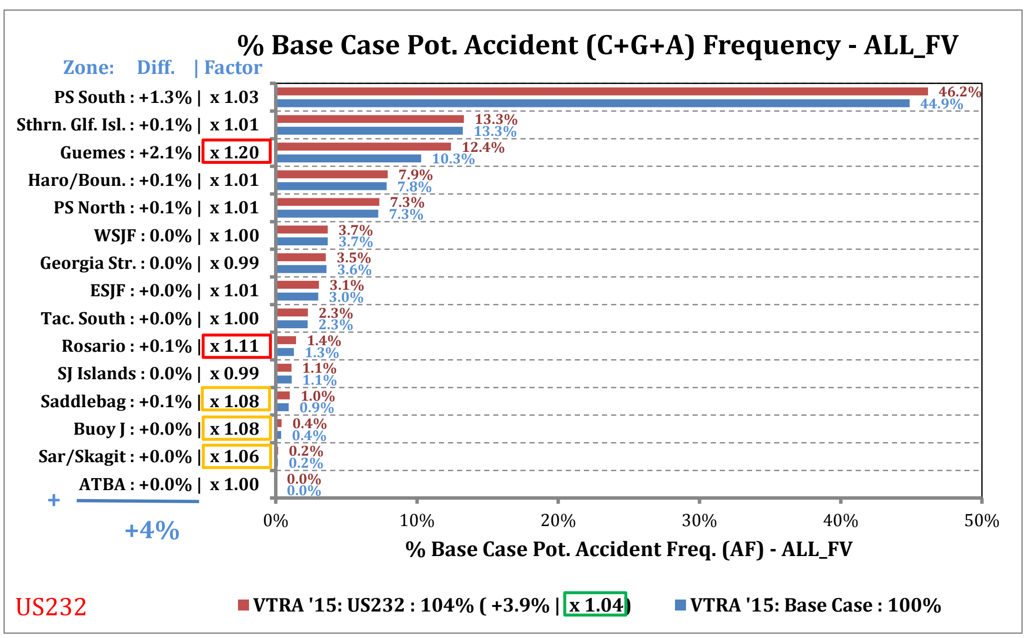

Figure 3-7. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Blue bars show the percentages by waterway zone for the Base Case 2015 Scenario, red bars show the percentages for What-If Scenario US232 both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

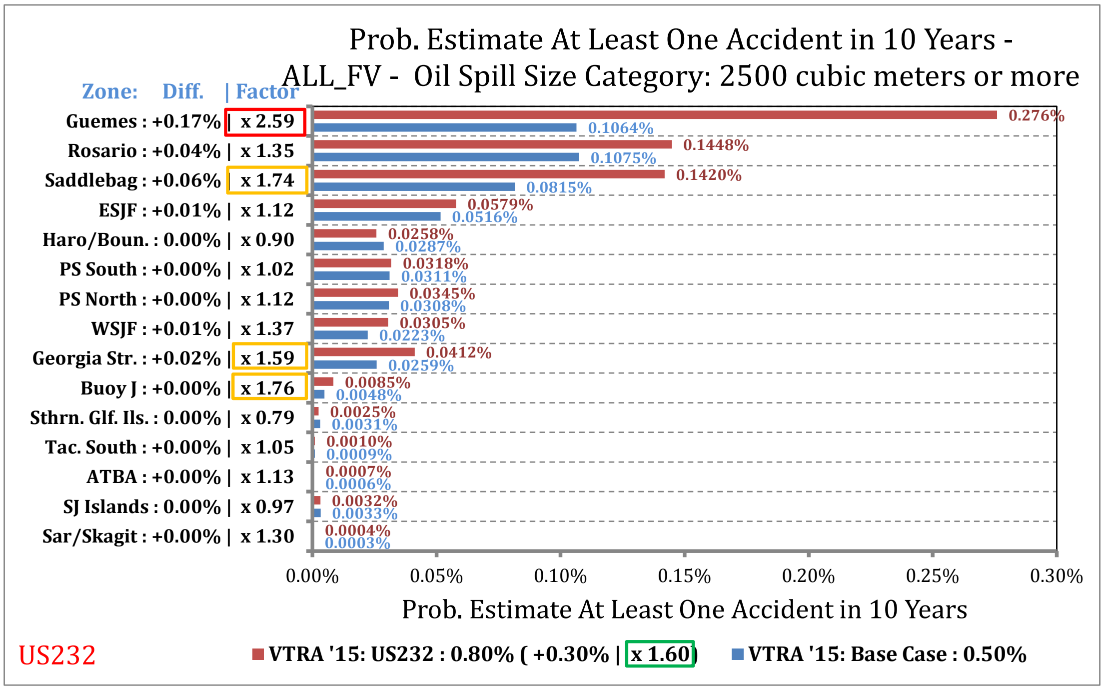

Figure 3-8. US232 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

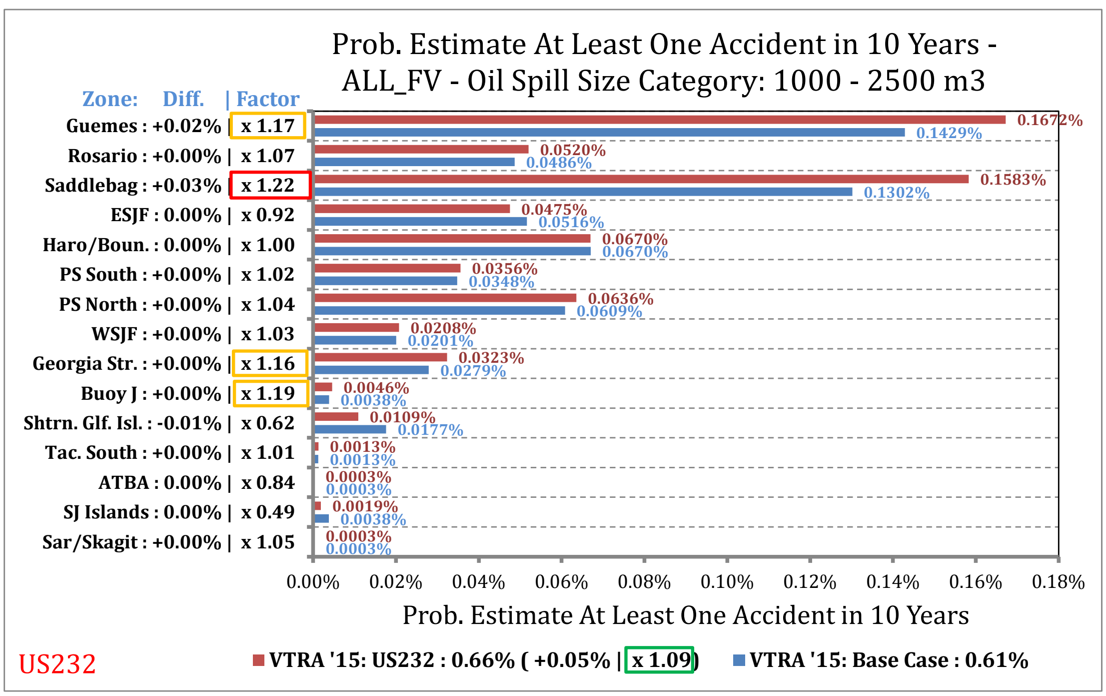

Figure 3-9. US232 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

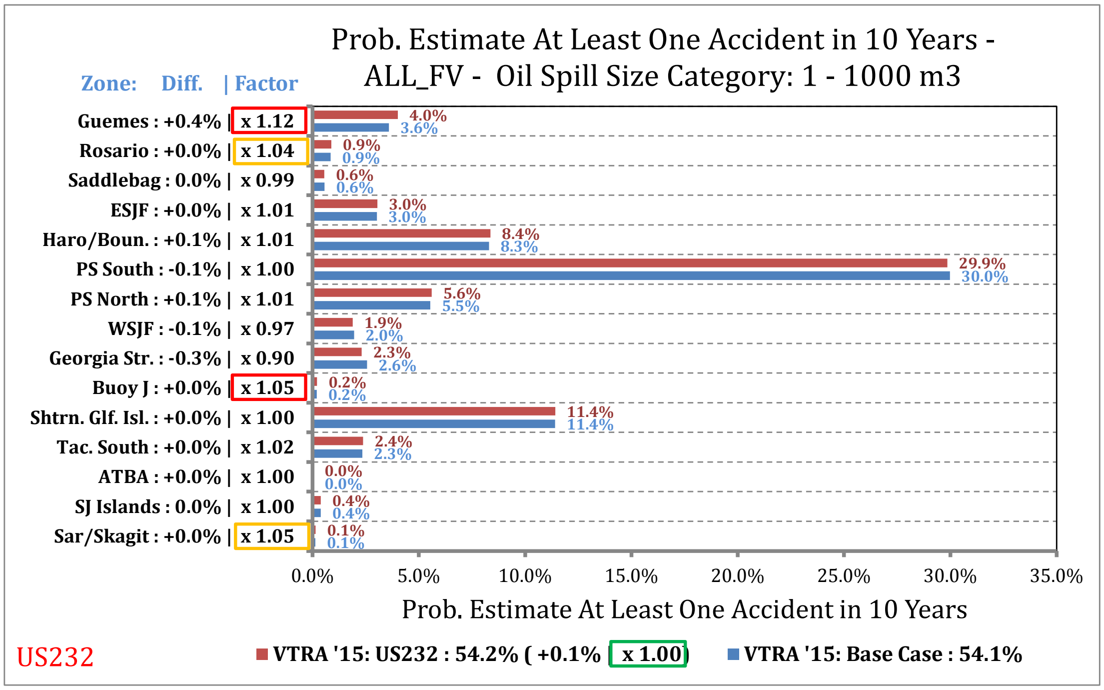

Figure 3-10. US232 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

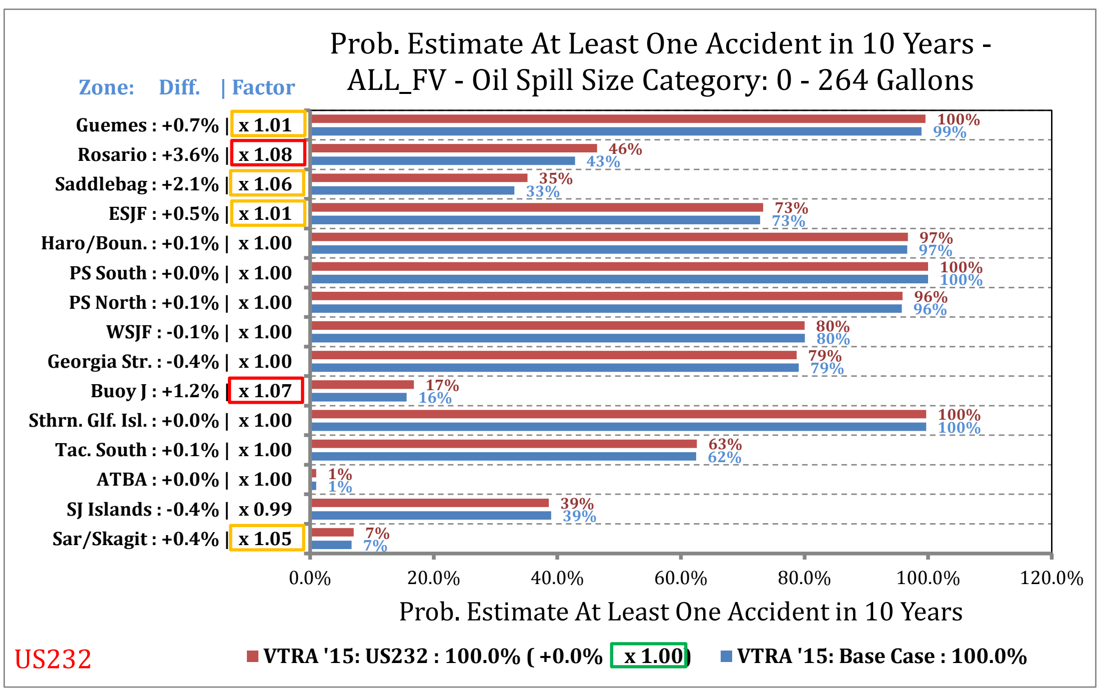

Figure 3-11. US232 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

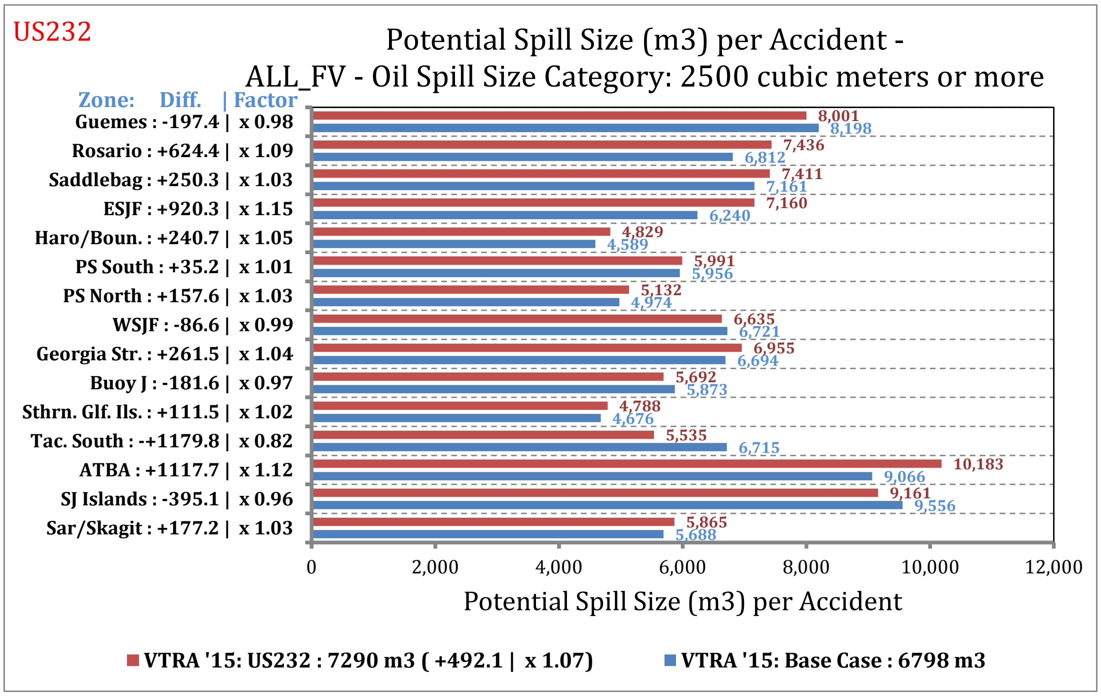

Figure 3-12. US232 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

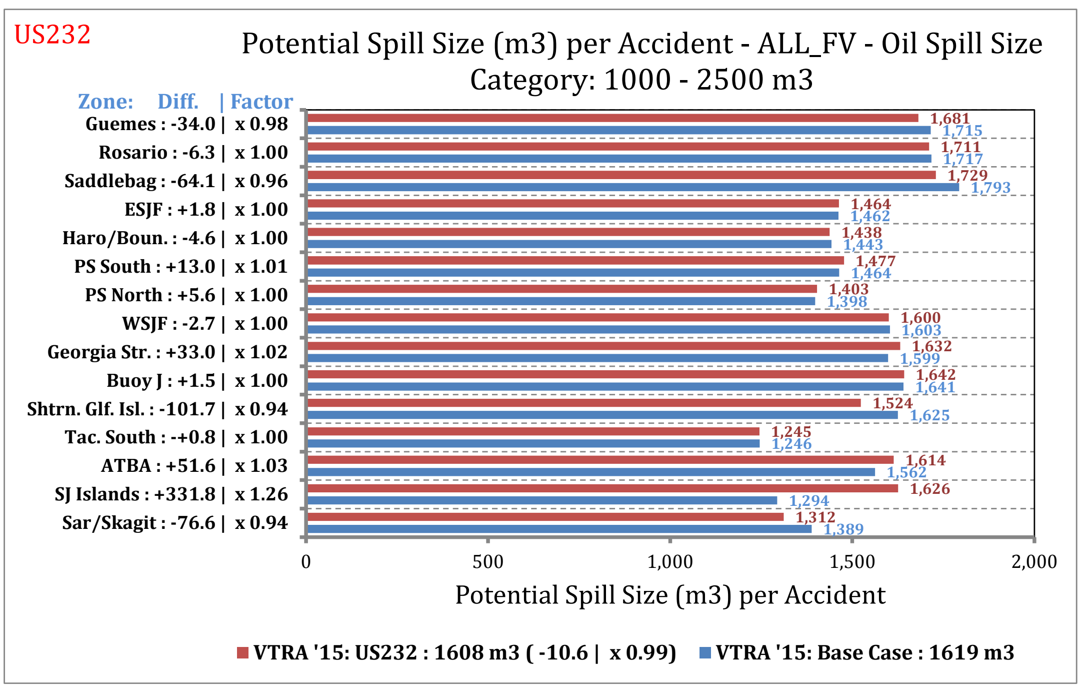

Figure 3-13. US232 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

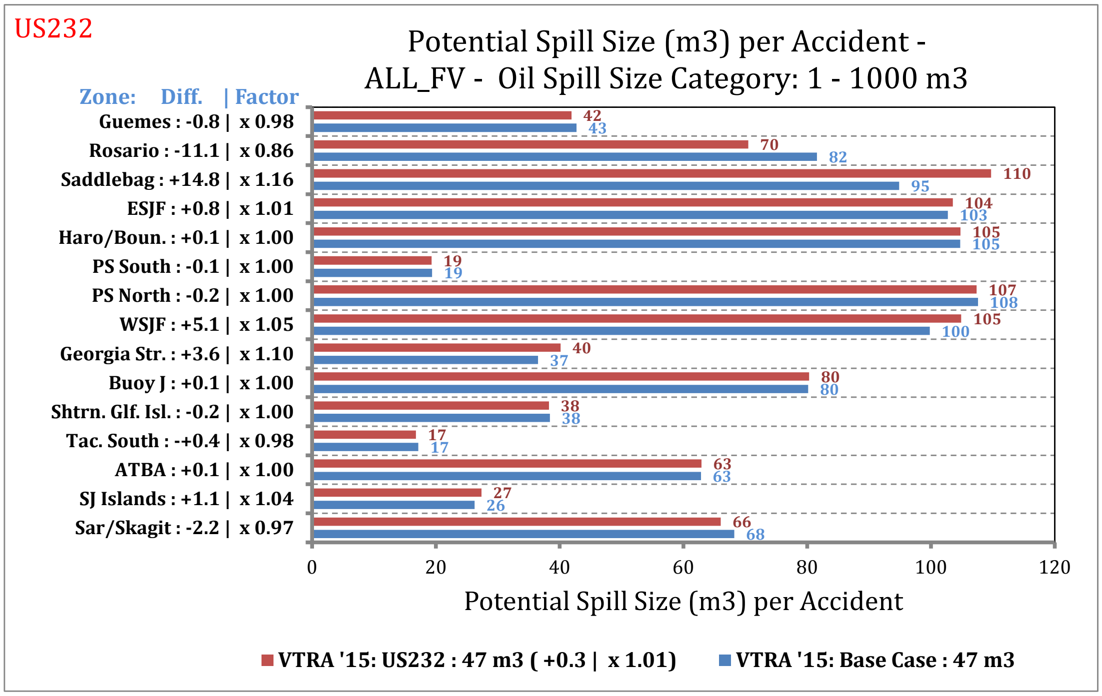

Figure 3-14. US232 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

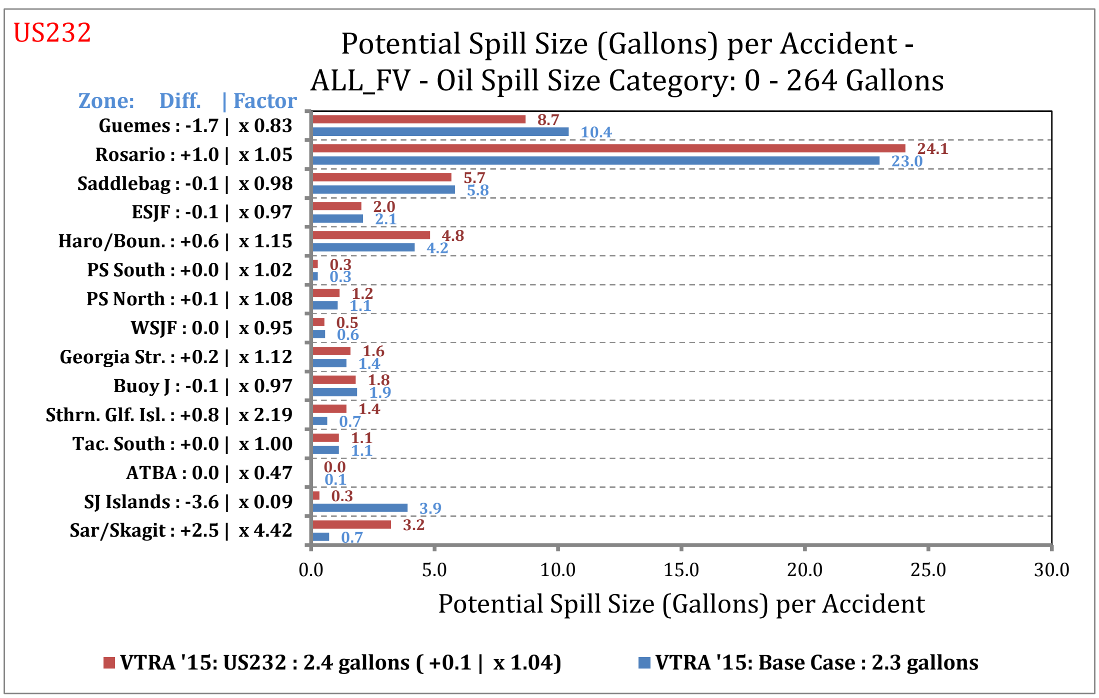

Figure 3-15. US232 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

KM348 analysis results

Below the KM348 What-If Scenario analysis results are evaluated for potential risk increases from the Base Case 2015 Scenario[5]. A summary description of the KM348 What-if Scenario is:

KM348: The Westridge Marine Terminal/Kinder Morgan pipeline expansion project adding an estimated 348 tankers to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 348 focus vessels travelling predominantly through Canadian (CA) Waters.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL accident frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was evaluated as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 3-16 one observes that overall for the KM348 What-If Scenario about a +21% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area. Figure 3-17 shows that the distribution of this about 121% of POTENTIAL Oil Loss was evaluated for the KM348 What-If Scenario as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@57% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@18% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@46% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 121% of POTENTIAL Oil Losses per year for the KM348 What-If Scenario (in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the Base Case 2015 Scenario one observes that of the +21% POTENTIAL Oil Loss increase about +15% is accounted for by the 2500 m^3 or

[5] Bunkering support for the various terminal projects was also modeled in the VTRA 2015 What-If Scenarios. Specifically, 17 bunker trips were added as part of the KM348 What-If Scenario descriptions.

more POTENTIAL Oil Loss Category, close to +6% by the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category, and nearly +1% is accounted for by the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category.

Figure 3-18 presents the relative increases of the total POTENTIAL Oil Loss evaluated for the KM348 Scenario by the fifteen waterway zones in the VTRA 2015 study area. First observe the overall multiplicative factor of 1.21 (green highlight in Figure 3-18) for the VTRA 2015 Study Area as a whole for the KM348 What-If Scenario. From Figure 3-18 one observes that the largest relative increases are evaluated by the VTRA 2015 Model in the Buoy J and Haro-Strait Boundary Pass waterway zones with relative multiplicative factor of about 2.48 and 2.04 (red highlights in Figure 3-18) in terms of POTENTIAL Oil loss. Thus, one observes that while overall a relative factor increase is observed of about 1.21 for the VTRA 2015 study area combined, these relative factors can be higher (or lower) within a particular waterway zone. In other words, the POTENTIAL Oil Loss evaluated in the Base Case 2015 Scenario increases within the Buoy J waterway zone by about a relative multiplicative factor of 2.48 in the KM348 What-If Scenario. Similarly, the POTENTIAL Oil Loss evaluated in the Base Case 2015 Scenario increases within the Haro-Strait Boundary Pass waterway zone by about a multiplicative factor of 2.04 in the KM348 What-If Scenario. The other waterway zones that experience about the same or a higher POTENTIAL Oil loss relative factor increase for the KM348 What-If Scenario than the VTRA Study Area, are the waterway zones East Strait of Juan de Fuca and West Strait of Juan de Fuca with relative factors of about 1.78 and 1.40 (yellow highlights in Figure 3-18), respectively.

Figure 3-19 presents the relative increases of the total POTENTIAL Accident Frequency evaluated for the KM348 Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.01 (green highlight in Figure 3-19) for the VTRA 2015 Study Area combined for the KM348 What-If Scenario. Thus overall, the VTRA 2015 Model evaluated about $1.01 \times 4.4 \approx 4.5$ number of accidents per year of which now (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 99.3% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category. From Figure 3-19 one observes that the largest relative increase is evaluated by the VTRA 2015 Model in the Rosario and Buoy J waterway zones with a relative factor of about 1.14 and 1.10 (red highlights in Figure 3-19), respectively, in terms of POTENTIAL Accident Frequency. What this demonstrates for the VTRA Maritime Transportation System (MTS) is that changes in a particular waterway zone (Haro-Strait/Boundary Pass in this case) may result in changes elsewhere in the VTRA Study area (in this case Rosario Strait) due to timing changes of vessel departures in the VTRA 2015 Model and as a result of POTENTIAL changes in the route that a focus vessel followed originally in the Base Case 2015 Scenario. This could be seen as an unintended consequence of the KM348 What-If Scenario. Summarizing, one observes that while overall a relative factor increase is observed of 1.01 for the VTRA 2015 study area combined, these relative factors can be higher (or lower) within a particular waterway zone. In others words, the POTENTIAL Accident Frequency evaluated in the Base Case 2015 Scenario increases within the

Rosario waterway zone and Buoy J Waterway zones by about a factor 1.14 and 1.10, respectively in the KM348 What-If Scenario. The other waterway zones that experience a higher POTENTIAL Accident Frequency relative factor increase for the KM348 What-If Scenario than the VTRA Study Area are the waterway zones San Juan Islands, Haro-Strait/Boundary Pass, and East Strait of Juan de fuca with relative multiplicative factors of about 1.09, 1.08, and 1.06 (yellow highlights in Figure 3-19), respectively.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) over a 10-year period. Thus, for example, Figure 3-20 shows an estimated probability[6] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area, of about 0.97%[7]. Recall from Figure 3-17A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 57% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for the KM348 What-If Scenario (@ ≈ 121%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 0.97% (up by a multiplicative factor of 1.95, green highlight in Figure 3-20, from the same probability evaluated for the Base Case 2015 Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 57% of the overall POTENTIAL Oil Loss (up by a factor 1.37 from POTENTIAL Oil loss evaluated for 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the KM348 What-If Scenario (which was evaluated overall at about 121% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to about half of the POTENTIAL Oil Loss evaluated for the KM348 What-If Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 3-20 for the KM348 What-If Scenario, one observes a relative multiplicative factor increase of 9.39 and 9.01 (red highlights in Figure 3-20) for the Haro-Strait/Boundary Pass and Southern Gulf Islands waterway zones for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period for these particular waterway zones. Other waterway zones that experience about the same or higher relative factors for these probabilities as compared to the VTRA Study area, are the

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[6] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f} \times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[7] A 1% probability equals to a probability of 1 in 100.

waterway zones East Strait of Juan de Fuca, Buoy J and West Strait of Juan de Fuca with relative multiplicative factors 4.60, 2.98 and 2.00, respectively.

Similar observations can be made from Figure 3-21, Figure 3-22, and Figure 3-23 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3, respectively. While close to 0% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the KM348 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-23 at about 100%. In other words, it is estimated that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will likely happen within the VTRA Study Area within a 10-year period. While about an 18% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (up by close to +6% from the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the KM348 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-21 at about 0.83%. Finally, while about a 46% POTENTIAL Oil Loss contribution is evaluated for 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (up by nearly +1% increase as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the KM348 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-22 at about 54.0% (about the same percentage as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category).

As was the case for Figure 3-20, red highlights shows the largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-21, Figure 3-22, and Figure 3-23. Yellow highlights shows the next largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-21, Figure 3-22, and Figure 3-23. Figure 3-24, Figure 3-25, Figure 3-26 and Figure 3-27 provide estimated average spill size per accident for the four POTENTIAL Oil Loss Categories for the VTRA study area and by waterway zone. Appendix D provides a summary table of by VTRA study area relative comparisons from the Base Case 2015 Scenario analysis to the KM348 What-if Scenario analysis for the different risk metrics evaluated/estimated in the VTRA 2015 study area. We encourage the readers to study in more detail the results in Figure 3-21, Figure 3-22, and Figure 3-23 in the manner it was described above for Figure 3-20, but also the summary table for the KM348 What-If Scenario comparison to the Base Case 2015 Scenario in Appendix D. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 0.97% for the

US232 What-If Scenario, a value of 0.10% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 2.41% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

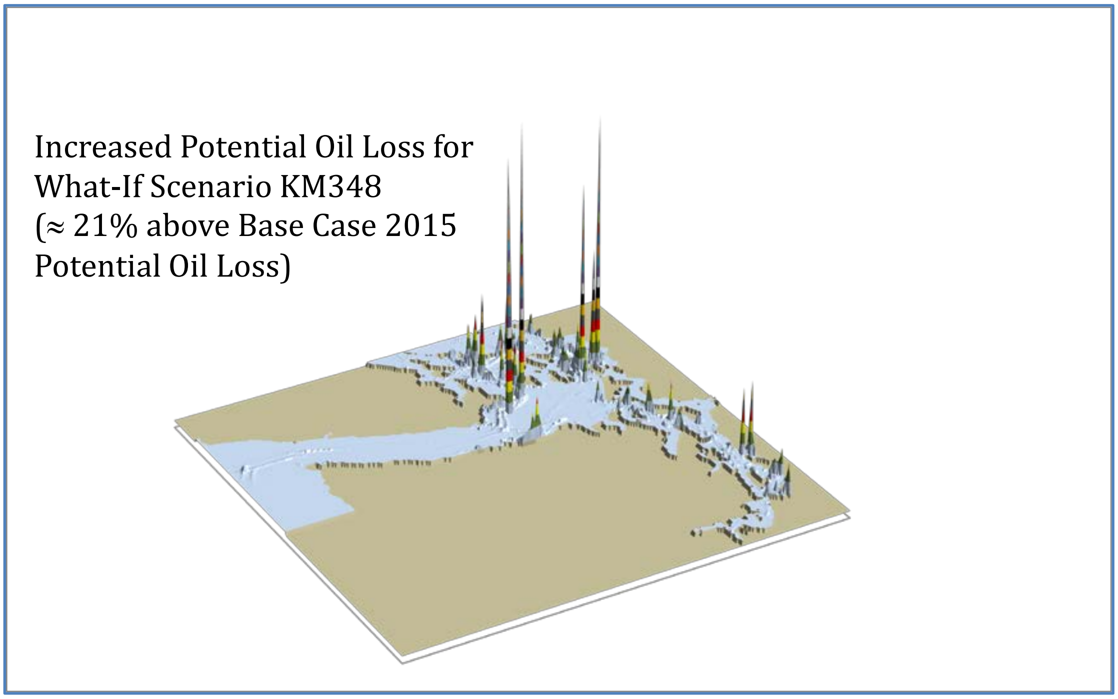

Figure 3-16. 3D Geographic profile of POTENTIAL oil loss for What-If Scenario KM348.

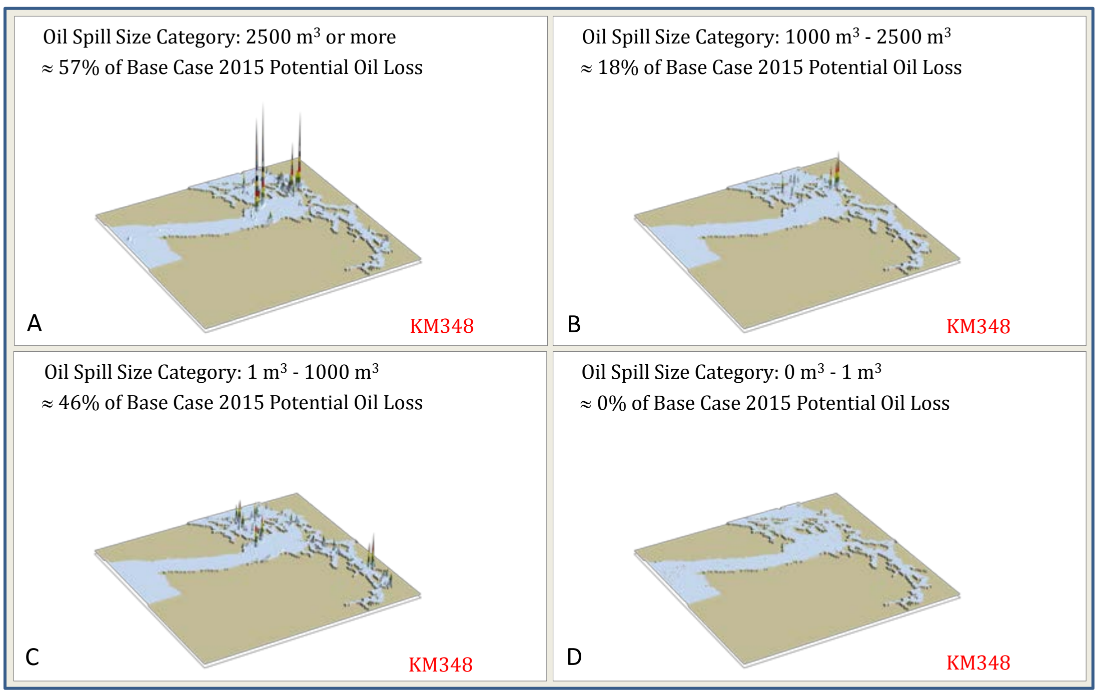

Figure 3-17. Components of 3D Geographic profile of KM348 What-If Scenario POTENTIAL oil loss. A: 57% in Oil Spill Size Category of 2500 m^3 or more; B: 18% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 46% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 0% in Oil Spill Size Category of 0 m^3 -1 m^3

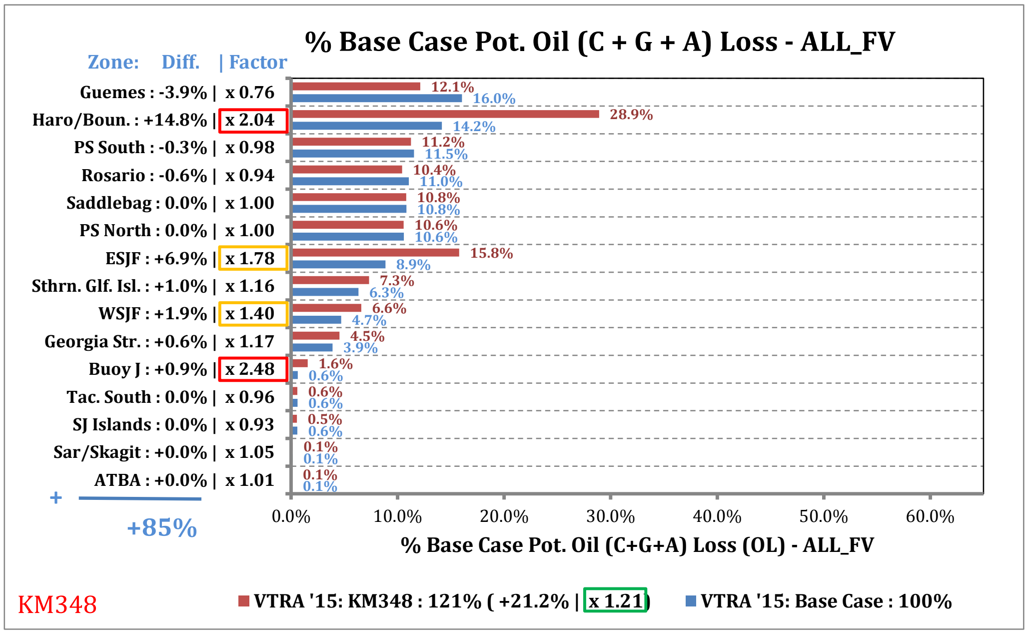

Figure 3-18. Relative comparison of POTENTIAL Oil Loss by waterway zone. Blue bars show the percentage by waterway zone for the Base Case 2015 Scenario, red bars show the percentage for What-If Scenario KM348 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

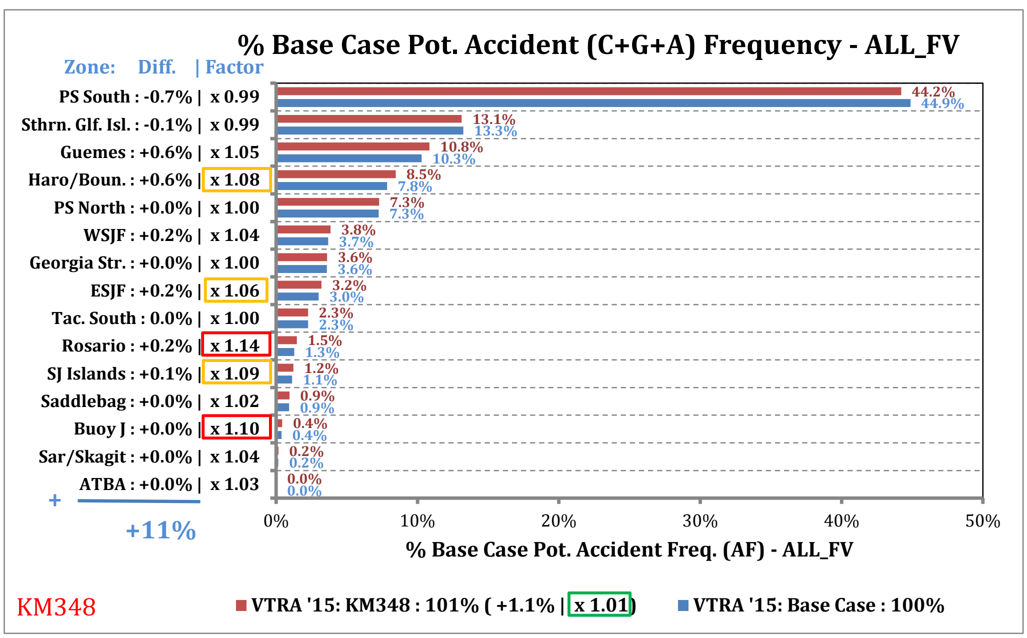

Figure 3-19. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Blue bars show the percentage by waterway zone for the Base Case 2015 Scenario, red bars show the percentage for What-If Scenario KM348 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

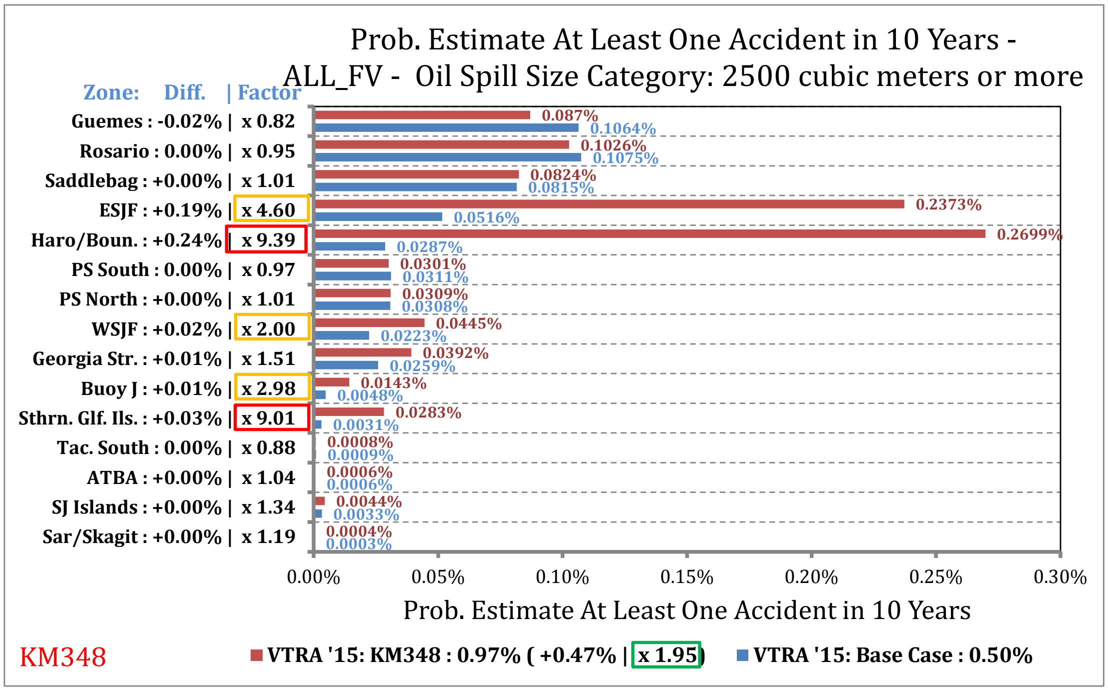

Figure 3-20. KM348 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

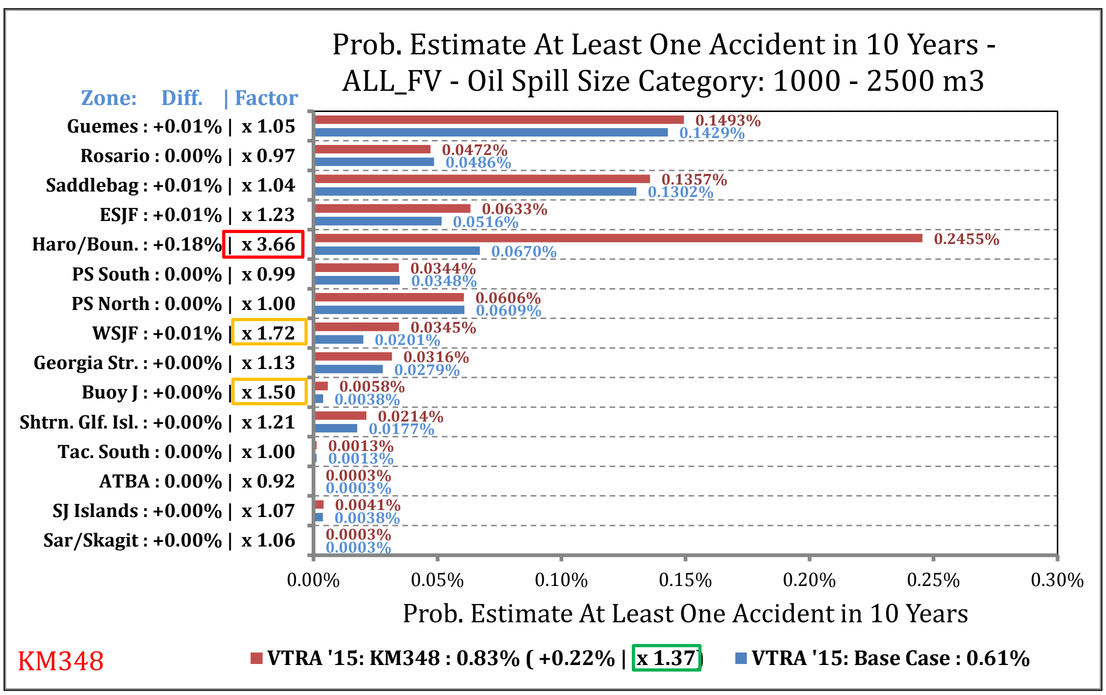

Figure 3-21. KM348 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

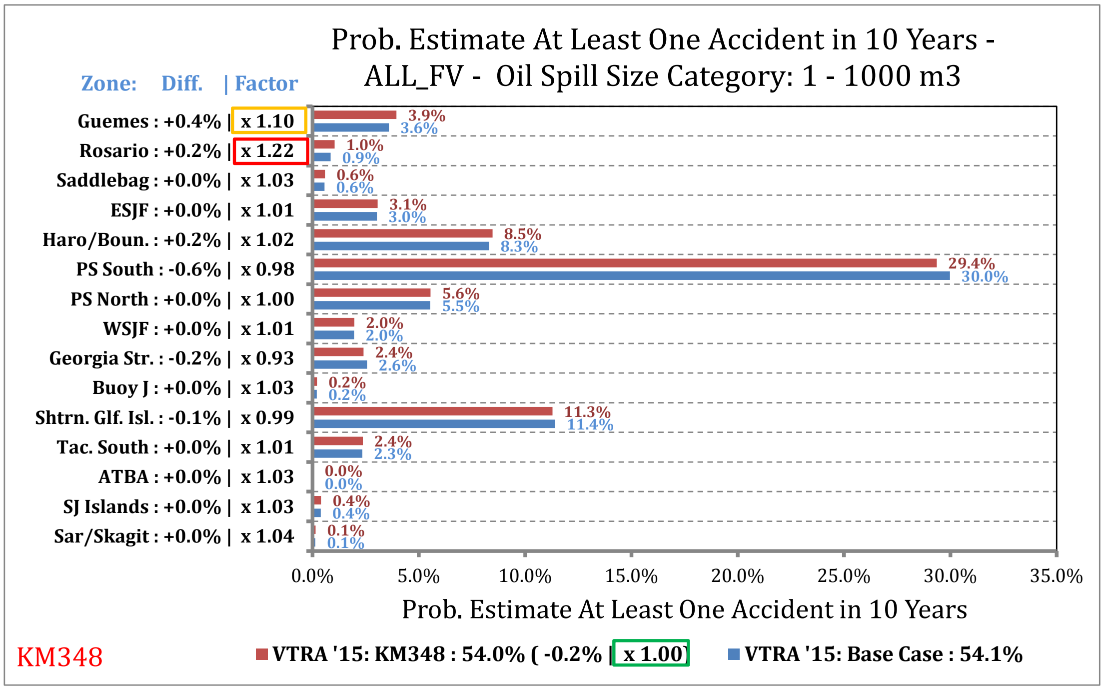

Figure 3-22. KM348 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

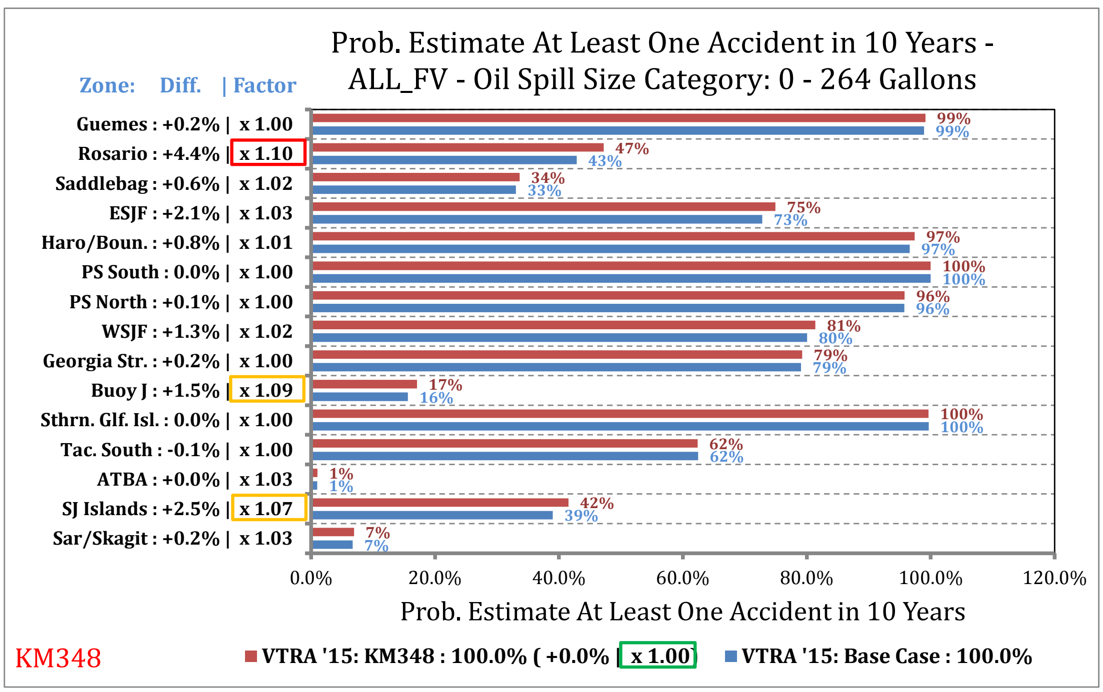

Figure 3-23. KM348 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

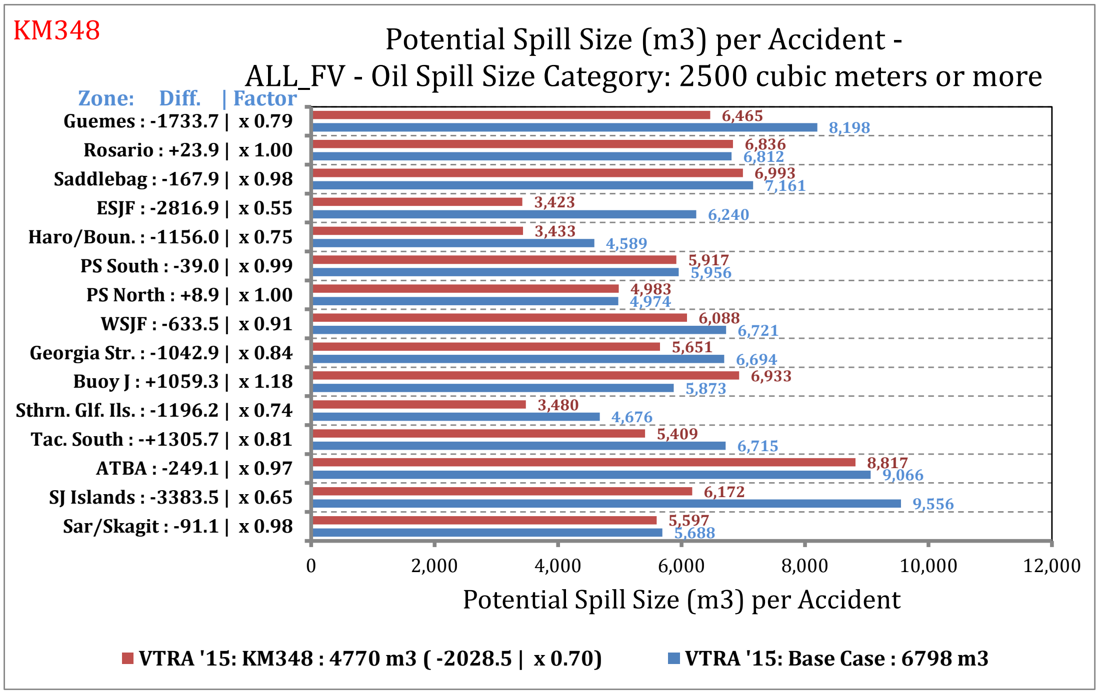

Figure 3-24. KM348 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

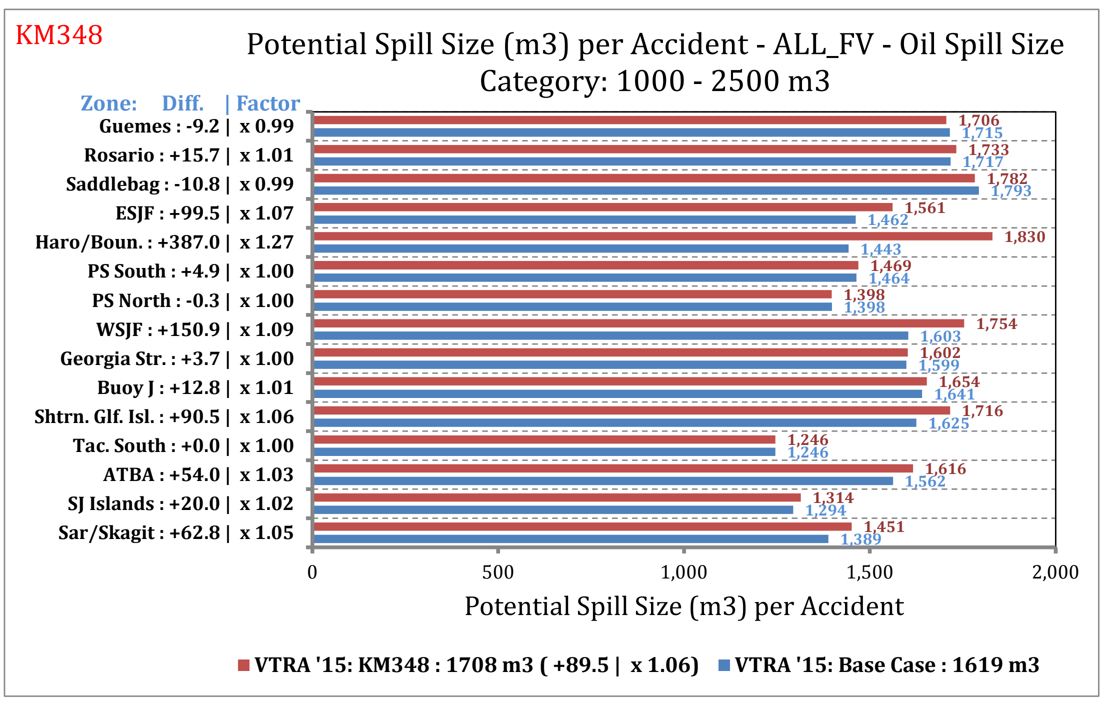

Figure 3-25. KM348 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

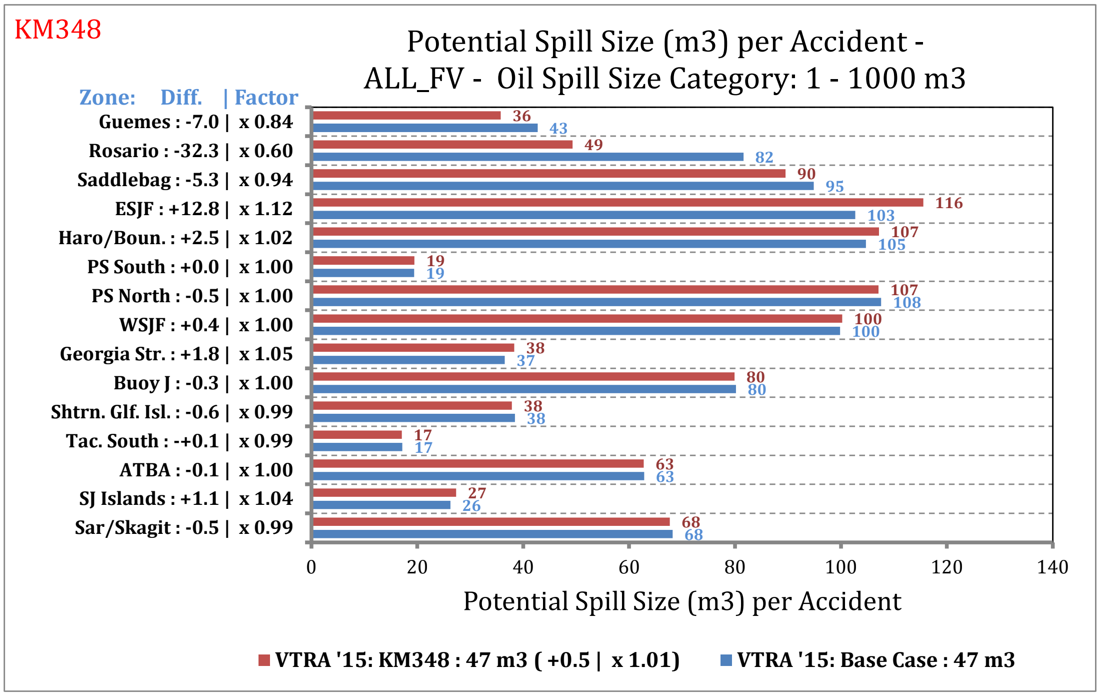

Figure 3-26. KM348 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

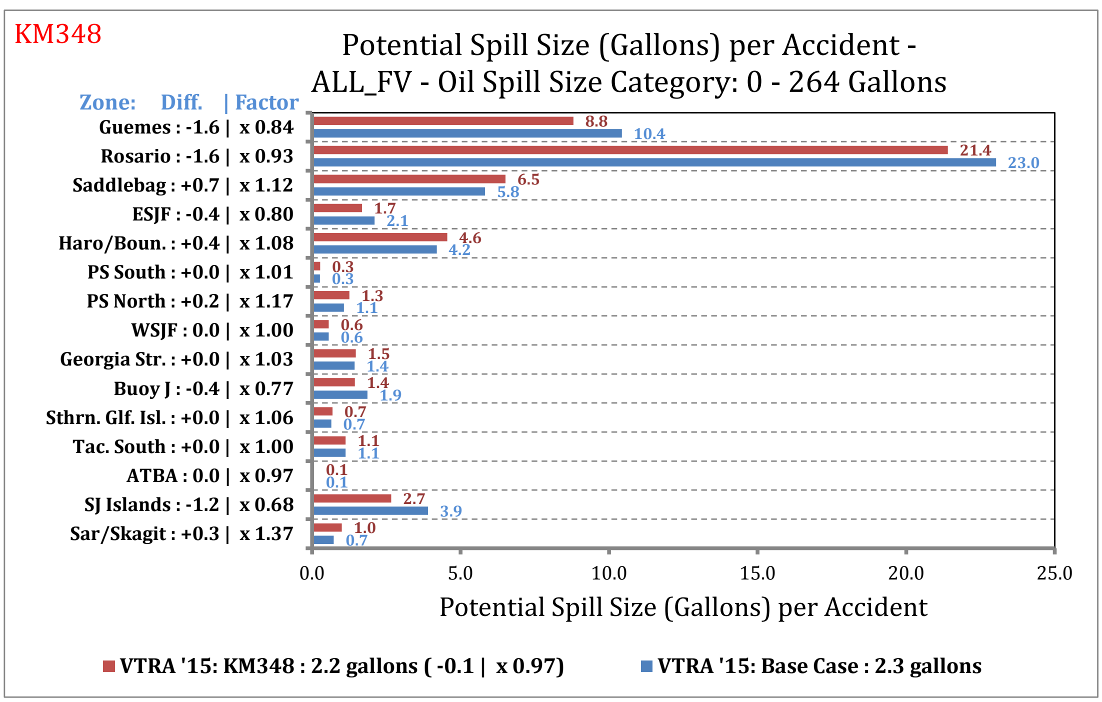

Figure 3-27. KM348 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

CA1020 analysis results

Below the CA1020 What-If Scenario analysis results are evaluated for potential risk increases from the Base Case 2015 Scenario[8]. A summary description of the CA1020 What-if Scenario is:

CA1020: A collection of terminal projects adding an estimated 1020 focus vessels (629 bulk carriers, 368 container ships and 23 tankers) to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 1020 focus vessels travelling predominantly through Canadian (CA) Waters.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL accident frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was evaluated as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 3-28Figure 3-40 one observes that overall for the CA1020 What-If Scenario about a +27% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area. Figure 3-29 shows that the distribution of this about 127% of POTENTIAL Oil Loss was evaluated for the CA1020 What-If Scenario as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@41% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@14% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@71% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 127% total POTENTIAL Oil Loss per year for the CA1020 What-If Scenario (in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the Base Case 2015 Scenario one observes that of the +27% POTENTIAL Oil Loss increase about +26% is accounted for by for by the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category. POTENTIAL Oil Loss in the 2500 m^3 or more POTENTIAL Oil Loss Category remained about the same showing a decrease by less than 1%, while the 1000

[8] Bunkering support for the various terminal projects was also modeled in the VTRA 2015 What-If Scenarios. Specifically, 111 bunker trips were added as part of the CA1020 What-If Scenario descriptions, respectively.

m^3 - 2500 m^3 POTENTIAL Oil Loss category experienced about a +2% increase and a less than +1% remainder is accounted for by an increase in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category.

Figure 3-30 presents the relative increases of the total POTENTIAL Oil Loss evaluated for the CA1020 Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.27 (green highlight in Figure 3-30) for the VTRA 2015 Study Area combined for the CA1020 What-If Scenario. From Figure 3-30 one observes that the largest relative increase is evaluated by the VTRA 2015 Model in the Haro-Strait/Boundary Pass waterway zone with a relative multiplicative factor of about 2.37 (red highlight in Figure 3-30) in terms of POTENTIAL Oil loss. Thus, one observes that while overall a relative factor increase is observed of about 1.27 for the VTRA 2015 study area combined, relative factors can be higher (or lower) within a particular waterway zone in the VTRA study area. In other words, the POTENTIAL Oil Loss evaluated in the Base Case 2015 Scenario increases within the Haro-Strait/Boundary Pass waterway zone by about a relative multiplicative factor of 2.37 in the CA1020 What-If Scenario. The other waterway zones that experience about the same or a higher POTENTIAL Oil loss relative factor increases for the CA1020 What-If Scenario than the VTRA Study Area are the waterway zones Buoy J, East Strait of Juan de Fuca and West Strait of Juan de Fuca with relative factors of about 1.71, 1.69 and 1.42 (yellow highlights in Figure 3-30), respectively.

Figure 3-31 presents the relative increases of the total POTENTIAL Accident Frequency evaluated for the CA1020 Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.07 (green highlight in Figure 3-31) for the VTRA 2015 study area combined for the CA1020 What-If Scenario. Thus overall, the VTRA 2015 Model evaluated about $1.07 \times 4.4 \approx 4.7$ number of accidents per year of which now (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 105% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category. From Figure 3-31 one observes that the largest relative increase is evaluated by the VTRA 2015 Model in the Haro-Strait/Boundary Pass and Buoy J waterway zones with relative multiplicative factors of about 1.54 and 1.51 (red highlights in Figure 3-31), respectively, in terms of POTENTIAL Accident Frequency. Thus, one observes that while overall a relative factor increase is observed of 1.07 for the VTRA 2015 study area combined, these relative factors can be higher (or lower) within a particular waterway zone. In other words, the POTENTIAL Accident Frequency evaluated in the Base Case 2015 Scenario increases within the Haro-Strait/Boundary Pass and Buoy J waterway zones by about a factor 1.54 and 1.51, respectively in the CA1020 What-If Scenario. The other waterway zones that experience a higher POTENTIAL Accident Frequency relative factor increase for the CA1020 What-If Scenario than the VTRA Study Area are the waterway zones East Strait of Juan de Fuca, West Strait of Juan de Fuca with relative factors of about 1.31 and 1.23 (yellow highlights in Figure 3-31), respectively.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) over a 10-year period. Thus, for example, Figure 3-32 shows an estimated probability[9] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area, of about 0.55%[10]. Recall from Figure 3-29A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 41% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for the CA1020 What-If Scenario (@ ≈ 127%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 0.55% (up by a multiplicative factor of 1.10, green highlight in Figure 3-32, from the same probability evaluated for the Base Case 2015 Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 41% of the overall POTENTIAL Oil Loss (up by a factor 1.10 from POTENTIAL Oil loss evaluated for 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the CA1020 What-If Scenario (which was evaluated at about 127% in total in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to about a third of the POTENTIAL Oil Loss evaluated for the CA1020 What-If Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 3-32 for the CA1020 What-If Scenario, one observes a relative factor increase of about 2.30 and 1.68 (red highlights in Figure 3-44) for the Haro-Strait/Boundary Pass and Buoy J waterway zones for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period for this particular waterway zones. Other waterway zones that experience higher relative factors for these probabilities as compared to the VTRA Study area, are the waterway zones West Strait of Juan de Fuca and East Strait of Juan de Fuca with estimated relative factors 1.41 and 1.23, respectively.

Similar observations can be made from Figure 3-33, Figure 3-34 and Figure 3-35 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3, respectively. While about 1% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the CA1020 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-35 at about 100%. In other words, it is estimated that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will likely

[9] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f}\times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[10] A 1% probability equals to a probability of 1 in 100.

happen within the VTRA Study Area within a 10-year period. While about a 14% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (up by close to +2% from the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the CA1020 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period in the VTRA study area is estimated in Figure 3-33 at about 0.67%. Finally, while about a 71% POTENTIAL Oil Loss contribution is evaluated for 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (over a +26% increase as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the CA1020 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-34 at about 56.9% (nearly a +3% percentage increase as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category).

As was the case for Figure 3-32, red highlights shows the largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-33, Figure 3-34 and Figure 3-35. Yellow highlights shows the next largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-33, Figure 3-34 and Figure 3-35. Figure 3-36, Figure 3-37, Figure 3-38 and Figure 3-39 provide estimated average spill size per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the CA1020 What-if Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 3-33, Figure 3-34 and Figure 3-35 in the manner it was described above for Figure 3-32, but also the summary table for the CA1020 What-If Scenario comparison to the Base Case 2015 Scenario in Appendix D. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 0.55% for the CA1020 What-If Scenario, a value of 0.05% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 1.37% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

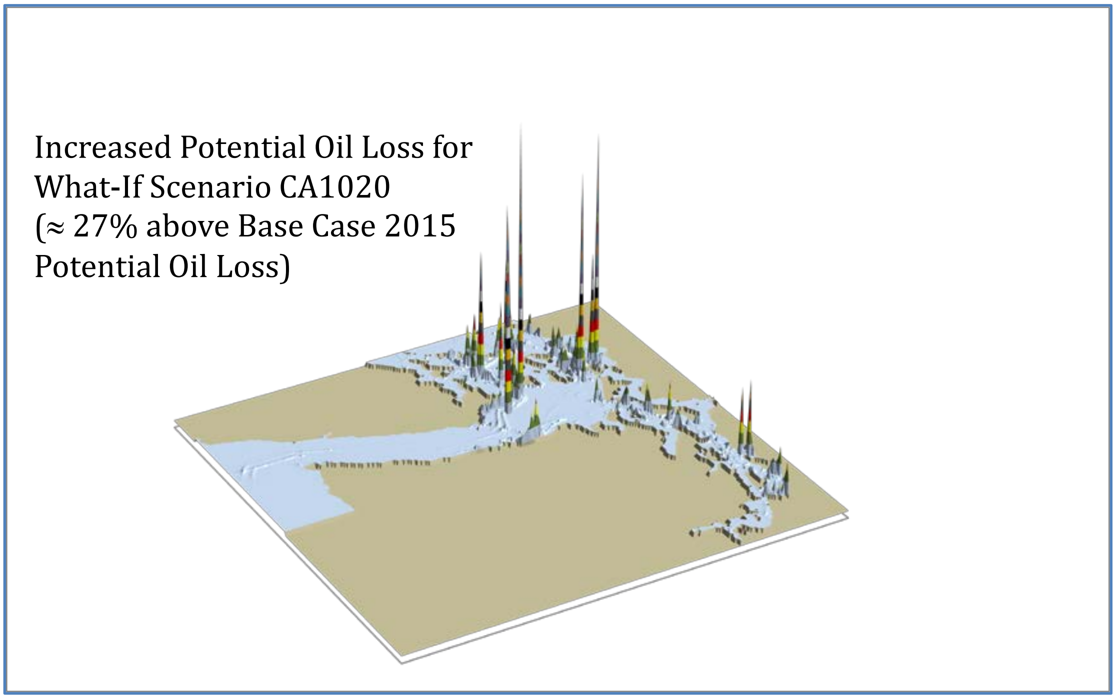

Figure 3-28. 3D Geographic profile of POTENTIAL oil loss for What-If Scenario CA1020.

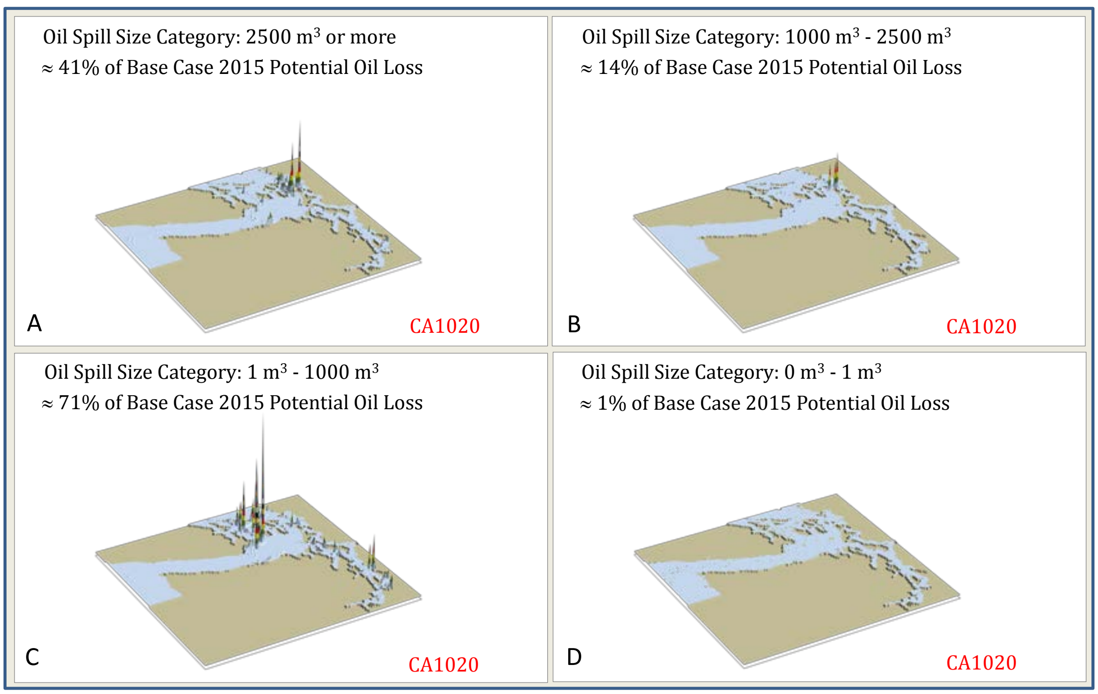

Figure 3-29. Components of 3D Geographic profile of CA1020 What-If Scenario POTENTIAL oil loss.
A: 41% in Oil Spill Size Category of 2500 m^3 or more; B: 14% in Oil Spill Size Category of 1000 m^3 -2500 m^3;
C: 71% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 1% in Oil Spill Size Category of 0 m^3 -1 m^3

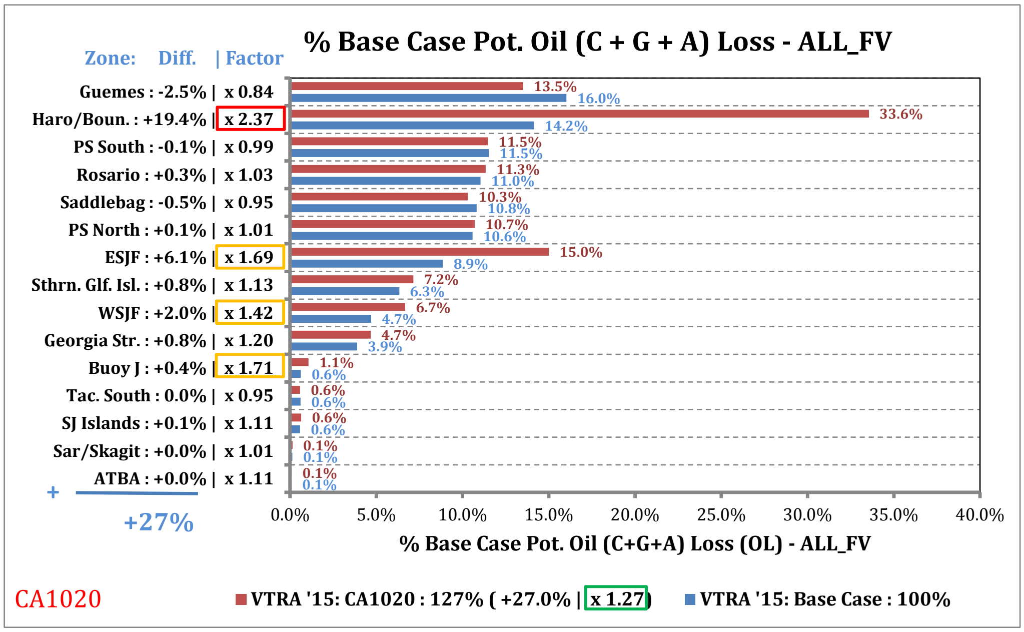

Figure 3-30. Relative comparison of POTENTIAL Oil Loss by waterway zone. Blue bars show the percentage by waterway zone for the Base Case 2015 Scenario, red bars show the percentage for What-If Scenario CA1020 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

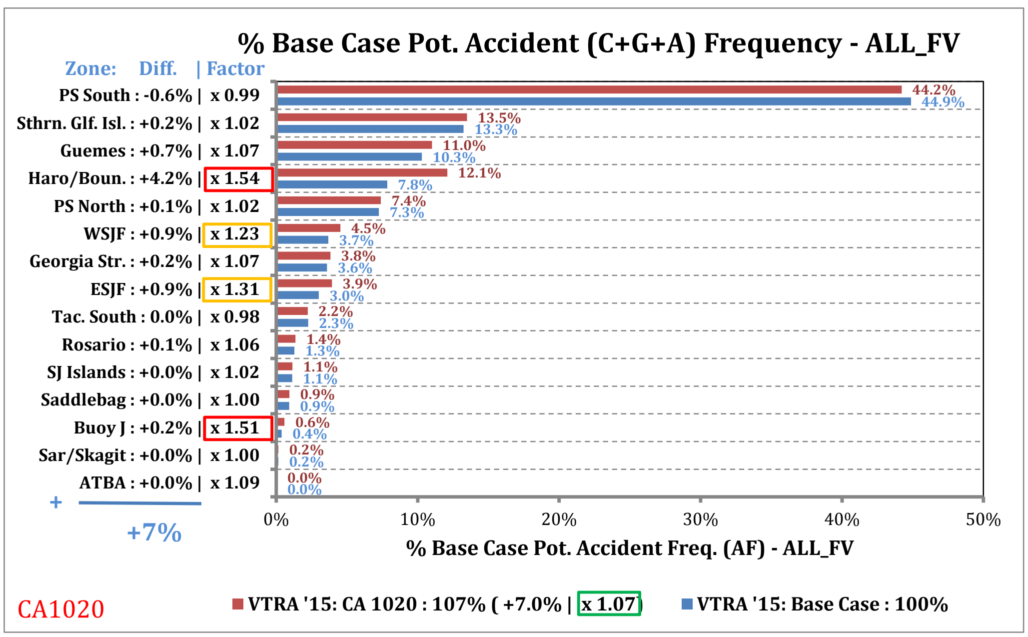

Figure 3-31. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Blue bars show the percentage by waterway zone for the Base Case 2015 Scenario, red bars show the percentage for What-If Scenario CA1020 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

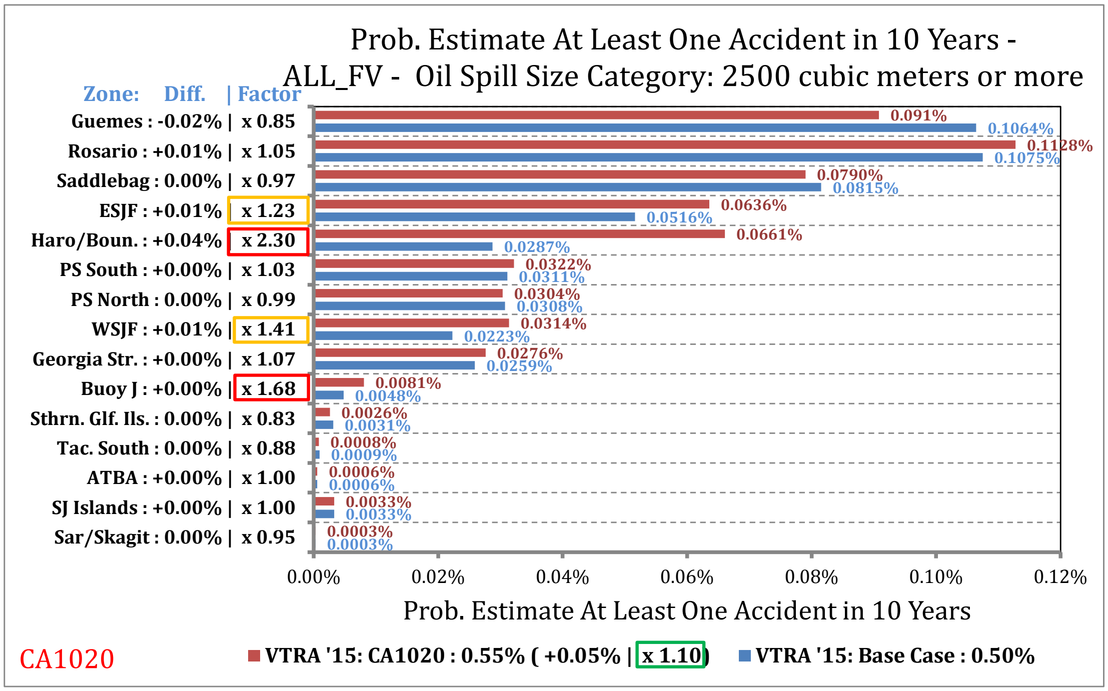

Figure 3-32. CA1020 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

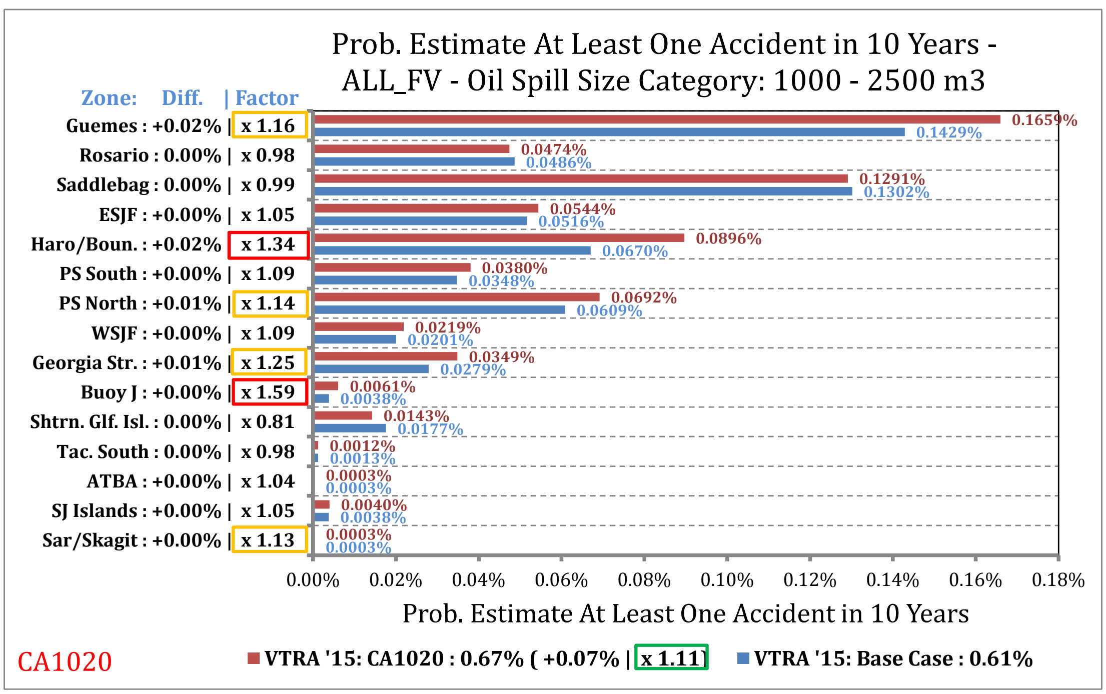

Figure 3-33. CA1020 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

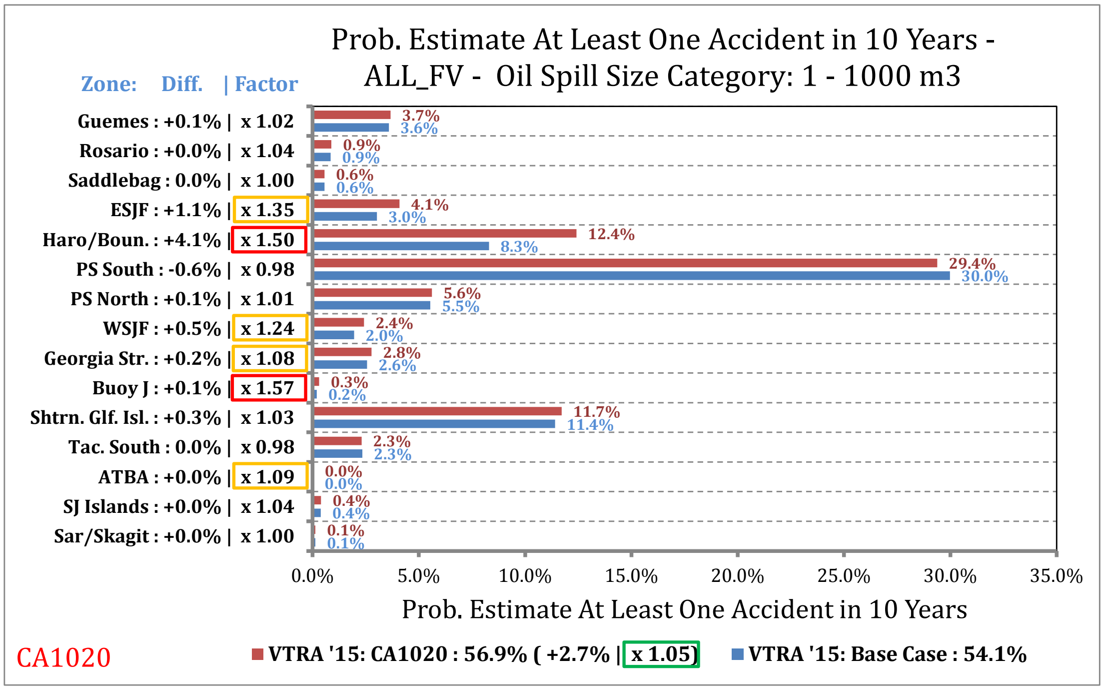

Figure 3-34. CA1020 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

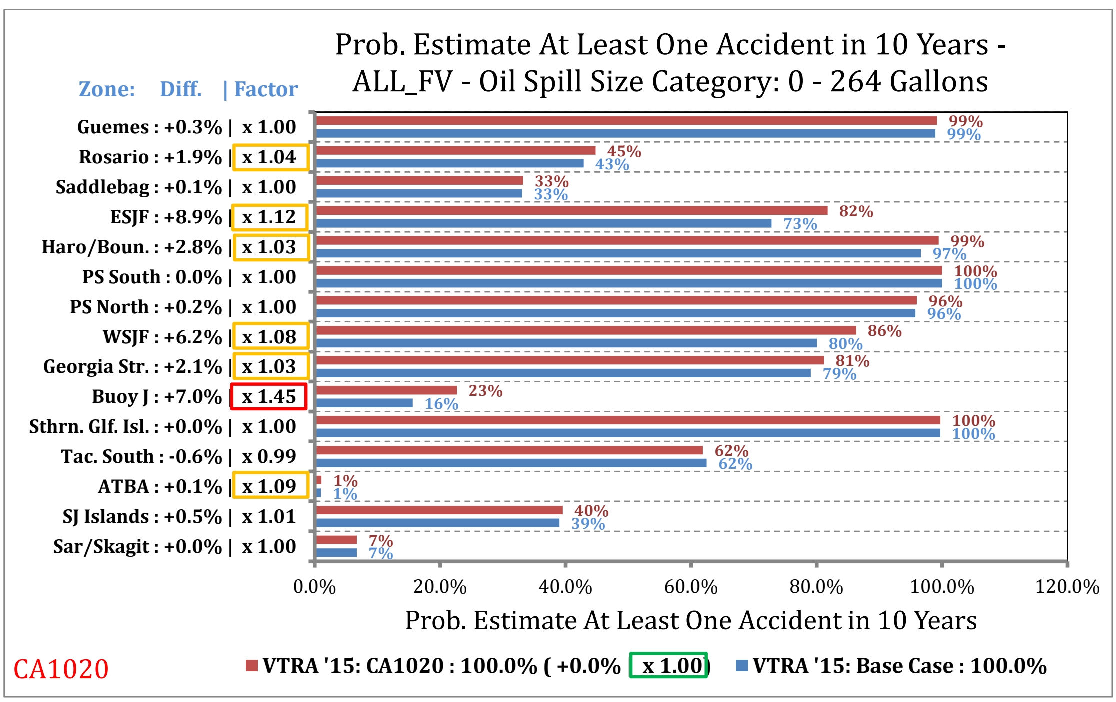

Figure 3-35. CA1020 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

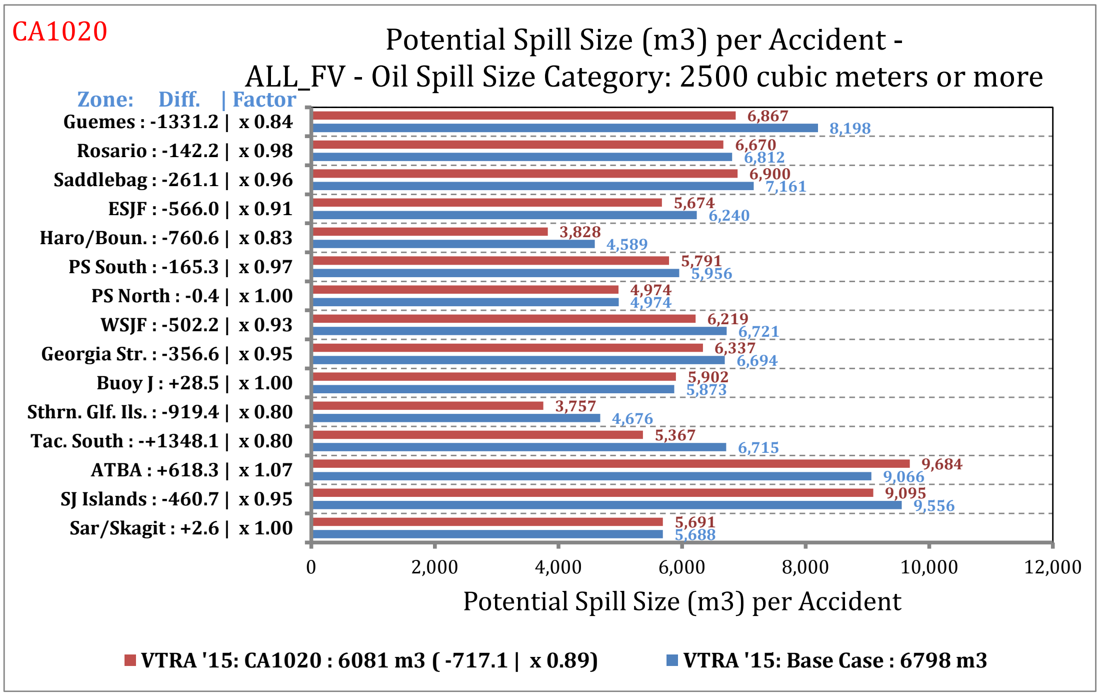

Figure 3-36. CA1020 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

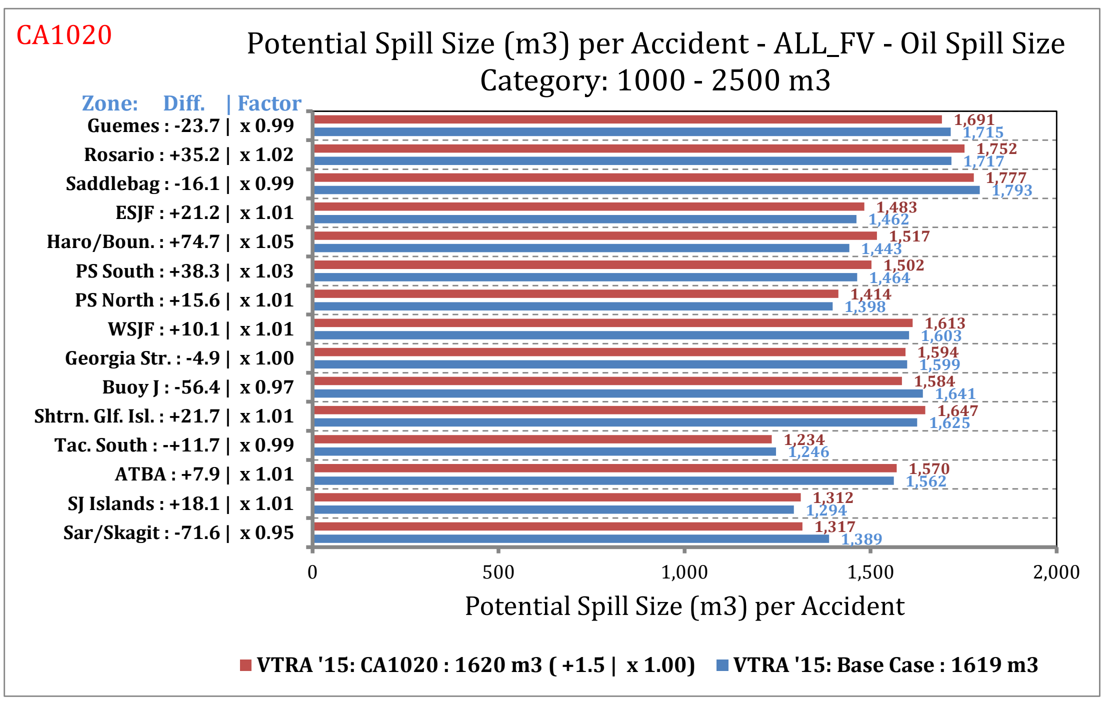

Figure 3-37. CA1020 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

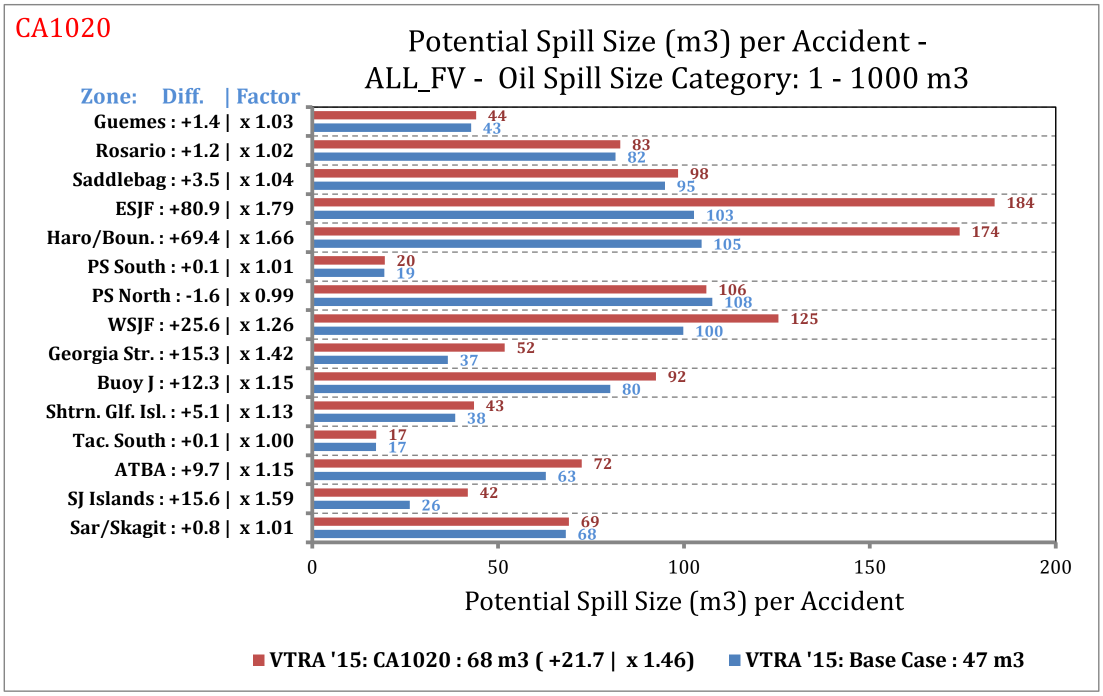

Figure 3-38. CA1020 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

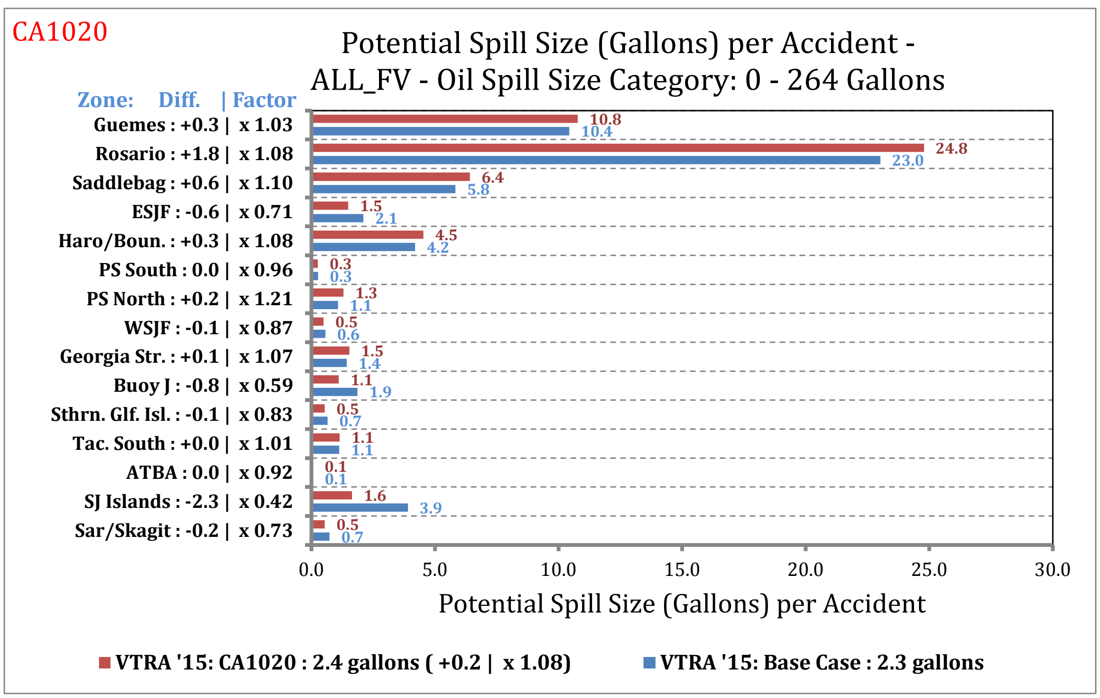

Figure 3-39. CA1020 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

USKMCA1600 analysis results

Below the USKMCA1600 What-If Scenario analysis results are evaluated for potential risk increases from the Base Case 2015 Scenario[11]. A summary description of the USKMCA1600 What-if Scenario is:

USKMCA1600: The combination of US232, KM348 and CA1020 What-If Scenarios (632 bulk carriers, 368 container ships, 403 tankers and 197 ATBs) while these 1600 focus vessels travel through US and Canadian (CA) Waters.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL accident frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was evaluated as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 3-40 one observes that overall for the USKMCA1600 What-If Scenario about a +85% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area. Figure 3-41 shows that the distribution of this about 185% of POTENTIAL Oil Loss was evaluated for the USKMCA1600 What-If Scenario as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@73% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 185% total POTENTIAL Oil Loss per year for the USKMCA1600 What-If Scenario (in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the Base Case 2015 Scenario one observes that of the +85% POTENTIAL Oil Loss increase about +49% is accounted for by the 2500 m^3 or more POTENTIAL Oil Loss Category, close to +28% is accounted for by the 1 m^3 - 1000 m^3

[11] Bunkering support for the various terminal projects was also modeled in the VTRA 2015 What-If Scenarios. Specifically, 177 bunker trips were added as part of the USKMCA1600 What-If Scenario description.

POTENTIAL Oil Loss Category, about +8% by the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category, and the nearly +1% remainder by the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category.

Figure 3-42 presents the relative increases of the total POTENTIAL Oil Loss evaluated for the USKMCA1600 Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.85 (green highlight in Figure 3-42) for the VTRA 2015 Study Area combined for the USKMCA1600 What-If Scenario. From Figure 3-42 one observes that the largest relative increases are evaluated by the VTRA 2015 Model in the Buoy J and Haro-Strait Boundary Pass waterway zones with relative multiplicative factor of about 4.09 and 3.53 (red highlights in Figure 3-42) in terms of POTENTIAL Oil loss. Thus, one observes that while overall a relative factor increase is observed of about 1.85 for the VTRA 2015 study area combined, these relative factors can be higher (or lower) within a particular waterway zone in the VTRA study area. In other words, the POTENTIAL Oil Loss evaluated in the Base Case 2015 Scenario increases within the Buoy J waterway zone by about a relative multiplicative factor of 4.09 in the USKMCA1600 What-If Scenario. Similarly, the POTENTIAL Oil Loss evaluated in the Base Case 2015 Scenario increases within the Haro-Strait/Boundary Pass waterway zone by about a factor 3.53 in the USKMCA1600 What-If Scenario. The other waterway zones that experience about the same or a higher POTENTIAL Oil loss relative factor increases for the USKMCA1600 What-If Scenario than the VTRA Study Area are the waterway zones East Strait of Juan de Fuca, West Strait of Juan de Fuca, Georgia Strait and Guemes with relative factors of about 2.64, 2.08, 1.83 and 1.82 (yellow highlights in Figure 3-42), respectively.

Figure 3-43 presents the relative increases of the total POTENTIAL Accident Frequency evaluated for the USKMCA1600 Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.11 (green highlight in Figure 3-43) for the VTRA 2015 study area combined for the USKMCA1600 What-If Scenario. Thus overall, the VTRA 2015 Model evaluated about $1.11 \times 4.4 \approx 4.9$ number of accidents per year of which now (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 109% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category. From Figure 3-43 one observes that the largest relative increase is evaluated by the VTRA 2015 Model in the Buoy J and Haro-Strait/Boundary Pass waterway zones with a relative factor of about 1.70 and 1.62 (red highlights in Figure 3-43), respectively, in terms of POTENTIAL Accident Frequency. Thus, one observes that while overall a relative factor increase is observed of 1.11 for the VTRA 2015 study area combined, these relative factors can be higher (or lower) within a particular waterway zone. In other words, the POTENTIAL Accident Frequency evaluated in the Base Case 2015 Scenario increases within the Buoy J waterway zone and Haro-Strait/Boundary Pass Waterway zones by about a factor 1.70 and 1.62, respectively in the USKMCA1600 What-If Scenario. The other waterway zones that experience a higher POTENTIAL Accident Frequency relative factor increase for the USKMCA1600 What-If Scenario than the VTRA Study Area are the waterway zones East Strait of Juan de Fuca, West Strait of Juan de Fuca, Guemes and Saddlebag with relative factors of about 1.40, 1.29, 1.18 and 1.12 (yellow highlights in Figure 3-43), respectively.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) over a 10-year period. Thus, for example, Figure 3-44 shows an estimated probability[12] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area, of about 1.35%[13]. Recall from Figure 3-40A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 91% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for the USKMCA1600 What-If Scenario (@ ≈ 185%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 1.35% (up by a multiplicative factor of 2.71, green highlight in Figure 3-44, from the same probability evaluated for the Base Case 2015 Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 91% of the overall POTENTIAL Oil Loss (up by a factor 2.17 from POTENTIAL Oil loss evaluated for 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the USKMCA1600 What-If Scenario (which was evaluated at about 185% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to about half of the POTENTIAL Oil Loss evaluated for the USKMCA1600 What-If Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 3-44 for the USKMCA1600 What-If Scenario, one observes a relative factor increase of 11.19 (red highlight in Figure 3-44) for the Haro-Strait/Boundary Pass waterway zone for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period for this particular waterway zone. Other waterway zones that experience about the same or higher relative factors for these probabilities as compared to the VTRA Study area, are the waterway zones Southern Gulf Islands, Buoy J, East Strait of Juan de Fuca and West Strait of Juan de Fuca with relative factors 6.04, 5.25, 5.06 and 3.10, respectively.

Similar observations can be made from Figure 3-45, Figure 3-46 and Figure 3-47 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3, respect-

[12] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f}\times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[13] A 1% probability equals to a probability of 1 in 100.

ively. While about 1% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the USKMCA1600 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-47 at about 100%. In other words, it is estimated that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will likely happen within the VTRA Study Area within a 10-year period. While about a 20% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (up by close to +8% from the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the USKMCA1600 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-45 at about 0.95%. Finally, while about a 71% POTENTIAL Oil Loss contribution is evaluated for 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (nearly a +28% increase as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the USKMCA1600 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-46 at about 57.2% (close to a +3% percentage increase as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category).

As was the case for Figure 3-44, red highlights shows the largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-45, Figure 3-46 and Figure 3-47. Yellow highlights shows the next largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-45, Figure 3-46 and Figure 3-47. Figure 3-48, Figure 3-49, Figure 3-50 and Figure 3-51 provide estimated average spill size per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the USKMCA1600 What-if Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 3-45, Figure 3-46 and Figure 3-47 in the manner it was described above for Figure 3-44, but also the summary table for the USKMCA1600 What-If Scenario comparison to the Base Case 2015 Scenario in Appendix D. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 1.35% for the USKMCA1600 What-If Scenario, a value of 0.14% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 3.35% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

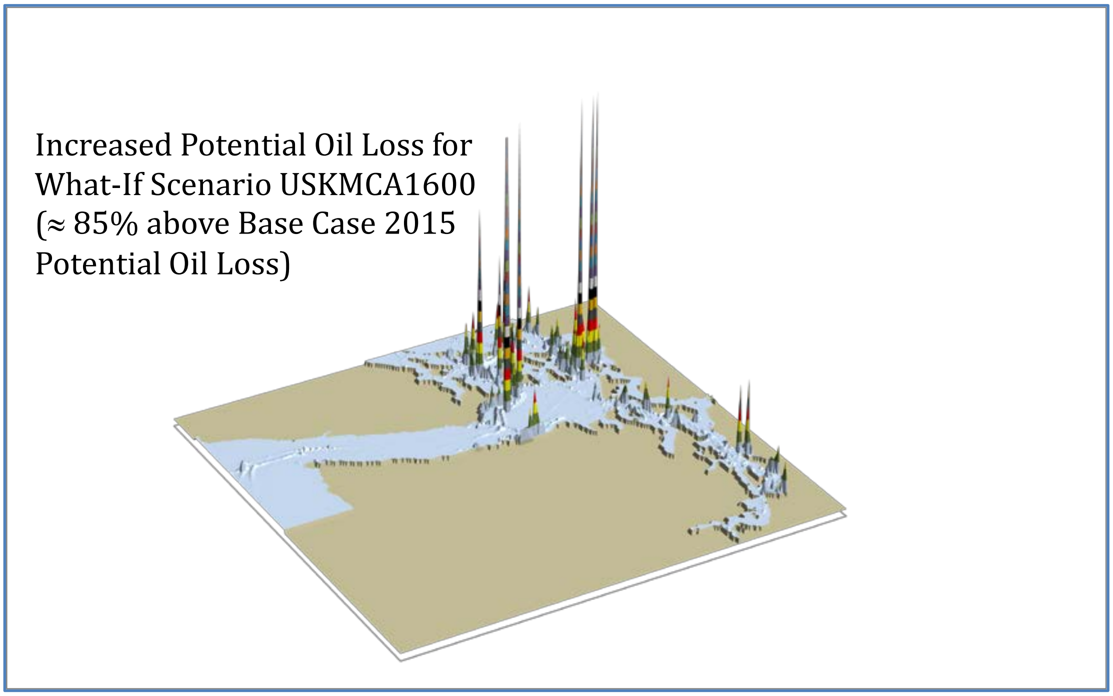

Figure 3-40. 3D Geographic profile of POTENTIAL oil loss for What-If Scenario USKMCA1600.

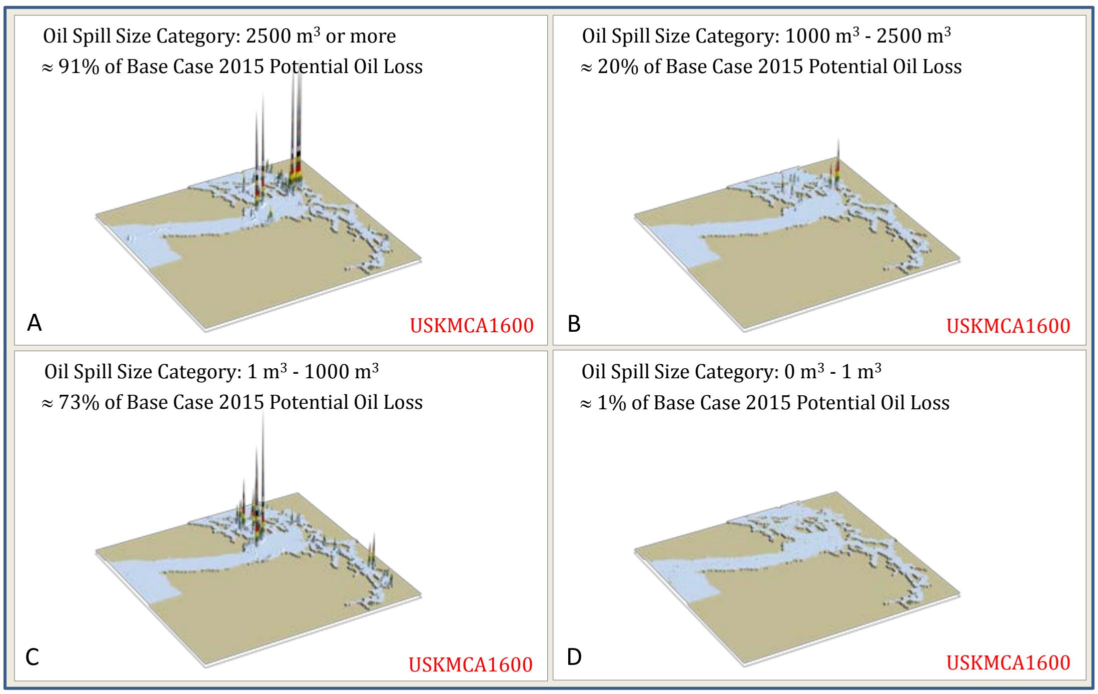

Figure 3-41. Components of 3D Geographic profile of USKMCA1600 What-If Scenario POTENTIAL oil loss. A: 91% in Oil Spill Size Category of 2500 m^3 or more; B: 20% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 73% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 1% in Oil Spill Size Category of 0 m^3 -1 m^3

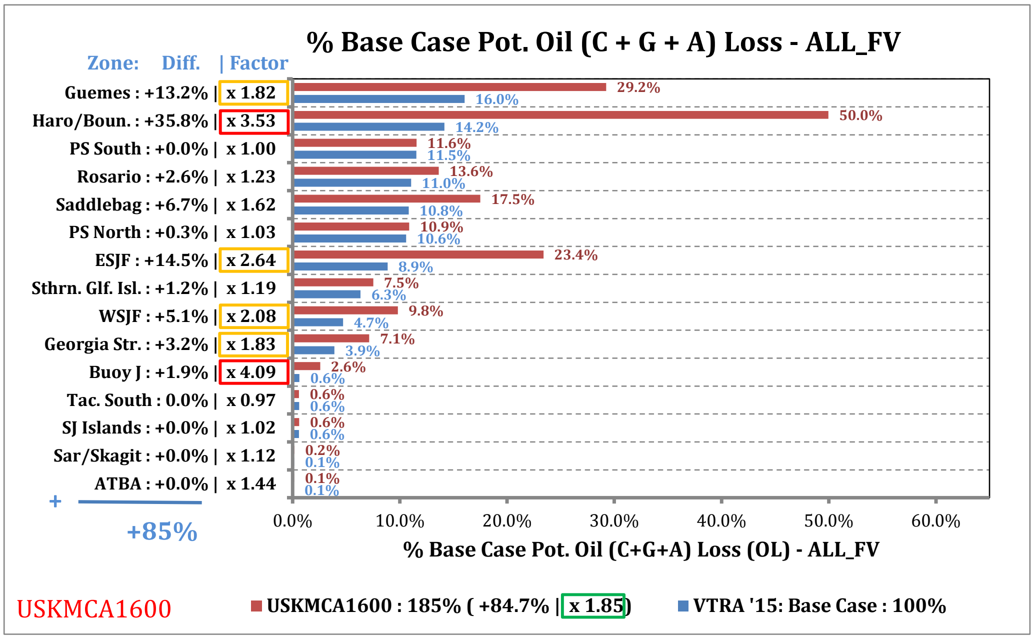

Figure 3-42. Relative comparison of POTENTIAL Oil Loss by waterway zone. Blue bars show the percentage by waterway zone for the Base Case 2015 Scenario, red bars show the percentage for What-If Scenario USKMCA1600 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

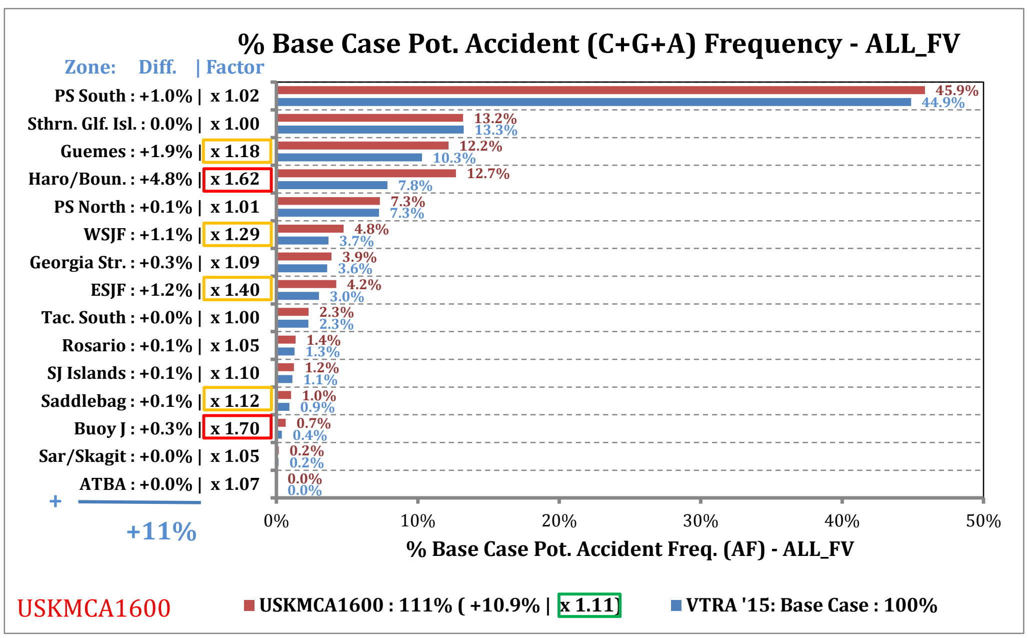

Figure 3-43. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Blue bars show the percentage by waterway zone for the Base Case 2015 Scenario, red bars show the percentage for What-If Scenario USKMCA1600 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

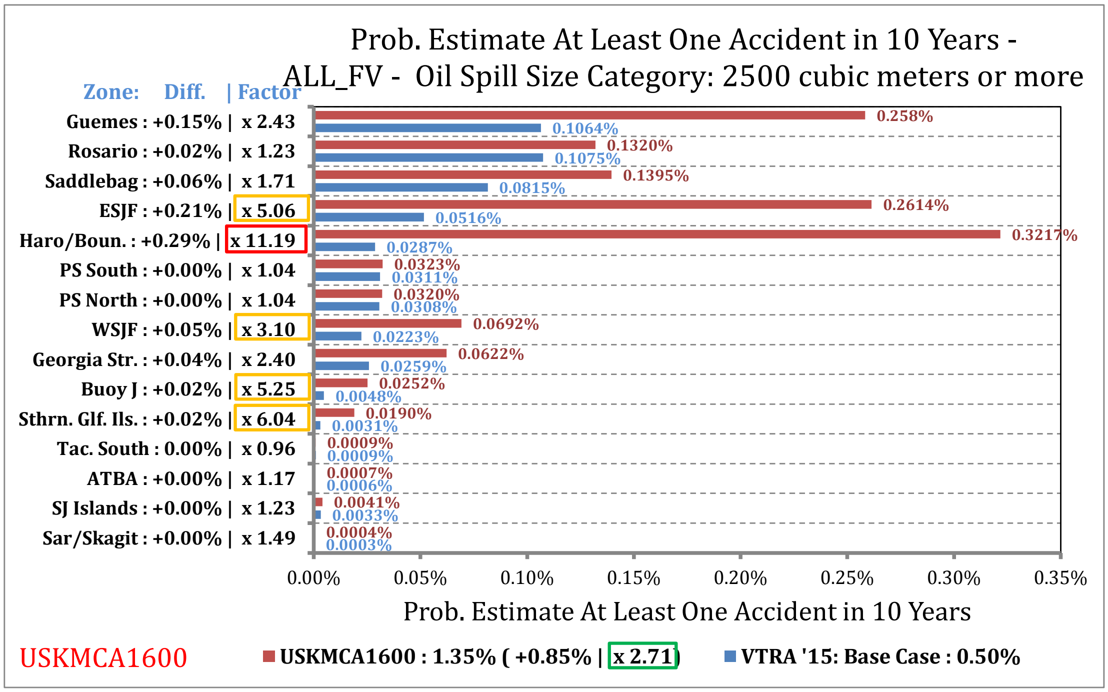

Figure 3-44. USKMCA1600 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

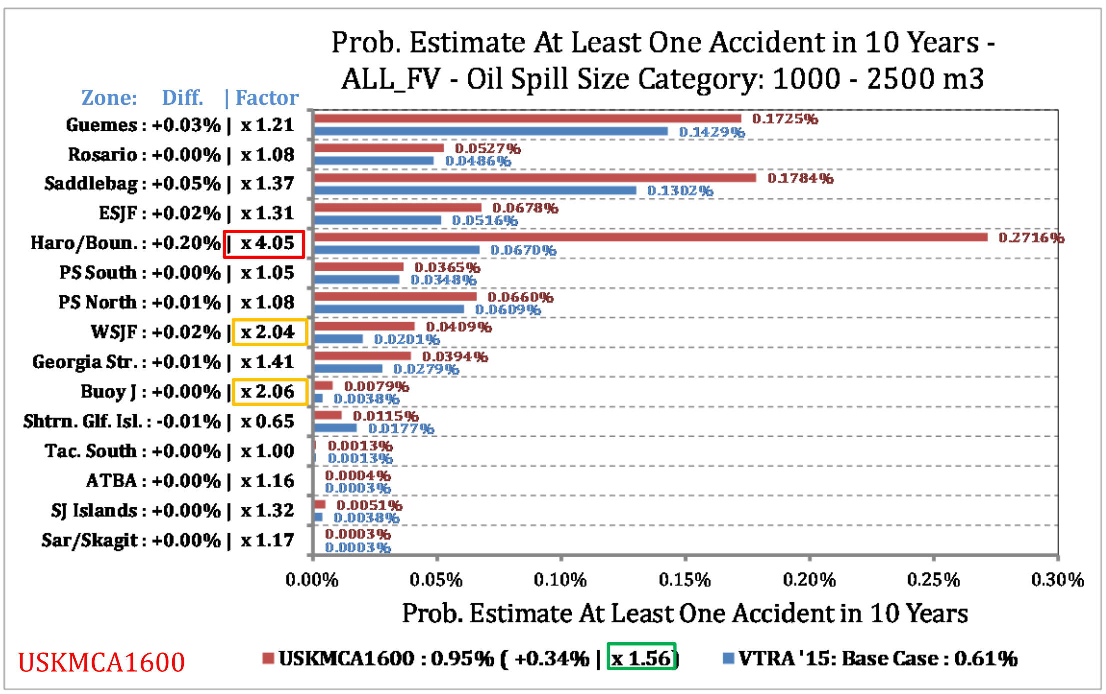

Figure 3-45. USKMCA1600 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

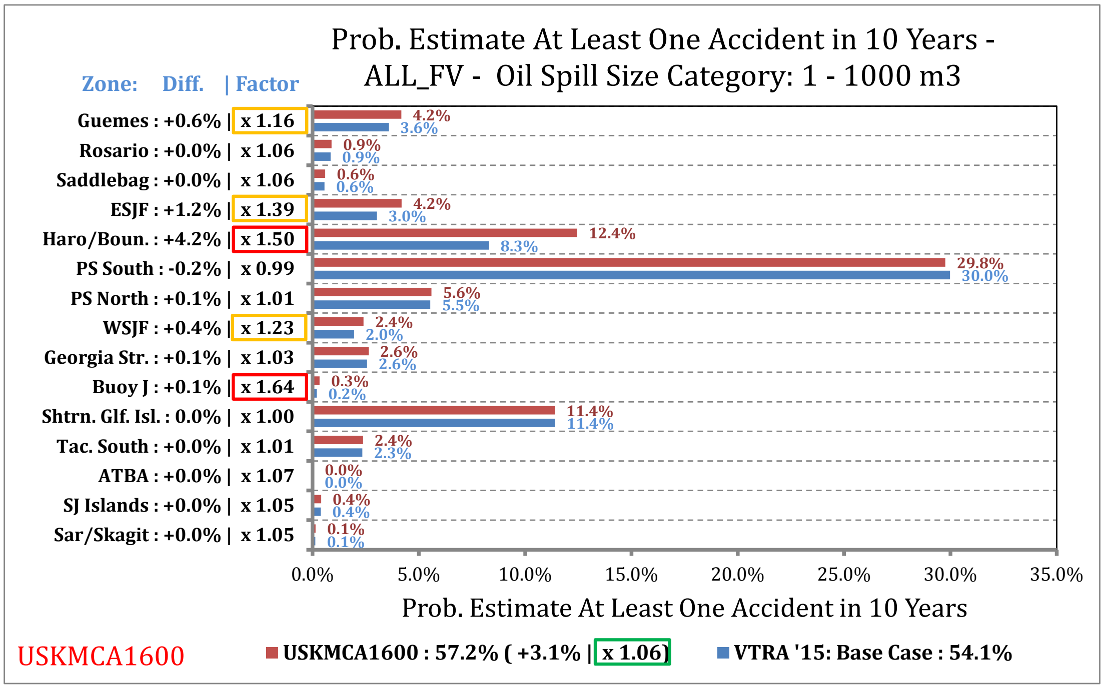

Figure 3-46. USKMCA1600 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

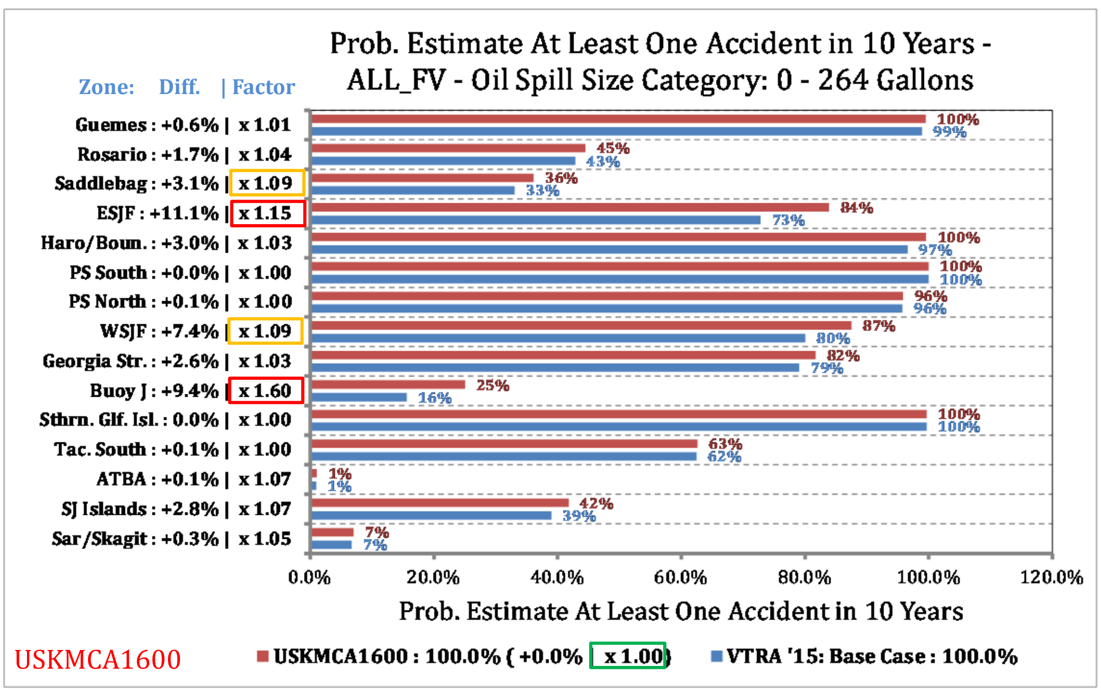

Figure 3-47. USKMCA1600 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

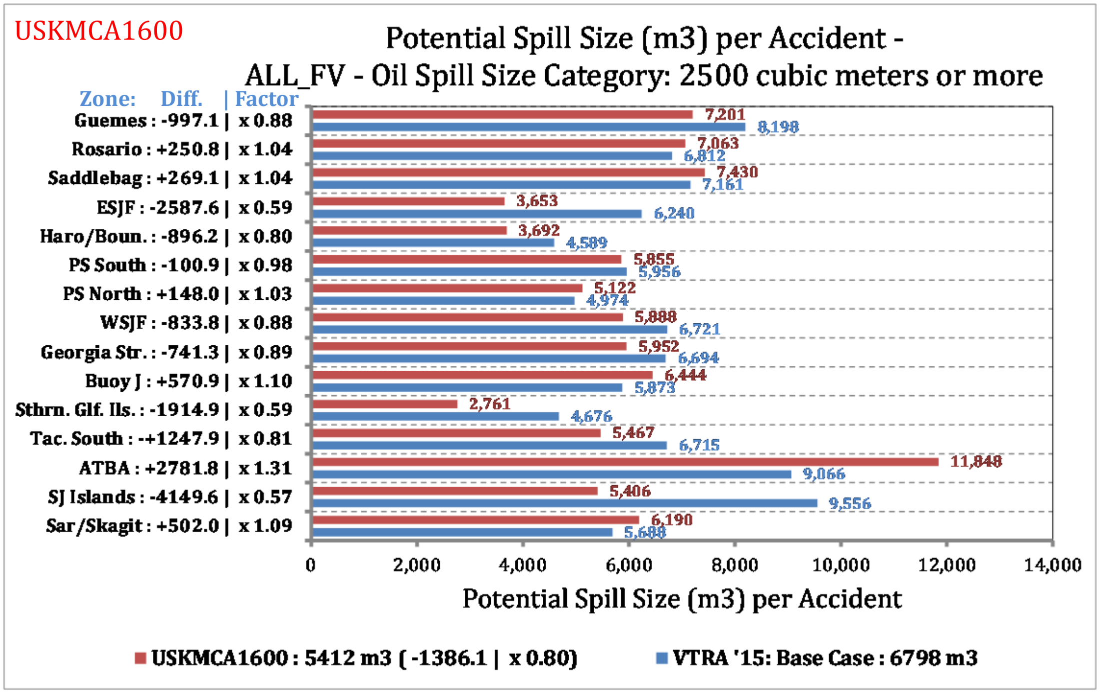

Figure 3-48. USKMCA1600 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

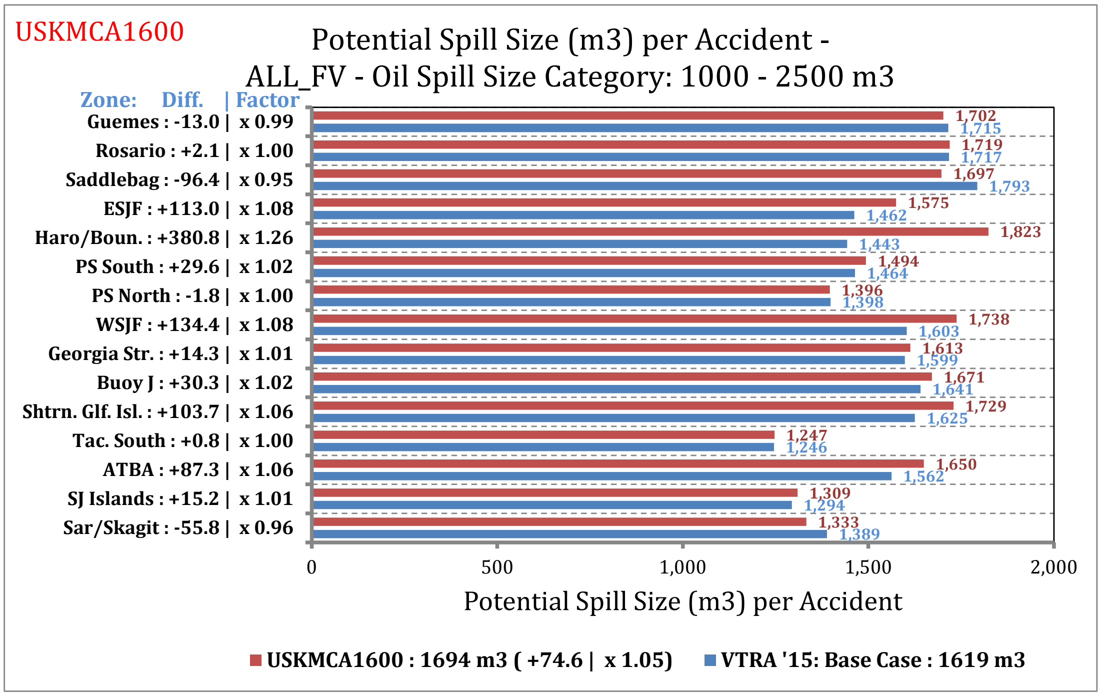

Figure 3-49. USKMCA1600 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

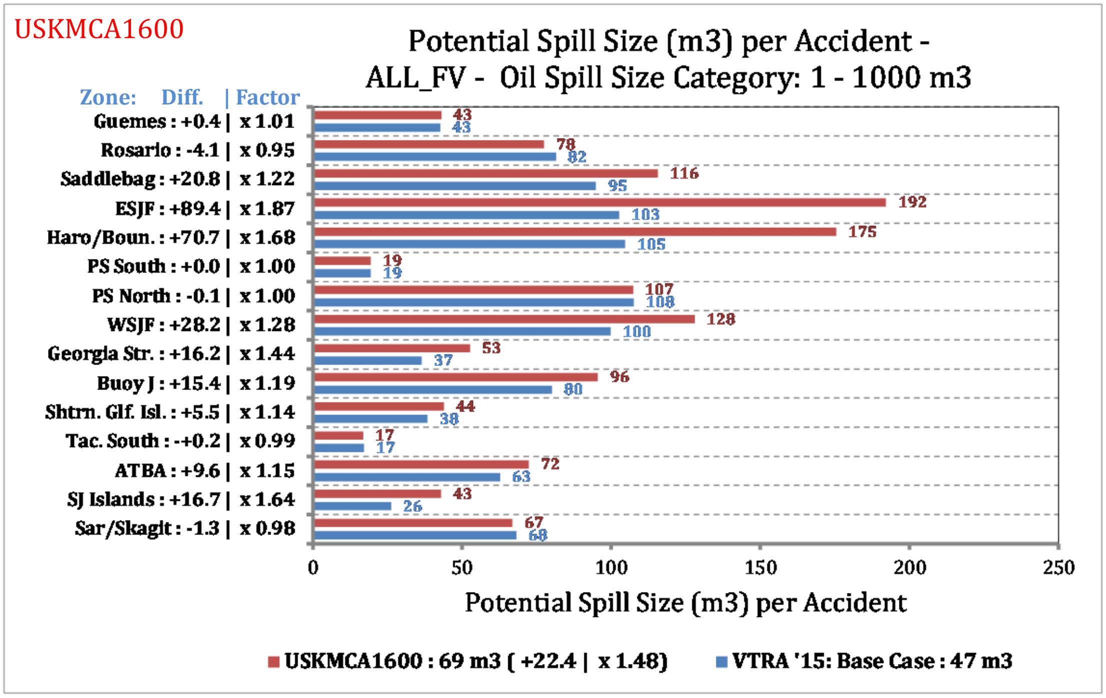

Figure 3-50. USKMCA1600 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m^3 or 1000 m^3.

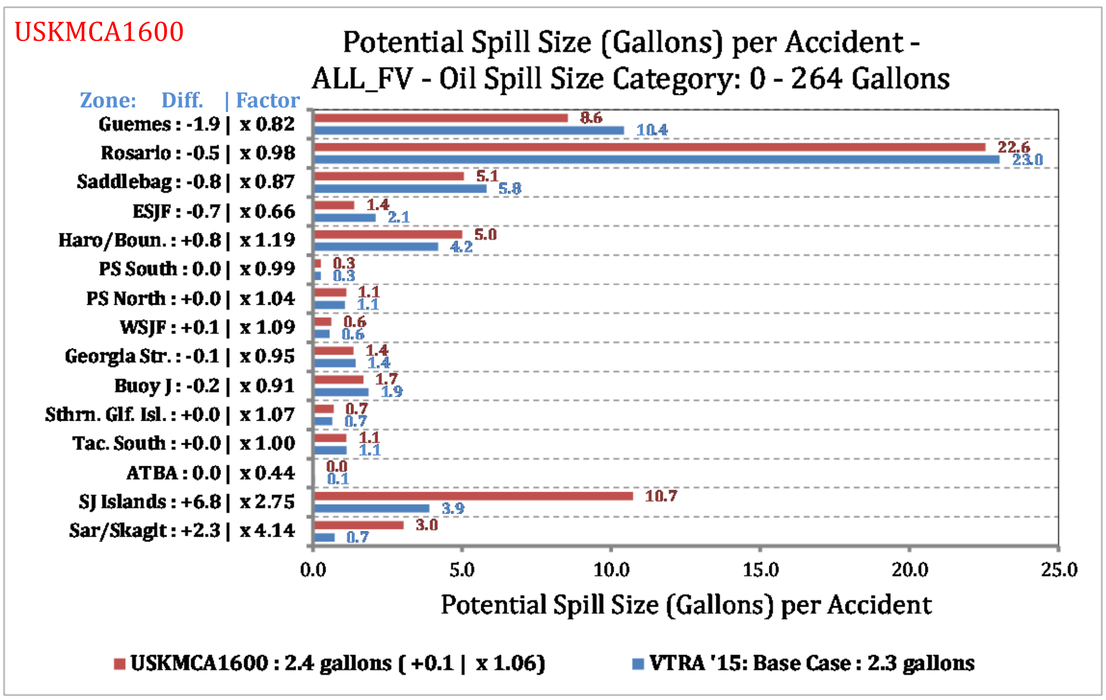

Figure 3-51. USKMCA1600 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m^3 or 1 m^3 (or 0 to 264 gallons).

USKMCALN2250 analysis results

Below the USKMCALN2250 What-If Scenario analysis results are evaluated for potential risk increases from the Base Case 2015 Scenario[14]. A summary description of the USKMCALN2250 What-if Scenario is:

USKMCALN2250: The combination of USKMCA1600 (632 bulk carriers, 368 container ships, 403 tankers and 197 ATBs) with a collection of terminal projects adding an additional estimated 650 LNG vessels to the VTRA 2015 modeled Base Case 2015 Scenario traffic while these 2250 focus vessel travel through US and Canadian (CA) Waters. **The VTRA 2015 Model, however, <u>does not</u> contain a model for the potential consequences of an accident with an LNG Tanker. Thus, LNG Tankers for the purposes of the VTRA 2015 study are <u>minimally modeled</u> for traffic impact as <u>cargo focus vessels</u> only. Hence, risk metrics evaluated for the USKMCALN2250 What-If Scenario ought to be considered <u>lower bounds of those risk metrics</u>.**

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL accident frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was evaluated as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 3-52 one observes that overall for the USKMCALN2250 What-If Scenario about a +104% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area[15]. Figure 3-53 shows that the distribution of this about 204% of POTENTIAL Oil Loss was evaluated for the USKMCALN2250 What-If Scenario as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@96% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@87% of Base Case POTENTIAL Oil Losses)

[14] Bunkering support for the various terminal projects was also modeled in the VTRA 2015 What-If Scenarios. Specifically, 207 bunker trips were added as part of the USKMCALN2250 What-If Scenario descriptions.
[15] Thus at least doubling the POTENTIAL Oil Loss evaluated for the Base Case 2015 Scenario over the VTRA Study Area.

D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 204% total POTENTIAL Oil Loss per year for the USKMCALN2250 What-If Scenario (in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the Base Case 2015 Scenario one observes that of the +104% POTENTIAL Oil Loss increase about +54% is accounted for by the 2500 m^3 or more POTENTIAL Oil Loss Category, close to +42% is accounted for by the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category, about +8% by the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category, and the nearly +1% remainder by the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category.

Figure 3-54 presents the relative increases of the total POTENTIAL Oil Loss evaluated for the USKMCALN2250 Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 2.05 (green highlight in Figure 3-54) for the VTRA 2015 Study Area combined for the USKMCALN2250 What-If Scenario. From Figure 3-54 one observes that the largest relative increases are evaluated by the VTRA 2015 Model in the Buoy J and Haro-Strait/Boundary Pass waterway zones with a relative multiplicative factor of about 5.27 and 4.29 (red highlights in Figure 3-54) in terms of POTENTIAL Oil loss. Thus, one observes that while overall a relative factor increase is observed of about 2.05 for the VTRA 2015 study area combined, these relative factors can be higher (or lower) within a particular waterway zone in the VTRA study area. In other words, the POTENTIAL Oil Loss evaluated in the Base Case 2015 Scenario increases within the Buoy J waterway zone by about a multiplicative factor of 5.27 in the USKMCALN2250 What-If Scenario. Similarly, the POTENTIAL Oil Loss evaluated in the Base Case 2015 Scenario increases within the Haro-Strait/Boundary Pass waterway zone by about a relative multiplicative factor of 4.29 in the USKMCALN2250 What-If Scenario. The other waterway zones that experience about the same or a higher POTENTIAL Oil loss relative factor increase for the USKMCALN2250 What-If Scenario than the VTRA Study Area are the waterway zones East Strait of Juan de Fuca, and West Strait of Juan de Fuca with relative factors of about 3.06 and 2.38 (yellow highlights in Figure 3-54), respectively.

Figure 3-55 presents the relative increases of the total POTENTIAL Accident Frequency evaluated for the USKMCALN2250 Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.17 (green highlight in Figure 3-55) for the VTRA 2015 Study Area as a whole for the USKMCALN2250 What-If Scenario. Thus overall, the VTRA 2015 Model evaluated about $1.17 \times 4.4 \approx 5.2$ number of accidents per year of which now (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 115% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category. From Figure 3-55 one observes that the largest relative increase is evaluated by the VTRA 2015 Model in the Buoy J and Haro-Strait/Boundary Pass waterway zones with a relative factor of about 2.15 and 2.04 (red highlights in Figure 3-55), respectively, in terms of POTENTIAL Accident Frequency. Thus, one observes that while overall a relative factor increase is observed of 1.17 for the VTRA 2015 study area combined, these relative factors can be higher (or lower) within a particular waterway zone in the VTRA study area. In others words, the POTENTIAL Accident Frequency evaluated in the Base Case 2015 Scenario increases within the Buoy J waterway zone and Haro-Strait/Boundary Pass waterway zone by about a factor 2.15 and 2.04, respectively in the USKMCALN2250 What-If Scenario. The other waterway zones that experience a higher POTENTIAL Accident Frequency relative factor increase for the USKMCALN2250 What-If Scenario analysis than the VTRA study area, are the waterway zones East Strait of Juan de Fuca, West Strait of Juan de Fuca, Guemes and Georgia Strait with relative factors of about 1.66, 1.47, 1.24 and 1.23 (yellow highlights in Figure 3-55), respectively.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) over a 10-year period. Thus, for example, Figure 3-56 shows an estimated probability[16] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area, of about 1.39%[17]. Recall from Figure 3-53A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 96% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for the USKMCALN2250 What-If Scenario (@ ≈ 205%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 1.39% (up by a multiplicative factor of 2.80, green highlight in Figure 3-56, from the same probability evaluated for the Base Case 2015 Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 96% of the overall POTENTIAL Oil Loss (up by a factor 2.29 from POTENTIAL Oil loss evaluated for 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the USKMCALN2250 What-If Scenario (which was evaluated at about 205% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages). In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to about half of the POTENTIAL Oil Loss evaluate for the USKMCALN2250 What-If Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 3-56 for the USKMCALN2250 What-If Scenario, one observes a relative factor increase of 11.86 (red highlight in Figure 3-56) for the Haro-Strait/Boundary Pass waterway zone for the estimated probability of one or more accidents

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[16] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f} \times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[17] A 1% probability equals to a probability of 1 in 100.

within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period for this particular waterway zone. Other waterway zones that experience about the same or higher relative factors for these probabilities as compared to the VTRA Study area, are the waterway zones Buoy J, Southern Gulf Islands, East Strait of Juan de Fuca, West Strait of Juan de Fuca, and Tacoma South with relative factors 6.73, 6.55, 5.03, 3.53 and 3.21, respectively.

Similar observations can be made from Figure 3-57, Figure 3-58 and Figure 3-59 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3, respectively. While close to a 1% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the USKMCALN2250 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-59 at about 100%. In other words, it is estimated that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will likely happen within the VTRA Study Area within a 10-year period. While about a 20% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (up by about +8% from the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the USKMCALN2250 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-57, at about 0.96%. Finally, while nearly a 87% POTENTIAL Oil Loss contribution is evaluated for 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (about a +42% increase as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category) in the USKMCALN2250 What-If Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 3-58 at about 59.4% (close to a +5% percentage increase as evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss Category).

As was the case for Figure 3-56, red highlights shows the largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-57, Figure 3-58 and Figure 3-59. Yellow highlights shows the next largest relative factor increases experienced by waterway zone than experienced for the VTRA 2015 Study area in Figure 3-57, Figure 3-58 and Figure 3-59. Figure 3-60, Figure 3-61, Figure 3-62 and Figure 3-63 provide estimated average spill size per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the USKMCALN2250 What-if Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 3-57, Figure 3-58 and Figure 3-59 in the manner it was described above for Figure 3-56, but also the summary table for the USKMCALN2250 What-If Scenario comparison to the Base Case 2015 Scenario in Appendix D. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 1.40% for the USKMCALN2250 What-If Scenario, a value of 0.14% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 3.45% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

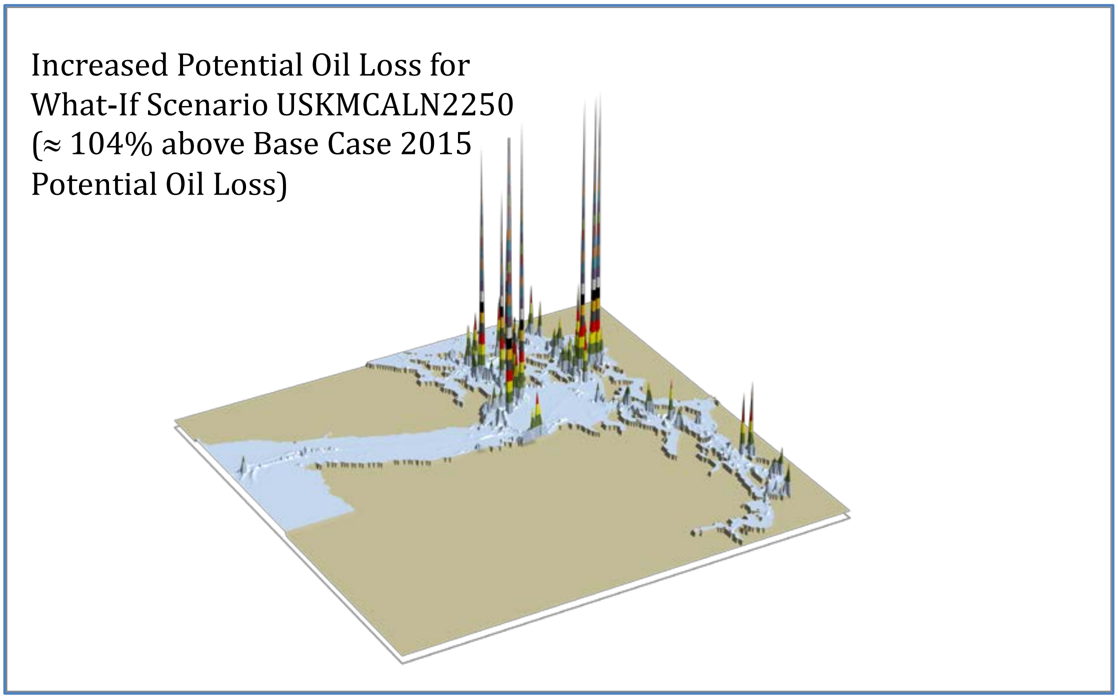

Figure 3-52. 3D Geographic profile of POTENTIAL oil loss for What-If Scenario USKMCALN2250 .

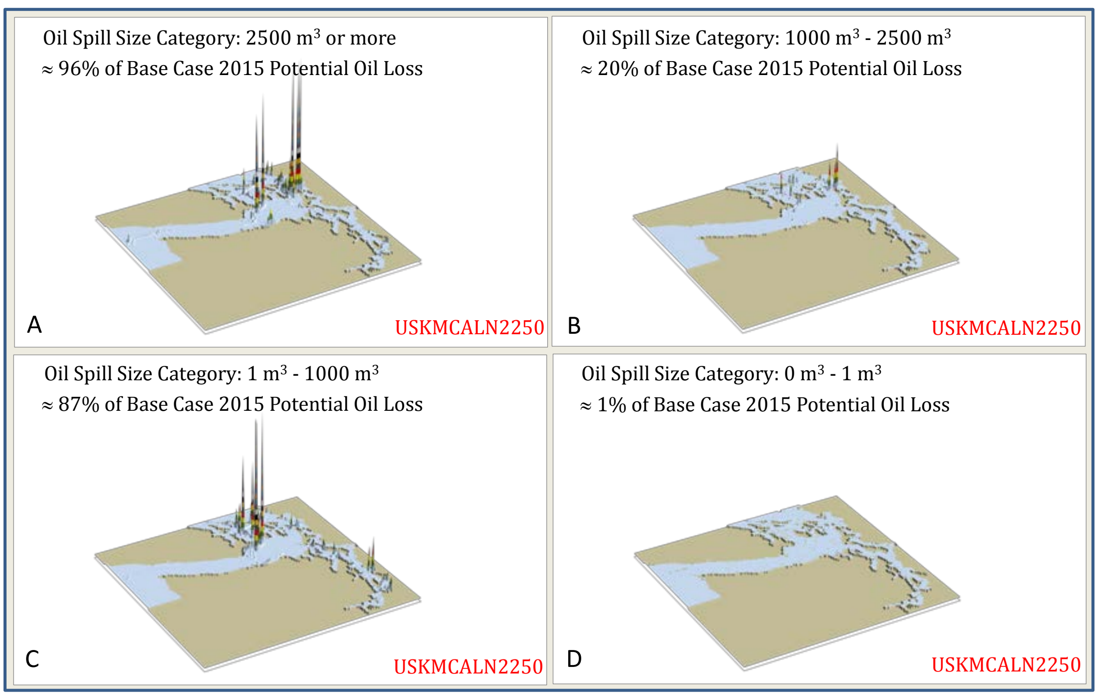

Figure 3-53. Components of 3D Geographic profile of USKMCALN2250 What-If Scenario POTENTIAL oil loss. A: 96% in Oil Spill Size Category of 2500 m^3 or more; B: 20% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 87% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 1% in Oil Spill Size Category of 0 m^3 -1 m^3

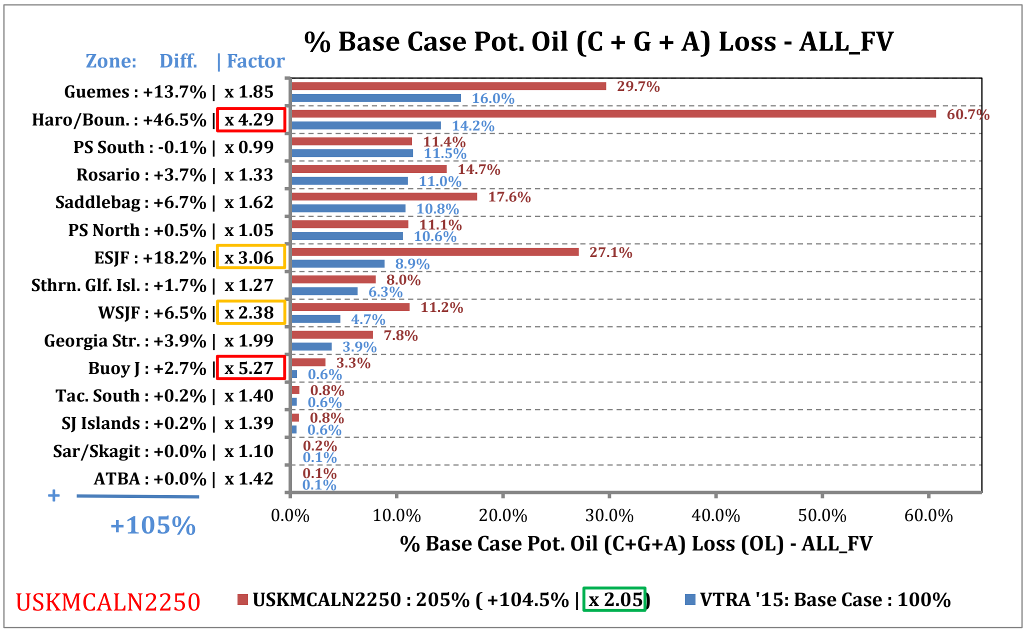

Figure 3-54. Relative comparison of POTENTIAL Oil Loss by waterway zone. Blue bars show the percentage by waterway zone for the Base Case 2015 Scenario, red bars show the percentage for What-If Scenario USKMCALN2250 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

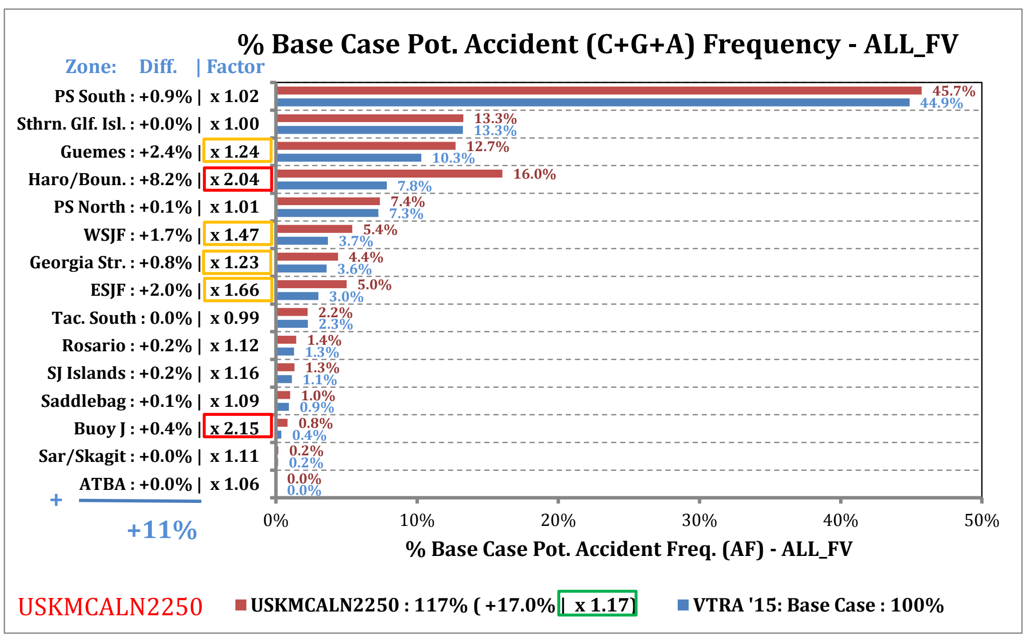

Figure 3-55. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Blue bars show the percentage by waterway zone for the Base Case 2015 Scenario, red bars show the percentage for What-If Scenario USKMCALN2250 in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

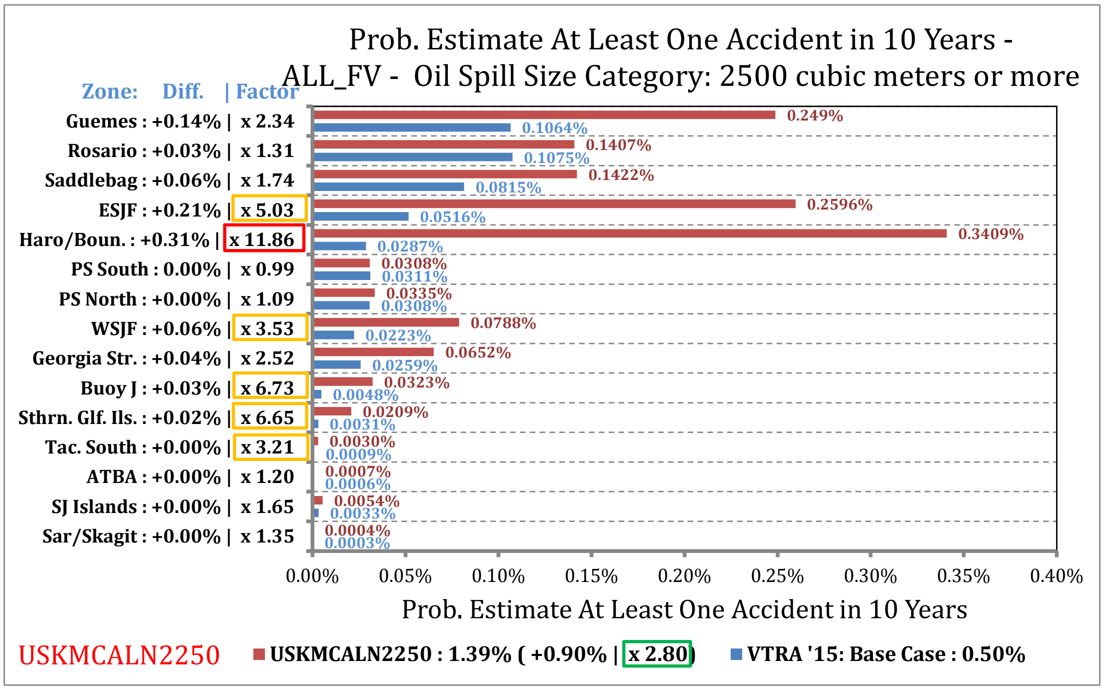

Figure 3-56. USKMCALN2250 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

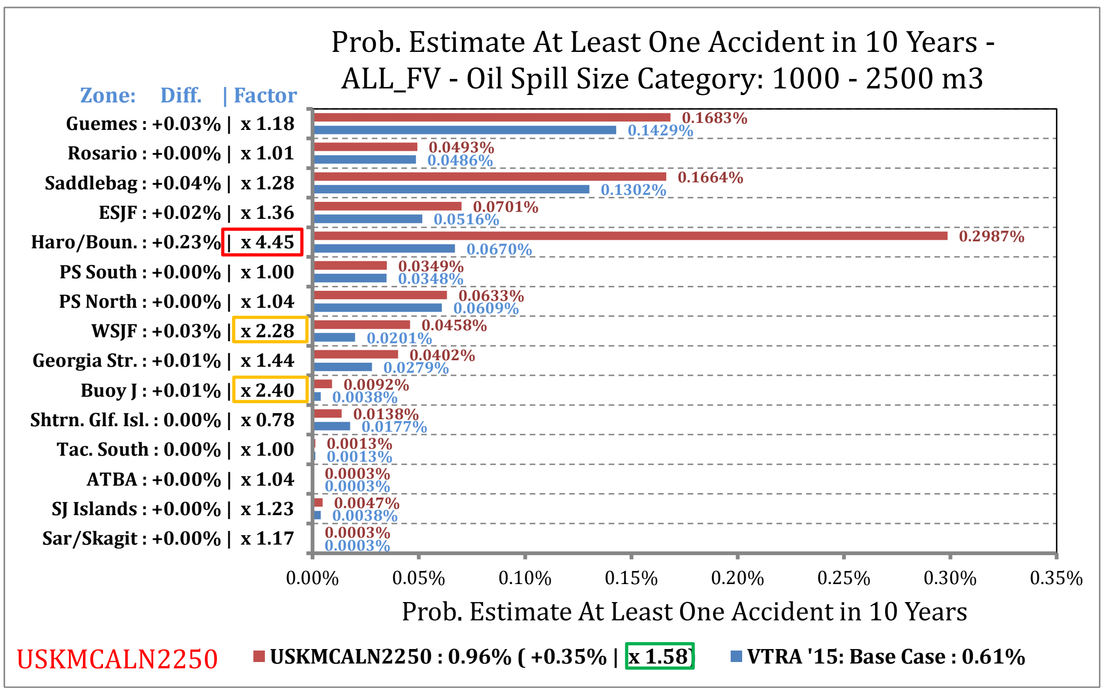

Figure 3-57. USKMCALN2250 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

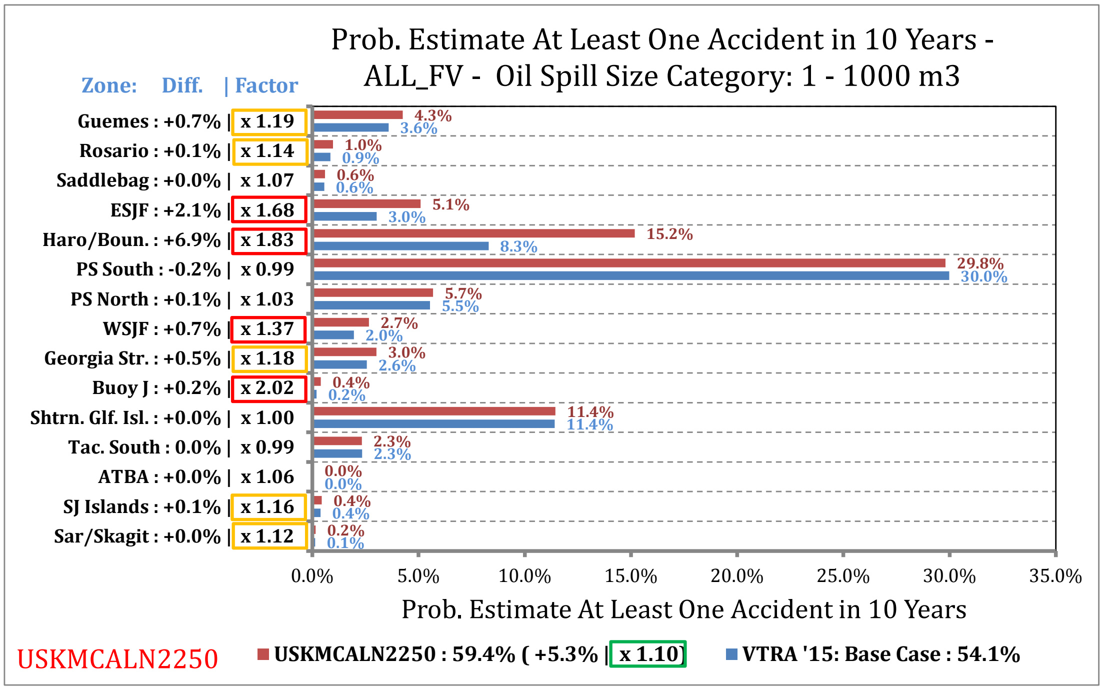

Figure 3-58. USKMCALN2250 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

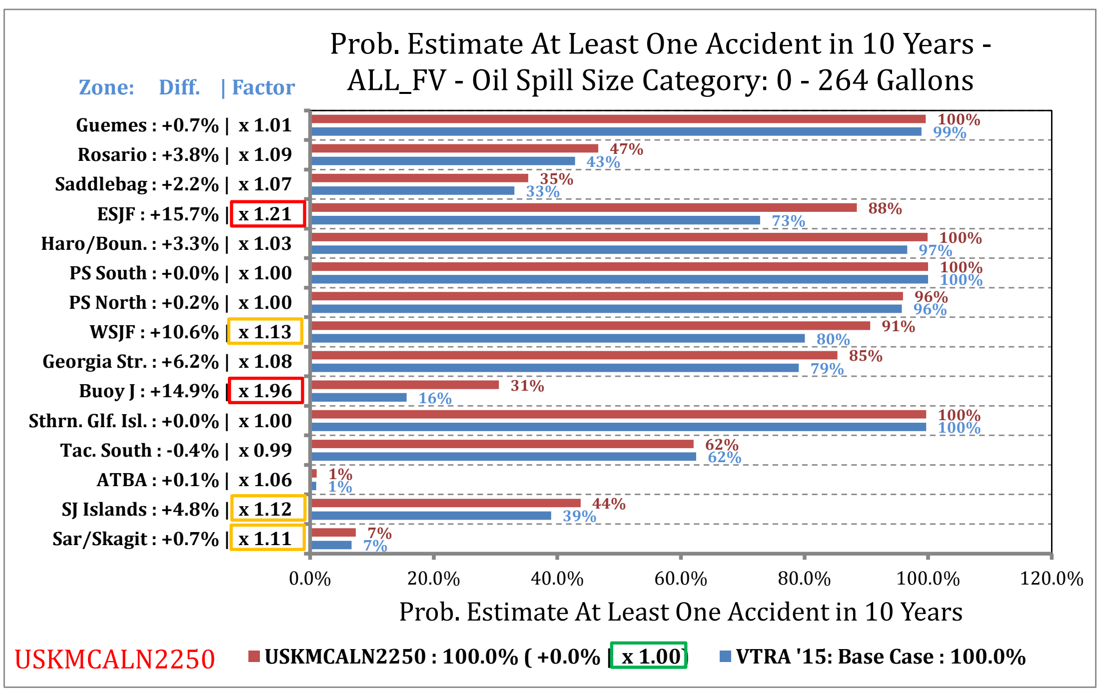

Figure 3-59. USKMCALN2250 relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

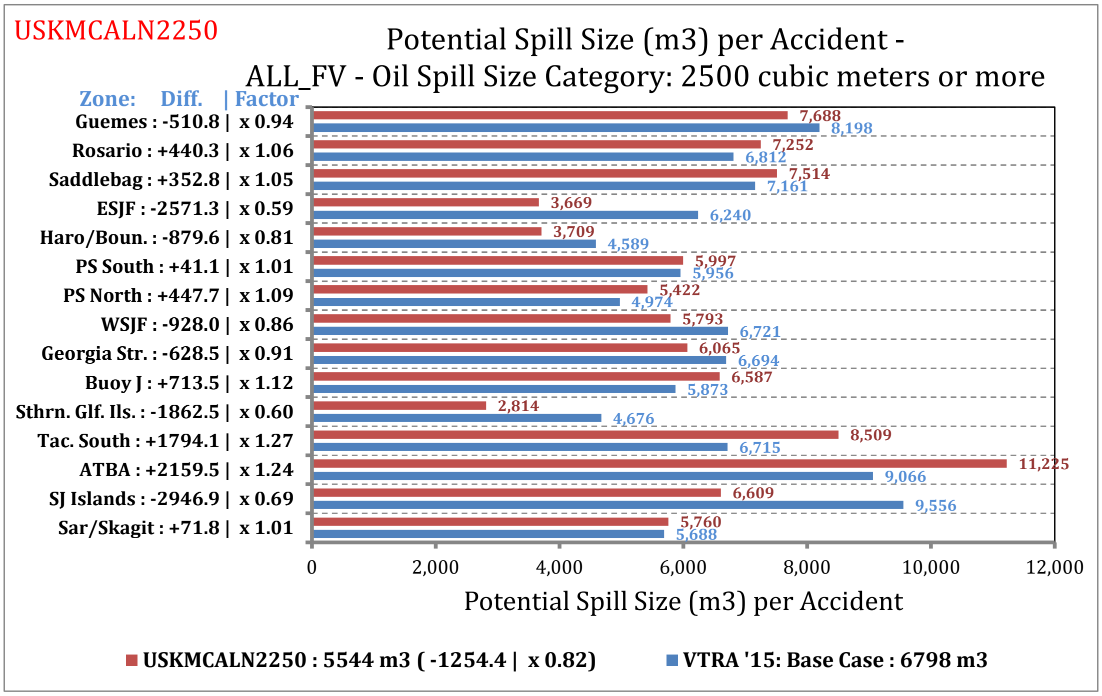

Figure 3-60. USKMCALN2250 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m^3 or more.

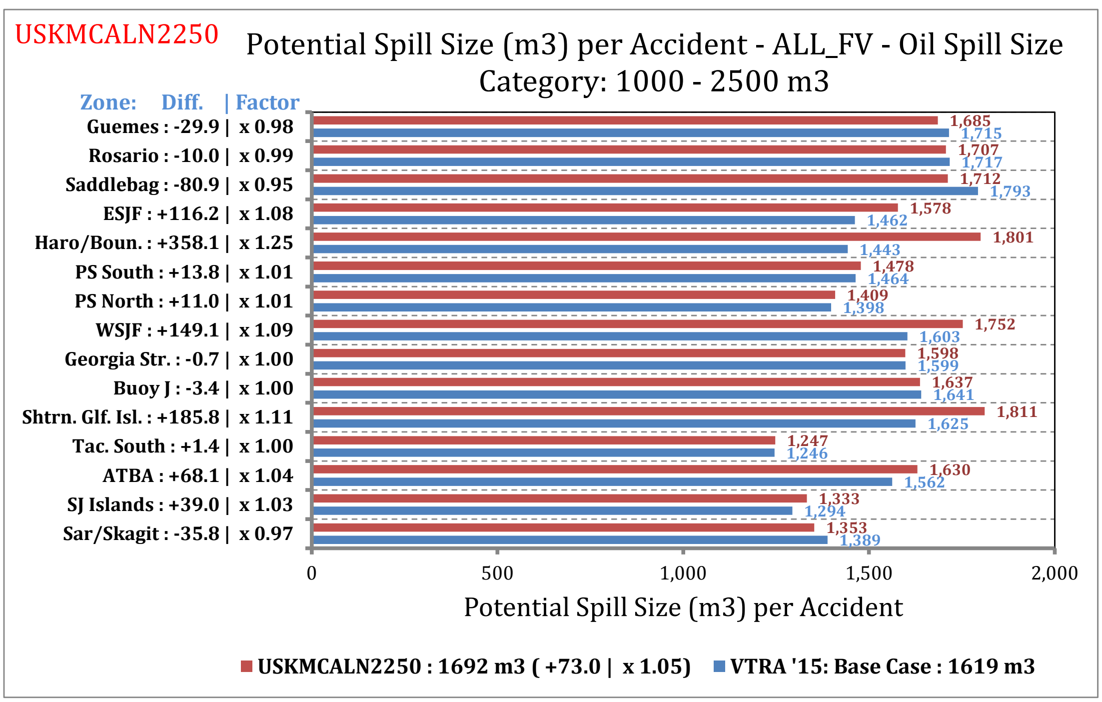

Figure 3-61. USKMCALN2250 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m^3 or 2500 m^3.

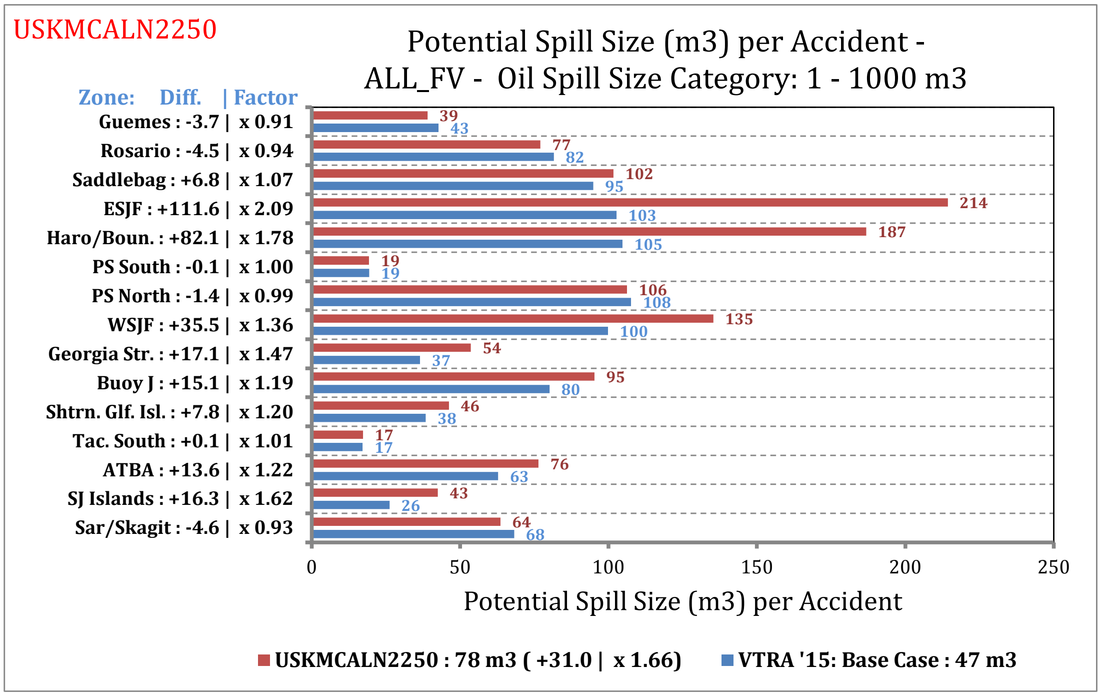

Figure 3-62. USKMCALN2250 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

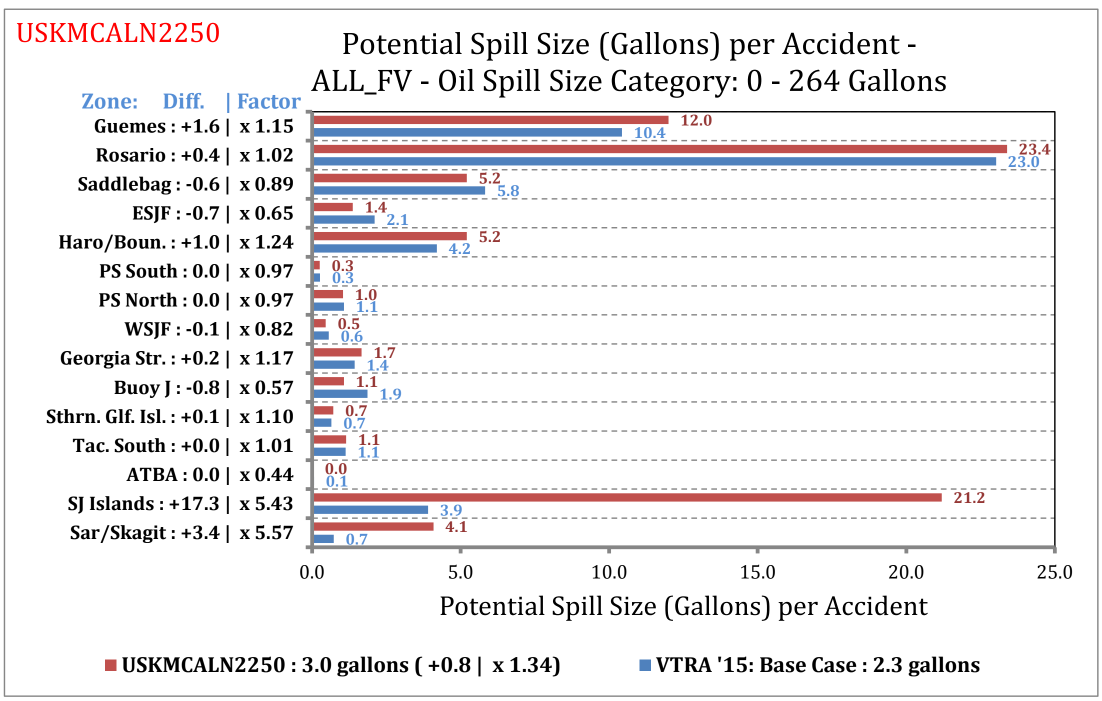

Figure 3-63. USKMCALN2250 relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

4. RMM SCENARIO DESCRIPTION AND ANALYSIS RESULTS

A series of risk mitigation measures were proposed over the course of this study either with involvement of the VTRA 2015 Working Group or by GW/VCU to help inform a risk management process should some of the maritime terminal development projects represented in the five What-If Scenarios USKMCALN2250, USKMCA1600, CA1020 KM348 or US232 come to fruition. However, the system-wide and waterway zone specific relative effectiveness of these risk mitigations measures were evaluated relative to the USKMCA1600 scenario only. In other words, caution is in order in not interpreting these relative RMM effectiveness evaluations as being applicable to other What-If Case Scenarios or the Base Case 2015 Scenario analysis for that matter.

To achieve risk reduction across the VTRA study area, we believe that the question “which risk mitigation measure should one implement?” is not the right question to ask, but rather one should ask oneself “which portfolio of risk mitigation measures should one implement”. This is graphically exemplified in Figure 4-1. Firstly, for an oil spill to occur there must be situations in which they could occur. Given such a situation, an incident, for example a propulsion failure, is preceded by the oil spill event, while, of course an incident does not have to lead to an accident nor an oil spill. Even when an incident leads to an accident, for example a vessel grounding, such a vessel grounding does not have to lead to an oil spill, but it certainly could. The sequence of events that could POTENTIALLY lead to an oil spill is indicated by the red ovals in Figure 4-1.

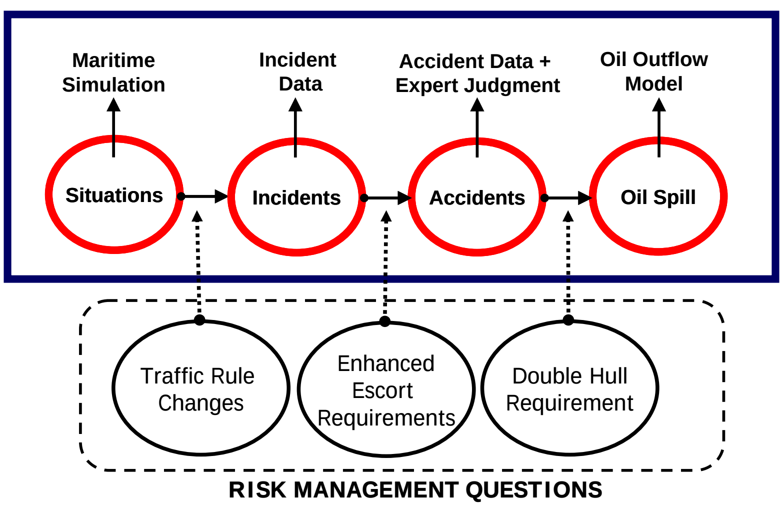

Figure 4-1. Graphical depiction of oil spill accident event chain with risk mitigation measures depicted as intervenors of causal pathways.

The connections between these red oval events in the oil spill accident event chain, indicated by the horizontal arrows in Figure 4-1 are referred to as “causal pathways”. To prevent oil spills from occurring each pathway provides an opportunity for risk mitigation to “block the causal pathway”.

Three examples of such risk mitigation measures are also depicted in Figure 4-1 as the ovals with black borders. A traffic rule risk mitigation measure could, for example, be the creation of a traffic separation scheme. To prevent an incident, e.g. a propulsion failure, from leading to an accident, for example a grounding accident, one could, for example, enhance escort requirements. Should the accident occur, one could reduce the likelihood of an oil spill by requiring double hulls of vessel compartments that contain oil. Hence, these three example risk mitigations measures depicted in Figure 4-1 are principally different, as they all attempt to intervene at a different causal pathway.

As implied by Figure 4-1, the VTRA 2015 Analysis Tool does not evaluate the POTENTIAL fates and effects of a POTENTIAL Oil Loss beyond the POTENTIAL volume of oil spilled. That is, the VTRA Model's oil spill causal chain analysis ends with volume of POTENTIAL Oil Loss in-the-water, should a POTENTIAL accident occur. The VTRA Oil Outflow model is described in [4] and modeled after the oil outflow model detailed in Special Report 259 [16] published by the Marine Board, Transportation Research Board of The National Academy of Sciences. That being said, the oil spill causal chain depicted in Figure 4-1 could be expanded further to the right of the oil spill event oval with, e.g., an immediate impact event oval and a delayed consequences event oval thereafter. The causal pathways between such added event ovals after the oil spill event oval to the causal chain depicted in Figure 4-1 provide for additional opportunities to mitigate risk. For example, a response capability following a POTENTIAL oil spill can be considered a risk mitigation measure that intervenes between the oil spill event oval and such an immediate impact event oval. Analogously, the oil spill causal chain event can be further expanded to the left of the situations event oval in in Figure 4-1 to identify additional POTENTIAL risk mitigation opportunities. Risk mitigation measures following the oil spill event oval attempt to mitigate “consequences”, whereas risk mitigation measures preceding the oil spill event oval are focused on “prevention”. The RMMs evaluated during the VTRA 2015 Study are of the “prevention” type.

While, hypothetically, the complete blocking of a causal pathway preceding the oil spill event oval could completely remove oil spill risk, this would be equivalent to saying that “risk is reduced to zero” or “the occurrence of an oil spill is an impossible event”, which is not the case. In fact, once a causal pathway has already been targeted through implemented risk mitigation measures, it may become progressively more difficult to reduce risk further at that particular causal pathway. As such, the modeling of a more detailed breakdown of a hypothetical oil spill accident event chain, be it locally or system wide, could be a worthwhile exercise in the search for causal pathway “blocking opportunities” that have not been targeted for risk mitigation. Needless to say, as part of that exercise, and to observe those opportunities, one would have to allocate risk mitigation measures already in place to these causal pathways along such an expanded oil spill accident event chain.

Unfortunately, just because risk mitigation is designed to intervene at a particular point in a causal pathway, this does not necessarily mean that it also results in a system wide risk reduction effect. That is, while a risk mitigation measure may be "locally" targeted, e.g. the establishment of a one way zone for traffic, and may result in a risk reduction in such a targeted location zone, it may also result in "unintended consequences" such as, e.g. a slowing down of traffic preceding the waterway zone which could lead to risk increases at those preceding location zones. Of course, one would prefer that the combined effect of a risk mitigation measure, i.e. the targeted risk reduction and POTENTIALLY unintended consequences of its operationalization, results in a "system wide" risk reduction effect.

Overall, we advocate a distributed approach towards risk mitigation, i.e. the identification of a portfolio of risk mitigation measures that intervenes or targets all causal pathways of an accident events chain, while achieving a system wide risk reduction effect. This may be thought of as the "defense in depth principle" of risk management. Two of these trial portfolio scenario analyses were evaluated utilizing the VTRA 2015 model and four separate risk mitigation measures were evaluated individually. Summarizing a total of six RMMs Scenarios were evaluated during the VTRA 2015 Study of which two were portfolios of RMMs. The POTENTIAL effectiveness of these six scenarios was evaluated utilizing the VTRA 2015 model, by implementing them on top of the USKMCA1600 Scenario <u>only</u>. As such, these analyses <u>solely</u> reflect POTENTIAL effectiveness evaluations of these RMMs <u>should</u> all the maritime development projects in the USKMCA1600 Scenario have come to fruition and subsequently these RMMs have been adopted thereafter.

Description of the six RMM Scenarios enacted upon the USKMCA1600 Scenario

A series of risk mitigation measures were proposed over the course of this study either with involvement of the VTRA 2015 Working Group or by GW/VCU to help inform a risk management process should some of the maritime terminal development projects represented in the five What-If Scenarios USKMCALN2250, USKMCA1600, CA1020 KM348 or US232 come to fruition. The manner of implementation of risk mitigations measure in the VTRA 2015 model enacted upon the USKMCA1600 What-If Scenario was as follows (in no specific order):

DH100-RMM: 100% Double Hull Fuel Protection of Cargo Focus Vessels (increased from 40% in the Base Case 2015 Scenario).

HM50-RMM: Reduce human error and mechanical failure on Tugs (Excluding Oil Barges) by 50%.

SE-RMM: Remove from the VTRA 2015 Simulation Model its special events, i.e. the modeled regatta, whale watching, and commercial and tribal fishing openers. Combined fishing vessels and yachts/recreational vessels account for about (39.5% + 3.6%) ≈ 43.1% of the non-focus vessel vessel time exposure (VTE) (see Figure E-4) in the VTRA 2015 model or (43.1 × 75.8%) ≈ 32.7%, i.e. about a third, of the overall VTRA Model traffic in terms of vessel time exposure (VTE). See also, Figure E-4 and Figure E-6A.

OAE-RMM: Continuously escort laden oil Barges and ATBs east of Port Angeles (unthethered).

KME-RMM: Extend escorting of Kinder Morgan outbound laden tankers to Buoy J.

SRT-RMM: Station a rescue tug at Sidney, BC and model its coverage in the same manner as the coverage model that was developed for the Neah Bay rescue tug in the VTRA 2005.

125-RMM: Lift the 125 DWT limit on laden crude inbound tankers while reducing the number of crude inbound tanker transits to keep the volume of crude inbound tankers approximately the same.

17-RMM: Reduce the speed of container vessel to 17 knots throughout the VTRA 2015 Study area, a speed restriction already practiced south of Admiralty Inlet (i.e. the entrance to the Puget Sound) by container ships.

VBRT-RMM: Station a rescue tug at Victoria, BC and Bedwell Harbor, BC and model its coverage in the same manner as the coverage model that was developed for the Neah Bay rescue tug in the VTRA 2005.

The first three components DH100-RMM, HM50-RMM and SE-RMM are referred to in combination as the USCG-RMM Suite. DH100-RMM is currently being phased in by vessel owners to meet the requirements of the International Maritime Organization (IMO) Convention for the Prevention of Pollution from Ships, Annex I, Regulation 12A. The intent of the HM50-RMM is to conduct a maximum benefit type evaluation utilizing the VTRA 2015 model through the on-going implementation of 46CFR Subchapter M, which establishes safety regulations governing the inspections, standards, and safety management systems of towing vessels. The intent of including the SE-RMM is to conduct a maximum benefit type evaluation utilizing the VTRA 2015 model through increased carriage of AIS transponders by fishing and passenger vessels, changes to USCG VTS software that will allow VTS operators to display additional small vessel and recreational boat AIS data, and mandatory safety inspections for commercial fishing vessels. The effect of the SE-RMM implementation in the VTRA 2015 model evaluations is the removal of all POTENTIAL collisions in the VTRA analysis with special event vessels and the removal of the contributing effect that the presence of these special event vessels may have on other focus vessel accidents. By no means ought the implementation method of the HM50-RMM and the SE-RMM in the VTRA 2015 model, and their effectiveness evaluation, be interpreted as the manner in which the HM50-RMM and the SE-RMM are operationalized in practice.

To achieve risk reduction across the VTRA study area, as previously stated in the introduction, we believe that the question "which risk mitigation measure should one implement?" is not the right question to ask, but rather one should ask oneself "which portfolio of risk mitigation measures should one implement". Two of these trial portfolio scenario analyses were conducted utilizing the VTRA 2015 model. The first portfolio is referred to as the **5RMM** Scenario and combines the USCG-RMM Suite[1] (DH100-RMM, HM50-RMM, SE-RMM combined), with the OAE-RMM, KME-RMM, SRT-RMM and 125-RMM Scenarios. The second portfolio is referred to as the **3RMM** Scenario combining the DH100-RMM, 17-RMM and the VBRT-RMM. Four RMMs were evaluated individually as an RMM Scenario: **OAE-RMM, SRT-RMM, KME-RMM and 125-RMM**. In the implementation of the 125-RMM Scenario, vessel time exposure of the tank focus vessel category evaluated by the VTRA model was reduced by about a factor 0.94 through the cancellation of inbound laden crude tankers in the VTRA 2015 model, while approximately maintaining the oil time exposure of the tank focus vessel category without the cancellation of these inbound laden crude tankers, i.e. by about a factor 0.99 specifically. Recall that this 125-RMM Scenario and the other five RMM Scenarios were evaluated as enacted upon the USKMCA1600 What-If Scenario. None of the other RMMs were evaluated individually as part of the VTRA 2010 Study, nor was the USCG-RMM Suite (i.e. DH100-RMM, HM50-RMM, SE-RMM combined) evaluated individually.

Summarizing, the six RMM Scenarios listed in bold in the paragraph above were the six RMM Scenarios evaluated during the VTRA 2015 study as enacted upon the USKMCA1600 What-If Scenario. To emphasize that the above RMM Scenarios are enacted upon the USKMCA1600 What-If Scenario, section headings, figure labels and captions in this chapter may depict descriptors similar to, e.g., "**USKMCA1600-5RMM**" to serve as a reminder that the RMM evaluations are enacted upon the USKMCA1600 What-If Scenario.

Description of enhanced escorting requirements represented in the six RMM Scenarios

Figure 4-2, Figure 4-3, Figure 4-4 and Figure 4-5 provide additional detail regarding potential enhanced escorting requirements represented in the six RMM Scenarios evaluated during the VTRA 2015 Study and enacted upon the USKMCA1600 What-If Scenario. Figure 4-2A depicts the assumed location of a pre-stationed rescue tug in Sidney, BC, for the SRT-RMM Scenario and modeled after the rescue tug model developed for the Neah Bay rescue tug during the VTRA 2005 and also utilized in the VTRA 2010. The location of the Neay Bay rescue tug is also depicted in Figure 4-2A. Figure 4-2B depicts the assumed location of a pre-stationed rescue tug in Victoria, BC, and in Bedwell Harbor, BC, for the USKMCA1600-3RMM Portfolio Scenario (i.e. DH100-RMM, 17-RMM and the VBRT-RMM combined) where the effect of both these rescue tugs were also modeled after the rescue tug model developed for the Neah Bay rescue tug during the VTRA 2005.

[1] Of course the wording "suite" is synonymous to "portfolio" in this context. However, this suite of risk mitigation measures DH-RMM, HM50-RMM, SE-RMM was not evaluated individually using the VTRA 2015 model and is therefore for that distinction in this report referred to as a "suite". Since this suite was not evaluated individually, this report does not contain analysis results that describe the POTENTIAL risk reduction effectiveness of that suite by itself.

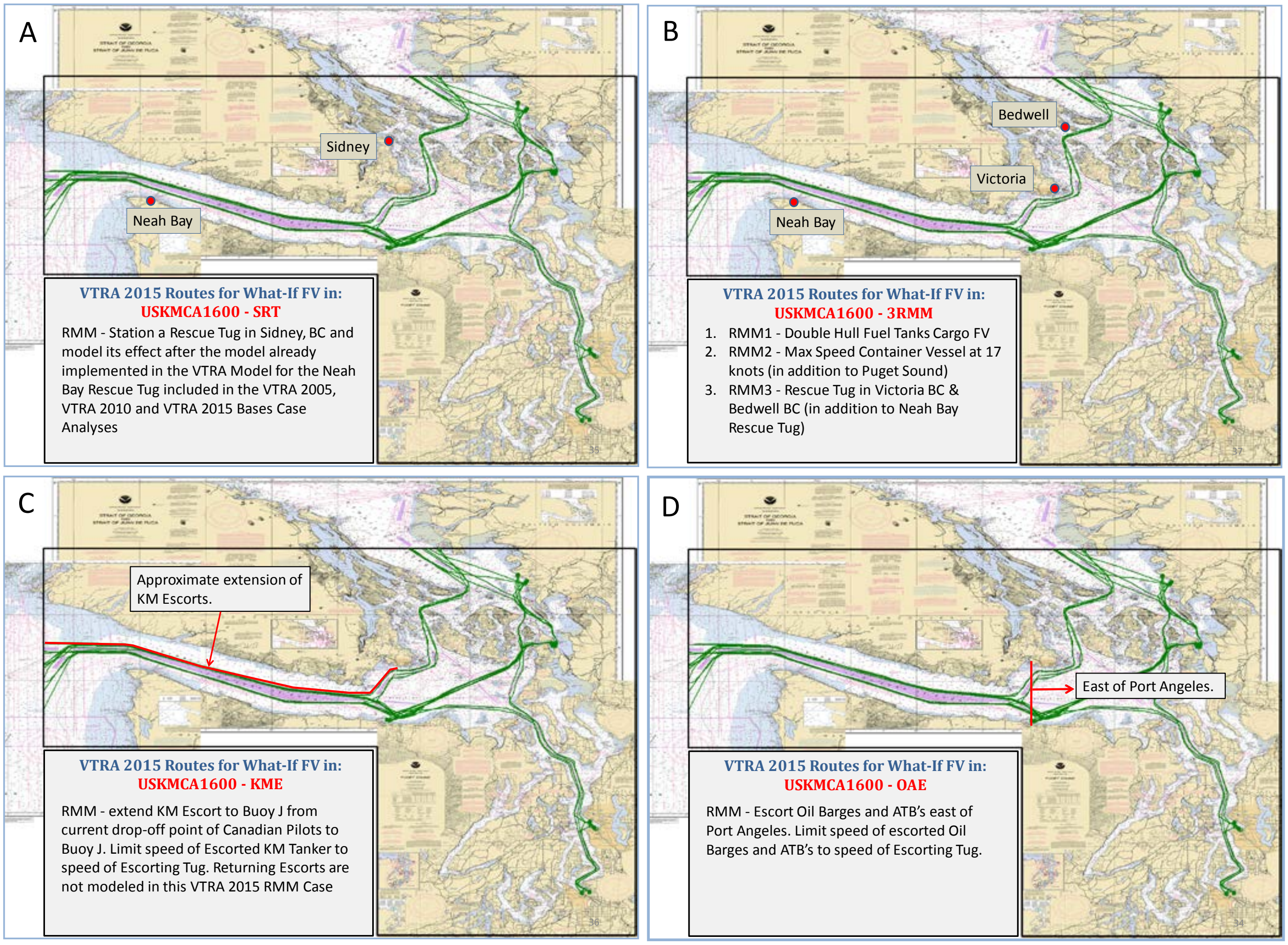

Figure 4-2. Additional detail for RMM Scenarios that model an additional escorting requirement in the VTRA 2015 model.

Figure 4-2C depicts the assumed escorting extension of laden outbound What-If tankers associated with the Westridge Marine Terminal/Kinder Morgan pipeline extension represented in the KME-RMM Scenario. Finally, Figure 4-2D depicts the area where one additional escort is assumed for laden Oil barges and ATBs in the VTRA 2015 model for the OAE-RMM Scenario. It is important to note that the enhanced escorting assumptions depicted in Figure 4-2A, C and D are all represented in the implementation of the **5RMM** Scenario (i.e. the USCG-RMM Suite, OAE-RMM, SRT-RMM, KME-RMM and 125-RMM combined and enacted upon the USKMCA1600 What-If Scenario) in the VTRA 2015 model. That being said, only the enhanced escorting requirement VBRT-RMM in Figure 4-2B was represented in the **3RMM** Portfolio Scenario. Moreover, the enhanced escorting requirement VBRT-RMM depicted in Figure 4-2B enacted upon the USKMCA1600 Scenario was not evaluated individually as part of the VTRA 2015 study, whereas the enhanced escorting requirements in Figure 4-2A, C and D were evaluated as the individual

OAE-RMM, SRT-RMM and KME-RMM Scenarios enacted upon the USKMCA1600 Scenario, respectively.

Figure 4-3 depicts the approximate escorting coverage in the VTRA model for the Neah Bay rescue tug. One observes from Figure 4-3 that focus vessels that travel in the locations indicated in Figure 4-3 with the red colored grid cells are not assigned any benefit attributable to the pre-stationing of the Neah Bay rescue tug (i.e. the focus vessels in these locations are assigned an escort number benefit equal to zero). Focus vessels that travel in the locations indicated in Figure 4-3 with the bright green color grid cells are on average assigned a single escort (i.e. the vessels that travel in these locations are assigned an escort number benefit close to 1 escort) in the VTRA grounding probability model in [3]. Observe from Figure 4-3 that these bright green colors are predominantly observed closer to the Neah Bay rescue tug location and south of the traffic separation zone and the approaches to the entrance of the Strait of Juan de Fuca.

The color scale located to the left and the bottom of Figure 4-3 , combined with the numerical scale next to it, shows in-between colors ranging from the color bright green to the color red, indicating that focus vessels travelling through grid cells with these in-between colors are assigned a partial escort number benefit attributable to the Neah Bay rescue tug. Specifically, the vessels travelling in these locations are assigned an escort number between 0 and 1. Thus, the escorting benefit in cells with the in-between colors is discounted from the value 1, which indicates an added single additional escort benefit, because the focus vessels travelling in these locations are not being continuously escorted by a single tug (and thus receive a partial escort benefit in the VTRA model due to the pre-stationed rescue tug at Neah Bay). One observes from Figure 4-3 that the closer a focus vessel is travelling to the Neah Bay rescue tug location, the larger the partial escort number benefit that is assigned to the focus vessel in the VTRA model with the maximum escort number benefit being assigned attributable to the Neah Bay rescue tug equaling to 1.

That being said, the partial escort number benefit assigned to a focus vessel is not just a function of the distance between the travelling focus vessel and the Neah Bay Rescue location, but also a function of whether the focus vessel is travelling towards or away from the Neah Bay Rescue tug and its closeness to the shoreline as defined in the VTRA Model. For example, one observes from Figure 4-3 that on average brighter yellow to orange colors are assigned in the Strait of Juan de Fuca and east of the Neah Bay rescue tug location but north of the traffic separation zone (with focus vessels travelling towards the Neah Bay tug location) and on average more orange to red colors are assigned east of the Neah Bay rescue tug location but south of the traffic separation zone in the Strait of Juan de Fuca (with focus vessels travelling away from the Neah Bay tug location).

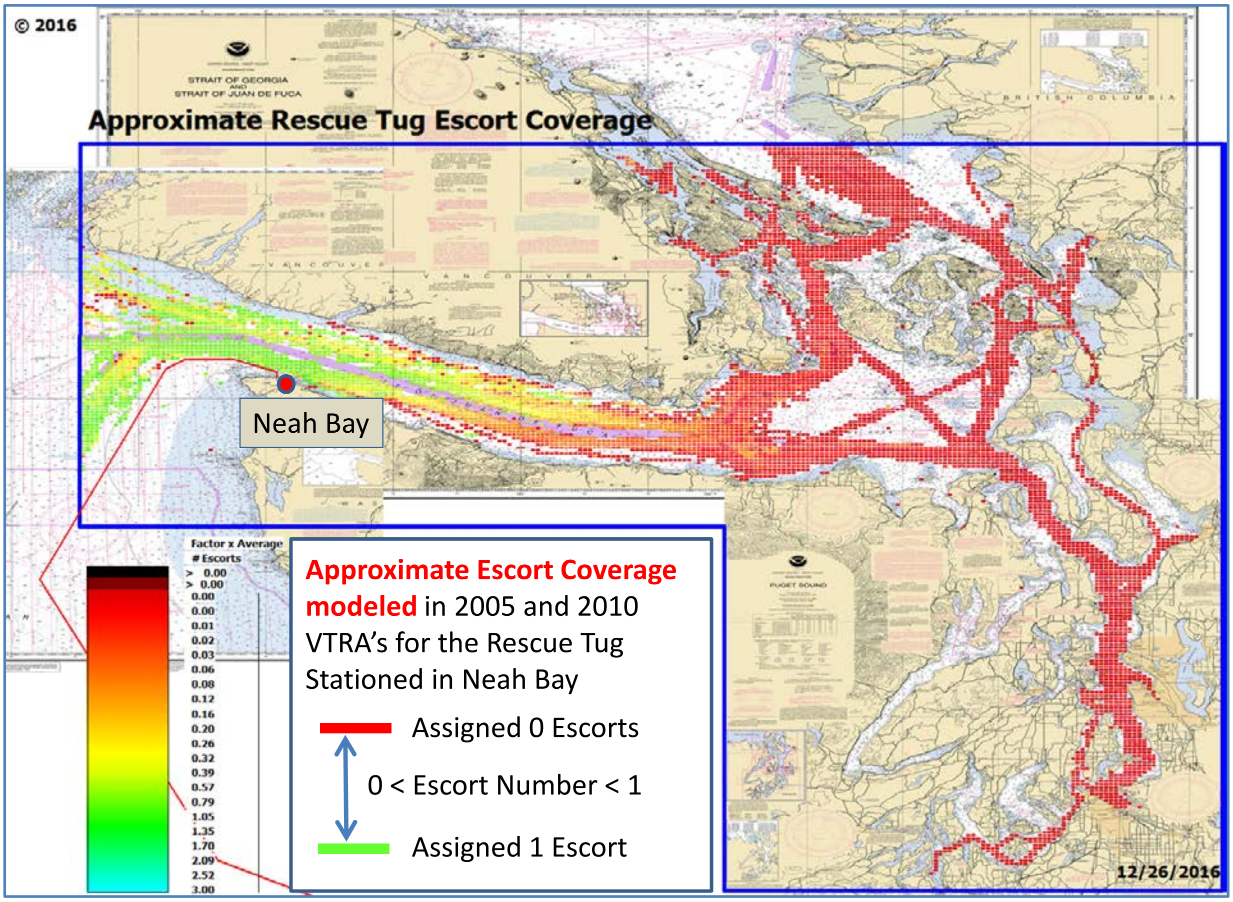

Figure 4-3. Graphical representation of approximate escorting coverage modeled for the Neah Bay Rescue Tug in the VTRA Model.

Following that same Neah Bay rescue tug model, Figure 4-4 depicts the approximate escorting coverage in the VTRA model for the Neah Bay and the modeled Sidney, BC, rescue tug combined. One observes from Figure 4-4 predominantly yellow colors on average being assigned to focus vessels travelling through the Haro-Strait/Boundary Pass and Southern Gulf Islands waterway zones indicating an assigned partial escort number benefit of about the value 0.3 attributable to the modeled Sidney, BC, rescue tug location. Comparatively to the Strait of Juan de Fuca, the Haro-Strait/Boundary Pass waterway zone is narrower than the Strait of Juan de Fuca North of the Neah Bay rescue tug location explaining in part that lower escort number benefit. More orange colors in the Haro-Strait/Boundary Pass and Southern Gulf Islands indicate a partial escort number benefit being assigned in the VTRA Model attributable to the modeled Sidney, BC, rescue tug location closer to the value 0.15 (or even a lesser value the darker the orange color in these grid cells). One does, however, observe some bright greener colored grid cells in the Haro-Strait/Boundary Pass and Southern Gulf Islands waterway zones that are on average assigned in the VTRA model to those focus vessels travelling towards the modeled Sidney, BC, rescue tug location both North and South of Turn-Point.

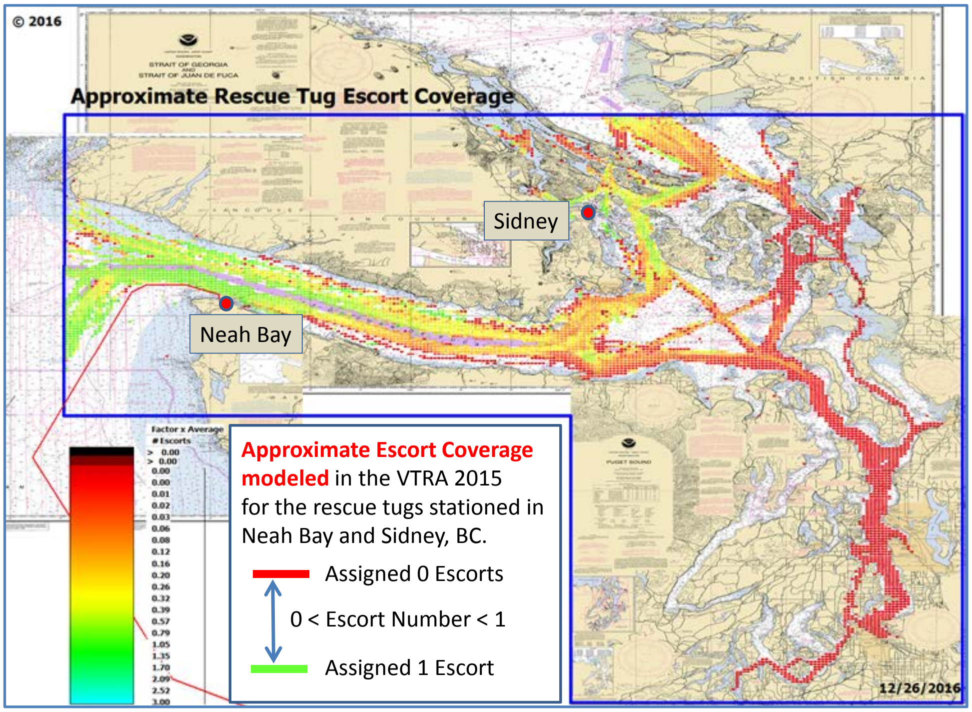

Figure 4-4. Graphical representation of approximate escorting coverage modeled for the Neah Bay and Sidney, BC, rescue tugs combined in the VTRA Model.

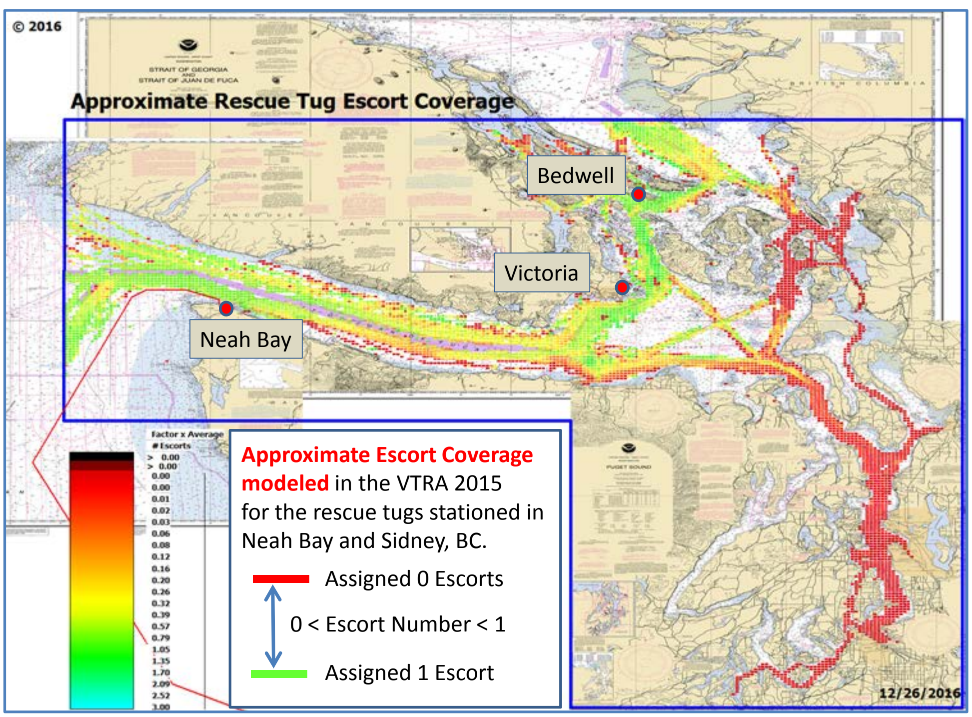

Figure 4-5. Graphical representation of approximate escorting coverage modeled for the Neah Bay, Victoria, BC, and Bedwell Harbor, BC, rescue tugs combined in the VTRA Model.

Following that same Neah Bay rescue tug model, Figure 4-5 depicts the approximate combined escorting coverage in the VTRA model for the Neah Bay rescue tug, a rescue tug modeled in Victoria, BC, and one modeled in Bedwell Harbor, BC. Comparing Figure 4-4 with Figure 4-5 one observes in Figure 4-5 more grids cells in the Haro-Strait/Boundary Pass and Southern Gulf Islands waterway zones with bright green colors indicating a partial escort number on average being assigned in the VTRA Model with a value closer to 1 in these waterway zones due to the presence of two pre-stationed rescue tug locations in Figure 4-5 as opposed to one pre-stationed rescue tug location modeled in these waterway zones in Figure 4-4.

The modeling of pre-stationed rescue tugs locations in the VTRA 2015 in the Haro-Strait/Boundary Pass waterway zone is another distinguishing feature between the VTRA 2015 and the VTRA 2010 studies. In the VTRA 2010 Study an additional escort was assigned to all focus vessels travelling though the Haro-Strait/Boundary Pass waterway zone to conduct a maximum benefit type evaluation of prepositioning tugs in this waterway zone. From the AIS passage line vessel count data in Appendix C one observes that about 2800 focus vessels cross the Haro-Strait/Boundary Pass AIS passage lines annually (either in a northern or southern direction). Hence, to achieve these maximum type benefits evaluated during the VTRA 2010 Study at that time, one would have needed a larger number of escort vessels (than the one or two pre-stationed rescue tugs represented in Figure 4-4 or Figure 4-5), in addition to not experiencing a potentially negative effect associated with such a larger number of escort vessels travelling the Haro-Strait/Boundary Pass waterway zone annually to serve these focus vessels crossing the Haro-Strait/Boundary Pass AIS passage lines. In other words, simply due to the fact that the VTRA 2015 models only one or two pre-stationed rescue tugs in the VTRA 2015 RMM Scenario analyses, one can expect the effectiveness of these pre-stationed rescue tugs in these VTRA 2015 RMM Scenarios analyzed to be less than a similar maximum benefit type analysis that assumes one added escort vessel for all focus vessels travelling through the Haro-Strait/Boundary Pass waterway zone. Another reason why one can expect that the effectiveness evaluations for a pre-stationed rescue tug or tugs in the Haro-Strait/Boundary Pass waterway zone to be less in that type of an analysis, is that the maximum benefit type analysis conducted during the VTRA 2010 study, by adding one escort vessels to all focus vessels, also assigned an escorting benefit in the collision accident probability model (e.g. attributable to an external vigilance role that such a continuously escorting tug may have). No escorting benefit is assigned in the VTRA 2015 analysis attributable to a pre-station rescue tug in its collision accident probability model, since such a pre-stationed rescue tug does not continuously escort a focus vessel.

In general, the challenge of risk management is for it to be location specific, taking into consideration the type and location of traffic and how it changes as a result of proposed traffic increases. The proposed RMM Scenarios evaluated herein were in part informed by evaluated changes in risk for the five What-If Scenarios. One must realize, however, in evaluating the VTRA

2015 RMM analysis results in the sections below that risk does not necessarily disappear when mitigated locally, but tends to migrate as demonstrated by some waterway zones experiencing increases in risk when other waterway zones are targeted for risk reductions. This is in large part a result of a maritime transportation system being a dynamic system, where a small traffic perturbation can precipitate traffic behavior changes in the future. Such migrations are preferably avoided in a sound risk management strategy, but some risk migration may be inevitable. In addition, the VTRA 2015 maritime simulation model contains some random elements in terms of it traffic simulation for what are termed "special events". These special events represented in the VTRA model are modeled whale watching activities, regattas and tribal and commercial fishing openers. As a result of these random elements, some risk changes in the evaluated RMM Scenarios (and the What-If Scenarios) are a result of these random elements changing their behavior from simulation run to simulation run[2].

[2] Combined fishing vessels, including commercial and tribal fishing openers, and yachts/recreational vessels account for about 43% of the non-focus vessel traffic vessel time exposure (VTE) modeled in the VTRA 2015 model which is equivalent to about a third of the overall modeled traffic in the VTRA Model in terms of vessel time exposure (VTE).

USKMCA1600 - 5RMM Scenario analysis results

The manner of implementation of the 5RMM Portfolio of RMMs in the VTRA 2015 model enacted upon the USKMCA1600 What-If Scenario was as follows (in no specific order):

DH100-RMM: 100% Double Hull Fuel Protection of Cargo Focus Vessels (increased from 40% in the Base Case 2015 Scenario).

HM50-RMM: Reduce human error and mechanical failure on Tugs (Excluding Oil Barges) by 50%.

SE-RMM: Remove from the VTRA 2015 Simulation Model its special events, i.e. the modeled regatta, whale watching, and commercial and tribal fishing openers. Combined fishing vessels and yachts/recreational vessels account for about $(39.5\% + 3.6\%) \approx 43.1\%$ of the non-focus vessel traffic (see Figure E-4) in the VTRA 2015 model or $(43.1 \times 75.8\%) \approx 32.7\%$, i.e. about a third, of the VTRA Model traffic in terms of vessel time exposure (VTE). See also, Figure E-4 and Figure E-6A.

OAE-RMM: Continuously escort laden Oil Barges and ATBs East of Port Angeles (unthethered).

KME-RMM: Extend escorting of Kinder Morgan outbound laden tankers to Buoy J.

SRT-RMM: Station a rescue tug at Sidney, BC and model its coverage in the same manner as the coverage model that was developed for the Neah Bay rescue tug in the VTRA 2005.

125-RMM: Lift the 125 DWT limit on laden crude inbound tankers while reducing the number of crude inbound tanker transits to keep the volume of crude inbound tankers approximately the same.

The first three components DH100-RMM, HM50-RMM and SE-RMM are referred to in combination as the USCG-RMM Suite. DH100-RMM is currently being phased in by vessel owners to meet the requirements of the International Maritime Organization (IMO) Convention for the Prevention of Pollution from Ships, Annex I, Regulation 12A. The intent of the HM50-RMM is to conduct a maximum benefit type evaluation utilizing the VTRA 2015 model through the on-going implementation of 46CFR Subchapter M, which establishes safety regulations governing the inspections, standards, and safety management systems of towing vessels. The intent of including the SE-RMM is to conduct a maximum benefit type evaluation utilizing the VTRA 2015 model through increased carriage of AIS transponders by fishing and passenger vessels, changes to USCG VTS software that will allow VTS operators to display additional small vessel and recreational boat AIS data, and mandatory safety inspections for commercial fishing vessels. The effect of the SE-RMM implementation in the VTRA 2015 model evaluations is the removal of all POTENTIAL collisions in the VTRA analysis with special event vessels and the removal of the contributing effect that the presence of these special event vessels may have on other focus vessel accidents. By no means ought the implementation method of the HM50-RMM and the SE-RMM in the VTRA

2015 model, and their effectiveness evaluation, be interpreted as the manner in which the HM50-RMM and the SE-RMM are operationalized in practice.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL Accident Frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was assessed as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

In Chapter 3 a POTENTIAL Accident Frequency was evaluated for the USKMCA1600 scenario of about $1.11 \times 4.4 \approx 4.9$ accidents per year. From Figure 3-40 in Chapter 3 one observes that overall for the USKMCA1600 What-If Scenario about a +85% increase of total POTENTIAL Oil Loss was evaluated by the VTRA 2015 model over the entire VTRA Study Area from the Base Case 2015 Scenario. Figure 3-41 shows that the distribution of this about 185% of POTENTIAL Oil Loss was evaluated for the USKMCA1600 What-If Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@73% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 185% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 4-6 one observes that overall for the 5RMM Scenario about a +31% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area from the Base Case 2015 Scenario, despite the consideration of the 5 risk mitigation measures (RMMs) enacted upon the USKMCA1600 Scenario. Figure 4-7 shows that the distribution of this about 131% of POTENTIAL Oil Loss was evaluated by the VTRA 2015 model for the 5RMM Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@83% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@13% of Base Case POTENTIAL Oil Losses)

C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@35% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 131% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the USKMCA1600 What-If Scenario, one observes that of the about 185% - 131% ≈ 54% POTENTIAL Oil Loss decrease from the USKMCA1600 Scenario, about 38% is accounted for by a reduction in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category, about 8% by a reduction in the 2500 m^3 or more POTENTIAL Oil Loss Category, about 7% by a reduction in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category and about a 1% reduction in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss Category. It should be noted, however, that the 5RMM Scenario makes maximum benefit type assumptions to evaluate risk reduction effectiveness of some of its components in this 5RMM Scenario portfolio analysis. On the other hand, the 5RMM Scenario also contains an RMM Component (the 125-RMM) that was evaluated individually by the VTRA 2015 model to have the unintended consequence of an increase in POTENTIAL Oil Loss (by about +12%). No doubt, when holding on to the maximum benefit type assumptions in the 5RMM Scenario components while removing the 125-RMM portfolio from the 5RMM portfolio, the risk reductions evaluated above would be higher, but how much higher cannot be stated, since such an RMM Portfolio Scenario analysis was not conducted in the VTRA 2015 study.

Figure 4-8 presents the relative decreases of the total POTENTIAL Oil Loss evaluated for the 5RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative reduction factor of 0.71 (green highlight in Figure 4-8) for the VTRA 2015 Study Area as a whole for the 5RMM Scenario. From Figure 4-8 one observes that the largest relative decreases in POTENTIAL Oil Loss are evaluated by the VTRA 2015 Model in the Saragota Skagit and Southern Gulf Islands waterway zones with relative multiplicative reduction factors of about 0.45 and 0.56 (red highlights in Figure 4-8). Thus, one observes that while overall a relative factor decrease is observed of about 0.71 for the VTRA 2015 study area as a whole, these relative reduction factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Oil Loss that was evaluated for the USKMCA1600 What-If Scenario is decreased in the 5RMM Scenario by a relative multiplicative reduction factor of about 0.45 within the Saragota Skagit waterway zone. Similarly, the POTENTIAL Oil Loss that was evaluated for the USKMCA1600 Scenario is decreased in the 5RMM Scenario by a factor of about 0.56 within the Southern Gulf Islands waterway zone. The other waterway zones that experience about the same or a higher POTENTIAL Oil loss relative reduction factors than the whole VTRA Study Area in the 5RMM Scenario are the waterway zones Puget Sound South, Haro-Strait/Boundary Pass, Georgia Strait, Saddlebag and Puget Sound North with relative reduction factors of about 0.59, 0.61, 0.62, 0.64 and 0.65 (yellow highlights in Figure 4-8) respectively. It should be noted that these are

POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Figure 4-9 presents the relative decreases of the total POTENTIAL Accident Frequency evaluated for the 5RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First, observe the overall multiplicative reduction factor of 0.76 (green highlight in Figure 4-9) for the VTRA 2015 Study Area as a whole for the 5RMM Scenario. Thus overall, the VTRA 2015 Model evaluated for the 5RMM Scenario about $0.76 \times 4.9 \approx 3.7$ number of accidents per year of which now (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 83% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category (a reduction of about 15% from the 98.2% evaluated for the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category). However, this 15% reduction in POTENTIAL Accident Frequency in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category evaluated for the 5RMM Scenario reduces POTENTIAL Oil Loss by about 1%. From Figure 4-9 one observes that the largest relative decrease in POTENTIAL Accident Frequency is evaluated by the VTRA 2015 Model in the Rosario, Guemes, and Saddlebag waterway zones with a relative reduction factor of about 0.51, 0.56 and 0.58 (red highlights in Figure 4-9), respectively. Thus, one observes that while an overall relative factor decrease is observed of 0.71 for the whole VTRA 2015 study area, these relative factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Accident Frequency evaluated for the USKMCA1600 Scenario decreases within the Rosario, Guemes and Saddlebag waterway zones by about a factor 0.51, 0.56 and 0.58 respectively in the 5RMM Scenario. The other waterway zones that experience higher POTENTIAL Accident Frequency relative reduction factors than the VTRA Study Area for the 5RMM Scenario are the waterway zones Haro-Strait/Boundary Pass and Tacoma South with relative reduction factors of about 0.66 and 0.75 (yellow highlights in Figure 4-9), respectively. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) within a 10-year period. Thus, for example, Figure 4-10 shows an estimated probability[3] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area, of about 1.13%[4]. Recall from Figure 4-7A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 83% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for

[3] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f}\times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[4] A 1% probability equals to a probability of 1 in 100.

the 5RMM Scenario (@ ≈ 131%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 1.13% (down by a multiplicative reduction factor of 0.85, green highlight in Figure 4-10, from the same probability evaluated for the USKMCA What-If Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 83% of the overall POTENTIAL Oil Loss (up by a multiplicative factor of 1.98 for the 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the 5RMM Scenario (which was evaluated in total at about 131% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages), despite the RMMs enacted upon the USKMCA1600 Scenario by the 5RMM Scenario. In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to more than half of the POTENTIAL Oil Loss evaluated for the 5RMM Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 4-10 for the 5RMM Scenario, one observes a relative reduction factor of 0.30, 0.59 and 0.61 (red highlights in Figure 4-10) for the Saragota Skagit, Georgia Strait and Rosario Strait waterway zones respectively, for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period, for these particular waterway zones. Other waterway zones that experience about the same or higher relative reduction factors for these probabilities as compared to the VTRA Study area as a whole, are the waterway zones Puget Sound South and Saddlebag with both relative reductions factors of about 0.76. It should be noted that these are decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Similar observations can be made from Figure 4-11, Figure 4-12 and Figure 4-13 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3 respectively. While about 0% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the 5RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-13 at about 100%. In other words, it is estimated by the VTRA 2015 Model that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will likely happen within the VTRA Study Area within a 10-year period in the 5RMM Scenario. While about a 13% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (up by about +1% from the Base Case 2015 Year in this particular POTENTIAL Oil Loss Category) in the 5RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-11 at about 0.63%. Finally, while about a 35% POTENTIAL Oil Loss contribution is evaluated for 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (about a 38% decrease evaluated from the USKMCA1600 What-If Scenario in this particular POTENTIAL Oil Loss Category) in the 5RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-11 at about 46.5% (about an 8% decrease in this probability from the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category).

As was the case for Figure 4-8, red highlights show the smallest relative reduction factors by waterway zone than experienced for the VTRA 2015 Study area in Figure 4-11, Figure 4-12 and Figure 4-13. Yellow highlights show the next smallest relative reduction factors experienced by waterway zones than experienced for the VTRA 2015 Study area as a whole in Figure 4-11, Figure 4-12 and Figure 4-13. Figure 4-14, Figure 4-15, Figure 4-16 and Figure 4-17 provide estimated average spill sizes per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the 5RMM Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 4-11, Figure 4-12 and Figure 4-13 in the manner it was described above for Figure 4-10, but also the summary table in Appendix D for the 5RMM Scenario comparison to the Base Case 2015 Scenario. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 1.13% for the 5RMM Scenario, a value of 0.11% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 2.81% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

One must realize in evaluating the VTRA 2015 RMM analysis results in Figure 4-11, Figure 4-12 and Figure 4-13 (and Figure 4-10) that risk does not necessarily disappear when mitigated locally, but tends to migrate as demonstrated by some waterway zones experiencing increases in risk when other waterway zones are targeted for risk reductions. This is in large part a result of a maritime transportation system being a dynamic system, where a small traffic perturbation can precipitate traffic behavior changes in the future. Such migrations are preferably avoided in a sound risk management strategy, but some risk migration may be inevitable. In addition, the VTRA 2015 maritime simulation model contains some random elements in terms of it traffic simulation for what are termed “special events”. These special events represented in the VTRA model are modeled whale watching activities, regattas and tribal and commercial fishing openers. As a result of these random elements, some risk changes in the evaluated RMM Scenarios (and the What-If (Scenarios) are a result of these random elements changing their behavior from simulation run to simulation run (see, also Figure E-6A).

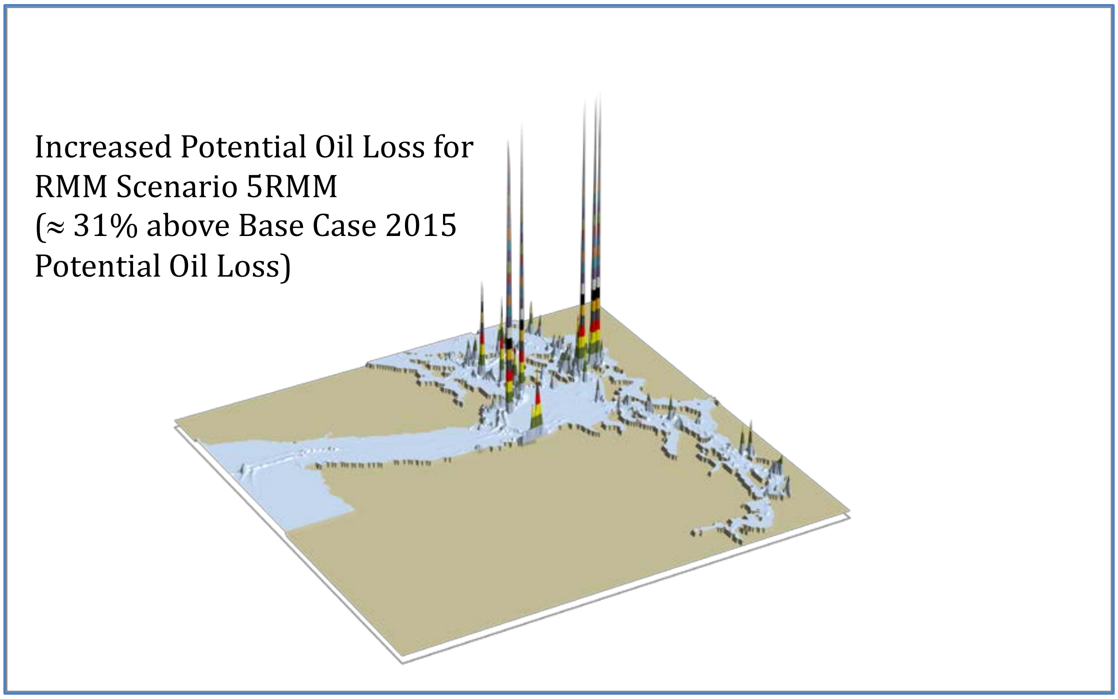

Figure 4-6. 3D Geographic profile of POTENTIAL oil loss for USKMCA1600-5RMM Scenario.

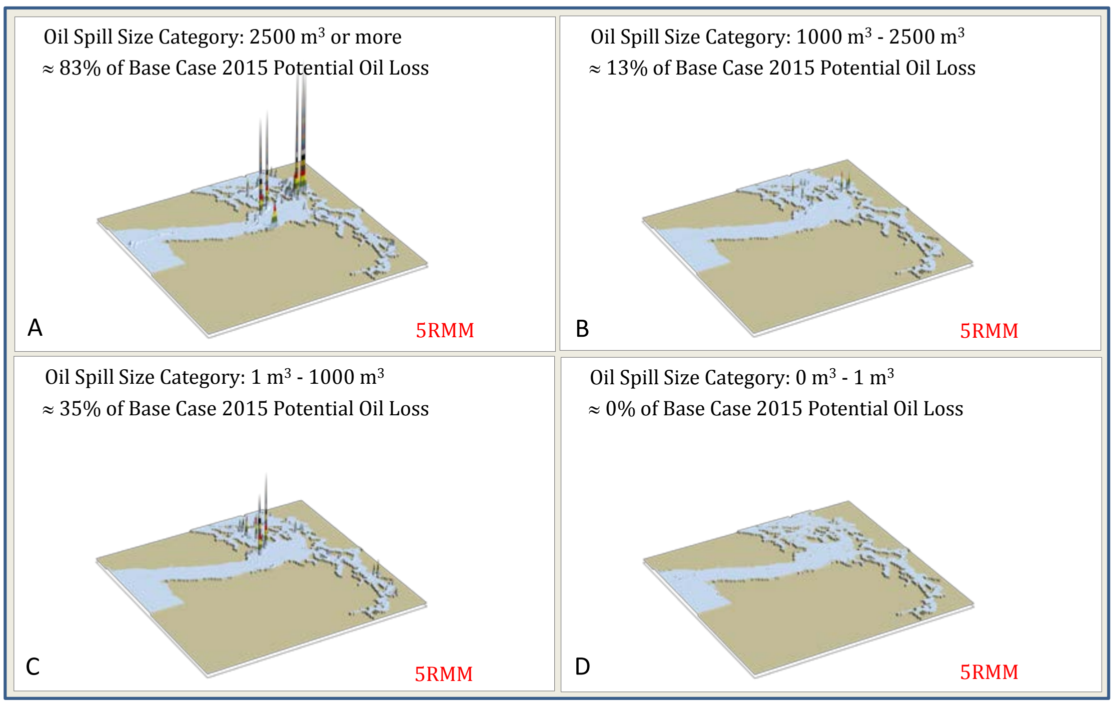

Figure 4-7. Components of 3D Geographic profile of USKMCA1600-5RMM Scenario POTENTIAL oil loss. A: 83% in Oil Spill Size Category of 2500 m^3 or more; B: 13% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 35% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 0% in Oil Spill Size Category of 0 m^3 -1 m^3

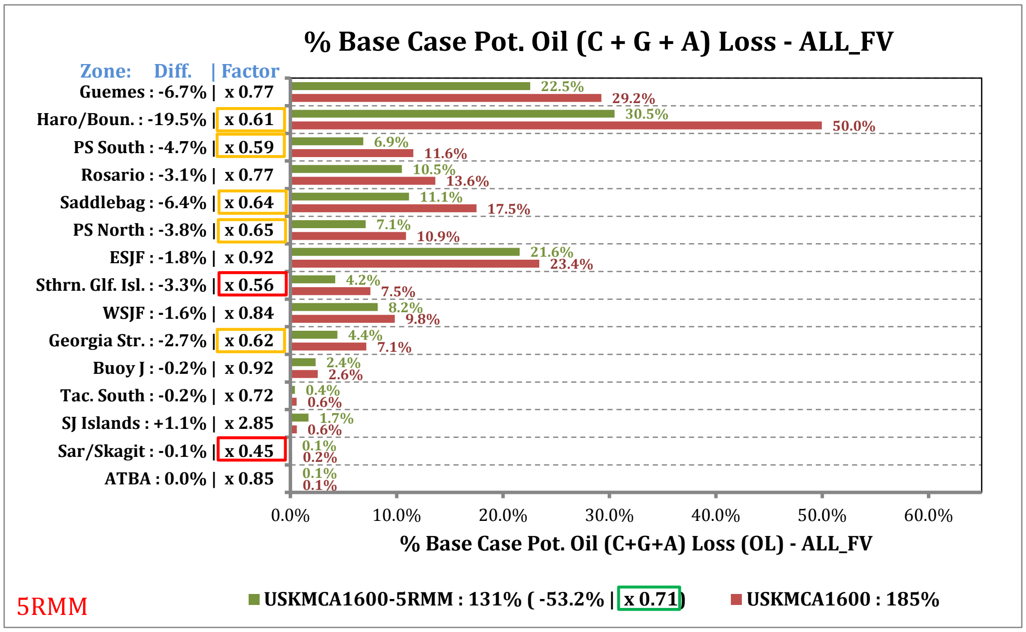

Figure 4-8. Relative comparison of POTENTIAL Oil Loss by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, green bars show the percentages for the USKMCA1600- 5RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

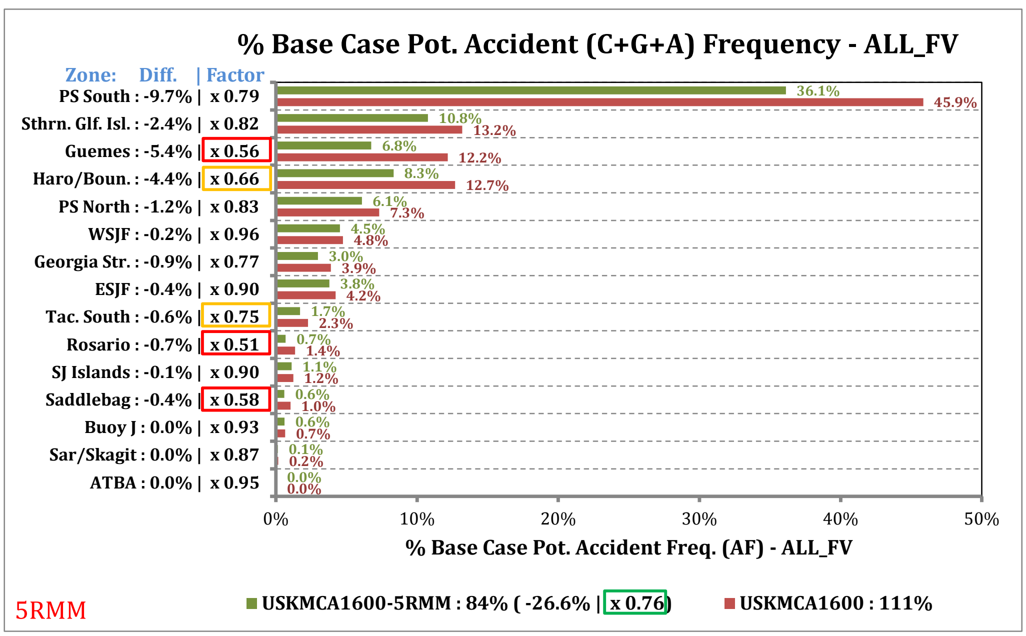

Figure 4-9. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, greens bars show the percentages for the USKMCA1600-5RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

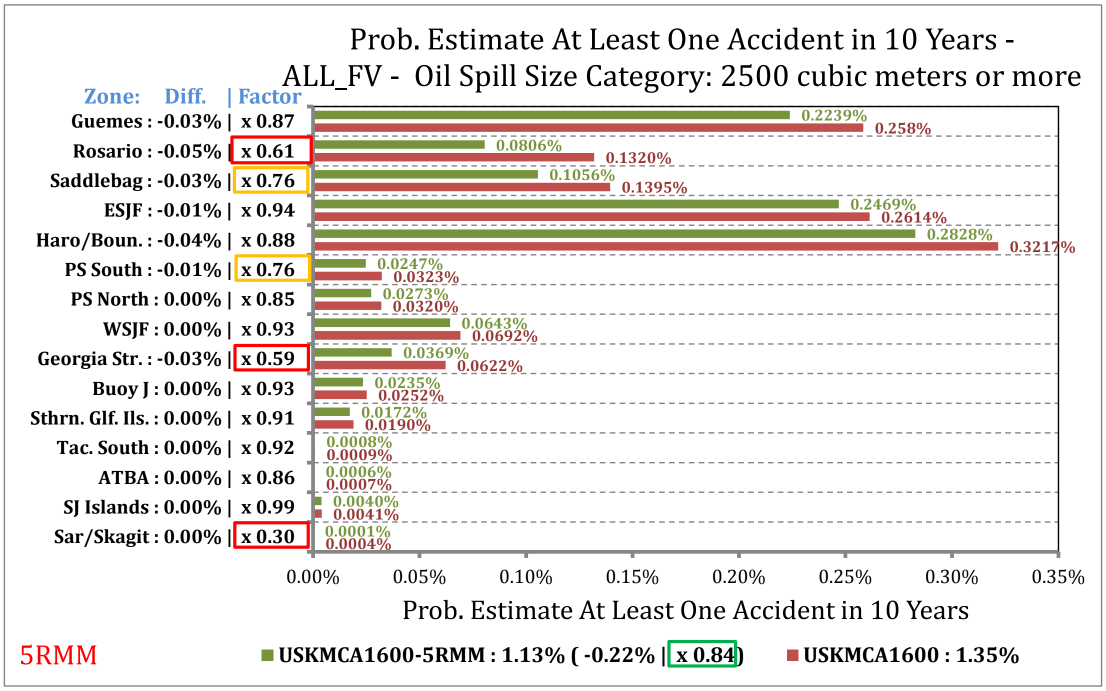

Figure 4-10. USKMCA1600-5RMM relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

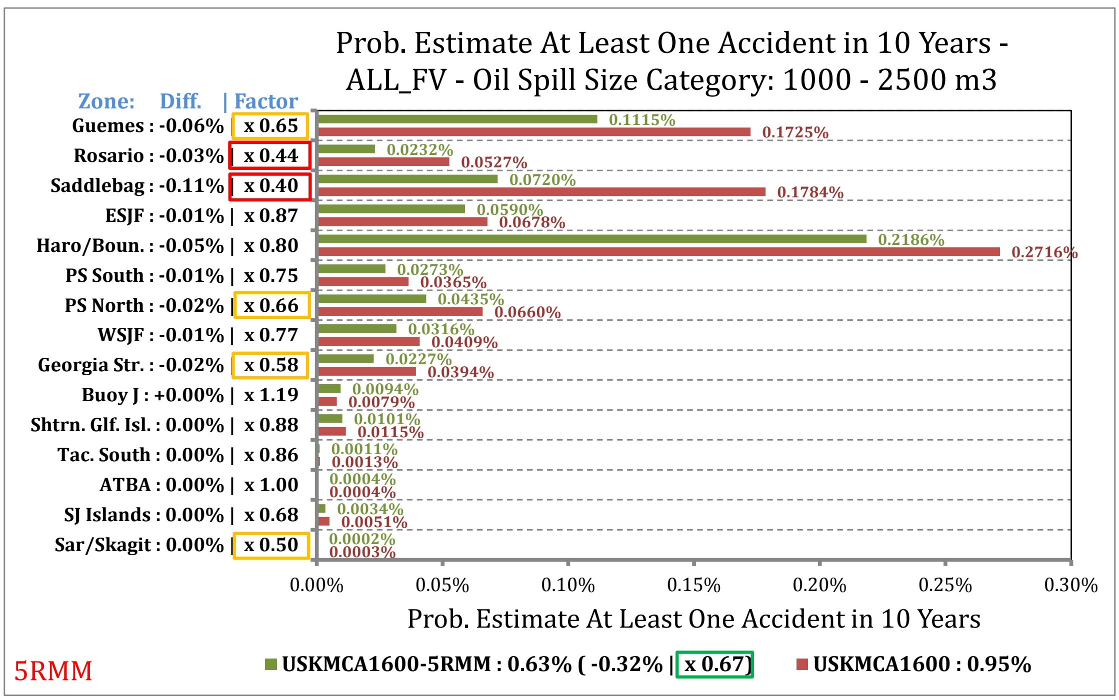

Figure 4-11. USKMCA1600-5RMM relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

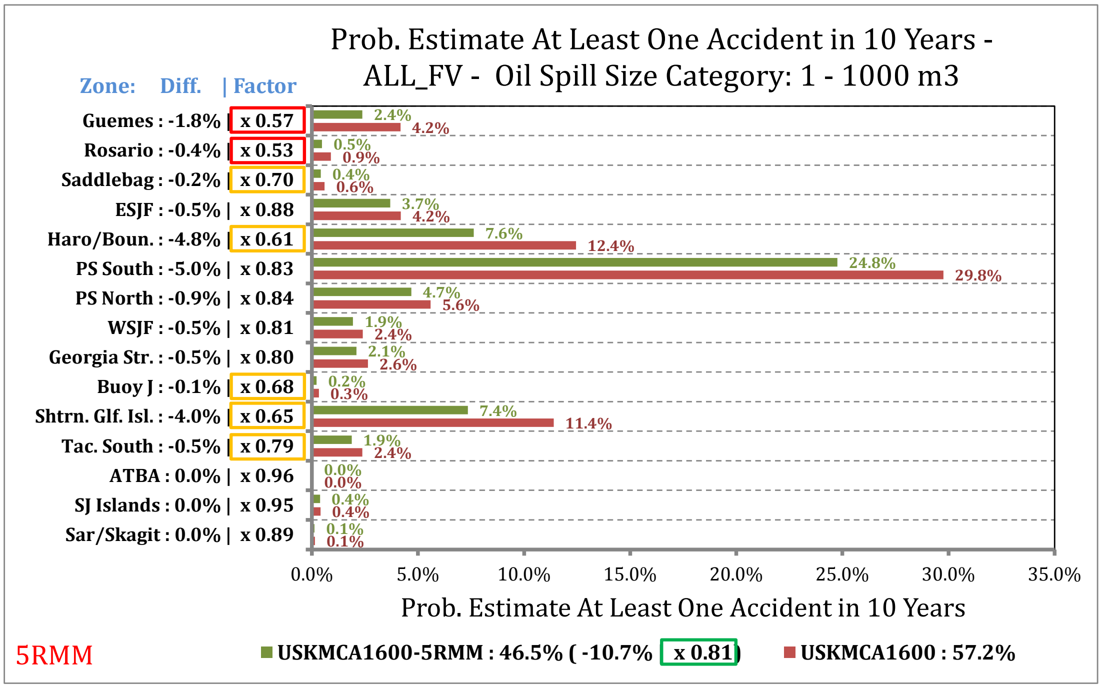

Figure 4-12. USKMCA1600-5RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

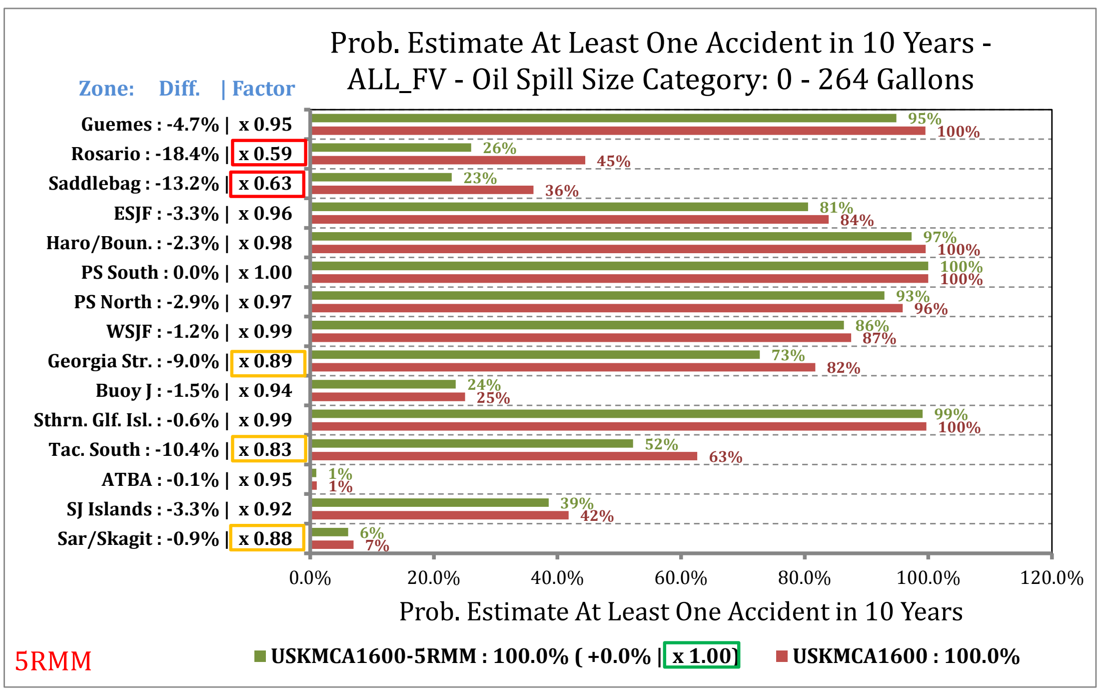

Figure 4-13. USKMCA1600-5RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

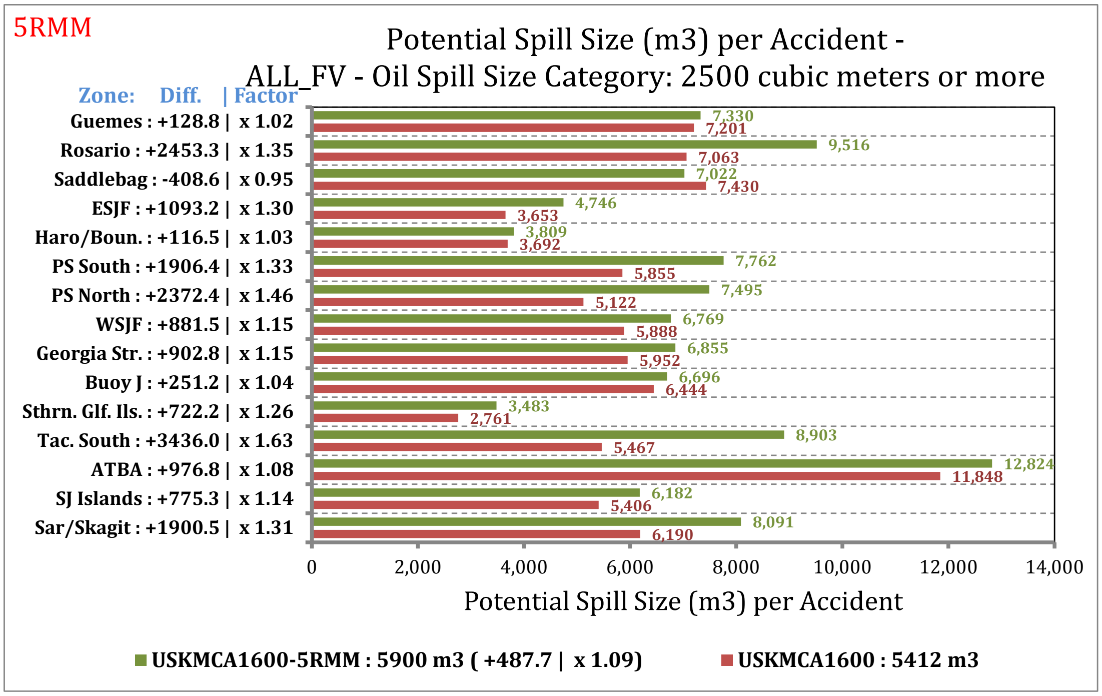

Figure 4-14. USKMCA1600-5RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

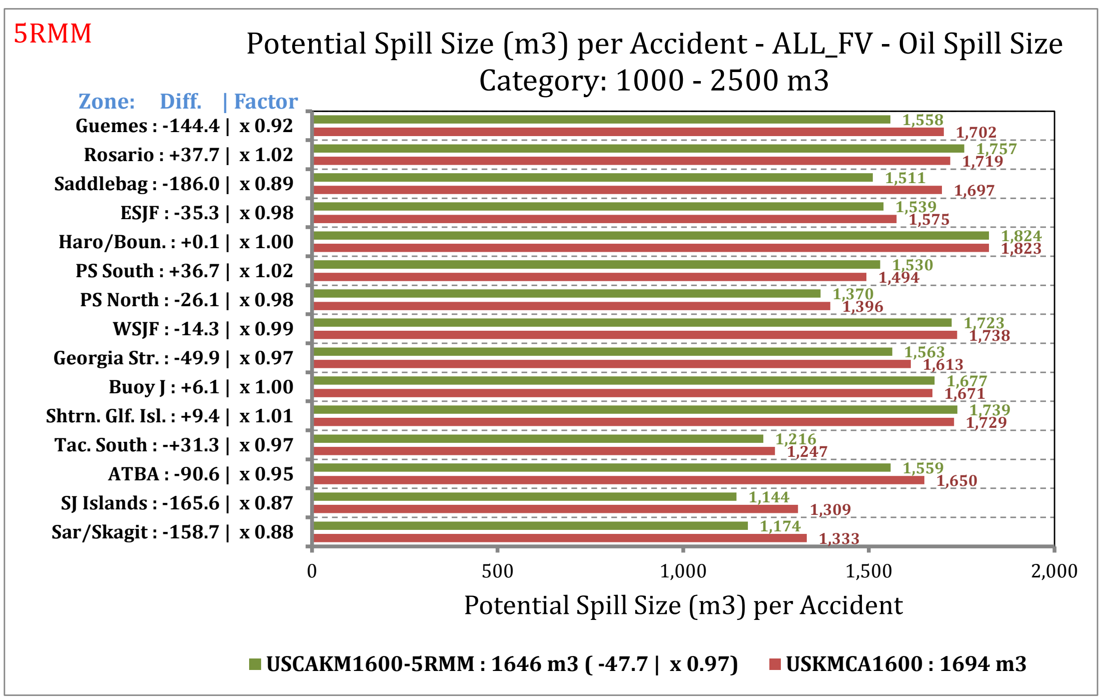

Figure 4-15. USKMCA1600-5RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

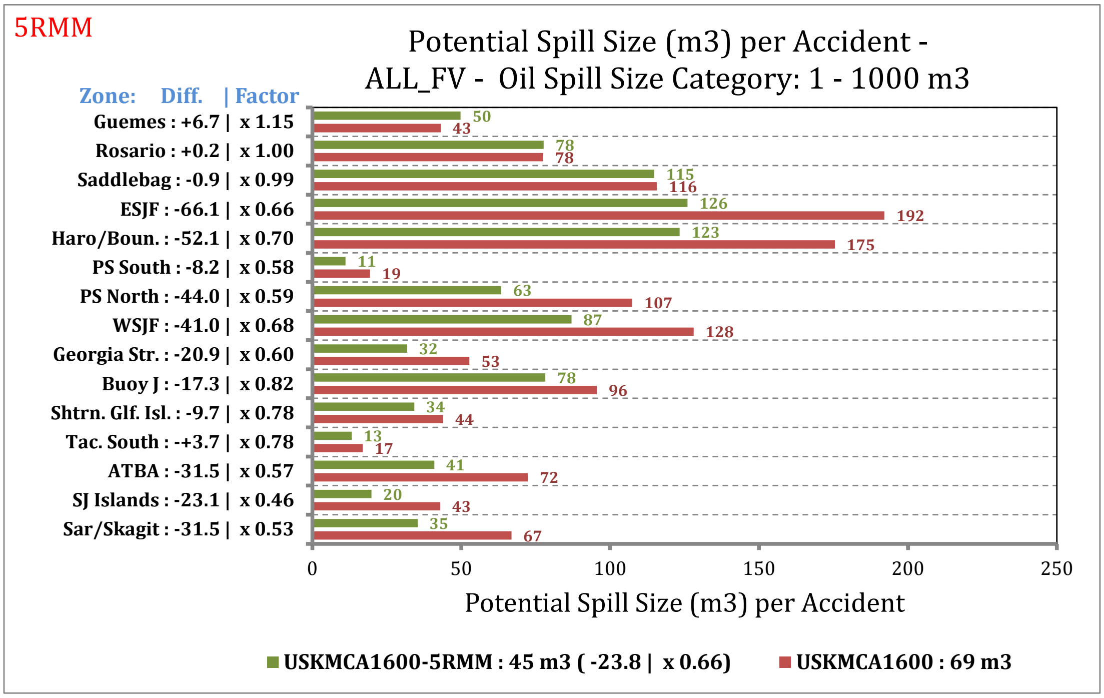

Figure 4-16. USKMCA1600-5RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

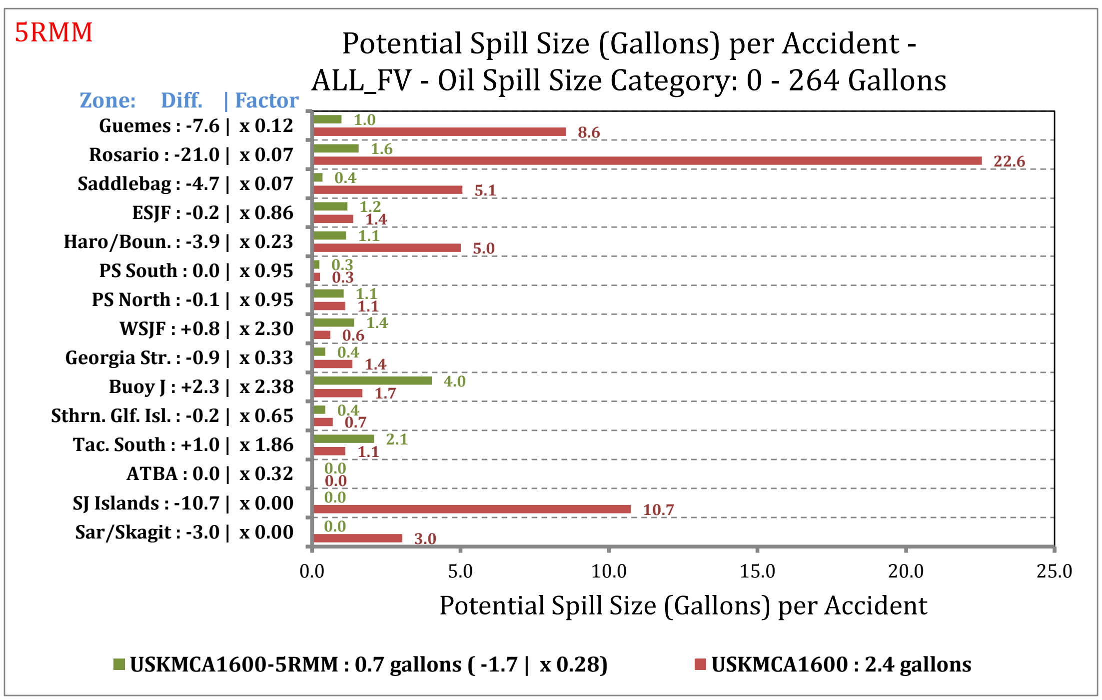

Figure 4-17. USKMCA1600-5RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

USKMCA1600 - 3RMM Scenario analysis results

The manner of implementation of the 3RMM Portfolio in the VTRA 2015 model enacted upon the USKMCA1600 What-If Scenario was as follows (in no specific order):

DH100-RMM: 100% Double Hull Fuel Protection of Cargo Focus Vessels (increased from 40% in the Base Case 2015 Scenario).

17-RMM: Reduce the speed of container vessel to 17 knots throughout the VTRA 2015 Study area, a speed restriction already practiced south of Admiralty Inlet (i.e. the entrance to the Puget Sound) by container ships.

VBRT-RMM: Station a rescue tug at Victoria, BC and Bedwell Harbor, BC and model its coverage in the same manner as the coverage model that was developed for the Neah Bay rescue tug in the VTRA 2005, see also Figure 4-2B.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL Accident Frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was assessed as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

In Chapter 3 a POTENTIAL Accident Frequency was evaluated for the USKMCA1600 scenario of about $1.11 \times 4.4 \approx 4.9$ accidents per year. From Figure 3-40 in Chapter 3 one observes that overall for the USKMCA1600 What-If Scenario about a +85% increase of total POTENTIAL Oil Loss was evaluated by the VTRA 2015 model over the entire VTRA Study Area from the Base Case 2015 Scenario. Figure 3-41 shows that the distribution of this about 185% of POTENTIAL Oil Loss was evaluated for the USKMCA1600 What-If Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@73% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 185% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 4-18 one observes that overall for the 3RMM Scenario about a +49% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area from the Base Case 2015 Scenario, despite the consideration of the 3 risk mitigation measures (RMMs) enacted upon the USKMCA1600 Scenario. Figure 4-19 shows that the distribution of this about 149% of POTENTIAL Oil Loss was evaluated by the VTRA 2015 model for the 3RMM Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@37% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 149% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the USKMCA1600 What-If Scenario, one observes that of the about 185% - 149% ≈ 36% POTENTIAL Oil Loss decrease from the USKMCA1600 Scenario about 36% is accounted for by a reduction in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category. Figure 4-20 presents the relative decreases of the total POTENTIAL Oil Loss evaluated for the 3RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative reduction factor of 0.81 (green highlight in Figure 4-20) for the VTRA 2015 Study Area as a whole for the 3RMM Scenario. From Figure 4-20 one observes that the largest relative decreases in POTENTIAL Oil Loss are evaluated by the VTRA 2015 Model in the Saragota Skagit and Southern Gulf Islands waterway zones with relative multiplicative reduction factors of about 0.44 and 0.48 (red highlights in Figure 4-20). Thus, one observes that while overall a relative factor decrease is observed of about 0.81 for the VTRA 2015 study area as a whole, these relative reduction factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Oil Loss that was evaluated for the USKMCA1600 What-If Scenario decreases within the Saragota Skagit waterway zone by about a relative multiplicative reduction factor of 0.44 in the 3RMM Scenario. Similarly, the POTENTIAL Oil Loss that was evaluated for the USKMCA1600 Scenario decreases within the Southern Gulf Islands waterway zone by about a factor 0.48 in the 3RMM Scenario. The other waterway zones that experience about the same or a higher POTENTIAL Oil loss relative reduction factors than the VTRA Study Area in the 3RMM Scenario are the waterway zones Puget Sound North, Puget Sound South, Haro-Strait/Boundary Pass, Tacoma South, West Strait of Juan de Fuca and East Strait of Juan de Fuca with relative reduction factors of about 0.54, 0.62, 0.68, 0.73, 0.75 and 0.80 (yellow highlights in Figure 4-20), respectively. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Figure 4-21 presents the relative decreases of the total POTENTIAL Accident Frequency evaluated for the 3RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative reduction factor of 0.95 (green highlight in Figure 4-9) for the VTRA 2015 Study Area as a whole for the 3RMM Scenario. Thus overall, the VTRA 2015 Model evaluated for the 3RMM Scenario about $0.95 \times 4.9 \approx 4.7$ number of accidents per year of which now (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 104% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category (an increase of about 6% from the 98.2% evaluated for the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category). However, this 6% increase in POTENTIAL Accident Frequency in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category evaluated for the 3RMM Scenario from the Base Case 2015 Scenario still accounts for about a 5% decrease in POTENTIAL Accident Frequency from the USKMCA1600 What-If Scenario. The POTENTIAL Oil Loss contribution in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category remained at about the 1% evaluated for the USKMCA1600 What-If Scenario in this POTENTIAL Oil Loss category.

From Figure 4-21 one observes that the largest relative decrease in POTENTIAL Accident Frequency is evaluated by the VTRA 2015 Model in the Southern Gulf Islands and Saragota Skagit waterway zones with a relative reduction factor of about 0.85 and 0.86 (red highlights in Figure 4-21) respectively. Thus, one observes that while overall a relative factor decrease is observed of 0.95 for the VTRA 2015 study area as a whole, these relative factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Accident Frequency evaluated for the USKMCA1600 Scenario decreases within the Southern Gulf Islands and Saragota Skagit waterway zones by about a factor 0.85 and 0.86 respectively, in the 3RMM Scenario. The other waterway zones that experience higher POTENTIAL Accident Frequency relative reductions factors than the VTRA Study Area for the 3RMM Scenario are the waterway zones Haro-Strait/Boundary Pass, Puget Sound North and the San Juan Islands with relative factors of about 0.93, 0.93 and 0.94 (yellow highlights in Figure 4-21), respectively. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) within a 10-year period. Thus, for example, Figure 4-22 shows an estimated probability[5] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period,

[5] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f} \times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

and over the entire VTRA 2015 study area of about 1.33%[6] (@ about the same level as evaluated for the USKMCA1600 Scenario). Recall from Figure 4-22A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 91% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for the 3RMM Scenario (@ ≈ 149%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 1.33% (down by a multiplicative reduction factor of 0.99, green highlight in Figure 4-22, from the same probability evaluated for the USKMCA What-If Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 91% of the overall POTENTIAL Oil Loss (up by a multiplicative factor of 2.2 for the 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the 3RMM Scenario (which was evaluated in total at about 149% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages), despite the RMMs enacted upon the USKMCA1600 Scenario by the 3RMM Scenario. In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to more than half of the POTENTIAL Oil Loss evaluated for the 3RMM Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 4-22 for the 3RMM Scenario, one observes a relative reduction factor of 0.31 and 0.88 (red highlights in Figure 4-22) for the Southern Gulf Islands and Puget Sound South waterway zones respectively, for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period, for these particular waterway zones. Other waterway zones that experience about the same or higher relative reduction factors for these probabilities as compared to the VTRA Study area as a whole, are the waterway zones West Strait of Juan de Fuca, Haro-Strait/Boundary Pass, Georgia Strait, Saragota Skagit, Puget Sound South and East Strait of Juan de Fuca with relative reductions factors of 0.93, 0.94, 0.95, 0.96, 0.97 and 0.98. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Similar observations can be made from Figure 4-23, Figure 4-24 and Figure 4-25 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3 respectively. While about a 1% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the 3RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-13 at about 100%. In other words, it is estimated by the VTRA 2015 Model that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will happen within the VTRA Study Area within a 10-year period in the 3RMM Scenario. While about a 20% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (about the same as evaluated for the USKMCA1600 Scenario in this

[6] A 1% probability equals to a probability of 1 in 100.

particular POTENTIAL Oil Loss Category) in the 3RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-23 at about 0.93%. Finally, while about a 37% POTENTIAL Oil Loss contribution is evaluated for 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (about a 36% decrease evaluated from the USKMCA1600 What-If Scenario in this particular POTENTIAL Oil Loss Category) in the 3RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-24 at about 50.7% (about a 4% decrease in this probability from the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category).

As was the case for Figure 4-22, red highlights shows the smallest relative reduction factors by waterway zone than experienced for the VTRA 2015 Study area in Figure 4-23, Figure 4-24 and Figure 4-25. Yellow highlights shows the next smallest relative reduction factors experienced by waterway zones than experienced for the VTRA 2015 Study area as a whole in Figure 4-23, Figure 4-24 and Figure 4-25. Figure 4-26, Figure 4-27, Figure 4-28 and Figure 4-29 provide estimated average spill sizes per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the 3RMM Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 4-23, Figure 4-24 and Figure 4-25 in the manner it was described above for Figure 4-22, but also the summary table in Appendix D for the 3RMM Scenario comparison to the Base Case 2015 Scenario. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 1.33% for the 3RMM Scenario, a value of 0.13% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 3.30% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

One must realize in evaluating the VTRA 2015 RMM analysis results in Figure 4-23, Figure 4-24 and Figure 4-25 (and Figure 4-22) that risk does not necessarily disappear when mitigated locally, but tends to migrate as demonstrated by some waterway zones experiencing increases in risk when other waterway zones are targeted for risk reductions. This is in large part a result of a maritime transportation system being a dynamic system, where a small traffic perturbation can precipitate traffic behavior changes in the future. Such migrations are preferably avoided in a sound risk management strategy, but some risk migration may be inevitable. In addition, the VTRA 2015 maritime simulation model contains some random elements in terms of it traffic simulation for what are termed “special events”. These special events represented in the VTRA model are modeled whale watching activities, regattas and tribal and commercial fishing openers. As a result of these random elements, some risk changes in the evaluated RMM Scenarios (and the What-If Scenarios) are a result of these random elements changing their behavior from simulation run to simulation run (see, also Figure E-6A).

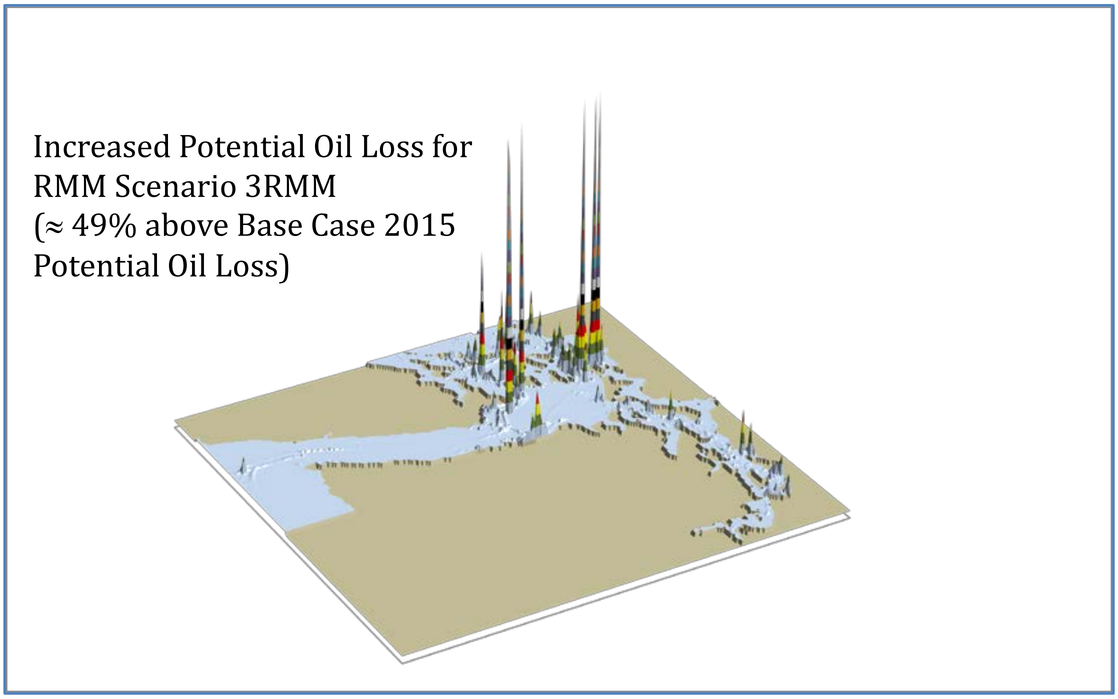

Figure 4-18. 3D Geographic profile of POTENTIAL oil loss for USKMCA1600-3RMM Scenario.

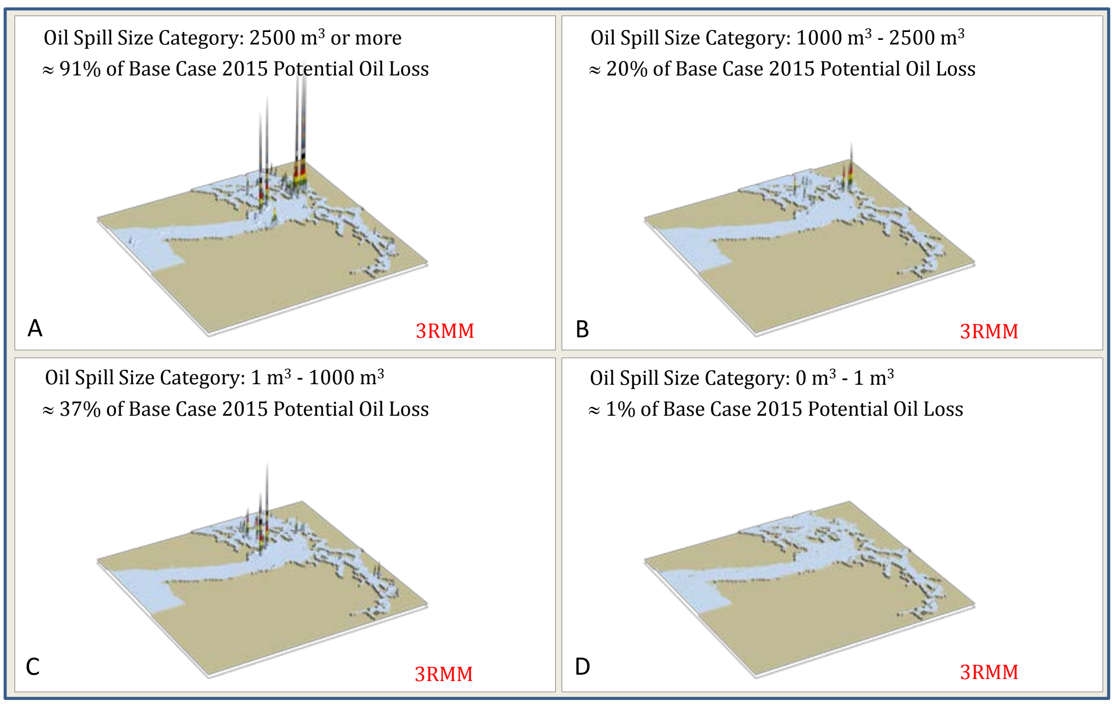

Figure 4-19. Components of 3D Geographic profile of USKMCA1600-3RMM Scenario POTENTIAL oil loss. A: 91% in Oil Spill Size Category of 2500 m^3 or more; B: 20% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 37% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 1% in Oil Spill Size Category of 0 m^3 -1 m^3

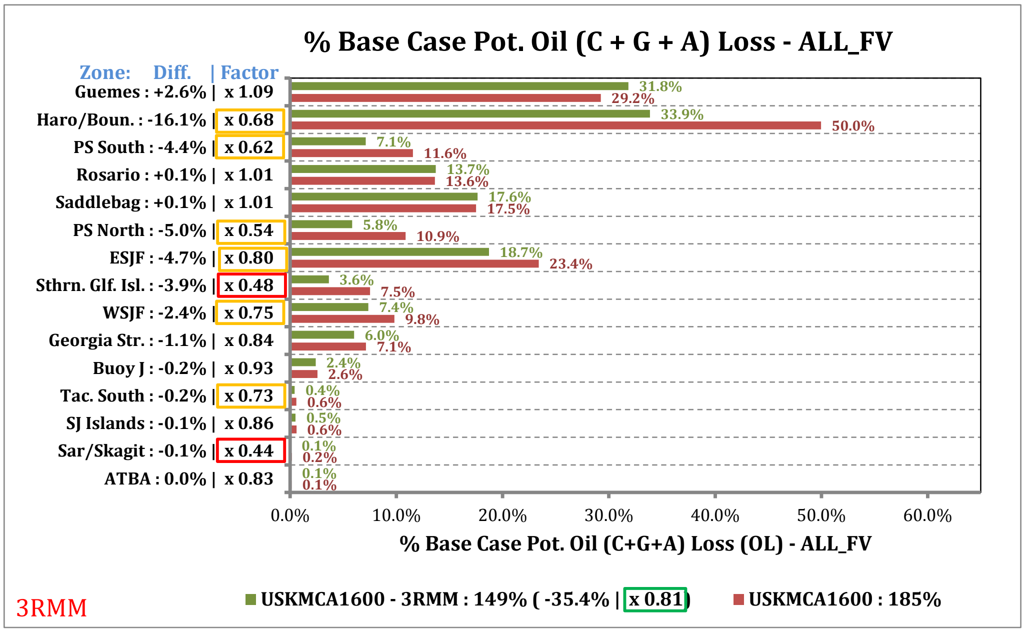

Figure 4-20. Relative comparison of POTENTIAL Oil Loss by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, green bars show the percentages for the USKMCA1600-3RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

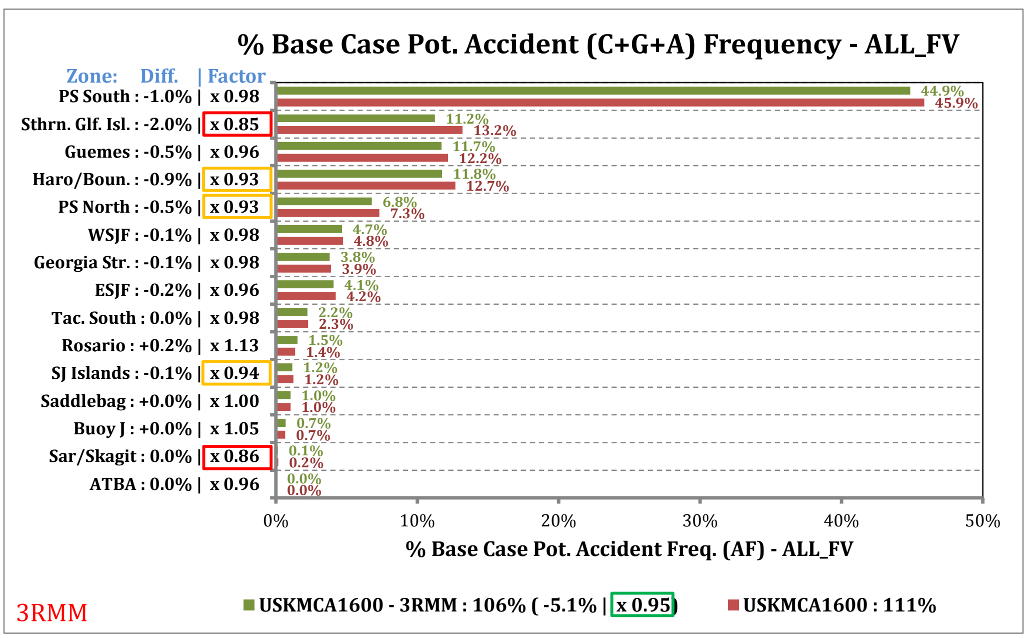

Figure 4-21. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, greens bars show the percentages for the USKMCA1600-3RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

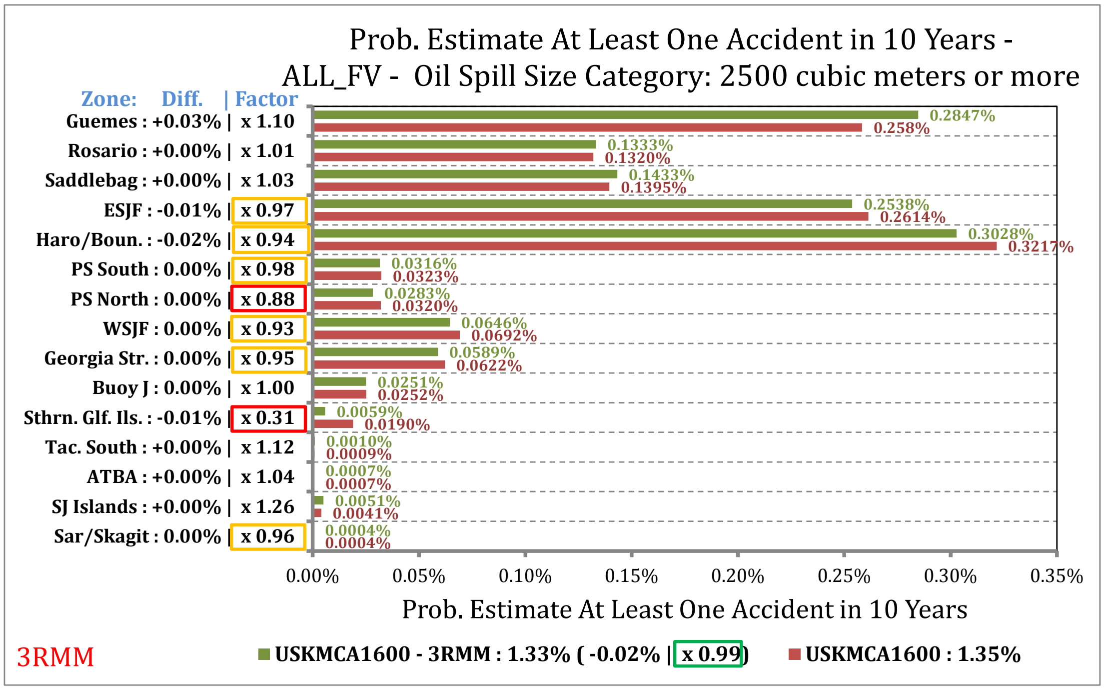

Figure 4-22. USKMCA1600-3RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

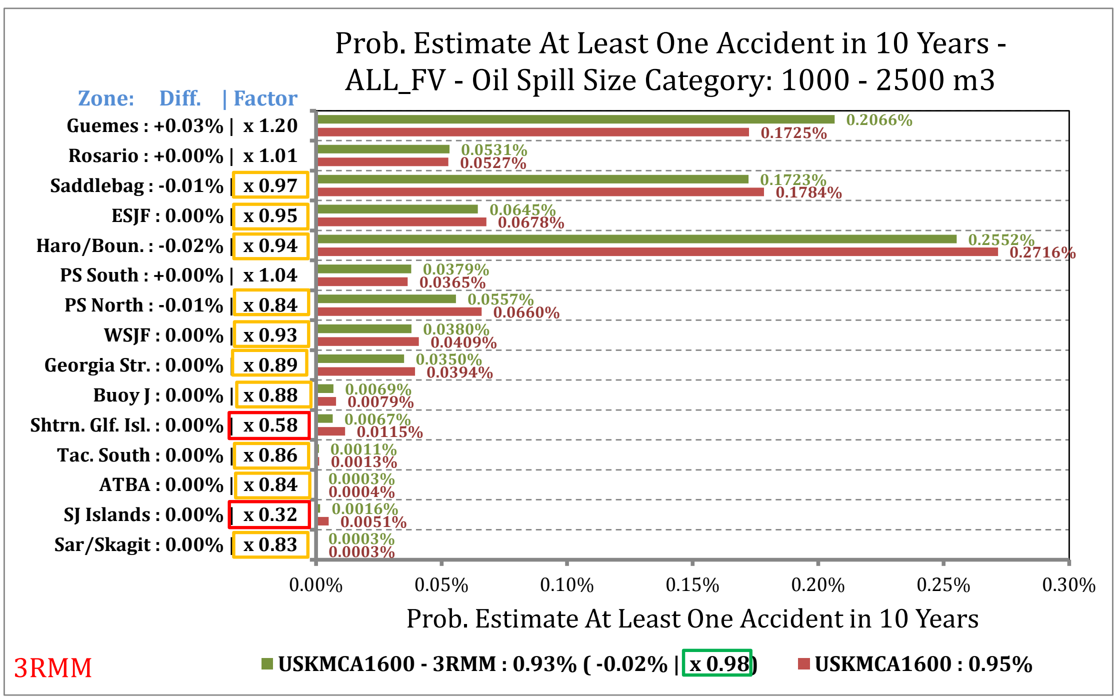

Figure 4-23. USKMCA1600-3RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

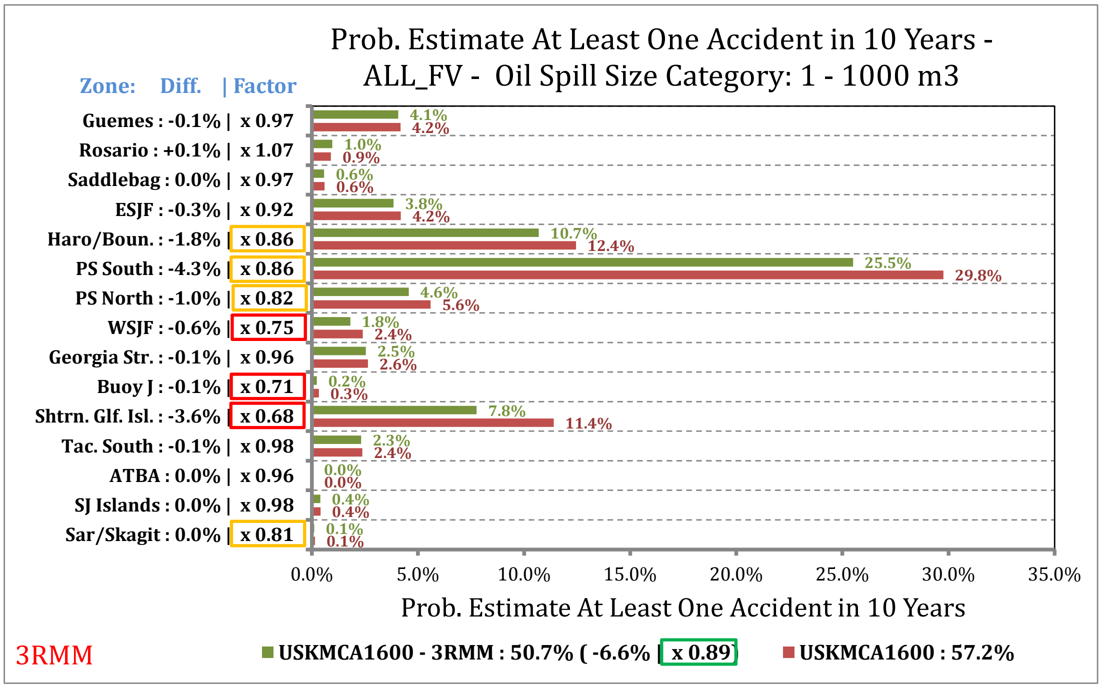

Figure 4-24. USKMCA1600-3RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

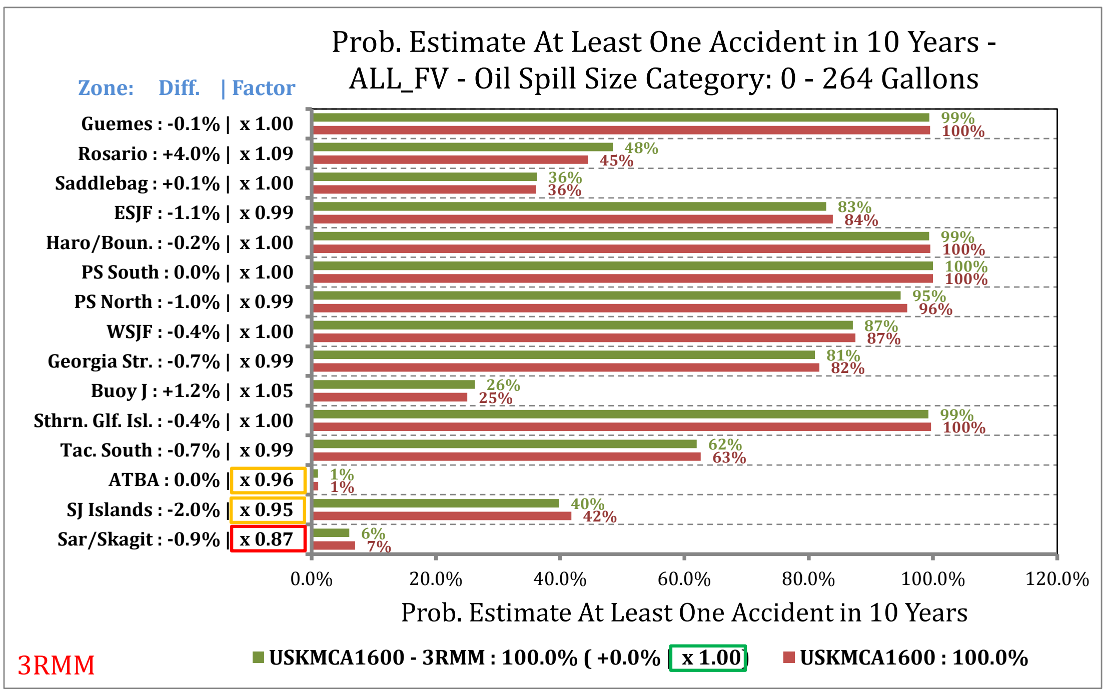

Figure 4-25. USKMCA1600-3RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

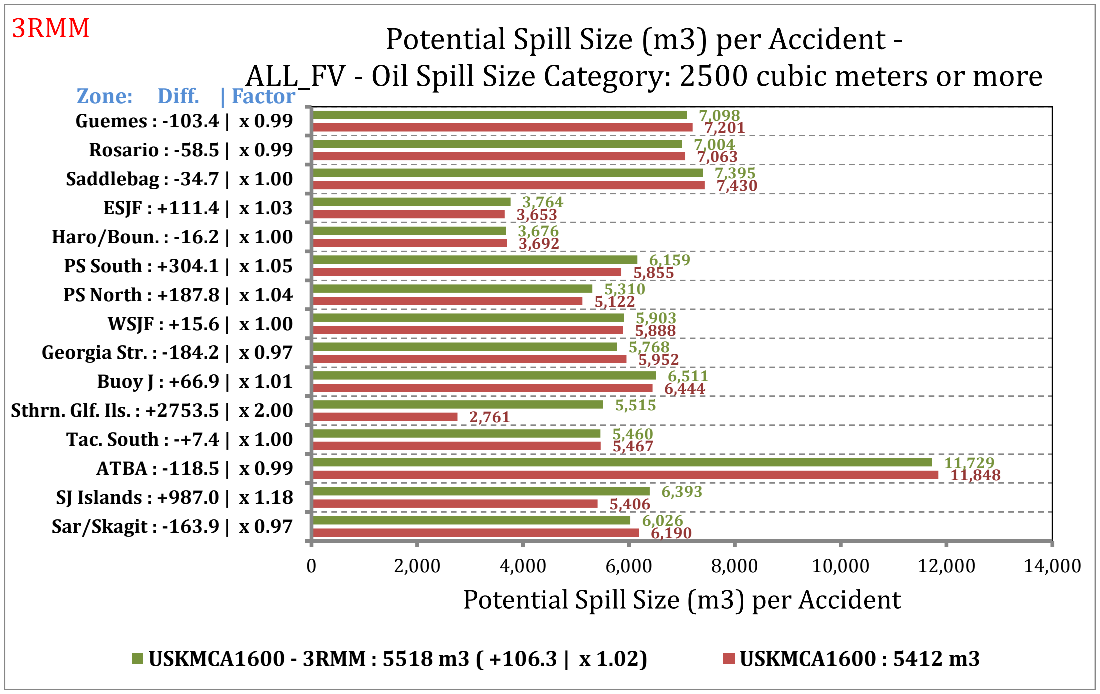

Figure 4-26. USKMCA1600-3RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

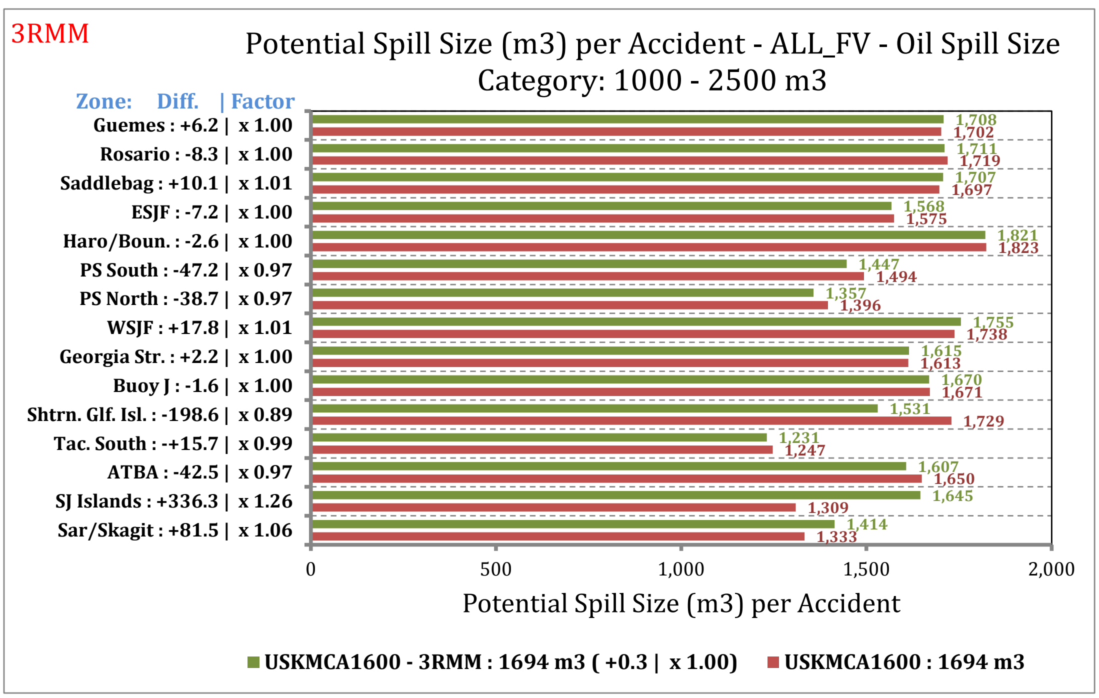

Figure 4-27. USKMCA1600-3RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

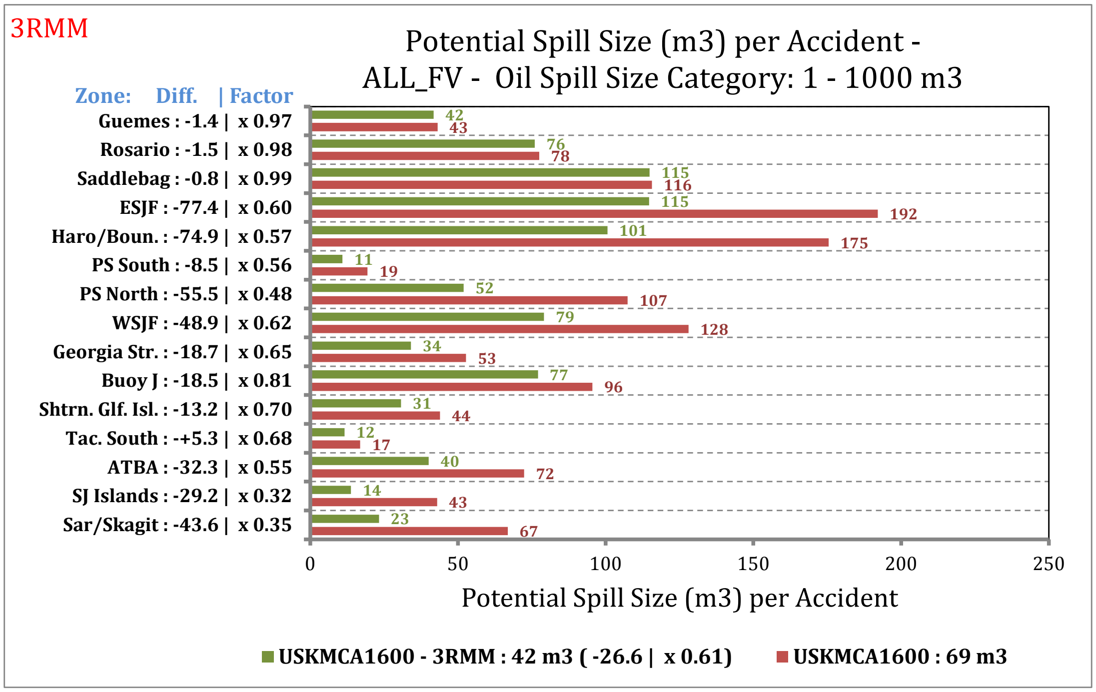

Figure 4-28. USKMCA1600-3RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

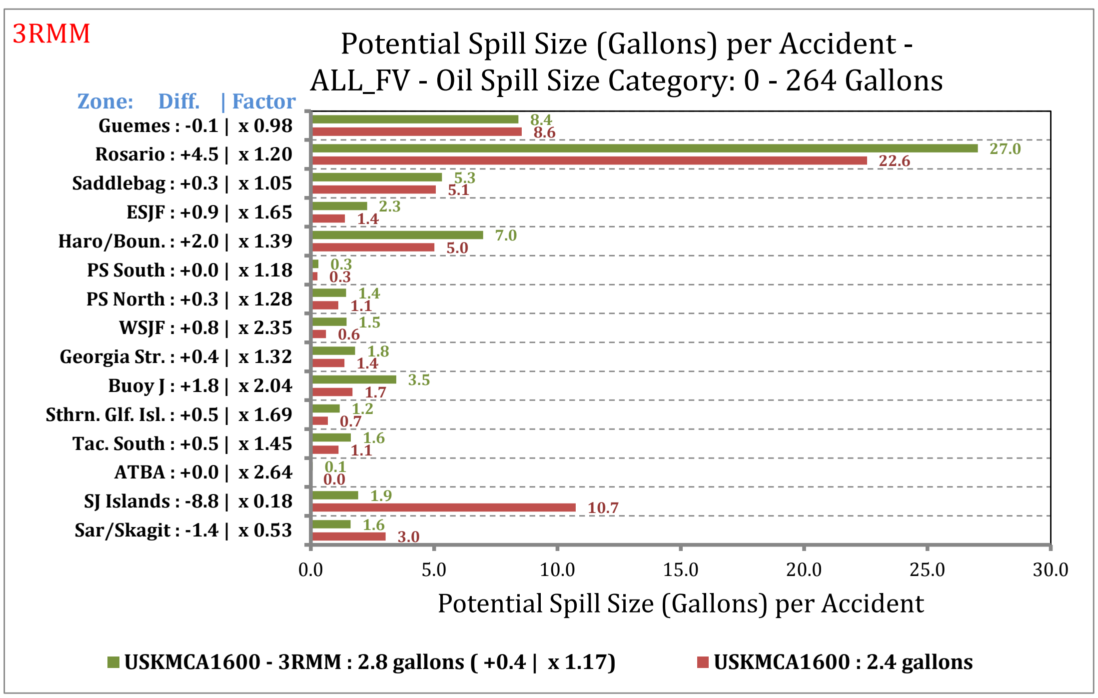

Figure 4-29. USKMCA1600-3RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

USKMCA1600 - OAE RMM Scenario analysis results

The manner of implementation of the OAE-RMM in the VTRA 2015 model enacted upon the USKMCA1600 What-If Scenario was as follows:

OAE-RMM: Continuously escort laden oil barges and ATBs east of Port Angeles (unthethered), see also Figure 4-2D.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL Accident Frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was assessed as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

In Chapter 3 a POTENTIAL Accident Frequency was evaluated for the USKMCA1600 scenario of about $1.11 \times 4.4 \approx 4.9$ accidents per year. From Figure 3-40 in Chapter 3 one observes that overall for the USKMCA1600 What-If Scenario about a +85% increase of total POTENTIAL Oil Loss was evaluated by the VTRA 2015 model over the entire VTRA Study Area from the Base Case 2015 Scenario. Figure 3-41 shows that the distribution of this about 185% of POTENTIAL Oil Loss was evaluated for the USKMCA1600 What-If Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@73% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 185% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 4-30 one observes that overall for the OAE-RMM Scenario about a +81% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area from the Base Case 2015 Scenario, despite the consideration of the individual OAE-RMM enacted upon the USKMCA1600 Scenario. Figure 4-31 shows that the distribution of this about 181% of

POTENTIAL Oil Loss was evaluated by the VTRA 2015 model for the OAE-RMM Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@92% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@18% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@71% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 181% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the USKMCA1600 What-If Scenario, one observes that of the about 185% - 181% ≈ 3%[7] POTENTIAL Oil Loss decrease from the USKMCA1600 Scenario about 2% is accounted for by a reduction in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category. Figure 4-32 presents the relative decreases of the total POTENTIAL Oil Loss evaluated for the OAE-RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative reduction factor of 0.98 (green highlight in Figure 4-32) for the VTRA 2015 Study Area as a whole for the OAE-RMM Scenario. From Figure 4-32 one observes that the largest relative decreases in POTENTIAL Oil Loss are evaluated by the VTRA 2015 Model in the Saragota Skagit and Rosario waterway zones with relative multiplicative reduction factors of about 0.85 and 0.86 (red highlights in Figure 4-32). Thus, one observes that while overall a relative factor decrease is observed of about 0.98 for the VTRA 2015 study area as a whole, these relative reduction factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Oil Loss that was evaluated for the USKMCA1600 What-If Scenario decreases within the Saragota Skagit waterway zone by about a relative multiplicative reduction factor of 0.85 in the OAE-RMM Scenario. Similarly, the POTENTIAL Oil Loss that was evaluated for the USKMCA1600 Scenario decreases within the Rosario waterway zone by about a factor 0.86 in the OAE-RMM Scenario. The other waterway zones that experience about the same or a higher POTENTIAL Oil loss relative reduction factors than the VTRA Study Area in the OAE-RMM Scenario are the waterway zones Georgia Strait, Saddlebag, Tacoma South, Puget Sound North, Southern Gulf Islands and West Strait of Juan de Fuca with relative reduction factors of about 0.88, 0.90, 0.93, 0.95, 0.96, and 0.97 (yellow highlights in Figure 4-32) respectively. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Figure 4-33 presents the relative decreases of the total POTENTIAL Accident Frequency evaluated for the OAE-RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative reduction factor of 0.87 (green highlight in Figure 4-33) for the

[7] About 3% and not 4% due to round-off phenomenon

VTRA 2015 Study Area as a whole for the OAE-RMM Scenario. Thus overall, the VTRA 2015 Model evaluated for the OAE-RMM Scenario about $0.87 \times 4.9 \approx 4.3$ number of accidents per year of which now (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 94% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category (a decrease of about 4% from the 98.2% evaluated for the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category). Moreover, this 4% decrease in POTENTIAL Accident Frequency in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category evaluated for the OAE-RMM Scenario compared to the Base Case 2015 Scenario accounts for about a 15% decrease in POTENTIAL Accident Frequency from the USKMCA1600 What-If Scenario by the OAE-RMM Scenario. The POTENTIAL Oil Loss contribution in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category is reduced by about 1% from the USKMCA1600 What-If Scenario by the OAE-RMM Scenario in this POTENTIAL Oil Loss category.

From Figure 4-33 one observes that the largest relative decrease in POTENTIAL Accident Frequency is evaluated by the VTRA 2015 Model in the Guemes waterway zone with a relative reduction factor of about 0.74 (red highlight in Figure 4-33). Thus, one observes that while overall a relative factor decrease is observed of 0.87 for the VTRA 2015 study area as a whole, these relative factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Accident Frequency evaluated for the USKMCA1600 Scenario decreases within the Guemes waterway zones by about a factor 0.74 in the OAE-RMM Scenario. The other waterway zones that experience higher POTENTIAL Accident Frequency relative reductions factors than the VTRA Study Area for the OAE-RMM Scenario are the waterway zones Tacoma-South, Rosario, Saddlebag and Puget Sound South with relative factors of about 0.78, 0.79, 0.79 and 0.84 (yellow highlights in Figure 4-33) respectively. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) within a 10-year period. Thus, for example, Figure 4-34 shows an estimated probability[8] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area of about 1.34%[9] (@ about the same level as evaluated for the USKMCA1600 Scenario). Recall from Figure 4-31A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 92% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for the OAE-RMM Scenario (@ ≈ 181%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500

[8] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f}\times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[9] A 1% probability equals to a probability of 1 in 100.

m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 1.34% (down by a multiplicative reduction factor of 0.99, green highlight in Figure 4-34, from the same probability evaluated for the USKMCA What-If Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 92% of the overall POTENTIAL Oil Loss (up by a multiplicative factor of 2.2 for the 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the OAE-RMM Scenario (which was evaluated in total at about 181% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages), despite this RMM enacted upon the USKMCA1600 Scenario. In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to more than half of the POTENTIAL Oil Loss evaluated for the OAE-RMM Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 4-34 for the OAE-RMM Scenario, one observes a relative reduction factor of 0.86, 0.86 and 0.89 (red highlights in Figure 4-34) for the Tacoma South, Georgia Strait and Rosario waterway zones respectively, for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period, for these particular waterway zones. Other waterway zones that experience about the same or higher relative reduction factors for these probabilities as compared to the VTRA Study area as a whole, are the waterway zones West Strait of Juan de Fuca, Puget Sound North, Saddlebag, East Strait of Juan de Fuca and Puget Sound South with relative reductions factors of 0.93, 0.94, 0.95, 0.96, 0.97 and 0.98. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Similar observations can be made from Figure 4-35, Figure 4-36 and Figure 4-37 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3 respectively. While about a 0% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the OAE-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-37 at about 100%. In other words, it is estimated by the VTRA 2015 Model that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will happen within the VTRA Study Area within a 10-year period in the OAE-RMM Scenario. While about a 18% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (about the same as evaluated for the USKMCA1600 Scenario in this particular POTENTIAL Oil Loss Category) in the OAE-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-35 at about 0.84%. Finally, while about a 71% POTENTIAL Oil Loss contribution is evaluated for 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (about a 2% decrease evaluated from the USKMCA1600 What-If Scenario in this particular POTENTIAL Oil Loss Category) in the OAE-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure

4-36 at about 55.6% (about a 2% decrease in this probability from the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category).

As was the case for Figure 4-34, red highlights shows the smallest relative reduction factors by waterway zone than experienced for the VTRA 2015 Study area in Figure 4-35, Figure 4-36 and Figure 4-37. Yellow highlights shows the next smallest relative reduction factors experienced by waterway zones than experienced for the VTRA 2015 Study area as a whole in Figure 4-35, Figure 4-36 and Figure 4-37. Figure 4-38, Figure 4-39, Figure 4-40 and Figure 4-41 provide estimated average spill sizes per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the OAE-RMM Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 4-35, Figure 4-36 and Figure 4-37 in the manner it was described above for Figure 4-34, but also the summary table in Appendix D for the OAE-RMM Scenario comparison to the Base Case 2015 Scenario. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 1.34% for the OAE-RMM Scenario, a value of 0.14% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 3.33% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

One must realize in evaluating the VTRA 2015 RMM analysis results in Figure 4-35, Figure 4-36 and Figure 4-37 (and Figure 4-34) that risk does not necessarily disappear when mitigated locally, but tends to migrate as demonstrated by some waterway zones experiencing increases in risk when other waterway zones are targeted for risk reductions. This is in large part a result of a maritime transportation system being a dynamic system, where a small traffic perturbation can precipitate traffic behavior changes in the future. Such migrations are preferably avoided in a sound risk management strategy, but some risk migration may be inevitable. In addition, the VTRA 2015 maritime simulation model contains some random elements in terms of it traffic simulation for what are termed “special events”. These special events represented in the VTRA model are modeled whale watching activities, regattas and tribal and commercial fishing openers. As a result of these random elements, some risk changes in the evaluated RMM Scenarios (and the What-If Scenarios) are a result of these random elements changing their behavior from simulation run to simulation run (see, also Figure E-6A).

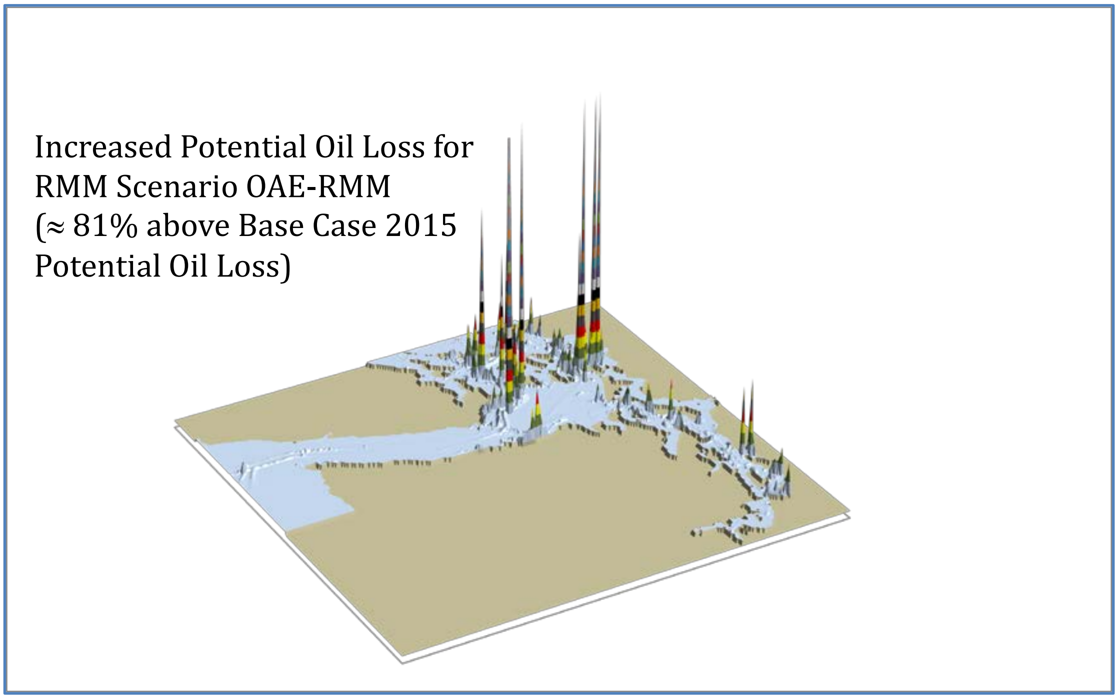

Figure 4-30. 3D Geographic profile of POTENTIAL oil loss for USKMCA1600-OAE RMM Scenario.

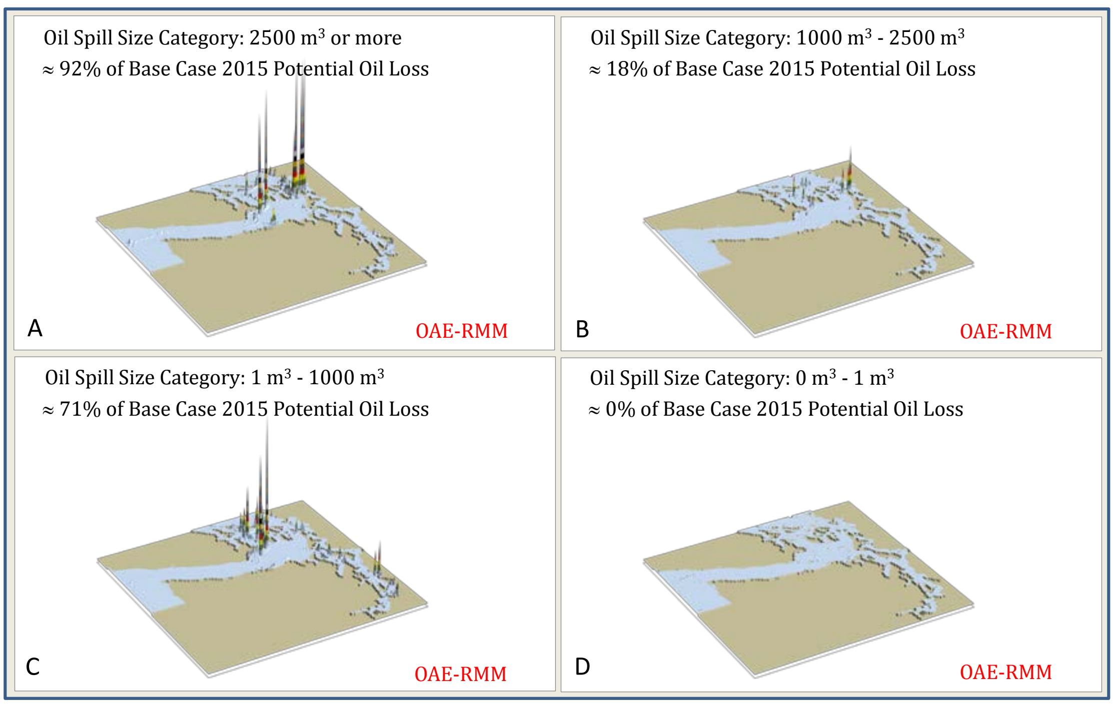

Figure 4-31. Components of 3D Geographic profile of USKMCA1600-OAE RMM Scenario POTENTIAL oil loss. A: 92% in Oil Spill Size Category of 2500 m^3 or more; B: 18% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 71% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 0% in Oil Spill Size Category of 0 m^3 -1 m^3

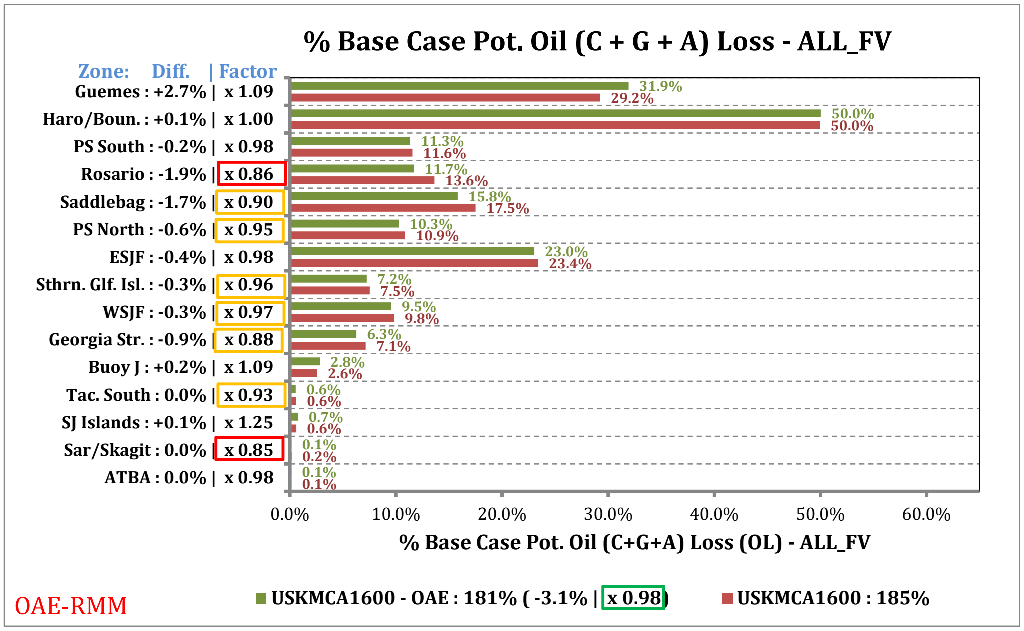

Figure 4-32. Relative comparison of POTENTIAL Oil Loss by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, green bars show the percentages for the USKMCA1600-OAE RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

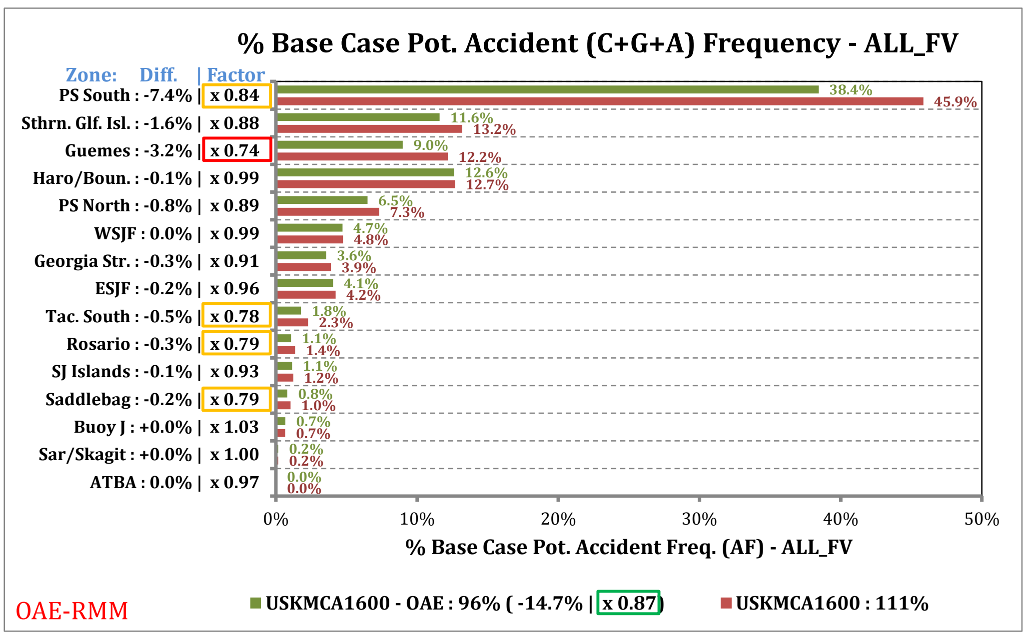

Figure 4-33. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, greens bars show the percentages for the USKMCA1600-OAE RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

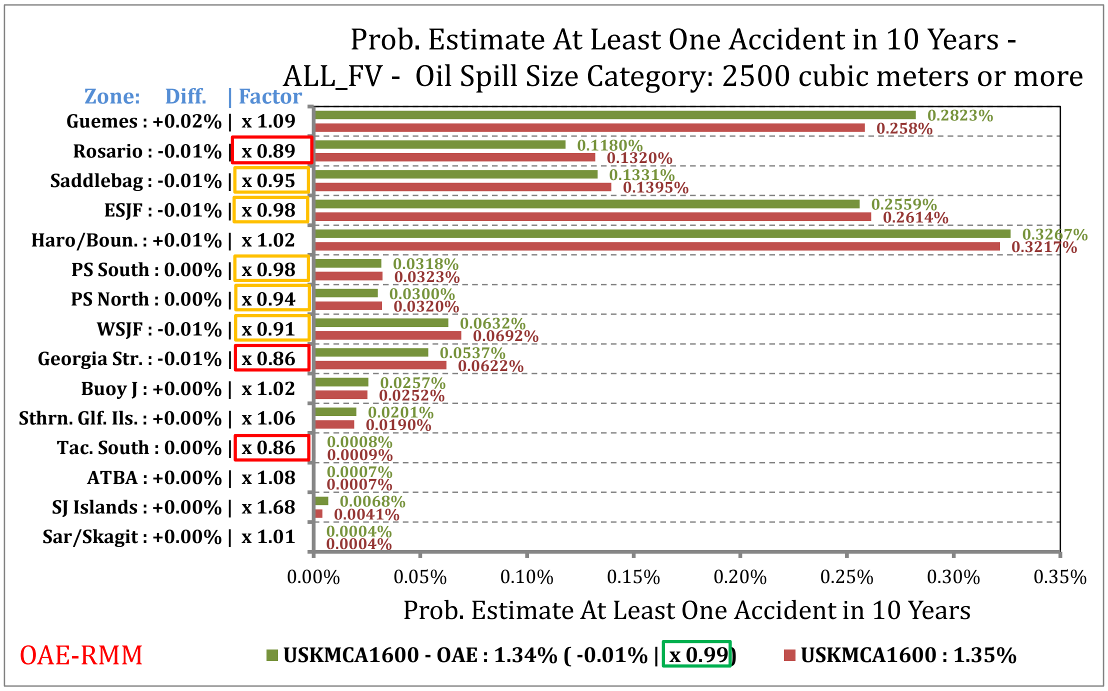

Figure 4-34. USKMCA1600-OAE RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

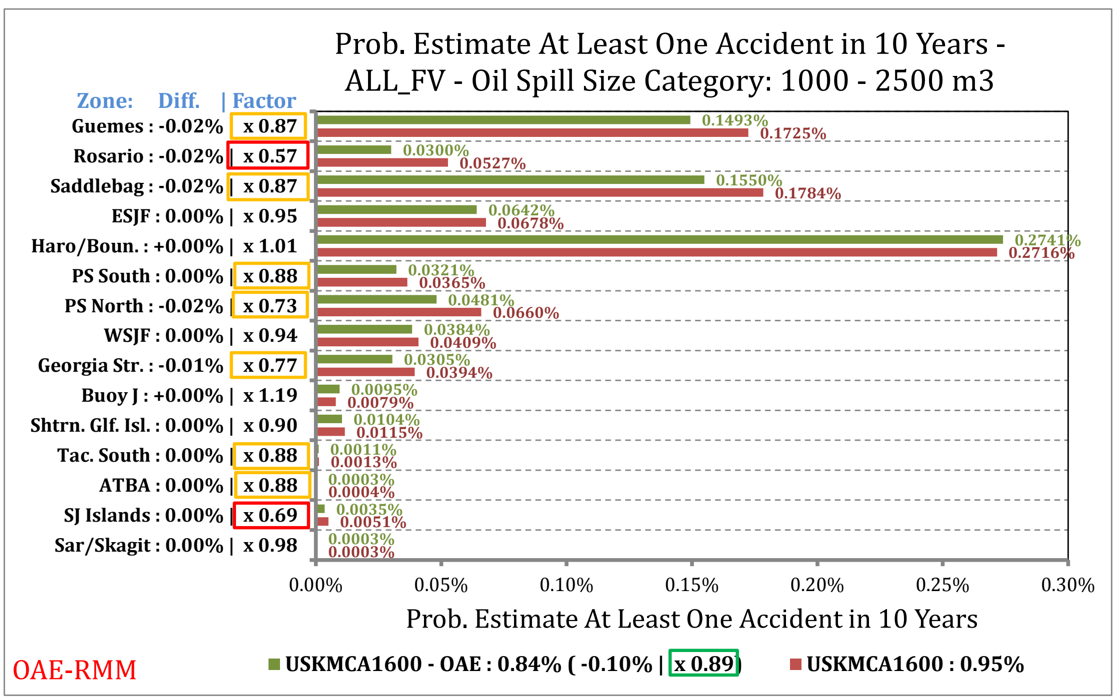

Figure 4-35. USKMCA1600-OAE RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

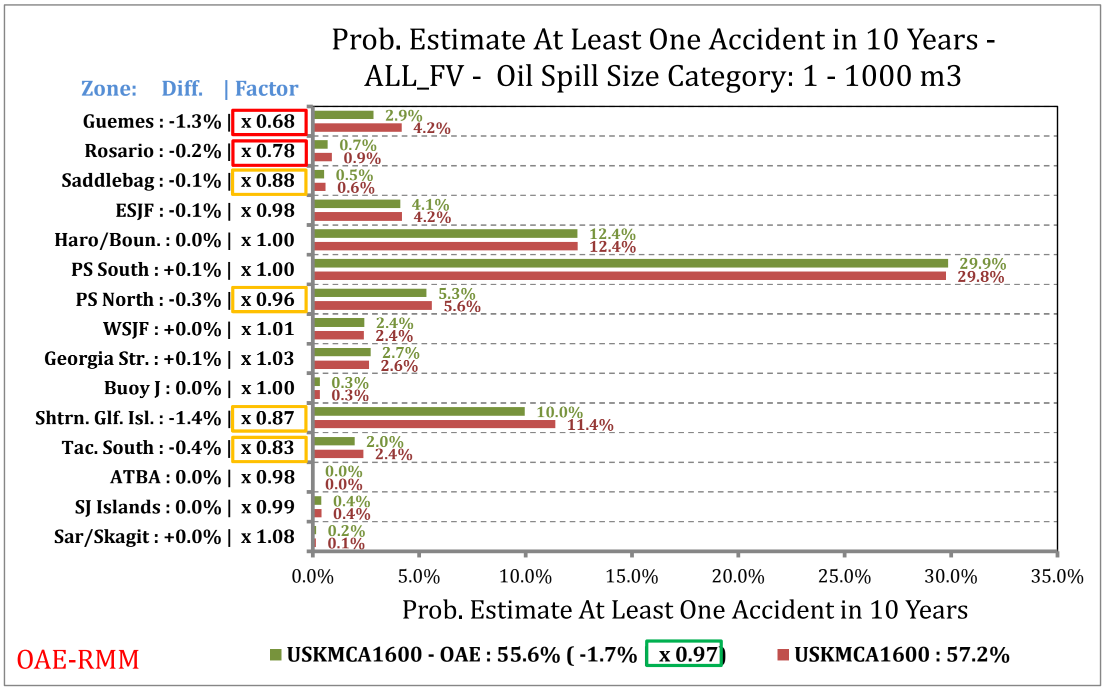

Figure 4-36. USKMCA1600-OAE RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

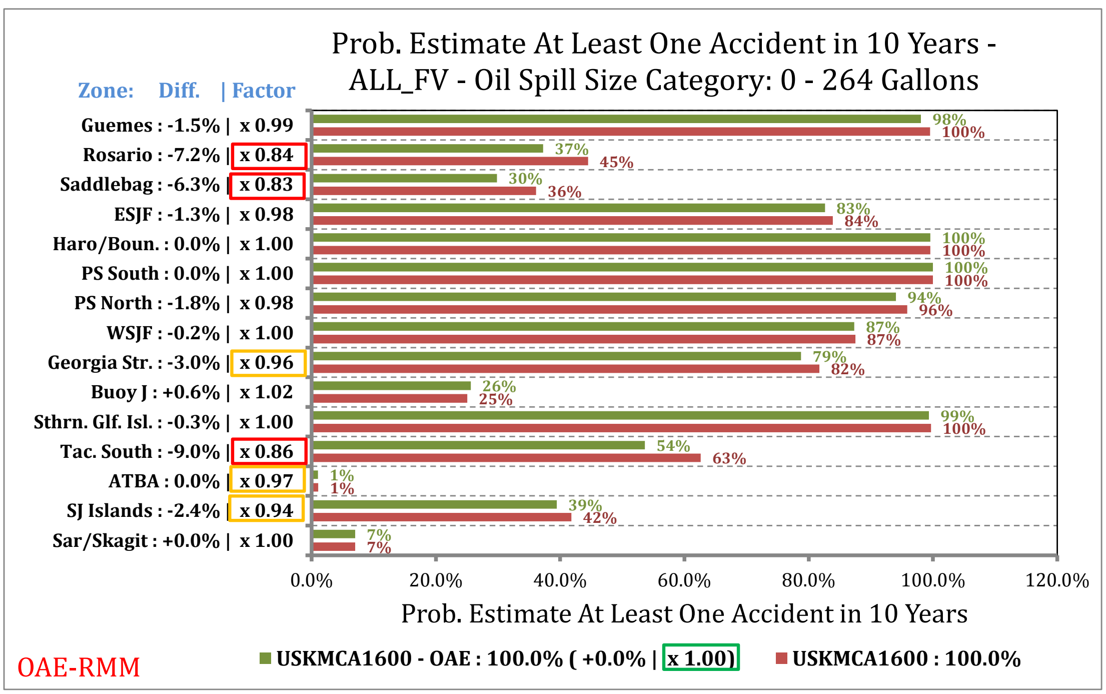

Figure 4-37. USKMCA1600-OAE RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

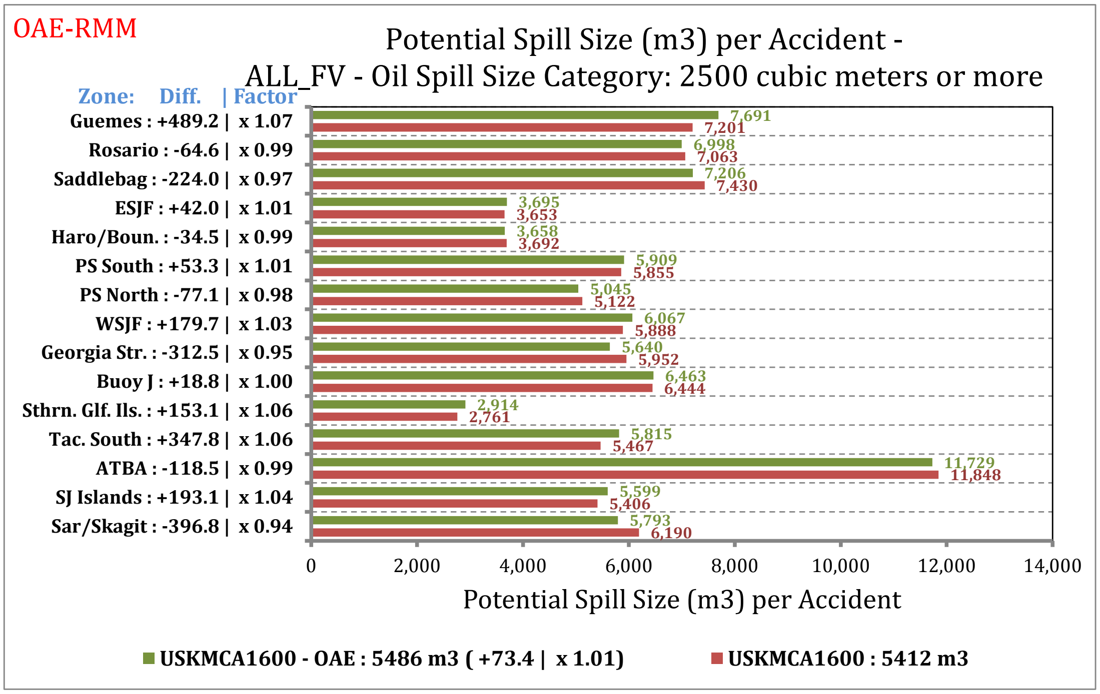

Figure 4-38. USKMCA1600-OAE RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

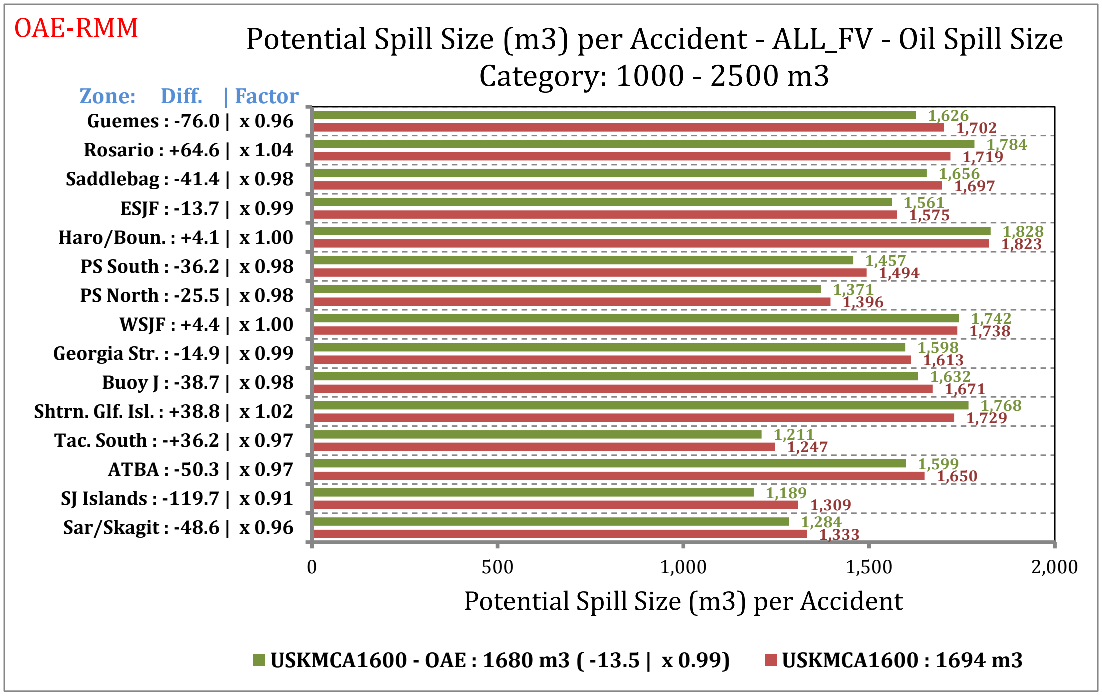

Figure 4-39. USKMCA1600-OAE RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

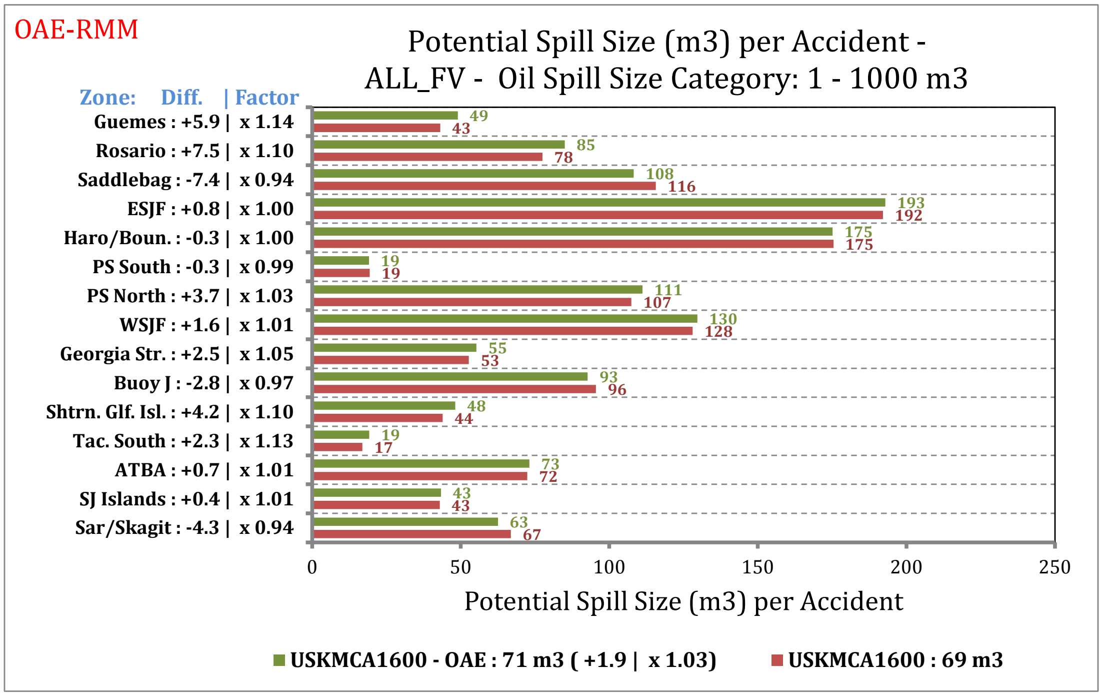

Figure 4-40. USKMCA1600-OAE RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

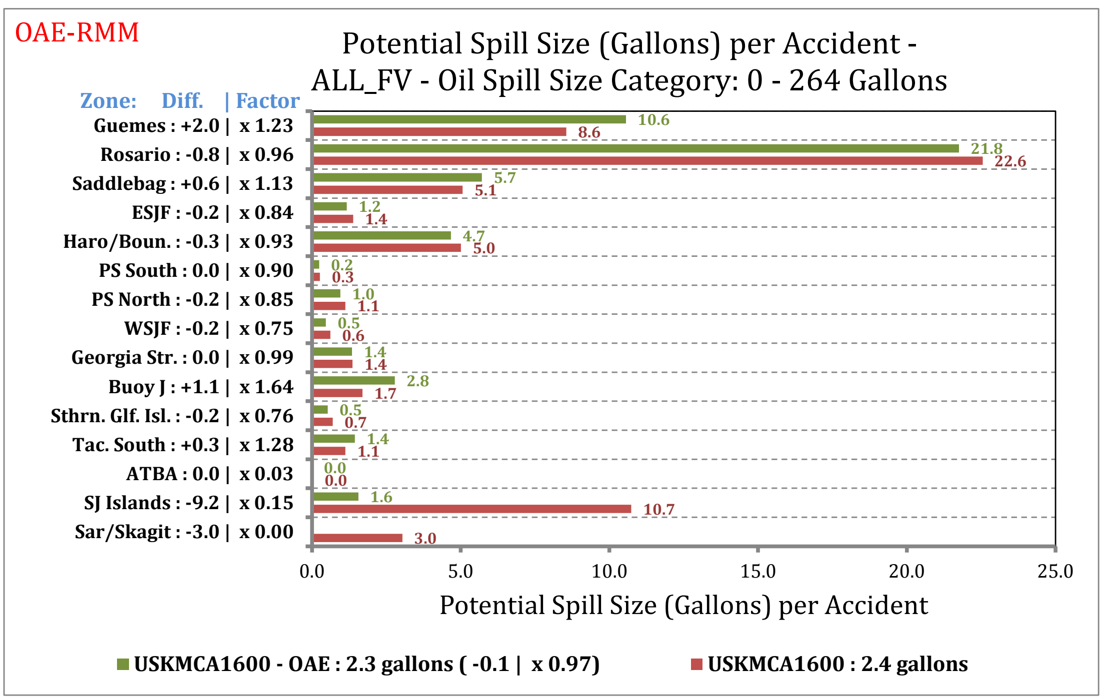

Figure 4-41. USKMCA1600-OAE RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

USKMCA1600 - SRT RMM Scenario analysis results

The manner of implementation of the SRT-RMM in the VTRA 2015 model enacted upon the USKMCA1600 What-If Scenario was as follows:

SRT-RMM: Station a rescue tug at Sidney, BC and model its coverage in the same manner as the coverage model that was developed for the Neah Bay rescue tug in the VTRA 2005, see also Figure 4-2A.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL Accident Frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was assessed as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

In Chapter 3 a POTENTIAL Accident Frequency was evaluated for the USKMCA1600 scenario of about $1.11 \times 4.4 \approx 4.9$ accidents per year. From Figure 3-40 in Chapter 3 one observes that overall for the USKMCA1600 What-If Scenario about a +85% increase of total POTENTIAL Oil Loss was evaluated by the VTRA 2015 model over the entire VTRA Study Area from the Base Case 2015 Scenario. Figure 3-41 shows that the distribution of this about 185% of POTENTIAL Oil Loss was evaluated for the USKMCA1600 What-If Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@73% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 185% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 4-42 one observes that overall for the SRT-RMM Scenario about a +83% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area from the Base Case 2015 Scenario, despite the consideration of the individual SRT-RMM enacted upon the USKMCA1600 Scenario. Figure 4-43 shows that the distribution of this about 183% of

POTENTIAL Oil Loss was evaluated by the VTRA 2015 model for the SRT-RMM Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@92% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@19% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@71% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 183% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the USKMCA1600 What-If Scenario, one observes that of the about 185% - 183% ≈ 2% POTENTIAL Oil Loss decrease from the USKMCA1600 Scenario about 2% is accounted for by a reduction in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category. Figure 4-46 presents the relative decreases of the total POTENTIAL Oil Loss evaluated for the SRT-RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative reduction factor of 0.99 (green highlight in Figure 4-46) for the VTRA 2015 Study Area as a whole for the SRT-RMM Scenario. From Figure 4-46 one observes that the largest relative decreases in POTENTIAL Oil Loss are evaluated by the VTRA 2015 Model in the Haro-Strait Boundary Pass waterway zone with relative multiplicative reduction factors of about 0.97 (red highlight in Figure 4-46). Thus, one observes that while overall a relative factor decrease is observed of about 0.99 for the VTRA 2015 study area as a whole, these relative reduction factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Oil Loss that was evaluated for the USKMCA1600 What-If Scenario decreases within the Haro-Strait/Boundary Pass waterway zone by about a relative multiplicative reduction factor of 0.97 in the SRT-RMM Scenario. The other waterway zone that experiences a higher POTENTIAL Oil loss relative reduction factor than the VTRA Study Area in the SRT-RMM Scenario is the waterway zone Southern Gulf Islands with a relative reduction factor of about 0.99 (yellow highlights in Figure 4-46) respectively. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Figure 4-45 presents the relative decreases of the total POTENTIAL Accident Frequency evaluated for the SRT-RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.00 (green highlight in Figure 4-45) for the VTRA 2015 Study Area as a whole for the SRT-RMM Scenario. Thus overall, the VTRA 2015 Model evaluated for the SRT-RMM Scenario about the same $1.00 \times 4.9 \approx 4.9$ number of accidents per year of which now (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 109% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category (an increase of about 11% from the 98.2% evaluated for the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category). On the other hand, this 11% increase in POTENTIAL Accident Frequency in the 0 m^3 – 1 m^3

POTENTIAL OIL Loss category evaluated for the SRT-RMM Scenario compared to the Base Case 2015 Scenario does not result in an increase to the POTENTIAL Oil Loss contribution in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category, which remained at about the 1% evaluated for this POTENTIAL Oil Loss Category in the USKMCA1600 Scenario.

From Figure 4-45 one observes that the largest relative decrease in POTENTIAL Accident Frequency is evaluated by the VTRA 2015 Model in the Southern Gulf Islands and the Haro-Strait/Boundary Pass waterway zones with a relative reduction factor of about 0.97 in both (red highlights in Figure 4-45). Thus, one observes that while overall a relative factor is observed of about 1.00 for the VTRA 2015 study area as a whole, these relative factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Accident Frequency evaluated for the USKMCA1600 Scenario decreases within the Southern Gulf Islands and the Haro-Strait/Boundary Pass waterway zones by about a relative reduction factor 0.97 in the SRT-RMM Scenario. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario. The other waterway zones that experience higher POTENTIAL Accident Frequency relative reductions factors than the VTRA Study Area for the SRT-RMM Scenario are the waterway zones Tacoma South, Buoy J and San Juan Islands waterway zones with relative reduction factors of about 0.98, 0.99 and 0.99 (yellow highlights in Figure 4-45) respectively. Needless to say, the latter evaluated reduction factors in POTENTIAL Accident Frequency in these latter waterway zones cannot be the result of the enactment of the SRT-RMM upon the USKMCA1600 Scenario.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) within a 10-year period. Thus, for example, Figure 4-46 shows an estimated probability[10] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area of about 1.35%[11] (@ about the same level as evaluated for the USKMCA1600 Scenario). Recall from Figure 4-43A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 92% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for the SRT-RMM Scenario (@ ≈ 183%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 1.35% (remaining VTRA Study area wide at about the same level as follows from multiplicative factor of about 1.00, green highlight in Figure 4-46, for the USKMCA What-If Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and

[10] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f}\times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[11] A 1% probability equals to a probability of 1 in 100.

is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 92% of the overall POTENTIAL Oil Loss (up by a multiplicative factor of 2.2 for the 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the SRT-RMM Scenario (which was evaluated in total at about 183% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages), despite the enactment of the SRT-RMM upon the USKMCA1600 Scenario. In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to about half of the POTENTIAL Oil Loss evaluated for the SRT-RMM Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 4-46 for the SRT-RMM Scenario, one observes a relative reduction factor of 0.96 (red highlight in Figure 4-46) for the Southern Gulf Islands waterway zone for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period, for this particular waterway zone. It should be noted that this POTENTIAL decrease is evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario. Other waterway zones that experience about the same or higher relative reduction factors for these probabilities as compared to the VTRA Study area as a whole, are the waterway zones Haro-Strait/Boundary Pass and Puget Sound South with relative reductions factors of 0.98 and 0.99, respectively. Needless to say, the latter evaluated reduction factor for this probability in Puget Sound waterway zone cannot be the result of the enactment of the SRT-RMM upon the USKMCA1600 Scenario.

Similar observations can be made from Figure 4-47, Figure 4-48 and Figure 4-49 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3 respectively. While about a 1% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the SRT-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-49 at about 100%. In other words, it is estimated by the VTRA 2015 Model that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will happen within the VTRA Study Area within a 10-year period in the SRT-RMM Scenario. While about a 19% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (about 1% less as evaluated for the USKMCA1600 Scenario in this particular POTENTIAL Oil Loss Category) in the SRT-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-47 at about 0.93%. Finally, while about a 71% POTENTIAL Oil Loss contribution is evaluated for the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (about a 2% decrease evaluated from the USKMCA1600 What-If Scenario in this particular POTENTIAL Oil Loss Category) in the SRT-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-48 at about 57.2% (about equal to the probability estimated for the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category).

As was the case for Figure 4-46, red highlights shows the smallest relative reduction factors by waterway zone than experienced for the VTRA 2015 Study area in Figure 4-47, Figure 4-48 and Figure 4-49. Yellow highlights shows the next smallest relative reduction factors experienced by waterway zones than experienced for the VTRA 2015 Study area as a whole in Figure 4-47, Figure 4-48 and Figure 4-49. Figure 4-50, Figure 4-51, Figure 4-52 and Figure 4-53 provide estimated average spill sizes per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the SRT-RMM Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 4-47, Figure 4-48 and Figure 4-49 in the manner it was described above for Figure 4-46, but also the summary table in Appendix D for the SRT-RMM Scenario comparison to the Base Case 2015 Scenario. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 1.35% for the SRT-RMM Scenario, a value of 0.14% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 3.34% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

One must realize in evaluating the VTRA 2015 RMM analysis results in Figure 4-47, Figure 4-48 and Figure 4-49 (and Figure 4-46) that risk does not necessarily disappear when mitigated locally, but tends to migrate as demonstrated by some waterway zones experiencing increases in risk when other waterway zones are targeted for risk reductions. This is in large part a result of a maritime transportation system being a dynamic system, where a small traffic perturbation can precipitate traffic behavior changes in the future. Such migrations are preferably avoided in a sound risk management strategy, but some risk migration may be inevitable. In addition, the VTRA 2015 maritime simulation model contains some random elements in terms of it traffic simulation for what are termed “special events”. These special events represented in the VTRA model are modeled whale watching activities, regattas and tribal and commercial fishing openers. As a result of these random elements, some risk changes in the evaluated RMM Scenarios (and the What-If Scenarios) are a result of these random elements changing their behavior from simulation run to simulation run (see, also Figure E-6A).

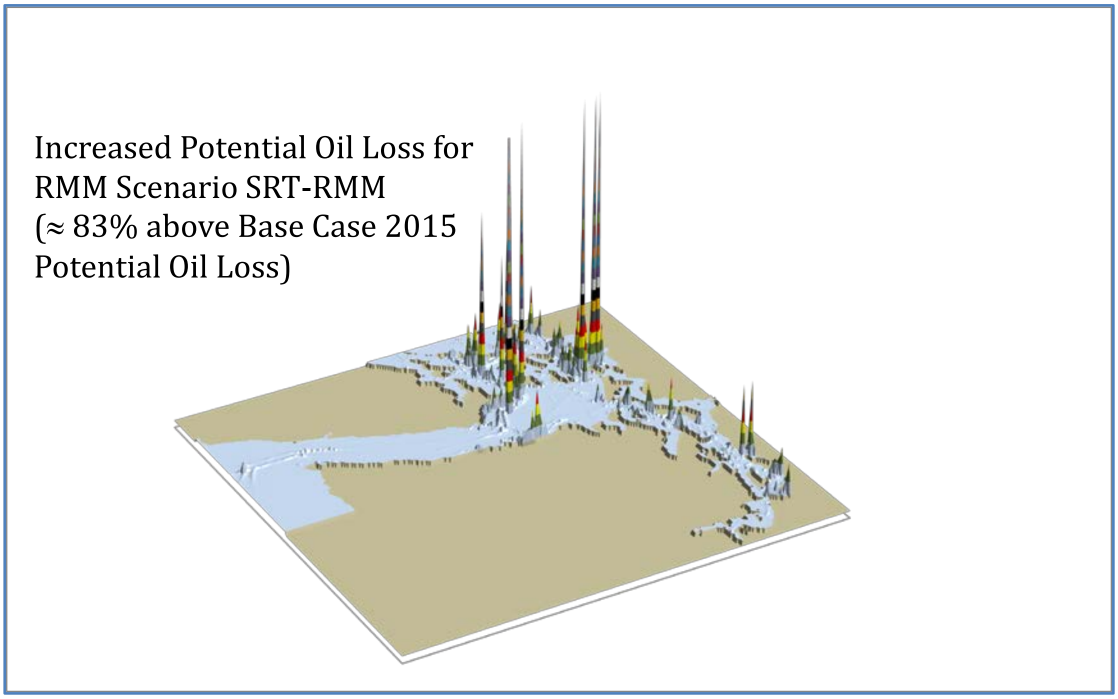

Figure 4-42. 3D Geographic profile of POTENTIAL oil loss for USKMCA1600-SRT RMM Scenario.

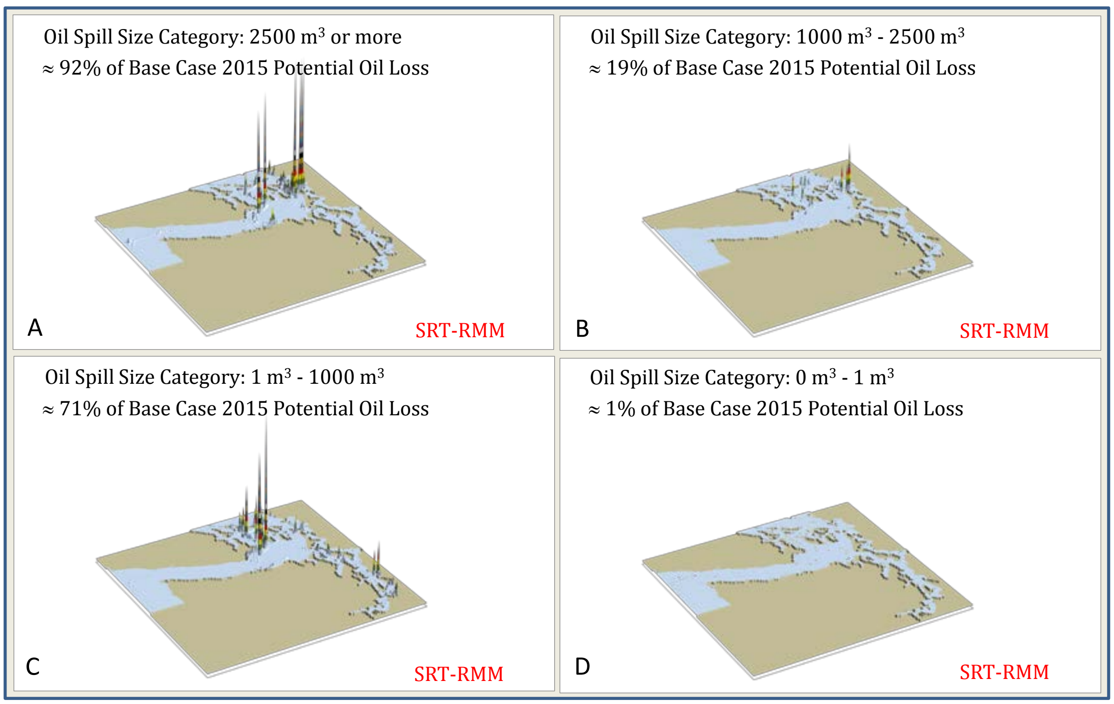

Figure 4-43. Components of 3D Geographic profile of USKMCA1600-SRT RMM Scenario POTENTIAL oil loss. A: 92% in Oil Spill Size Category of 2500 m^3 or more; B: 19% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 71% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 1% in Oil Spill Size Category of 0 m^3 -1 m^3

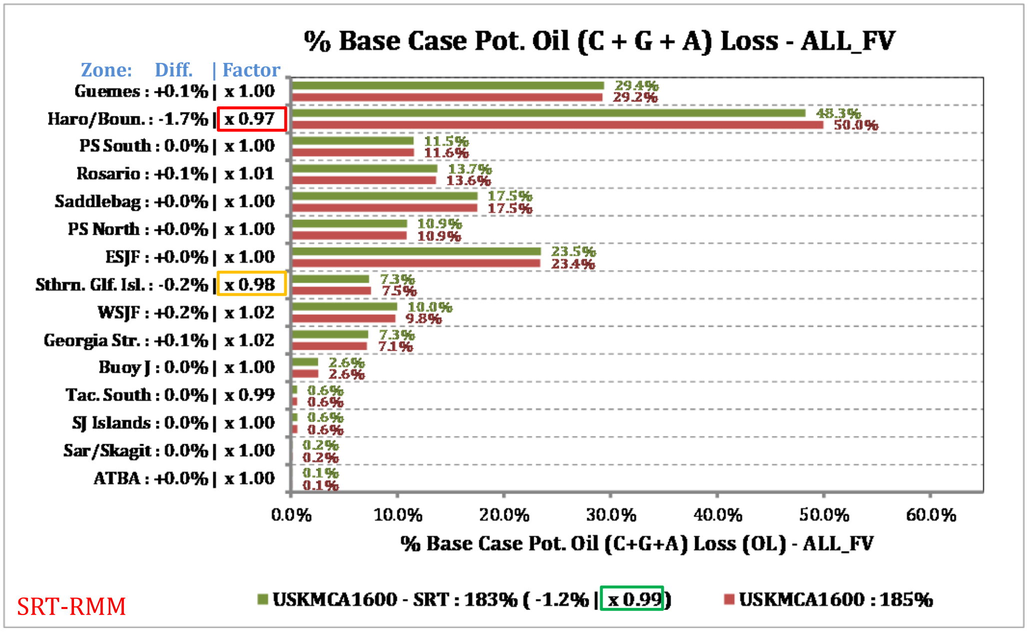

Figure 4-44. Relative comparison of POTENTIAL Oil Loss by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, green bars show the percentages for the USKMCA1600-SRT RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

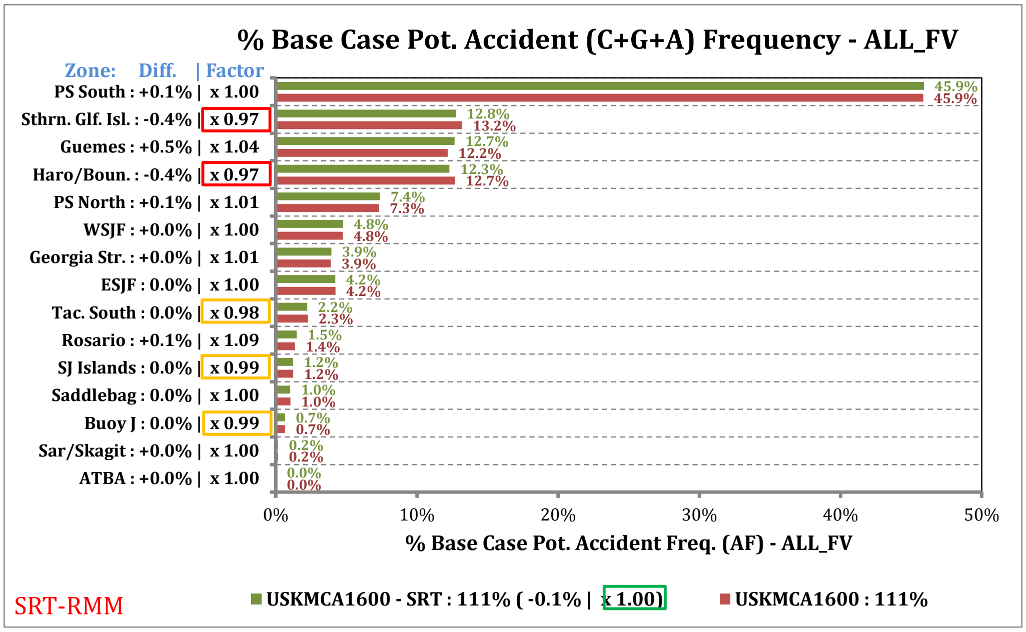

Figure 4-45. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, greens bars show the percentages for the USKMCA1600-SRT RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

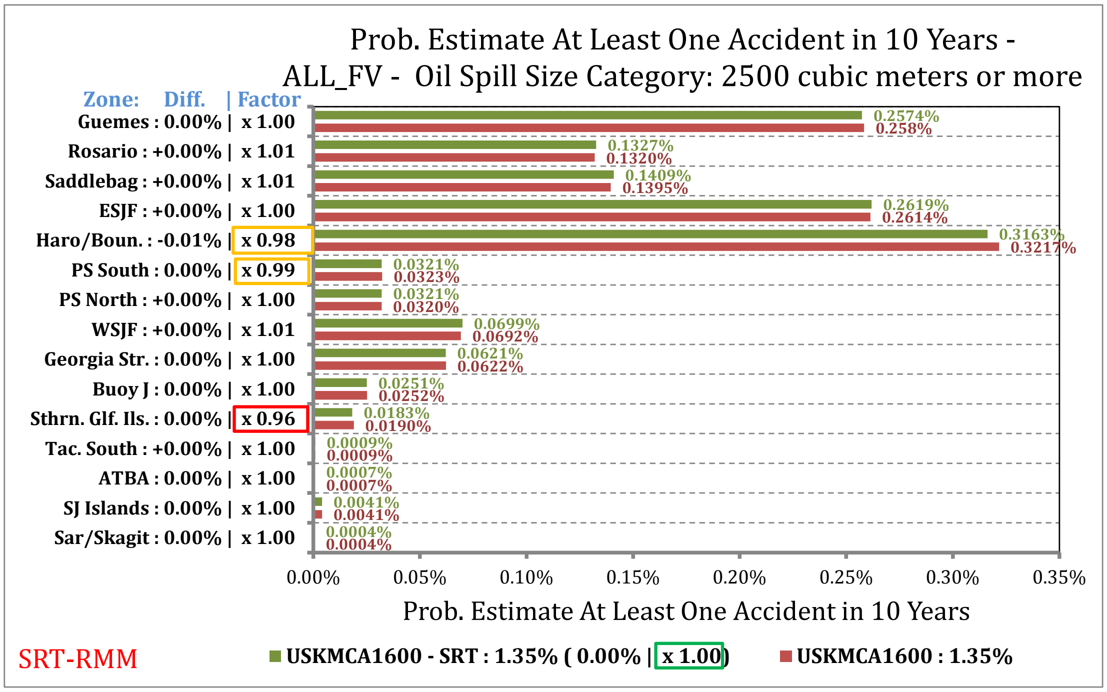

Figure 4-46. USKMCA1600-SRT RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

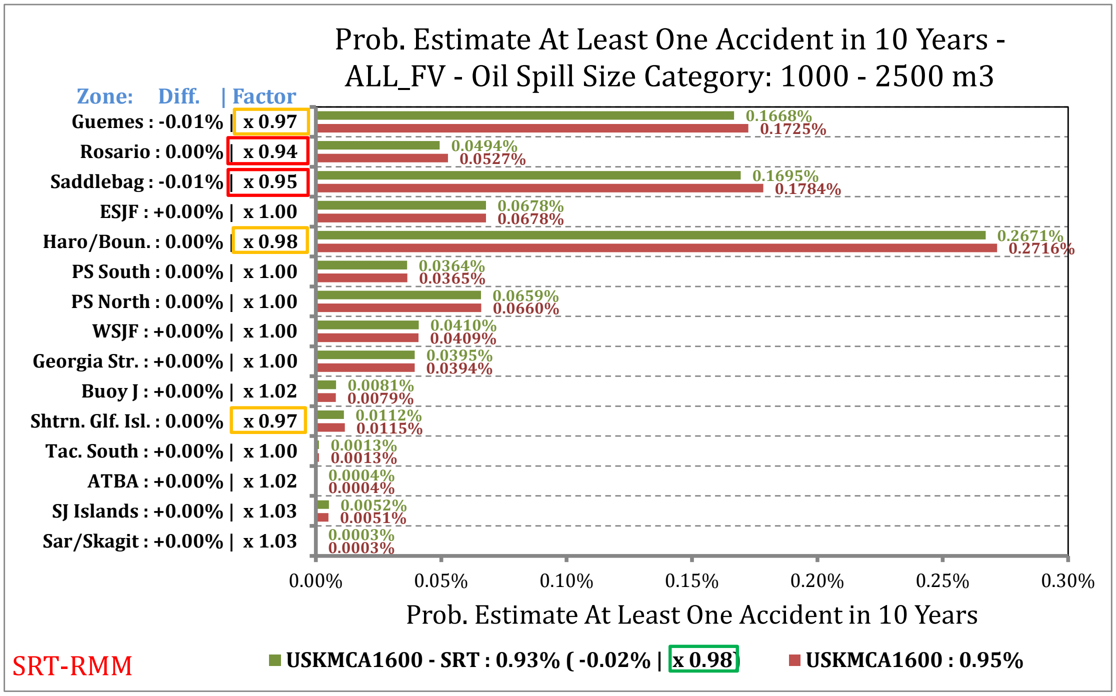

Figure 4-47. USKMCA1600-SRT RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

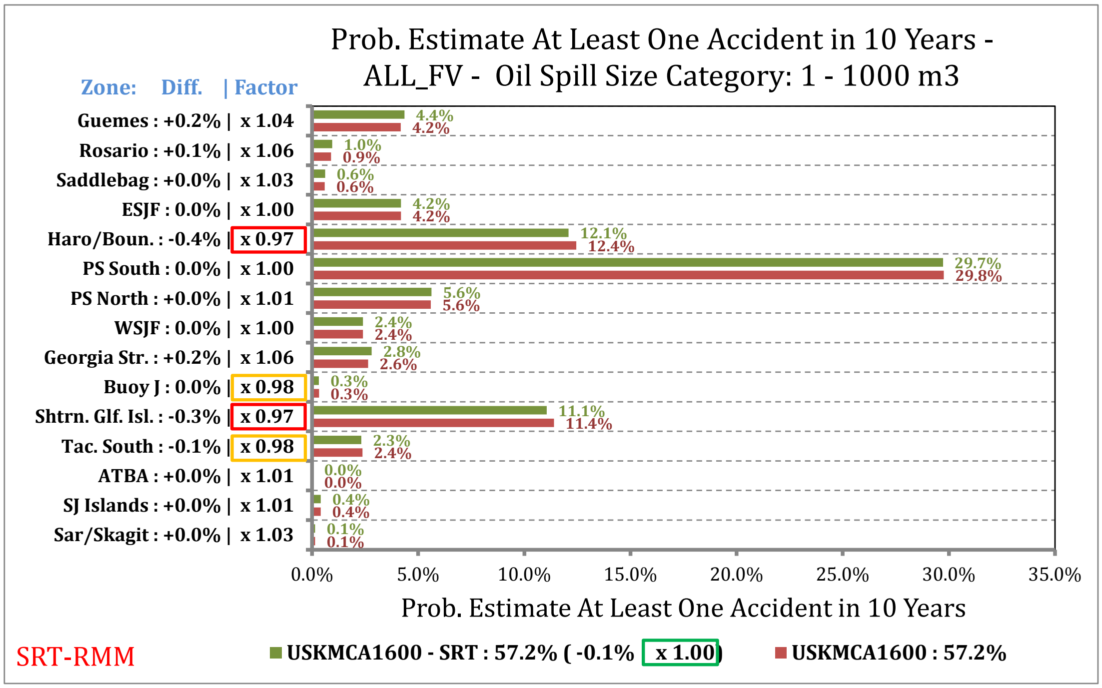

Figure 4-48. USKMCA1600-SRT RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

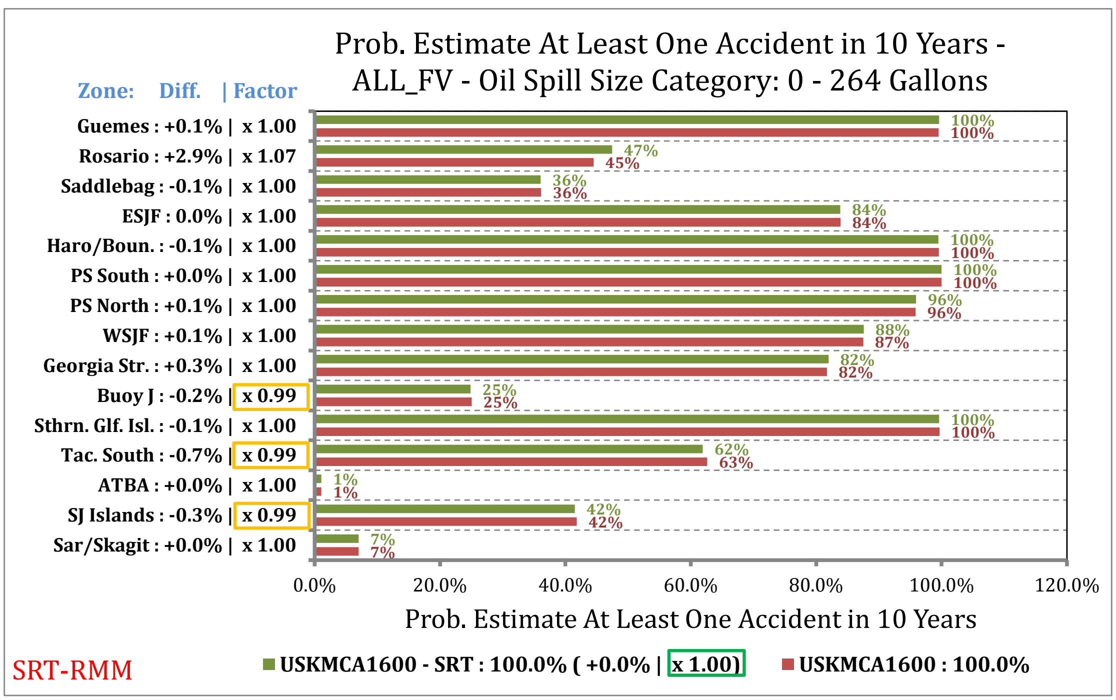

Figure 4-49. USKMCA1600-SRT RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

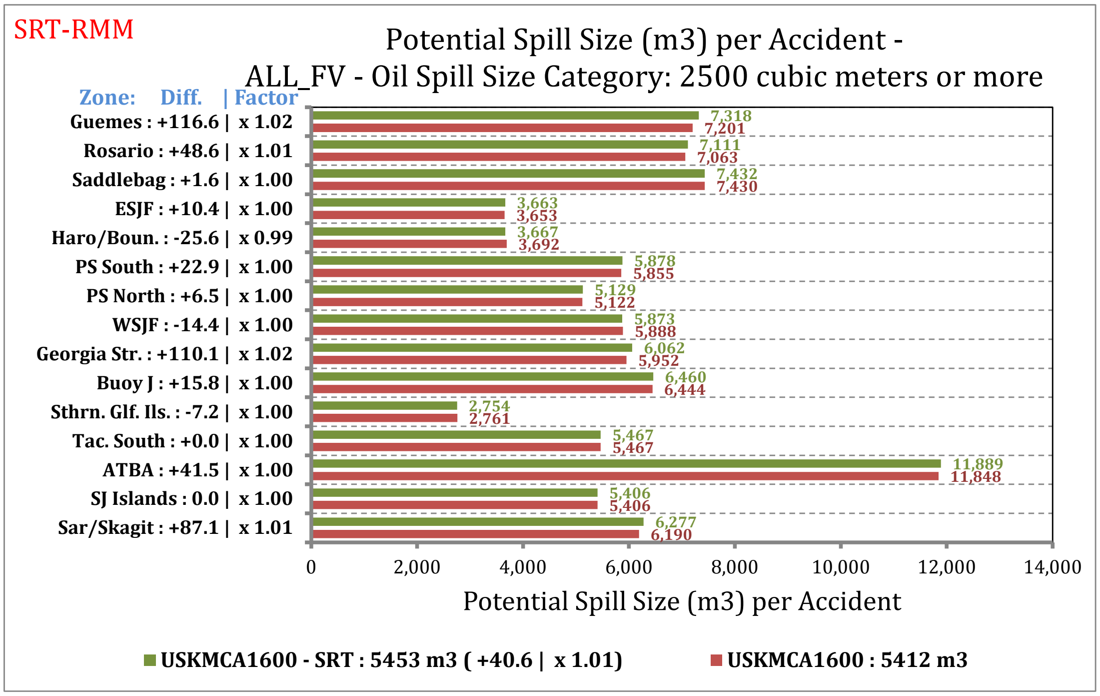

Figure 4-50. USKMCA1600-SRT RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

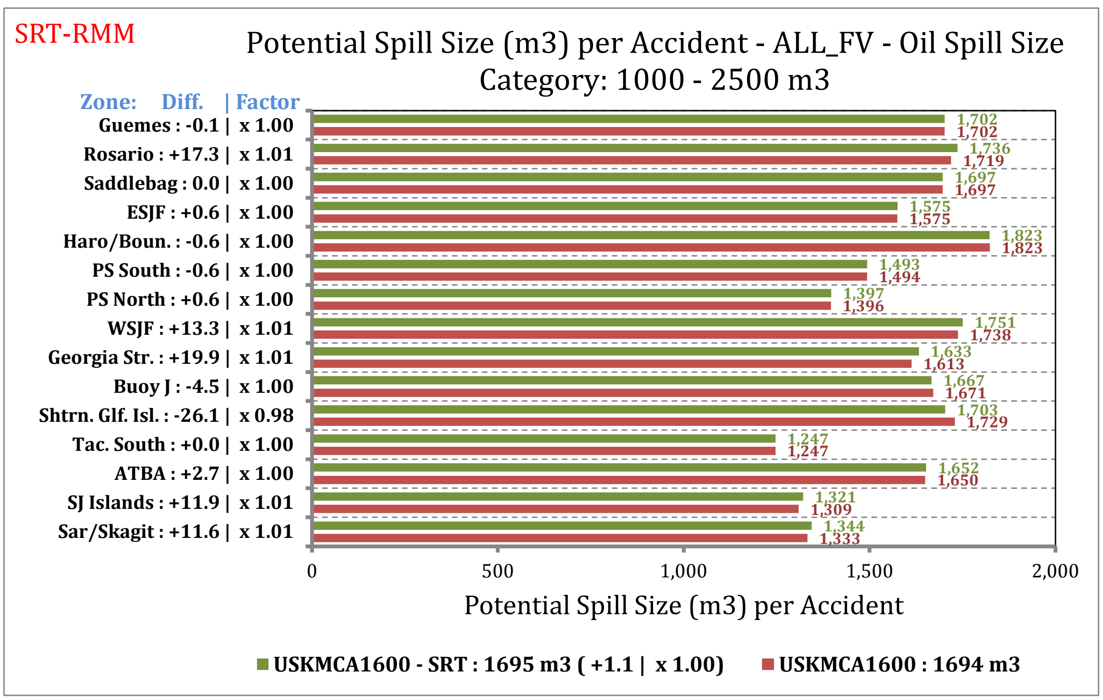

Figure 4-51. USKMCA1600-SRT RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

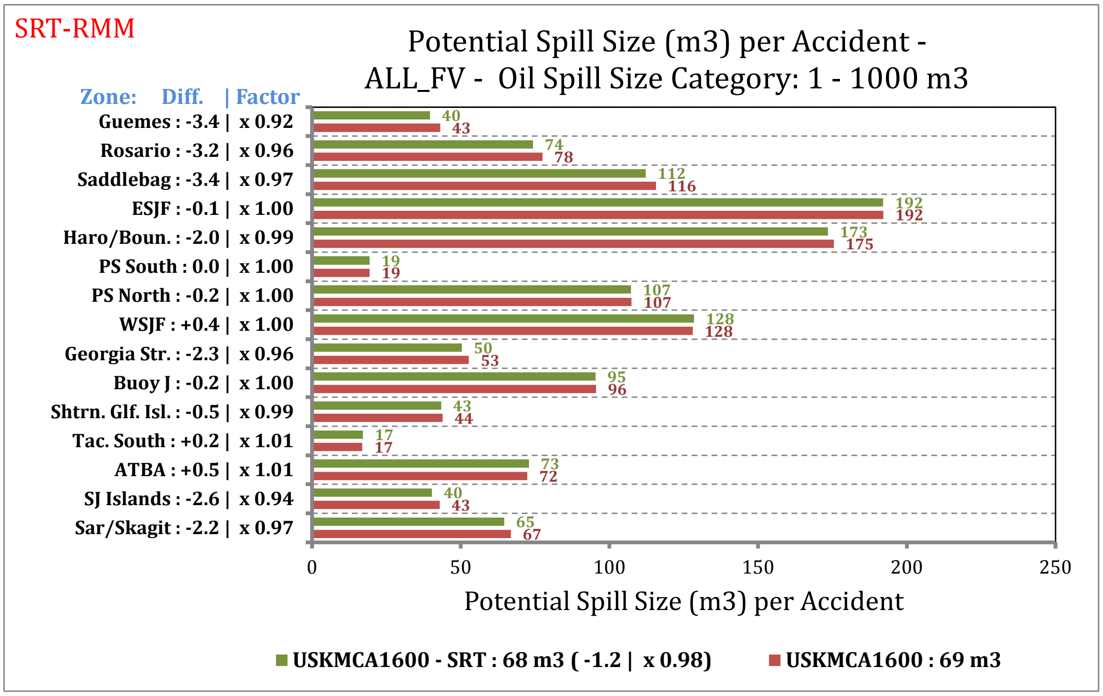

Figure 4-52. USKMCA1600-SRT RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

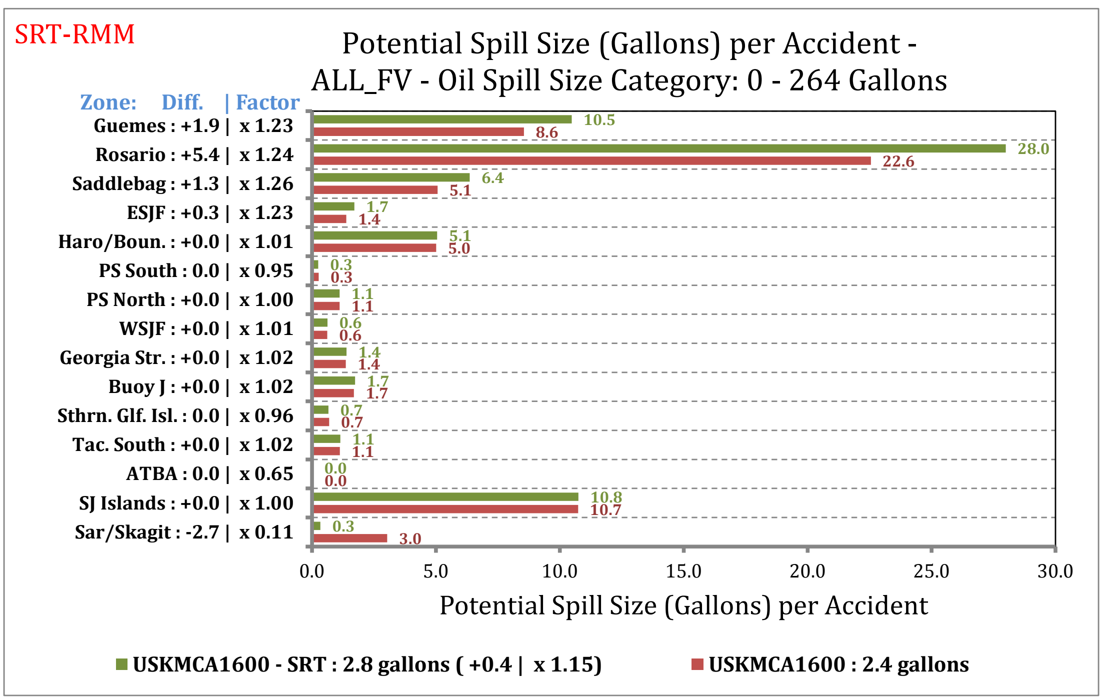

Figure 4-53. USKMCA1600-SRT RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

USKMCA1600 - KME RMM Scenario analysis results

The manner of implementation of the KME-RMM in the VTRA 2015 model enacted upon the USKMCA1600 What-If Scenario was as follows:

KME-RMM: Extend escorting of Kinder Morgan outbound laden tankers to Buoy J, see also Figure 4-2C.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL Accident Frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was assessed as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

In Chapter 3 a POTENTIAL Accident Frequency was evaluated for the USKMCA1600 scenario of about $1.11 \times 4.4 \approx 4.9$ accidents per year. From Figure 3-40 in Chapter 3 one observes that overall for the USKMCA1600 What-If Scenario about a +85% increase of total POTENTIAL Oil Loss was evaluated by the VTRA 2015 model over the entire VTRA Study Area from the Base Case 2015 Scenario. Figure 3-41 shows that the distribution of this about 185% of POTENTIAL Oil Loss was evaluated for the USKMCA1600 What-If Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@73% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 185% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 4-54 one observes that overall for the KME-RMM Scenario about a +85% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area from the Base Case 2015 Scenario, despite the consideration of the individual KME-RMM enacted upon the USKMCA1600 Scenario. Figure 4-55 shows that the distribution of this about 185% of

POTENTIAL Oil Loss was evaluated by the VTRA 2015 model for the KME-RMM Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@73% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 185% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the USKMCA1600 What-If Scenario, one observes that for each of these categories the POTENTIAL Oil Loss evaluated for the VTRA 2015 study area as a whole remained about the same in the KME-RMM analysis by the VTRA 2015 Model. Figure 4-56 presents the relative decreases of the total POTENTIAL Oil Loss evaluated for the KME-RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative reduction factor of about 1.00 (green highlight in Figure 4-56) for the VTRA 2015 Study Area as a whole for the KME-RMM Scenario. From Figure 4-56 one observes that the largest relative decreases in POTENTIAL Oil Loss are evaluated by the VTRA 2015 Model in the Buoy J waterway zone with a relative multiplicative reduction factor of about 0.94 (red highlight in Figure 4-56). Thus, one observes that while overall it was evaluated that POTENTIAL Oil Loss remained about the same for the KME-RMM Scenario, these relative reduction factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Oil Loss that was evaluated for the USKMCA1600 What-If Scenario decreases within the Buoy J waterway zone by about a relative multiplicative reduction factor of 0.94 in the KME-RMM Scenario. The other waterway zones that experience higher POTENTIAL Oil loss relative reduction factors than the VTRA Study Area in the KME-RMM Scenario are the waterway zones West Strait of Juan de Fuca and East Strait of Juan de Fuca with both relative reduction factors of about 0.99 (yellow highlights in Figure 4-56) respectively. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Figure 4-57 presents the relative change in the total POTENTIAL Accident Frequency evaluated for the KME-RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.01 (green highlight in Figure 4-57) for the VTRA 2015 Study Area as a whole for the KME-RMM Scenario. Thus overall, the VTRA 2015 Model evaluated for the KME-RMM Scenario about the same $1.01 \times 4.9 \approx 4.9$ number of accidents per year of which (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 110% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category (an increase of about 11% from the 98.2% evaluated for the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category). On the other hand, this 11% increase in POTENTIAL Accident Frequency in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category evaluated for the KME-RMM Scenario compared to the Base Case 2015 Scenario does not result in an increase to the POTENTIAL Oil Loss contribution in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category, which remained at about the 1% evaluated for this POTENTIAL Oil Loss Category in the USKMCA1600 Scenario.

From Figure 4-57 one observes that the largest relative decrease in POTENTIAL Accident Frequency is evaluated by the VTRA 2015 Model in the Buoy J and the Tacoma South waterway zones with a relative reduction factor of about 0.98 in both (red highlights in Figure 4-57). Thus, one observes that while overall a relative factor is observed of about 1.00 for the VTRA 2015 study area as a whole, these relative factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Accident Frequency evaluated for the USKMCA1600 Scenario decreases within the Buoy J and the Tacoma South waterway zones by about a relative reduction factor 0.98 in the KME-RMM Scenario. Firstly, it should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario. Secondly, the evaluated reduction factor in POTENTIAL Accident Frequency in the Tacoma South waterway zone by the VTRA 2015 Model cannot be the result of the enactment of the KME-RMM upon the USKMCA1600 Scenario. One other waterway zone experiences a higher POTENTIAL Accident Frequency relative reduction factor than the VTRA Study Area for the KME-RMM Scenario being the San Juan Islands waterway zone with a relative reduction factor of about 0.99 (yellow highlight in Figure 4-57). Needless to say, this latter evaluated reduction factor in POTENTIAL Accident Frequency too cannot be the result of the enactment of the KME-RMM upon the USKMCA1600 Scenario.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) within a 10-year period. Thus, for example, Figure 4-58 shows an estimated probability[12] of one or more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area of about 1.35%[13] (@ about the same level as evaluated for the USKMCA1600 Scenario). Recall from Figure 4-55A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 92% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for the KME-RMM Scenario (@ ≈ 185%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 1.35% (remaining VTRA Study area wide at about the same level as follows from multiplicative factor of about 1.00, green highlight in Figure 4-46, for the USKMCA

[12] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f} \times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[13] A 1% probability equals to a probability of 1 in 100.

What-If Scenario), its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 92% of the overall POTENTIAL Oil Loss (up by a multiplicative factor of 2.2 for the 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the KME-RMM Scenario (which was evaluated in total at about 185% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages), despite the enactment of the KME-RMM upon the USKMCA1600 Scenario. In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to about half of the POTENTIAL Oil Loss evaluated for the KME-RMM Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 4-58 for the KME-RMM Scenario, one observes a relative reduction factor of 0.93 (red highlight in Figure 4-58) for the Buoy J waterway zone for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period, for this particular waterway zone. Other waterway zones that experience about the same or higher relative reduction factors for these probabilities as compared to the VTRA Study area as a whole, are the waterway zones West Strait of Juan de Fuca and East Strait of Juan de Fuca with relative reductions factors of 0.98 and 0.99, respectively. It should be noted that this POTENTIAL decrease is evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Similar observations can be made from Figure 4-59, Figure 4-60 and Figure 4-61 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3 respectively. While about a 1% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the KME-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-58 at about 100%. In other words, it is estimated by the VTRA 2015 Model that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will happen within the VTRA Study Area within a 10-year period in the KME-RMM Scenario. While about a 20% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category (about the same as evaluated for the USKMCA1600 Scenario in this particular POTENTIAL Oil Loss Category) in the KME-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-59 at about 0.93%. Finally, while about a 73% POTENTIAL Oil Loss contribution is evaluated for the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (about the same as evaluated from the USKMCA1600 What-If Scenario in this particular POTENTIAL Oil Loss Category) in the KME-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-60 at about 57.4% (about equal to the probability estimated for the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category).

As was the case for Figure 4-58, red highlights shows the smallest relative reduction factors by waterway zone than experienced for the VTRA 2015 Study area in Figure 4-59, Figure 4-60 and

Figure 4-61. Yellow highlights shows the next smallest relative reduction factors experienced by waterway zones than experienced for the VTRA 2015 Study area as a whole in Figure 4-59, Figure 4-60 and Figure 4-61. Figure 4-62, Figure 4-63, Figure 4-64 and Figure 4-65 provide estimated average spill sizes per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the KME-RMM Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 4-59, Figure 4-60 and Figure 4-61 in the manner it was described above for Figure 4-58, but also the summary table in Appendix D for the KME-RMM Scenario comparison to the Base Case 2015 Scenario. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 1.35% for the KME-RMM Scenario, a value of 0.14% was estimated for this POTENTIAL Oil Loss category and this probability over a 1-year period and a value of 3.33% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

One must realize in evaluating the VTRA 2015 RMM analysis results in Figure 4-59, Figure 4-60 and Figure 4-61 (and Figure 4-58) that risk does not necessarily disappear when mitigated locally, but tends to migrate as demonstrated by some waterway zones experiencing increases in risk when other waterway zones are targeted for risk reductions. This is in large part a result of a maritime transportation system being a dynamic system, where a small traffic perturbation can precipitate traffic behavior changes in the future. Such migrations are preferably avoided in a sound risk management strategy, but some risk migration may be inevitable. In addition, the VTRA 2015 maritime simulation model contains some random elements in terms of it traffic simulation for what are termed “special events”. These special events represented in the VTRA model are modeled whale watching activities, regattas and tribal and commercial fishing openers. As a result of these random elements, some risk changes in the evaluated RMM Scenarios (and the What-If Scenarios) are a result of these random elements changing their behavior from simulation run to simulation run (see, also Figure E-6A).

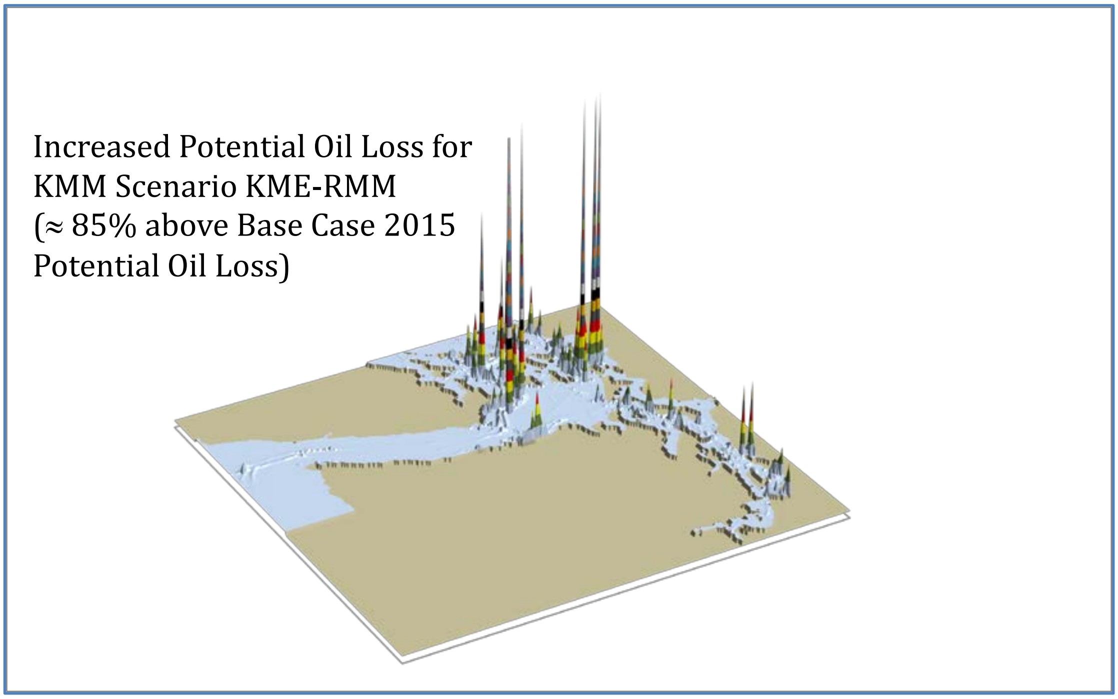

Figure 4-54. 3D Geographic profile of POTENTIAL oil loss for USKMCA1600-KME RMM Scenario.

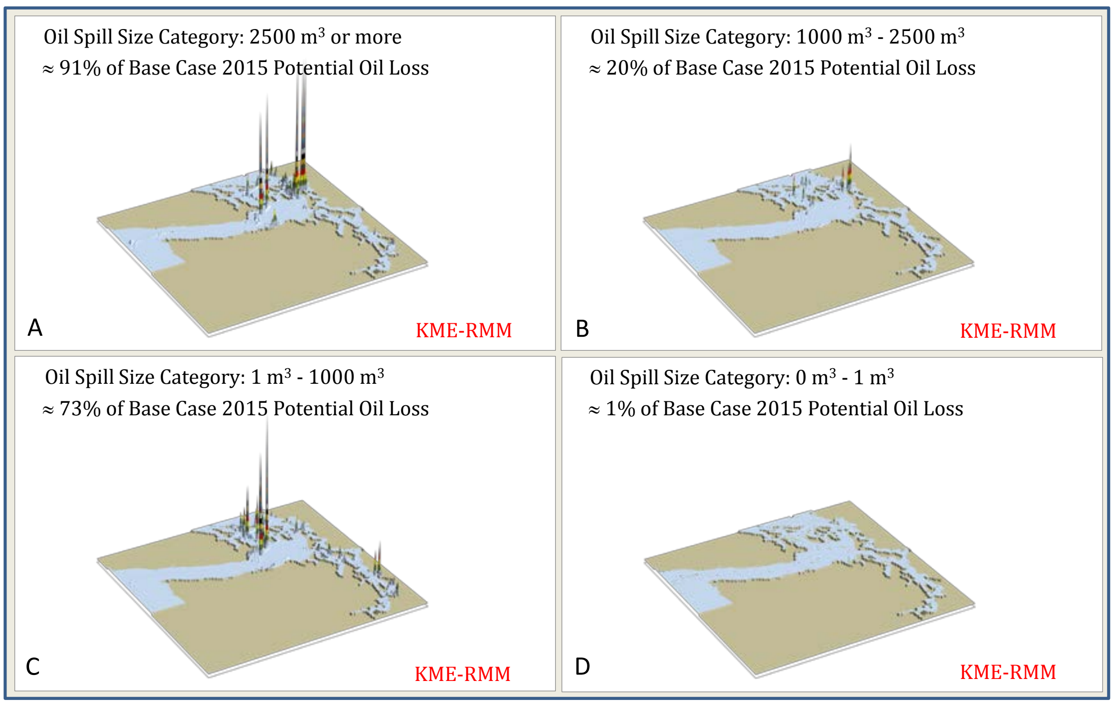

Figure 4-55. Components of 3D Geographic profile of USKMCA-KME RMM Scenario POTENTIAL oil loss. A: 91% in Oil Spill Size Category of 2500 m^3 or more; B: 20% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 73% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 1% in Oil Spill Size Category of 0 m^3 -1 m^3

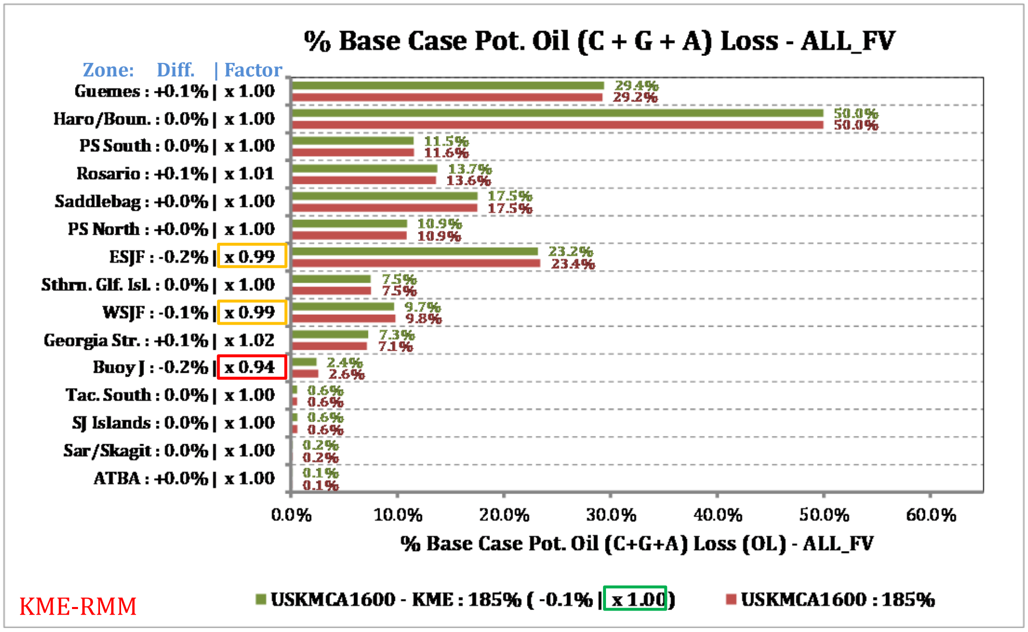

Figure 4-56. Relative comparison of POTENTIAL Oil Loss by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, green bars show the percentages for the USKMCA1600-KME RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

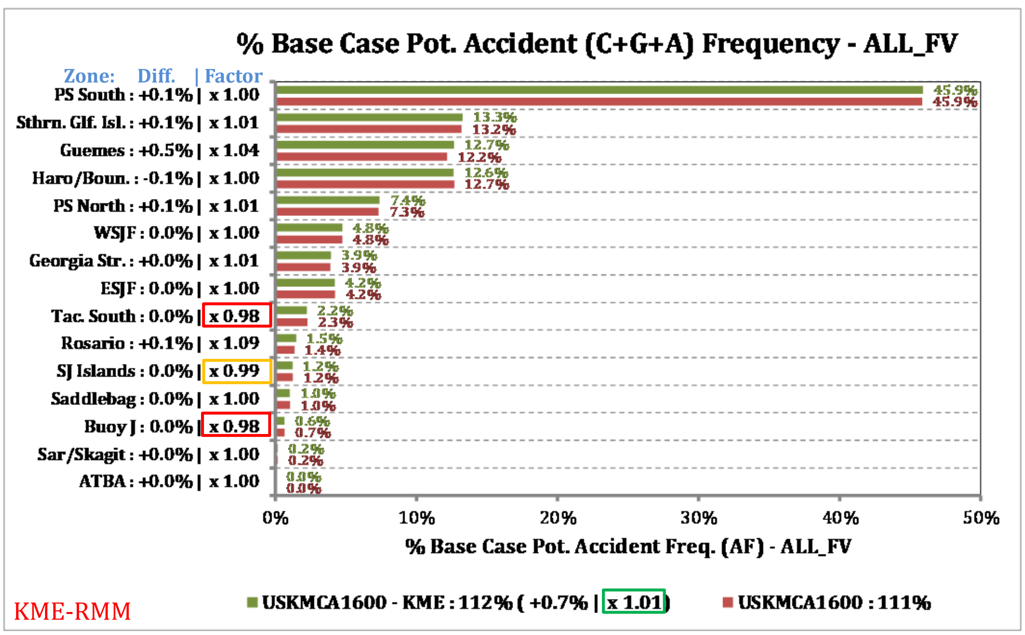

Figure 4-57. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, greens bars show the percentages for the USKMCA1600-KME RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

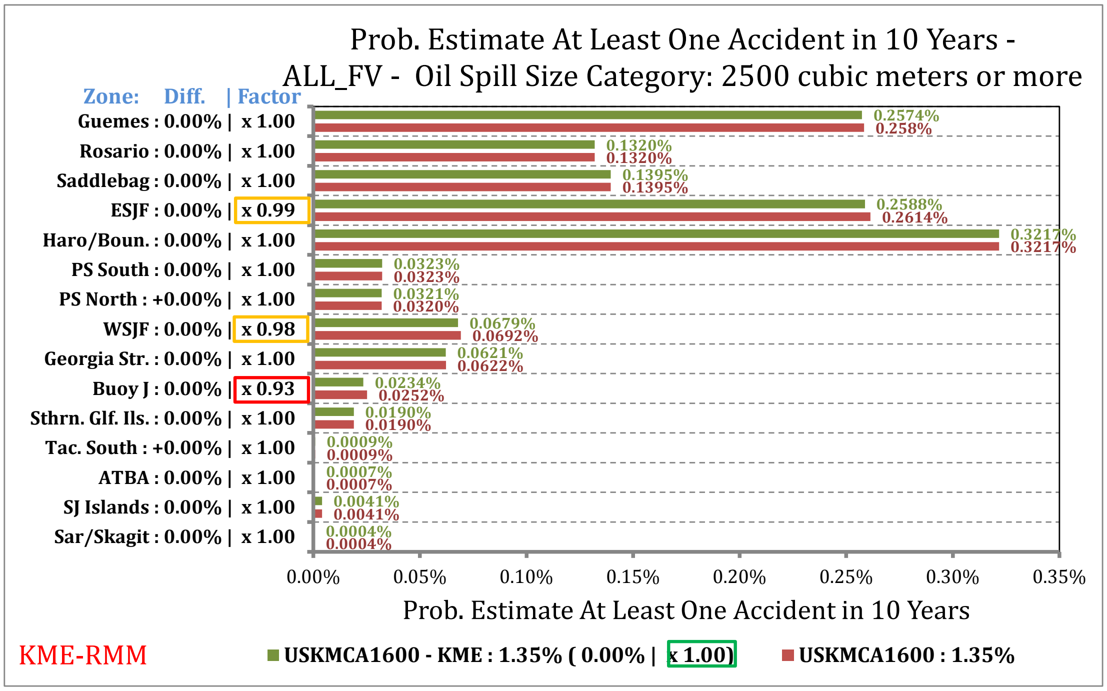

Figure 4-58. USKMCA1600-KME RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

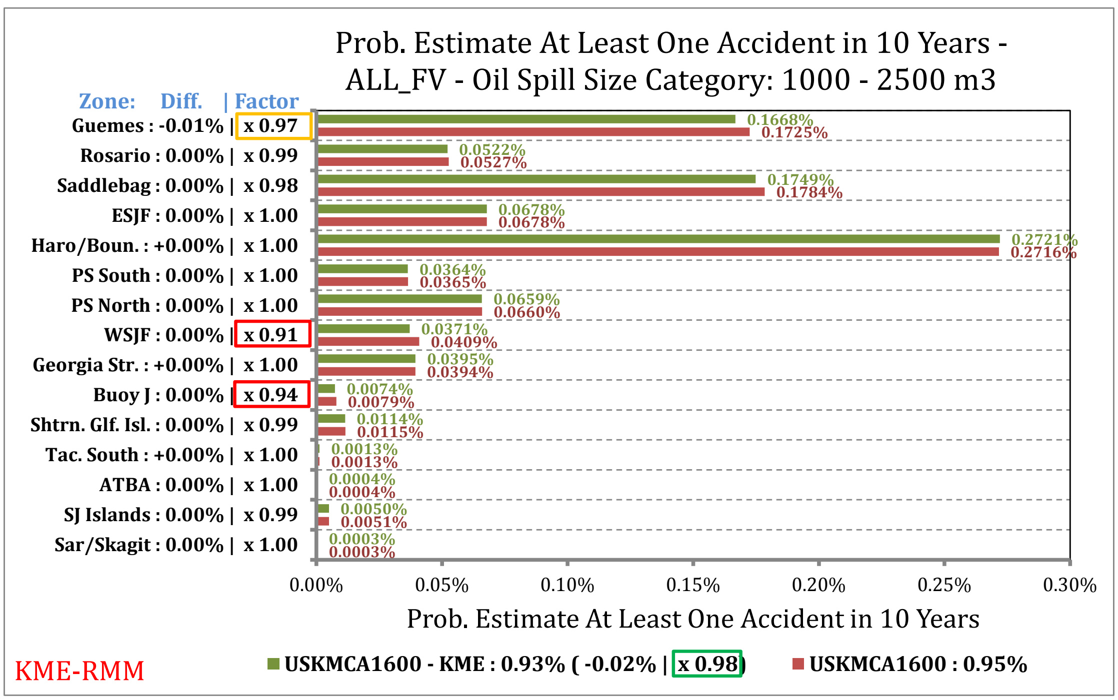

Figure 4-59. USKMCA1600-KME RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

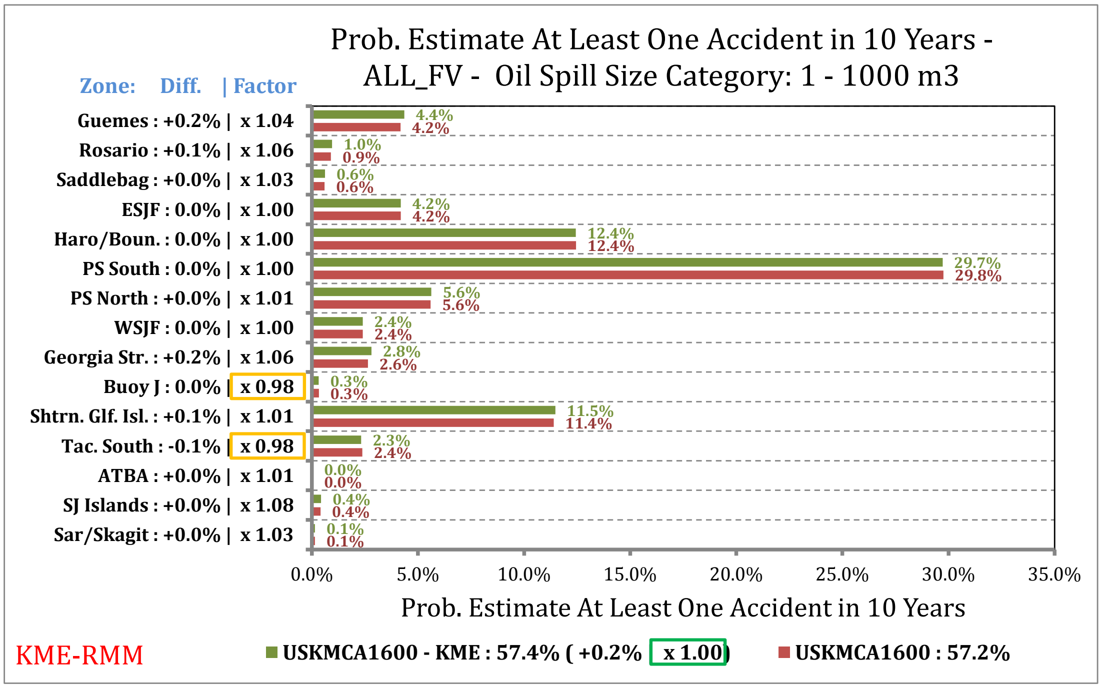

Figure 4-60. USKMCA1600-KME RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

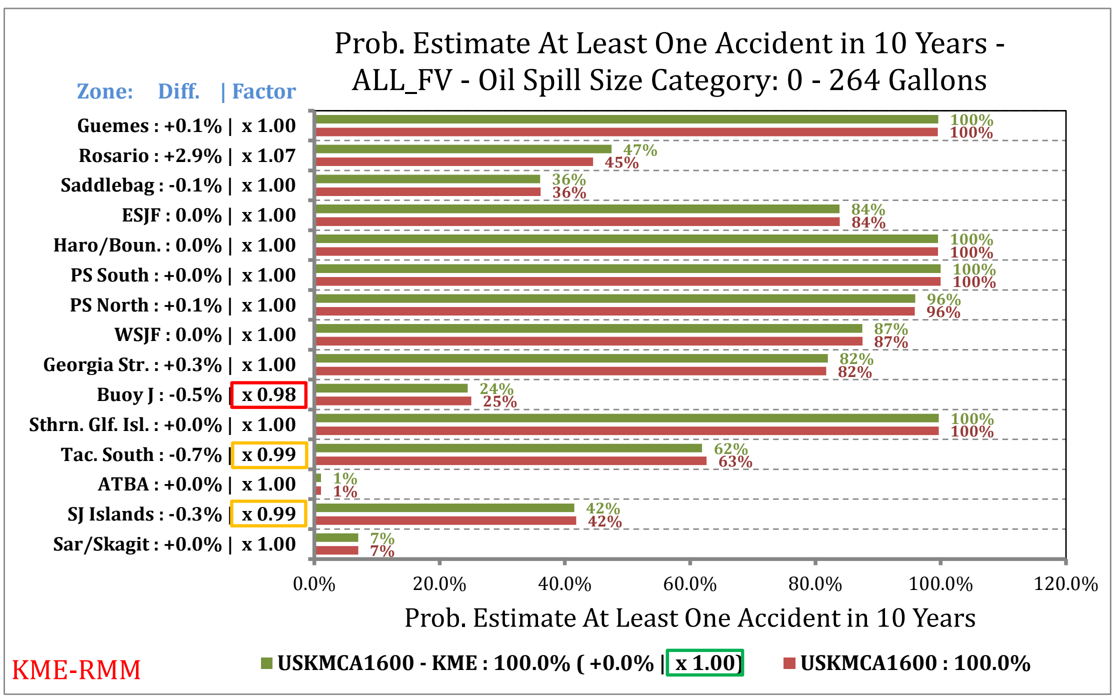

Figure 4-61. USKMCA1600-KME RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

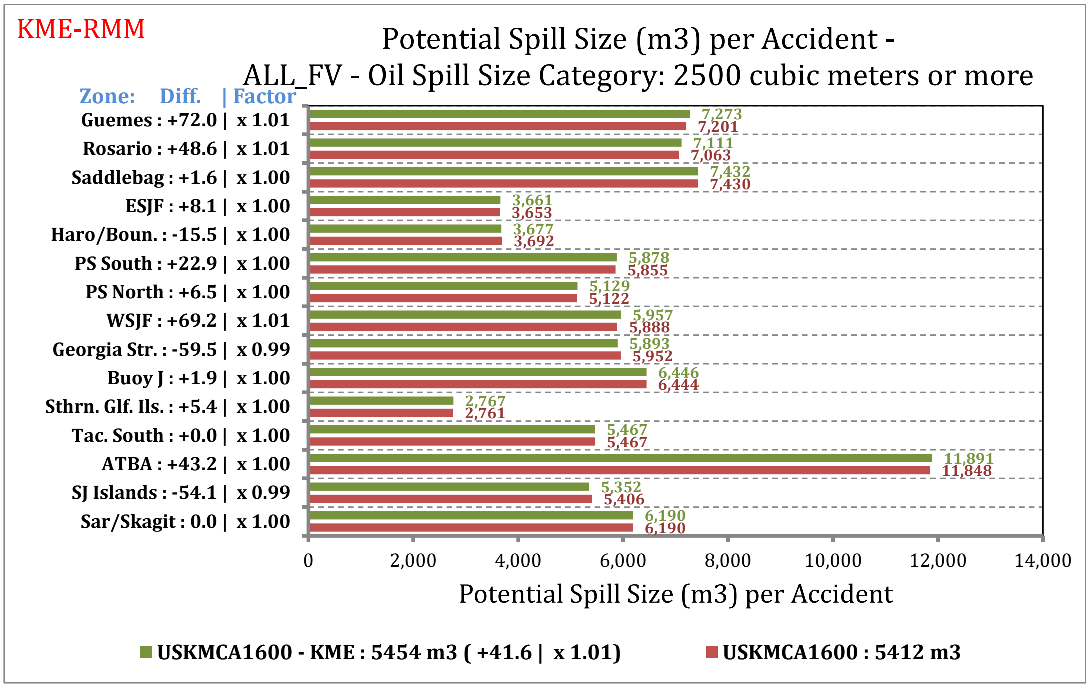

Figure 4-62. USKMCA1600-KME RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

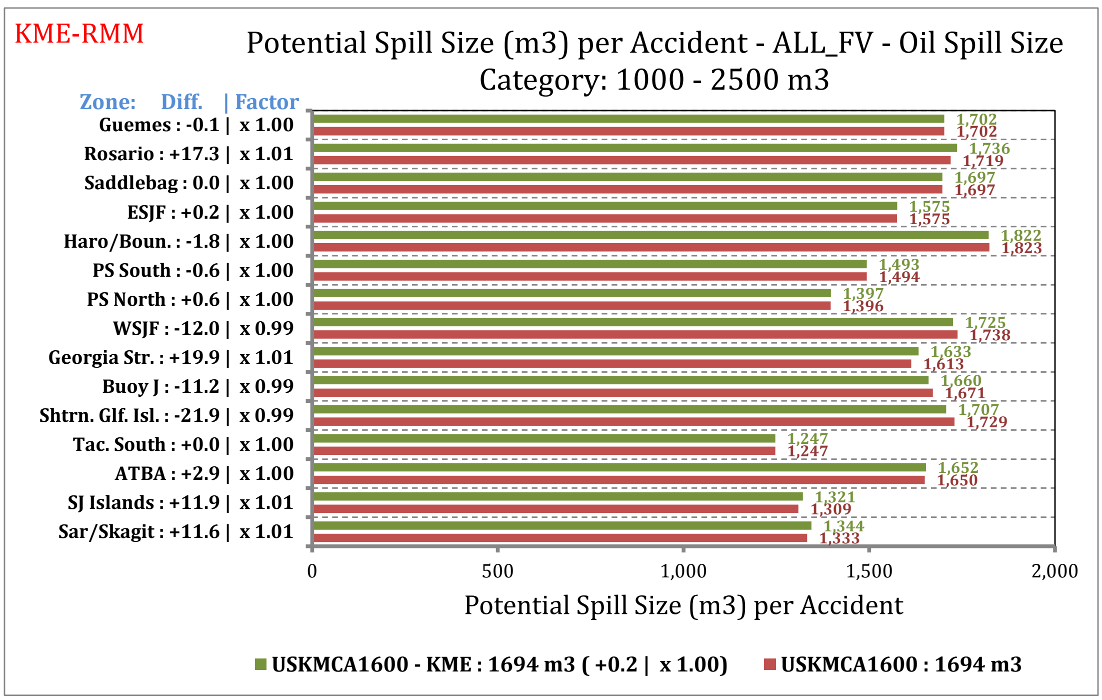

Figure 4-63. USKMCA1600-KME RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

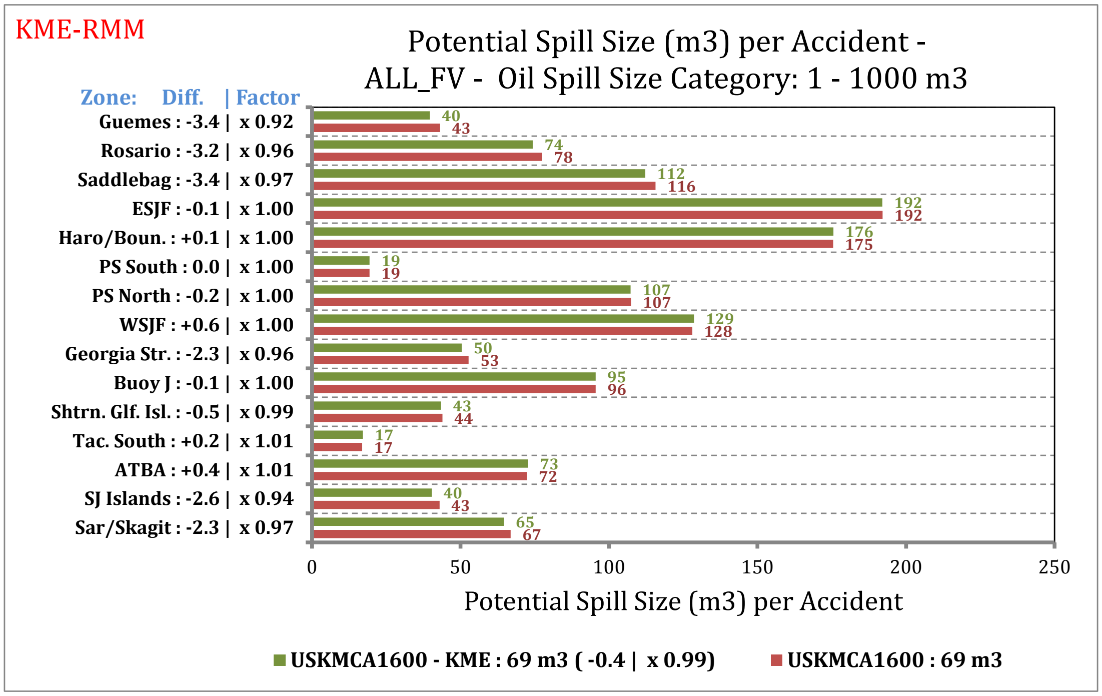

Figure 4-64. USKMCA1600-KME RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

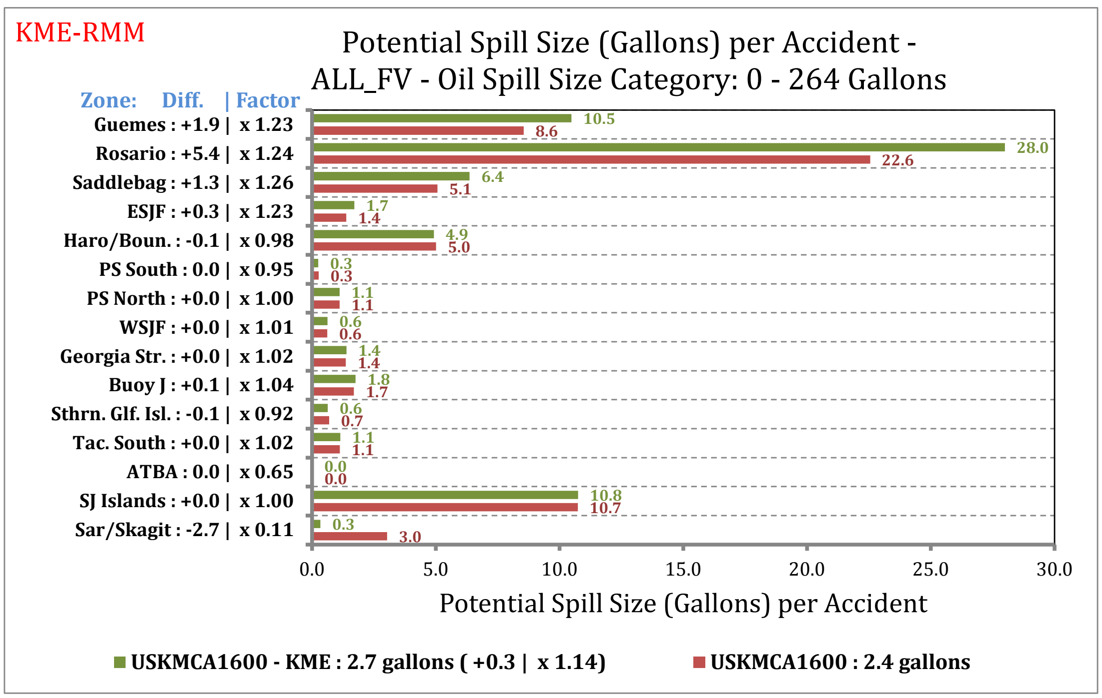

Figure 4-65. USKMCA1600-KME RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

USKMCA1600 - 125 RMM Scenario analysis results

The manner of implementation of the 125-RMM measure in the VTRA 2015 model enacted upon the USKMCA1600 What-If Scenario was as follows:

125-RMM: Lift the 125 DWT limit on laden crude inbound tankers while reducing the number of crude inbound tanker transits to keep the volume of crude inbound tankers approximately the same.

Please recall from Chapter 2 that through the calibration process the VTRA 2015 model was calibrated to a POTENTIAL Accident Frequency per year of approximately 4.4 accidents per year for the Base Case 2015 Scenario analysis, where of these 4.4 accidents about 98.2% fell in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category and the remainder (i.e. 100% - 98.2% = 1.8%) fell in the POTENTIAL Oil Loss category of 1 m^3 and above. It was also evaluated for the Base Case 2015 Scenario analysis that the split of total POTENTIAL Oil loss per year across four different POTENTIAL Oil Loss categories was assessed as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@42% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@12% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@45% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@0% of Base Case POTENTIAL Oil Losses)

These four categories combine in total to 100% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

In Chapter 3 a POTENTIAL Accident Frequency was evaluated for the USKMCA1600 scenario of about $1.11 \times 4.4 \approx 4.9$ accidents per year. From Figure 3-40 in Chapter 3 one observes that overall for the USKMCA1600 What-If Scenario about a +85% increase of total POTENTIAL Oil Loss was evaluated by the VTRA 2015 model over the entire VTRA Study Area from the Base Case 2015 Scenario. Figure 3-41 shows that the distribution of this about 185% of POTENTIAL Oil Loss was evaluated for the USKMCA1600 What-If Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@91% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@20% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@73% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 185% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario.

From Figure 4-66 one observes that overall for the 125-RMM Scenario about a +97% increase of total POTENTIAL Oil Loss is evaluated by the VTRA model over the entire VTRA Study Area from the Base Case 2015 Scenario, despite the consideration of the individual 125-RMM enacted upon the USKMCA1600 Scenario. Figure 4-55 shows that the distribution of this about 197% of

POTENTIAL Oil Loss was evaluated by the VTRA 2015 model for the 125-RMM Scenario across the above four different POTENTIAL Oil Loss categories as follows:

A. 2500 m^3 or more of POTENTIAL Oil Losses (@107% of Base Case POTENTIAL Oil Losses)
B. 1000 m^3 - 2500 m^3 POTENTIAL Oil Losses (@18% of Base Case POTENTIAL Oil Losses)
C. 1 m^3 - 1000 m^3 POTENTIAL Oil Losses (@72% of Base Case POTENTIAL Oil Losses)
D. 0 m^3 – 1 m^3 POTENTIAL OIL Losses (@1% of Base Case POTENTIAL Oil Losses)

Thus these four categories combine in total to about 197% of the total POTENTIAL Oil Loss per year for the Base Case 2015 Scenario. Comparing the percentages of each POTENTIAL Oil Loss Category with the percentage of the POTENTIAL Oil Loss categories of the USKMCA1600 What-If Scenario, one observes that of the about 197% - 185% ≈ +12% POTENTIAL Oil Loss increase evaluated from the USKMCA1600 Scenario is accounted for by about a +15% increase in POTENTIAL Oil Loss in the 2500 m^3 or more POTENTIAL Oil Loss Category, by about 2% reduction in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category, and by a less than 1% reduction in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category. While envisioned as a risk reduction measure, it would appear from the analysis results that the VTRA 2015 model evaluates that the 125-RMM Scenario leads to the unintended consequence of increasing overall POTENTIAL Oil Loss, despite decreases evaluated for the 125-RMM Scenario in the 1000 m^3 - 2500 m^3 and the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Categories.

Figure 4-68 presents the relative increases of the total POTENTIAL Oil Loss evaluated for the 125-RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 1.07 (green highlight in Figure 4-68) for the VTRA 2015 Study Area as a whole for the 125-RMM Scenario. From Figure 4-68 one observes that the largest relative increases in POTENTIAL Oil Loss are evaluated by the VTRA 2015 Model in the Buoy J, Guemes and Rosario waterway zones with relative multiplicative factors of about 1.19, 1.18 and 1.16 (red highlights in Figure 4-68). Thus, one observes that while overall a relative factor increase is observed of about 1.07 for the VTRA 2015 study area as a whole, these relative factors can be higher (or lower) within a particular waterway zone. In other words, the POTENTIAL Oil Loss that was evaluated for the USKMCA1600 What-If Scenario increases within the Buoy J waterway zone by about a relative multiplicative factor of 1.19 in the 125-RMM Scenario increasing POTENTIAL OIL loss in this particular waterway zone from the USKMCA1600 What-If Scenario evaluations. Analogous statements can be made for the other tw0 waterway zones mentioned above, i.e. Guemes and Rosario. Other waterway zones that experience higher POTENTIAL Oil Loss relative multiplicative factors than the VTRA Study Area in the 125-RMM Scenario are the waterway zones East Strait of Juan de Fuca, West Strait of Juan de Fuca, and Saragota Skagit with relative factors of about 1.11, 1.09, and 1.08 (yellow highlights in Figure 4-68), respectively. It should be noted that these are POTENTIAL increases evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Figure 4-69 presents the relative change in the total POTENTIAL Accident Frequency evaluated for the 125-RMM Scenario by the fifteen waterway zones in the VTRA 2015 Study area. First observe the overall multiplicative factor of 0.99 (green highlight in Figure 4-69) for the VTRA 2015 Study Area as a whole for the 125-RMM Scenario. Thus overall, the VTRA 2015 Model evaluated for the 125-RMM Scenario about the same $0.99 \times 4.9 \approx 4.9$ number of accidents per year of which (in terms of Base Case 2015 POTENTIAL Accident frequency percentages) about 108% fall in 0 m^3 – 1 m^3 POTENTIAL OIL Loss category (an increase of about 10% from the 98.2% evaluated for the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category). On the other hand, this 10% increase in POTENTIAL Accident Frequency in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category evaluated for the 125-RMM Scenario compared to the Base Case 2015 Scenario does not result in an increase to the POTENTIAL Oil Loss contribution in the 0 m^3 – 1 m^3 POTENTIAL OIL Loss category, which remained at about the 1% evaluated for this POTENTIAL Oil Loss Category in the USKMCA1600 Scenario.

From Figure 4-69 one observes that the largest relative decrease in POTENTIAL Accident Frequency is evaluated by the VTRA 2015 Model in the San Juan Islands waterway zones with a relative reduction factor of about 0.93 (red highlight in Figure 4-69). Thus, one observes that while overall a relative reduction factor is observed of about 0.99 for the VTRA 2015 study area as a whole, these relative reduction factors can be lower (or higher) within a particular waterway zone. In other words, the POTENTIAL Accident Frequency evaluated for the USKMCA1600 Scenario decreases within the San Juan Island waterway zones by about a relative reduction factor 0.93 in the 125-RMM Scenario within this particular waterway zone. Thus, decreases in POTENTIAL Accident Frequency are demonstrated by the VTRA 2015 Model in the 125-RMM Scenario Analysis. It should be noted, however, that these POTENTIAL decreases are evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario. Other waterway zones that experience higher POTENTIAL Accident Frequency relative reduction factors than the VTRA Study Area for the 125-RMM Scenario are the Guemes, Georgia Strait, Tacoma South, ATBA, West Strait of Juan de Fuca, and East Strait of Juan de Fuca waterway zones (yellow highlights in Figure 4-69). The latter two with relative reduction factors of about 0.98 and the former four waterway zones with a relative reduction factor of about 0.97, respectively. It should be noted that these are POTENTIAL decreases evaluated from the USKMCA1600 Scenario and not the Base Case 2015 Scenario.

Another distinguishing feature of the VTRA 2015 from the VTRA 2010 is the evaluations of the probability of one or more accidents (said differently, the probability of at least one accident) within a 10-year period. Thus, for example, Figure 4-70 shows an estimated probability[14] of one or

[14] These estimated probabilities $\hat{p}$ have a direct relationship $\hat{p}(\hat{f}|t) = 1 - e^{-\hat{f}\times t}$ to their estimated annual POTENTIAL accident frequencies $\hat{f}$, where t equals the length of the time period. Thus $\hat{p}(\hat{f}|t)$ increases when the length of the time

more accidents in the POTENTIAL Oil Loss category of 2500 m^3 or more within a 10-year period, and over the entire VTRA 2015 study area of about 1.41%[15] (@ a multiplicative factor 1.04 higher than evaluated for the USKMCA1600 Scenario). Recall from Figure 4-67A it was evaluated that this POTENTIAL Oil Loss Category contributes on the other hand to about 107% (in terms of Base Case 2015 Scenario Percentages) of the overall POTENTIAL Oil Loss evaluated for the 125-RMM Scenario (@ ≈ 197%). These numbers demonstrate that while one or more POTENTIAL accidents in the 2500 m^3 or more POTENTIAL Oil Loss Category within a 10-year period may be considered a low probability event evaluated at 1.41% for the 125-RMM Scenario, green highlight in Figure 4-70, its probability is not evaluated by the VTRA 2015 model to be equal to zero and is thus evaluated as an event that could happen. Moreover, overall this 2500 m^3 or more POTENTIAL Oil Loss Category contributes to about 107% of the overall POTENTIAL Oil Loss (up by a multiplicative factor of 2.5 for the 2500 m^3 or more POTENTIAL Oil Loss Category evaluated for the Base Case 2015 Scenario) for the 125-RMM Scenario (which was evaluated in total at about 197% in terms of Base Case 2015 Scenario POTENTIAL Oil Loss percentages), despite the enactment of the 125-RMM upon the USKMCA1600 Scenario. In other words, this 2500 m^3 or more POTENTIAL Oil Loss category contributes to more than half of the POTENTIAL Oil Loss evaluated for the 125-RMM Scenario, however unlikely the occurrence of such an event might be.

Delving deeper into the evaluations of Figure 4-70 for the 125-RMM Scenario, one observes a relative multiplicative factor of 1.32 (red highlight in Figure 4-70) for the Saddlebag waterway zone for the estimated probability of one or more accidents within the POTENTIAL Oil Loss category 2500 m^3 or more within a 10-year period, for this particular waterway zone. Other waterway zones that experience about the same or higher relative multiplicative factors for these probabilities as compared to the VTRA Study area as a whole, are the waterway zones Buoy J, San Juan Islands, Guemes and the Southern Gulf Islands with relative multiplicative factors of 1.15 and 1.14, 1.12 and 1.12, respectively. It should be noted that these POTENTIAL increases are evaluated from the USKMCA1600 What-If Scenario and not from the Base Case 2015 Scenario.

Similar observations can be made from Figure 4-71, Figure 4-72 and Figure 4-73 for the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3 respectively. While about a 1% POTENTIAL Oil Loss contribution is evaluated for 0 m^3 - 1 m^3 POTENTIAL Oil Loss category in the 125-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-58 at about 100%. In other words, it is estimated by the VTRA 2015 Model that an accident in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss category will happen within the VTRA Study Area within a 10-year period in the 125-RMM Scenario. While about an 18% POTENTIAL Oil Loss contribution is evaluated for 1000 m^3 - 2500

period t increases and for a large enough POTENTIAL accident frequency $\hat{f}$ and a long enough time period t, $\hat{p}(\hat{f}|t)$ can mathematically attain an estimated value of 1.

[15] A 1% probability equals to a probability of 1 in 100.

m^3 POTENTIAL Oil Loss category (about a 2% reduction in POTENTIAL Oil Loss in this particular Oil Loss Category as evaluated for the USKMCA1600 Scenario) in the 125-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-71 at about 0.86%. Finally, while about a 72% POTENTIAL Oil Loss contribution is evaluated for the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category (about less than 1% less than as evaluated from the USKMCA1600 What-If Scenario in this particular POTENTIAL Oil Loss Category) in the 125-RMM Scenario, the probability of one or more of those accidents happening in a 10-year period is estimated in Figure 4-48 at about 57.0% (about a 3% increase in the probability estimated for the Base Case 2015 Scenario for this particular POTENTIAL Oil Loss Category).

As was the case for Figure 4-70, red highlights shows the smallest relative factors by waterway zone than experienced for the VTRA 2015 Study area in Figure 4-71, Figure 4-72 and Figure 4-73. Yellow highlights shows the next smallest relative factors experienced by waterway zones than experienced for the VTRA 2015 Study area as a whole in Figure 4-71, Figure 4-72 and Figure 4-73. Figure 4-74, Figure 4-75, Figure 4-76 and Figure 4-77 provide estimated average spill sizes per accident for the four POTENTIAL Oil Loss Categories for the VTRA Study area and by waterway zone. Observe from Figure 4-74 the increases in average spill size per accident evaluated by the VTRA 2015 model in the waterway zones Guemes, Rosario, East Strait of Juan de Fuca, West Strait of Juan de Fuca, San Juan Islands, Georgia Strait and Buoy J. This can in part be explained by the increased volume per compartment in the Oil Outflow model in the 125-RMM Scenario, but also by POTENTIAL increases in longitudinal and transversal damage extent evaluated by the oil outflow model described in [4] in the VTRA 2015 Model[16], modeled after the oil out flow model in the SR259 report [5] of the National Research Council. Appendix D provides a summary table of by VTRA Study area relative comparisons from the Base Case 2015 Scenario to the 125-RMM Scenario for the different risk metrics evaluated/estimated in the VTRA 2015 Study. We encourage the readers to study in more detail the results in Figure 4-71, Figure 4-72 and Figure 4-73 in the manner it was described above for Figure 4-70, but also the summary table in Appendix D for the 125-RMM Scenario comparison to the Base Case 2015 Scenario. In addition to the estimated probabilities of one or more accident occurring in the VTRA Study area by POTENTIAL Oil Loss category in a 10-year period for a Scenario, either a What-If Scenario or an RMM Scenario, these summary tables in Appendix D also provide values for these estimated probabilities for a 1-year period and a 25-year period. For example, while for the 2500 m^3 or more POTENTIAL Oil loss category the probability of one or more accident occurring in the VTRA study area in this POTENTIAL Oil Loss category was estimated at the above value of 1.41% for the 125-RMM Scenario, a value of 0.14% was estimated for this POTENTIAL Oil Loss category and this

[16] The oil outflow model in the VTRA model assumes that once a tanker compartment is breached all oil in such a tanker compartment is lost.

probability over a 1-year period and a value of 3.49% was estimated for this POTENTIAL Oil Loss category and this probability over a 25-year period.

One must realize in evaluating the VTRA 2015 RMM analysis results in Figure 4-71, Figure 4-72 and Figure 4-73 (and Figure 4-70) that risk does not necessarily disappear when mitigated locally, but tends to migrate as demonstrated by some waterway zones experiencing increases in risk when other waterway zones are targeted for risk reductions. This is in large part a result of a maritime transportation system being a dynamic system, where a small traffic perturbation can precipitate traffic behavior changes in the future. Such migrations are preferably avoided in a sound risk management strategy, but some risk migration may be inevitable. In addition, the VTRA 2015 maritime simulation model contains some random elements in terms of it traffic simulation for what are termed “special events”. These special events represented in the VTRA model are modeled whale watching activities, regattas and tribal and commercial fishing openers. As a result of these random elements, some risk changes in the evaluated RMM Scenarios (and the What-If Scenarios) are a result of these random elements changing their behavior from simulation run to simulation run (see, also Figure E-6A).

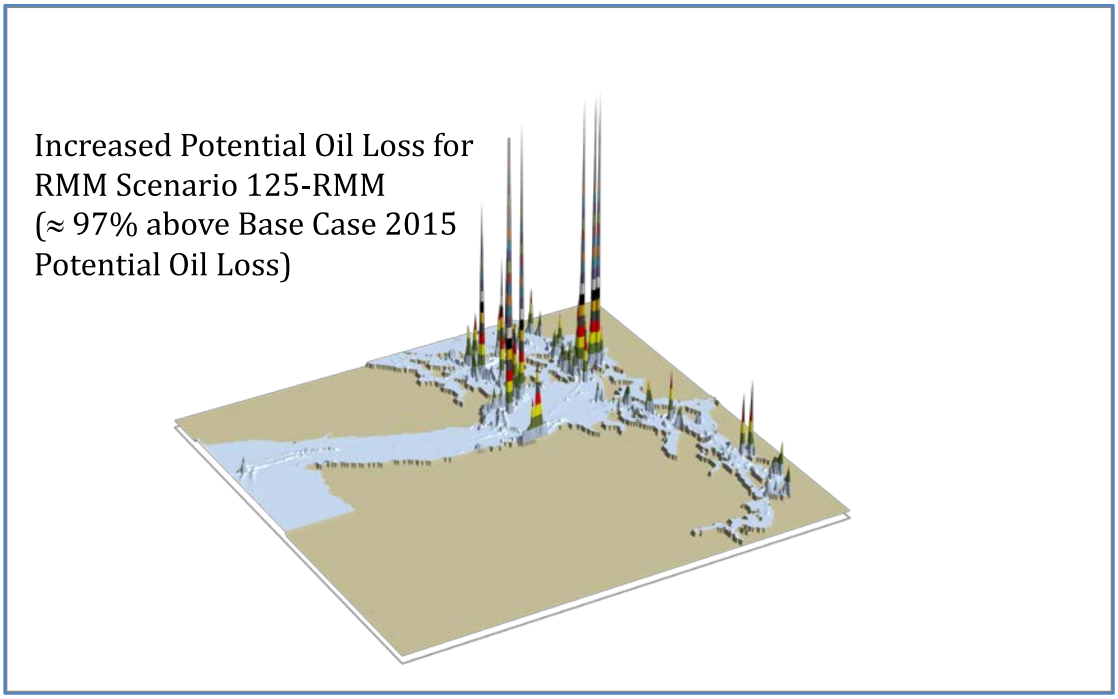

Figure 4-66. 3D Geographic profile of POTENTIAL oil loss for USKMCA1600-125 RMM Scenario.

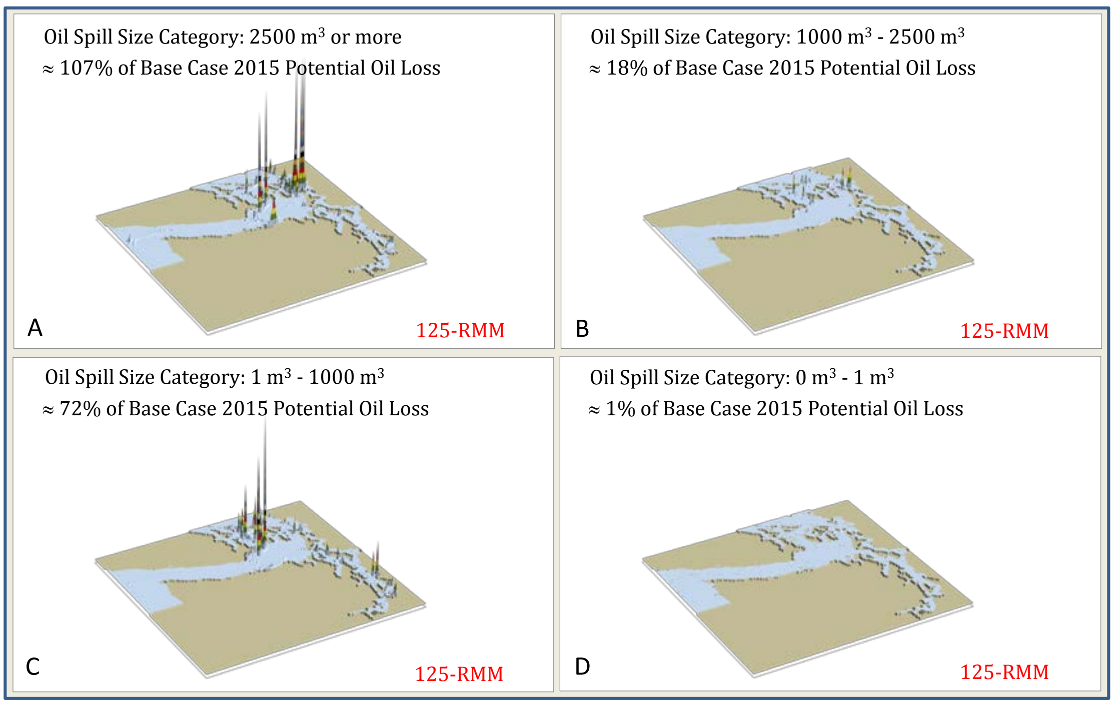

Figure 4-67. Components of 3D Geographic profile of USKMCA1600-125 RMM Scenario POTENTIAL oil loss. A: 107% in Oil Spill Size Category of 2500 m^3 or more; B: 18% in Oil Spill Size Category of 1000 m^3 -2500 m^3; C: 72% in Oil Spill Size Category of 1 m^3 -1000 m^3; D: 1% in Oil Spill Size Category of 0 m^3 -1 m^3

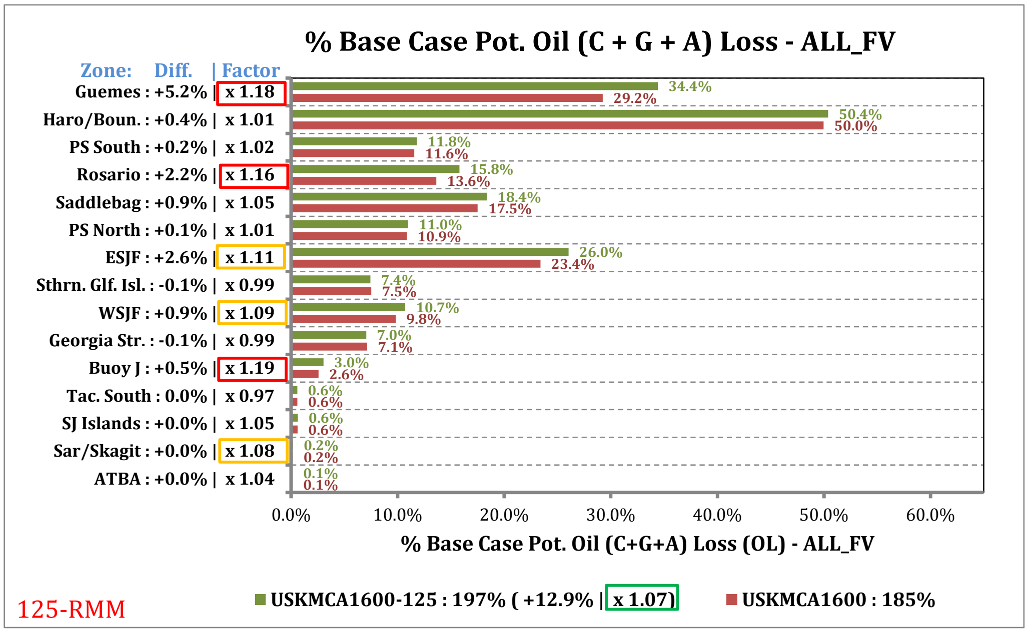

Figure 4-68. Relative comparison of POTENTIAL Oil Loss by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, green bars show the percentages for the USKMCA1600-125 RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

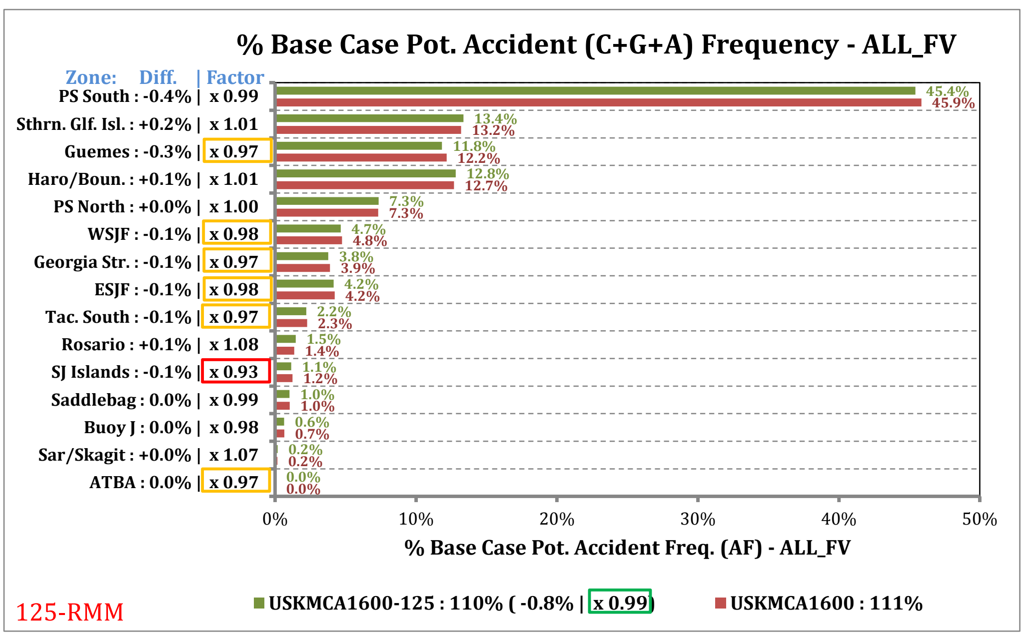

Figure 4-69. Relative comparison of POTENTIAL Accident Frequency by waterway zone. Red bars show the percentages by waterway zone for the USKMCA1600 What-If Scenario, greens bars show the percentages for the USKMCA1600-125 RMM Scenario both in terms of base case percentages. Absolute differences by waterway zone and relative multipliers by waterway zone are provided in the y-axis labels.

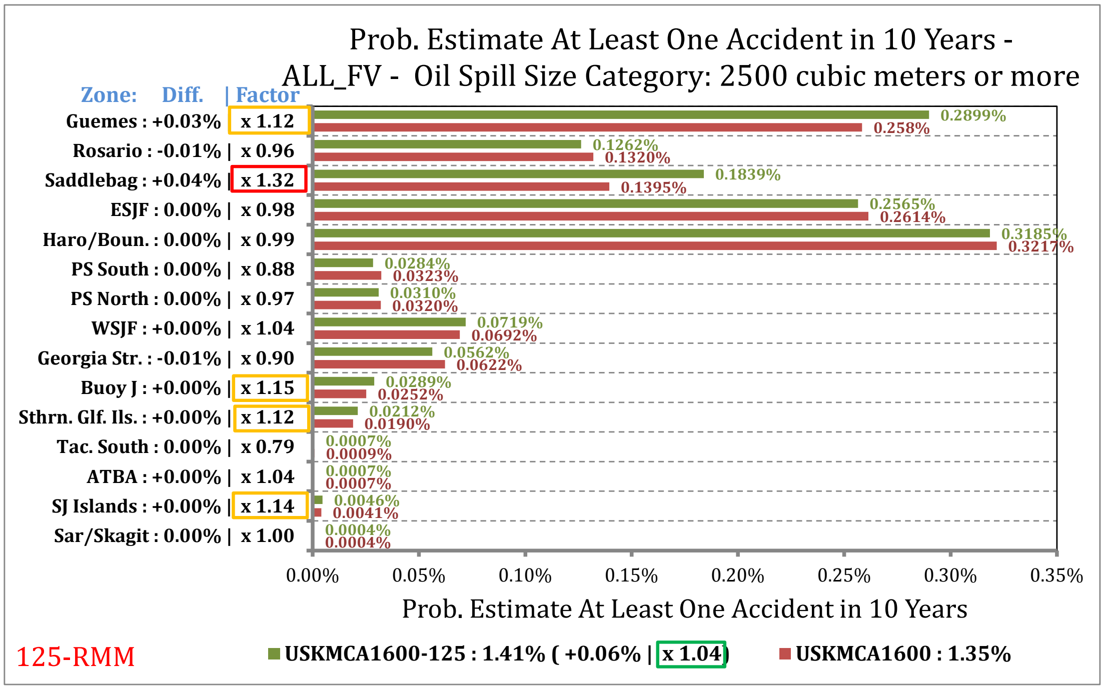

Figure 4-70. USKMCA1600-125 RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 2500 m³ or more.

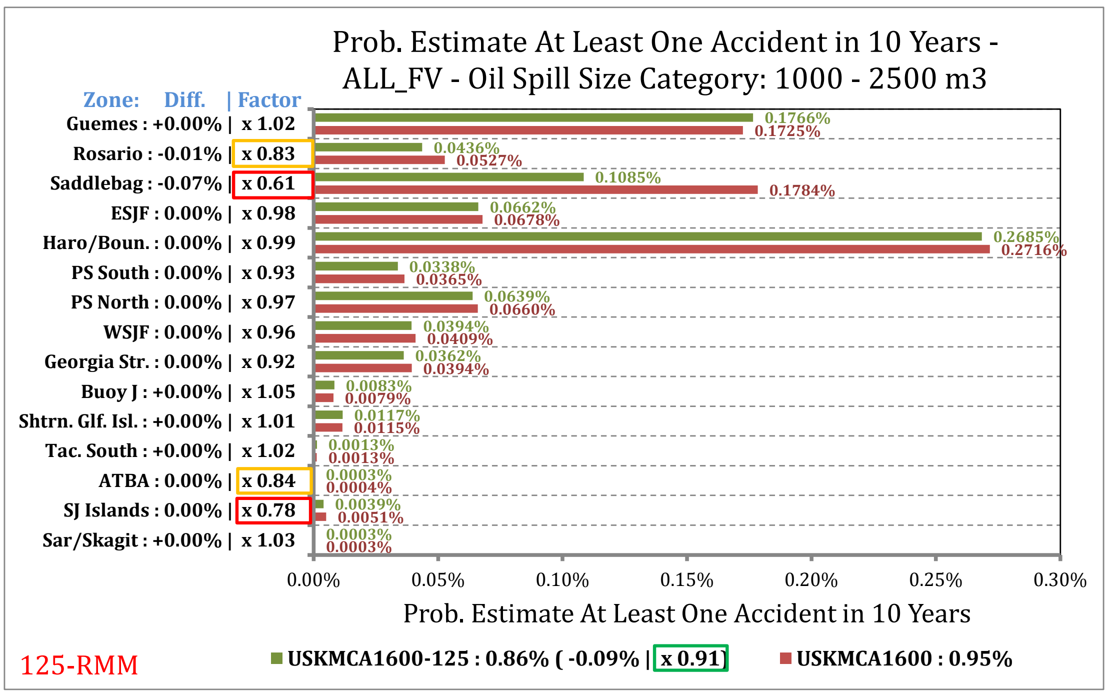

Figure 4-71. USKMCA1600-125 RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1000 m³ to 2500 m³

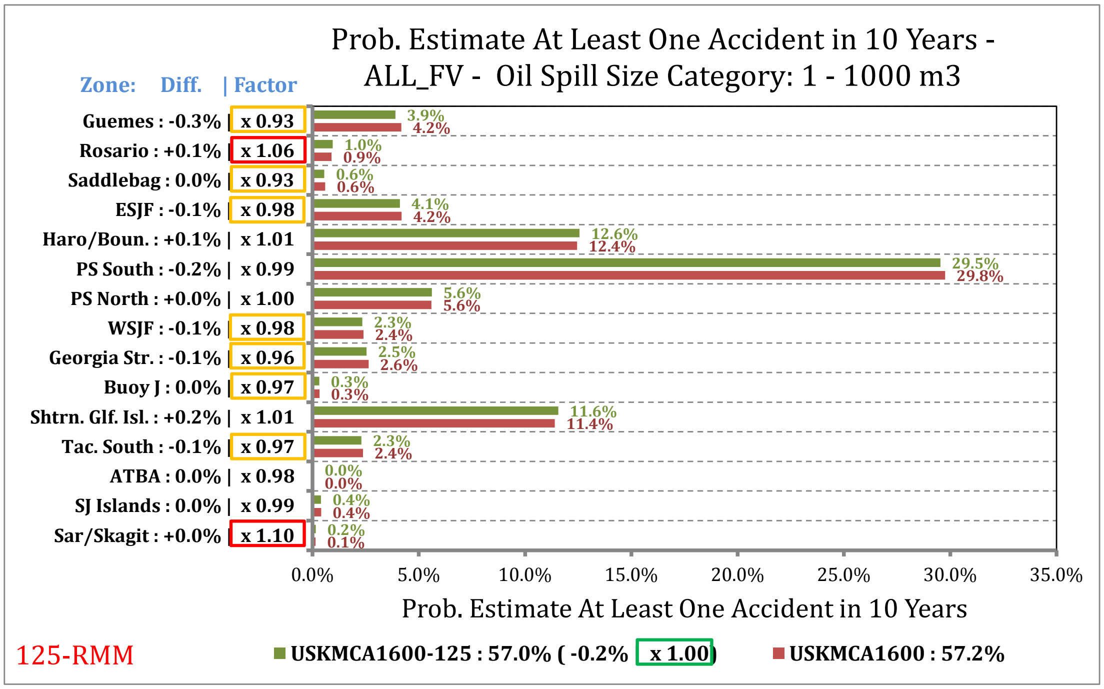

Figure 4-72. USKMCA1600-125 RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 1 m³ to 1000 m³

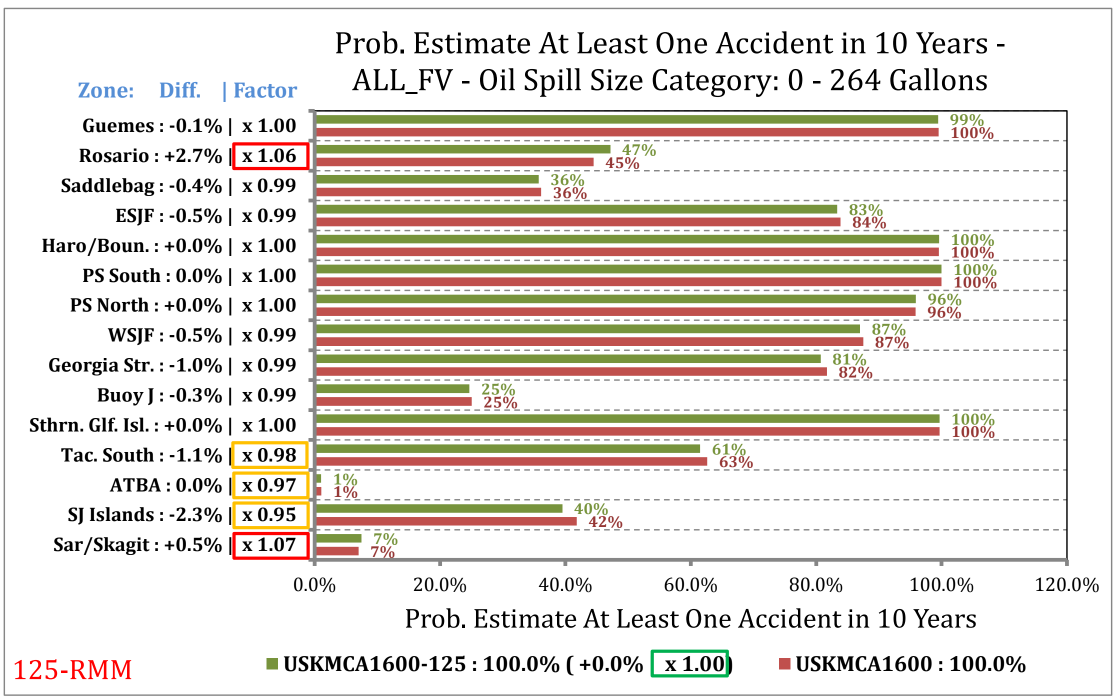

Figure 4-73. USKMCA1600-125 RMM Scenario relative comparison of probability estimate of at least one accident in a 10-year period by waterway zone for the POTENTIAL Oil Loss category 0 m³ to 1 m³ (or 0 to 264 gallons).

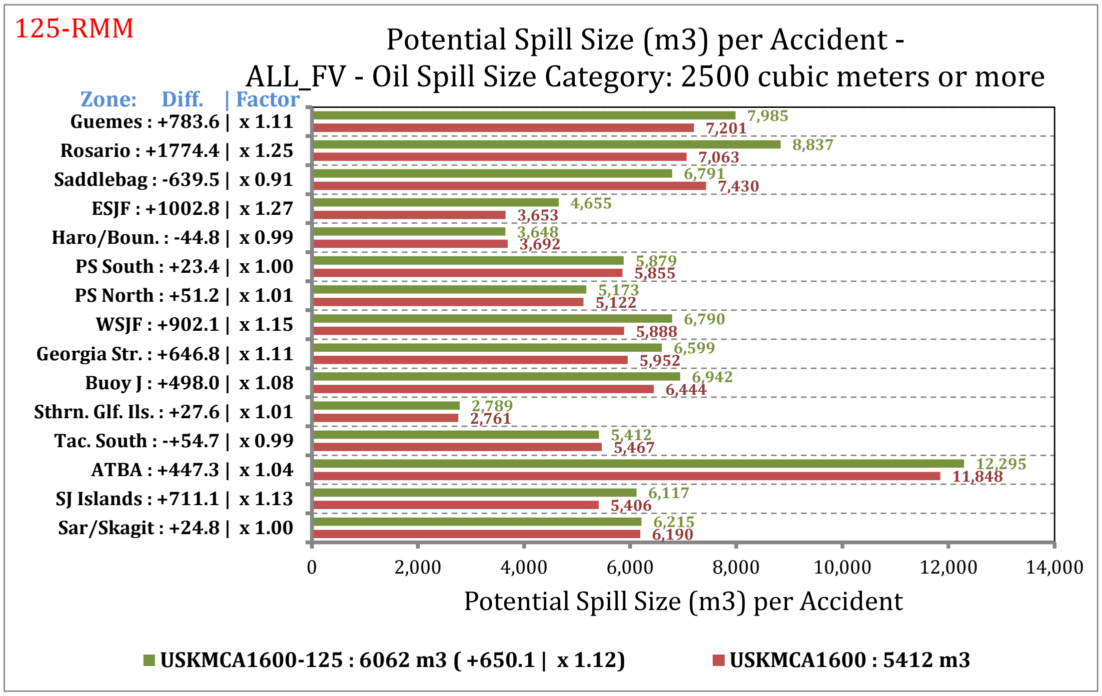

Figure 4-74. USKMCA1600-125 RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 2500 m³ or more.

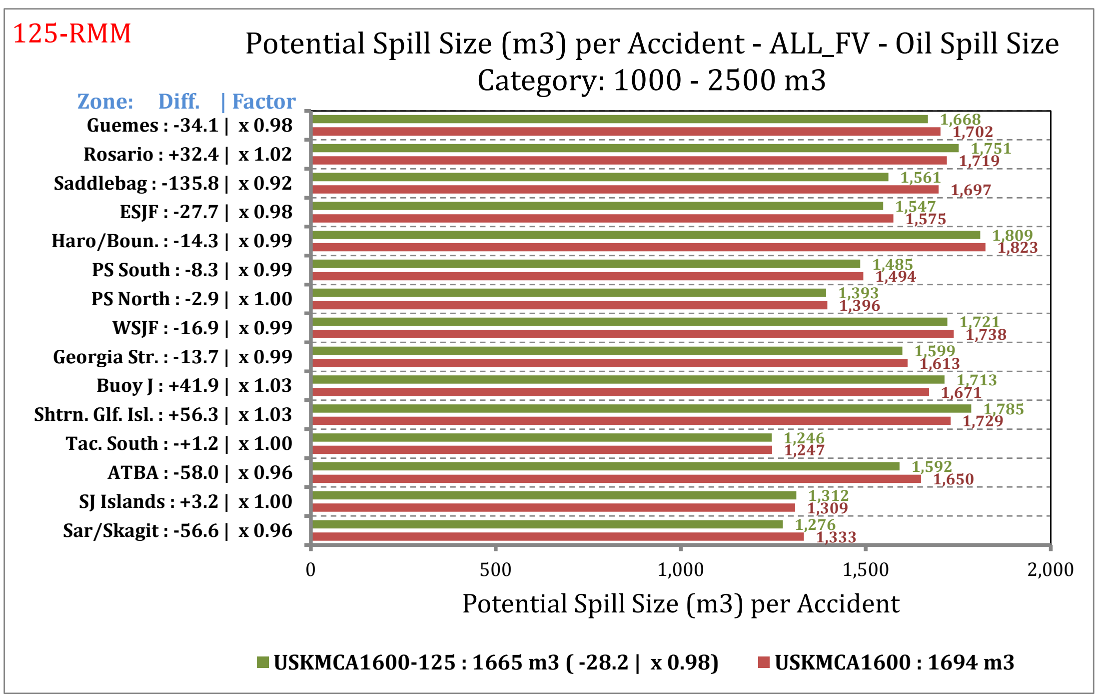

Figure 4-75. USKMCA1600-125 RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1000 m³ or 2500 m³.

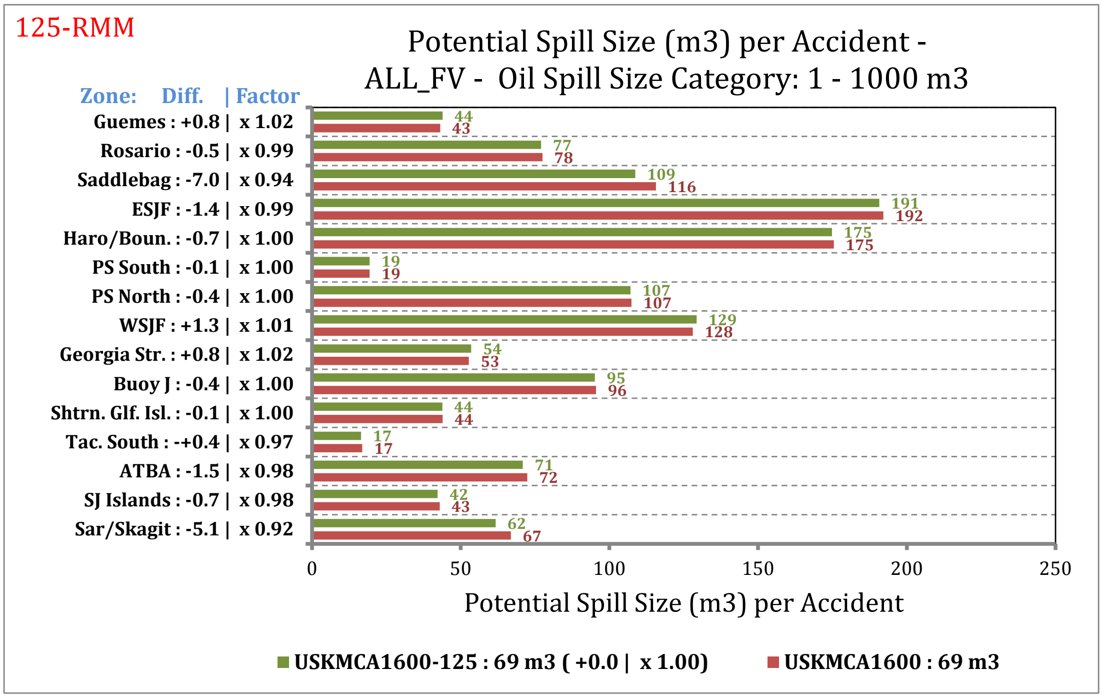

Figure 4-76. USKMCA1600-125 RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 1 m³ or 1000 m³.

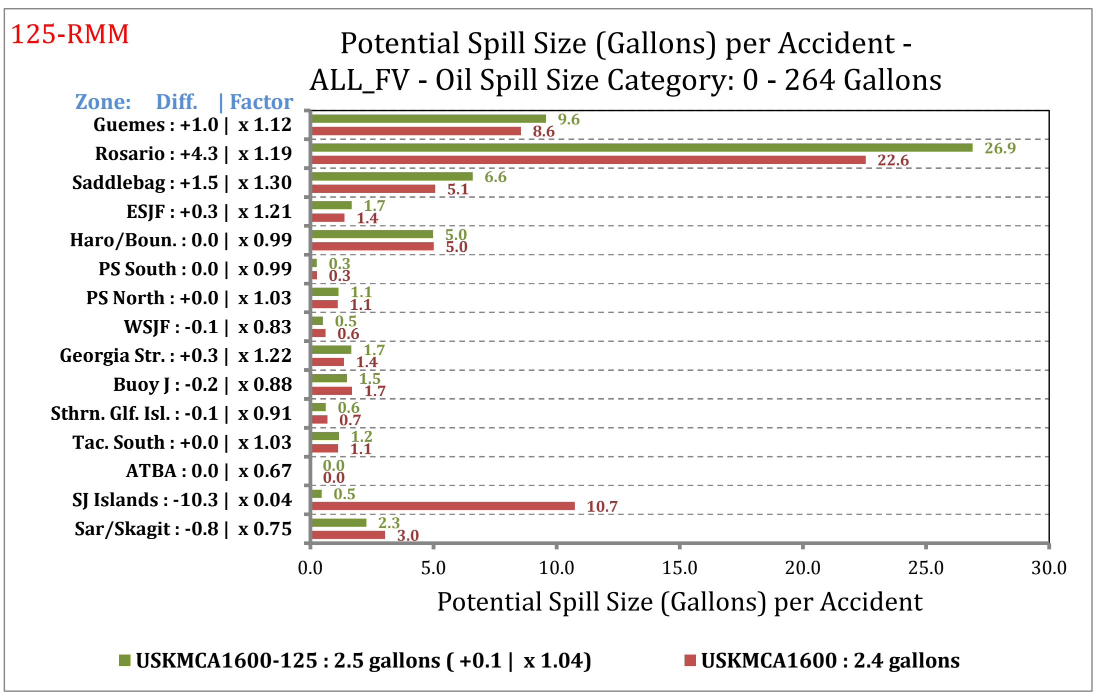

Figure 4-77. USKMCA1600-125 RMM Scenario relative comparison of the average POTENTIAL spill size per accident by waterway zone for the by POTENTIAL Oil Loss category 0 m³ or 1 m³ (or 0 to 264 gallons).

5. A CURSORY LOOK AT A HYPOTHETICAL CRUDE EXPORT ANALYSIS

A hypothetical analysis was requested to evaluate the POTENTIAL effect of a crude export scenario. The analysis is deemed hypothetical as the assumption was made in these scenario analyses that the traffic volume (in terms of the number of vessels) remains the same, but that the same crude tanker that arrives laden to the VTRA 2015 Study area would depart laden from the VTRA Study area by increasing the volumetric outbound crude per tanker by 25%, 50%, 75% and 100% in separate scenario analysis simulation runs of the VTRA 2015 Model. Thus, no increase is modeled in crude tanker vessel traffic within the VTRA 2015 model for this analysis, but rather that crude outbound export is increased per tanker by 25%, 50%, 75% and 100% utilization of its crude tankers volumetric capacity. These scenario analyses were conducted on top of the Base 2015 Scenario Analysis.

For the 25%, 50%, 75% and 100% Crude Export Scenario Analysis it was evaluated that the POTENTIAL average spill size per POTENTIAL Accident increased by about 1403 m^3, 1956 m^3, 2452 m^3 and 2919 m^3 in the POTENTIAL Oil Loss Category 2500 m^3 or more, respectively. The POTENTIAL average spill size in the other three POTENTIAL Oil Loss Categories 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 and 0 m^3 - 1 m^3 remained about the same. The effect of these POTENTIAL average spill size increases per POTENTIAL accident is depicted in Figure 5-1. From Figure 5-1 one observes that the VTRA 2015 model estimates an about 20%, 24%, 28% and 31% increase in POTENTIAL Oil loss for the VTRA 2015 Study area as a whole in terms of Base Case 2015 POTENTIAL Oil Loss percentages.

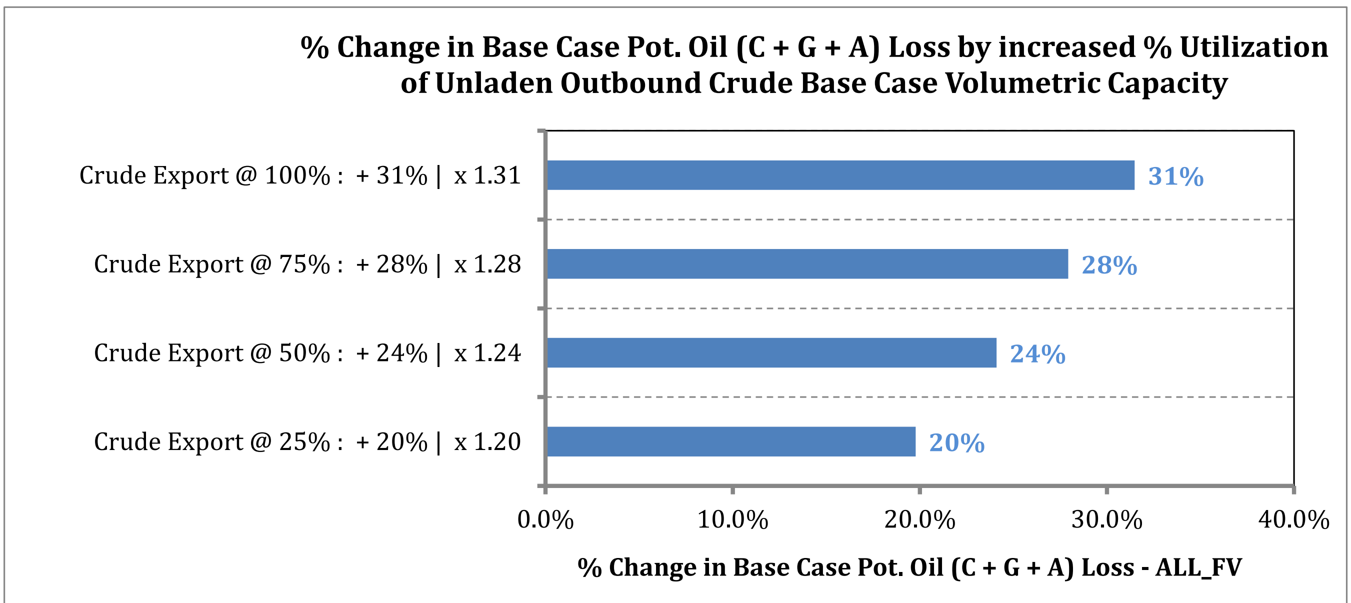

Figure 5-1. % Increase POTENTIAL Oil loss evaluated by the VTRA 2015 Model in terms of Base Case 2015 Scenario percentages by increasing outbound crude oil transport @ 25%, 50%, 75% and 100% utilization of base case crude tankers volumetric capacity.

The results in Figure 5-1 can in part be explained by the increased volume per tanker compartment in the oil outflow model in these Crude Export Scenarios and its POTENTIAL Oil Loss when such a tanker compartment is penetrated in a POTENTIAL Accident, but also by POTENTIAL increases in longitudinal and transversal damage extent of tankers evaluated by the oil outflow model[1] described in [4] in the VTRA 2015 Model, modeled after the oil outflow model in the SR259 report [5] of the National Research Council. In particular, it would appear that between a 0% and 25% increase in utilization of crude outbound volumetric capacity per tanker, a threshold point exists increasing on average the number of compartments penetrated in a POTENTIAL accident. The VTRA 2015 Model assumes that all oil from a penetrated tanker compartment is lost. Since following the initial increase of 20% POTENTIAL Oil Loss for the @25% crude export scenario, the POTENTIAL Oil Loss increase by about 4% for the VTRA 2015 Study area as a whole for each 25% increase in volumetric crude export per outbound crude tanker and that the average spill size increases by about 500 m^3 for each of the Crude Export Scenarios Analysis evaluated, it would appear that on average the POTENTIAL number of tanker compartments penetrated evaluated by the VTRA 2015 Model remains on average about the same in each of the other three hypothetical (i.e. 50%, 75%, and 100%) Crude Export Scenarios evaluated by the VTRA 2015 model.

[1] An increase in mass of a vessel leads, when keeping speed of the vessel the same, to an increase of kinetic energy in a POTENTIAL accident, which in turn leads to increases in transversal and longitudinal damage extend in a POTENTIAL accident, which may results in an increase of the POTENTIAL number of compartments penetrated in a POTENTIAL accident.

6. CONCLUSIONS

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

The starting point for the 2015 VTRA analysis is the VTRA 2010 Model. The VTRA 2015 model has been updated during the VTRA 2015 study from the VTRA 2010 model using additional accident data from the period 1990 to 2015 and AIS passage line vessel count data from 2010 to 2015. The VTRA 2010 Model and the update of the 2005 VTRA model to using 2010 VTOSS data and the validation of this update with 2010 AIS passage line count data are described in [21] and [20], respectively. To distinguish the study described herein from the previous 2010 VTRA study conducted from 2012-2013 it is labeled the VTRA 2015. The VTRA 2015 Study Area is defined by the black border in Figure E-2 covering US/Canadian trans-boundary waters including: portions of the Washington outer coast, the Strait of Juan de Fuca and the approaches to and passages through the San Juan Islands, Puget Sound and Haro-Strait/Boundary Pass. It is worthwhile to note that while Canadian bound traffic passes through the VTRA 2015 Study Area, the Port of Vancouver is located north of the VTRA 2015 Study Area boundary. The VTRA 2015 Study Area is divided into 15 separate waterway zones outlined in Figure E-2. Focus vessels are the vessels of primary interest in the VTRA 2015 study and are subdivided into tank focus vessels (tankers, chemical carriers, articulated tug barges and oil barges) and cargo focus vessels (bulk carriers, container ships and other cargo vessels). Non-focus vessels are represented in the VTRA 2015 as they can potentially collide with the focus vessel class or contribute to potential grounding of focus vessels (besides potential accidents amongst focus vessels themselves).

Base Case Scenario 2015 Analysis Observations

The analysis observations for the Base Case 2015 Scenario evaluated using the VTRA 2015 model and provided in the Executive Summary are:

Analysis Observation 1: About 24.2% of the total modeled traffic time-on-the-water in the VTRA 2015 Model, called Vessel Time Exposure (VTE), is accounted for by focus vessels that are of primary interest within the VTRA 2015 Study. This 24.2% of Base Case 2015 Scenario VTE comprises of cargo focus vessels VTE (@16.2%) and tank focus vessels VTE (@8.0%). Thus, within the VTRA Study Area nearly a third of the total time that focus vessels are underway in the VTRA 2015 model is accounted for by focus vessels that carry oil products as cargo. The remaining about two thirds is attributed to focus vessels that carry other cargo (see Figure E-3 and Figure E-5).

Analysis Observation 2: About 75.8% of the total modeled traffic time on the water in the VTRA 2015 Model, called Vessel Time Exposure (VTE), is accounted for by non-focus vessel traffic that can potentially collide with focus-vessel traffic or contribute to potential grounding of focus vessels (See Figure E-4). This 75.8% of Base Case 2015 Scenario VTE comprises of movements of smaller vessels (less than 20 meters in length) VTE (@32.7%), ferries VTE (@17.2%), tug and tug-tow traffic (excl. oil barges) VTE (@17.0%) and other non-focus vessel VTE (@8.9%), see Figure E-6.

Analysis Observation 3: Within the VTRA Study Area, the VTRA 2015 Model evaluates that the largest contributing POTENTIAL Oil Loss category is the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category @45% of Base Case 2015 Scenario POTENTIAL Oil Losses. The remainder is split between the 2500 m^3 or more of POTENTIAL Oil Loss Category (@42%), the 1000 m^3 -2500 m^3 POTENTIAL Oil Loss Category (@12%) and the 0 m^3 – 1 m^3 POTENTIAL Oil Loss category (@0%).

Analysis Observation 4: About 98.2% of the POTENTIAL Accident Frequency evaluated by the VTRA 2015 model in the Base Case 2015 Scenario is accounted for by the 0 m^3 – 1 m^3 category of which its contribution to Base Case 2015 Scenario POTENTIAL Oil Loss is about 0%. The remaining 1.8% of POTENTIAL Accident Frequency is split over the other three VTRA POTENTIAL Oil Loss categories 1 m^3 - 1000 m^3, 1000 m^3 -2500 m^3 and 2500 m^3 or more. Overall the Base Case 2015 Scenario was calibrated to about 4.4 accidents per year.

What-If Scenario Analysis Observations

In the VTRA 2015 study, the VTRA 2015 Working Group (see Figure E-1) selected planned maritime terminal projects, in various stages of a permitting process, to be grouped in What-If Scenarios for further study. In each What-If Scenario, focus vessels are added to a maritime simulation model representing the year 2015 (Base Case). The following five What-If Scenarios were modeled in the study and evaluated for potential risk increases from the Base Case 2015 Scenario Analysis[1]:

(1) **US232:** A collection of terminal projects adding an estimated 232 focus vessels (32 tankers, 197 ATBs and 3 bulk carriers) to the VTRA 2015 modeled Base Case 2015 Scenario traffic with these 232 vessels travelling predominantly through US Waters.

(2) **KM348:** The Westridge Marine Terminal/Kinder Morgan pipeline expansion project adding an estimated 348 tankers to the VTRA 2015 modeled Base Case 2015 Scenario traffic.

(3) **CA1020:** A collection of terminal projects adding an estimated 1020 focus vessels (629 bulk carriers, 368 container ships and 23 tankers) to the VTRA 2015 modeled Base Case

[1] Bunkering support for the various terminal projects was also modeled in the VTRA 2015 What-If Scenarios.

2015 Scenario traffic with these 1020 vessels travelling predominantly through Canadian (CA) Waters.

(4) **USKMCA1600:** The combination of US232, KM348 and CA1020 What-If Scenarios (632 bulk carriers, 368 container ships, 403 tankers and 197 ATBs) while these 1600 focus vessels travel through US and Canadian (CA) Waters.

(5) **USKMCALN2250:** The combination of USKMCA1600 with a collection of terminal projects adding an additional estimated 650 LNG vessels to the VTRA 2015 modeled Base Case 2015 Scenario traffic while predominantly travelling through Canadian Waters. **The VTRA 2015 Model, however, does not contain a model for the potential consequences of an accident with an LNG Tanker. Thus, LNG Tankers for the purposes of the VTRA 2015 study are minimally modeled for traffic impact as cargo focus vessels only. Hence, risk metrics evaluated for the USKMCALN2250 What-If Scenario ought to be considered lower bounds of those risk metrics.**

The analyses observations evaluated using the VTRA 2015 model for the five What-If Scenarios above and provided in the Executive Summary are:

Analysis Observation 5: There is about a 10-fold difference or more in the number of tankers and ATBs that are being added to Base Case 2015 Scenario for the US232 (32 tankers and 197 ATBs) and KM348 (348 tankers) What-if Scenarios, on the one hand, and the CA1020 What-If Scenarios (23 tankers), on the other hand. That being said, the CA1020 What-If Scenario adds about 997 cargo focus vessels to the Base Case 2015 Scenario, whereas the US232 scenario only adds 3 bulk carriers and the KM348 What-If Scenario adds no cargo focus vessels. The USKMCA1600 What-If Scenario combines the US232, KM348 and CA1020 What-If Scenarios.

Analysis Observation 6: Should the maritime terminal projects in a What-If Scenario come to fruition POTENTIAL Oil Loss risk does not change by the same relative factor across the four POTENTIAL Oil Loss categories: 2500 m^3 or more, 1000 m^3 - 2500 m^3, 1 m^3 - 1000 m^3 or 0 m^3 – 1 m^3. While for the USKMCA1600 Scenario a relative factor 1.85 increase is evaluated in terms of Base Case 2015 Scenario POTENTIAL Oil Loss across the VTRA 2015 Study Area, relative factor increases 2.17, 1.61 and 1.56 were evaluated within the 2500 m^3 or more, the 1 m^3 - 1000 m^3 and the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss categories, respectively.

Analysis Observation 7: The Buoy J and Haro-Strait/Boundary Pass waterway zone specific increases in POTENTIAL Oil Loss was evaluated to be larger than a relative multiplier 3.5 (red highlights in Figure E-12), should all maritime terminal developments in the What-If Scenario USKMCA1600 come to fruition.

Analysis Observation 8: The estimated probability of one or more accidents in the VTRA Study Area over a 10-year period within the POTENTIAL Oil loss category 2500 m^3 or more increased from an estimated 0.50% for the Base Case 2015 Scenario to an estimated 1.35% for the

USKMCA1600 What-if Scenario (i.e. an increase by a relative factor of 2.71, green highlight in Figure E-13). For the Haro-Strait/Boundary Pass waterway zone this and its estimated probability was evaluated to increase by a relative multiplier larger than a factor 11.0 (red highlight in Figure E-13), should all maritime terminal developments in the What-If Scenario USKMCA1600 come to fruition.

Analysis Observation 9: The estimated probability of one or more accidents in the VTRA Study Area over 10-year period within the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category increased from an estimated 0.61% for the Base Case 2015 Scenario to an estimated 0.96% for the USKMCA1600 What-if Scenario (i.e. an increase by a relative factor of 1.56). For the waterway zone Haro-Strait/Boundary Pass this and its estimated probability was evaluated to increase by a relative multiplier larger than 4.0 (red highlight in Figure E-14), should all maritime terminal developments in the What-If Scenario USKMCA1600 come to fruition.

Analysis Observation 10: The estimated probability of one or more accidents in the VTRA Study Area over a 10-year period within the loss category 1 m^3 - 1000 m^3 increased from an estimated 54.2% for the Base Case 2015 Scenario to an estimated 57.2% for the USKMCA1600 What-if Scenario (i.e. an increase by a relative factor 1.06). For the Buoy J and Haro-Strait/Boundary Pass waterway zones this probability was evaluated to increase by about a relative factor 1.64 and 1.50 (red highlight in Figure E-15), respectively, should all maritime terminal developments in the What-If Scenario USKMCA1600 come to fruition.

Analysis Observation 11: The relative multipliers for the estimated probabilities of one or more accidents occurring in the VTRA Study Area over a 10-year period by and large increase by oil spill size category within the five different What-If Scenarios evaluated. While the relative multiplier for the CA1020 What-If Scenario is amongst the highest for the 1 m^3 – 1000 m^3 POTENTIAL Oil Loss category, its relative multiplier is the lowest for the 2500 m^3 or more POTENTIAL Oil Loss category.

RMM Scenario Analysis Observations

Following the What-If Scenario analyses utilizing the VTRA 2015 model, six Risk Mitigation Measure (RMM) Scenarios were implemented on top of the VTRA 2015 model in an attempt to mitigate POTENTIAL increases in vessel time exposure, accident frequency and oil loss as evaluated by the VTRA 2015 What-If Scenario analyses. The manner of implementation of these risk mitigations measure in the VTRA 2015 model was as follows (in no specific order):

DH100-RMM: 100% Double hull fuel protection of cargo focus vessels (increased from 40% in the Base Case 2015 Scenario).

HM50-RMM: Reduce human error and mechanical failure on tugs (excluding oil barges) by 50%.

SE-RMM: Remove from the VTRA 2015 Simulation Model its special events, i.e. the modeled regatta, whale watching, and commercial and tribal fishing openers. Combined fishing vessels and yachts/recreational vessels account for about (39.5% + 3.6%) ≈ 43.1% of the non-focus vessel traffic (see Figure E-4) in the VTRA 2015 model or (43.1 × 75.8%) ≈ 32.7%, i.e. about a third, of the VTRA Model traffic in terms of vessel time exposure (VTE). See also, Figure E-4 and Figure E-6A.

OAE-RMM: Continuously escort laden oil barges and ATBs east of Port Angeles (unthethered).

KME-RMM: Extend escorting of Kinder Morgan outbound laden tankers to Buoy J.

SRT-RMM: Station a rescue tug at Sidney, BC and model its coverage in the same manner as the coverage model that was developed for the Neah Bay rescue tug in the VTRA 2005.

125-RMM: Lift the 125 DWT limit on laden crude inbound tankers while reducing the number of crude inbound tanker transits to keep the volume of crude inbound tankers approximately the same.

17-RMM: Reduce the speed of container vessel to 17 knots throughout the VTRA 2015 Study Area, a speed restriction practiced south of Admiralty Inlet (i.e. the entrance to the Puget Sound) by container ships.

VBRT-RMM: Station a rescue tug at Victoria, BC, and Bedwell Harbor, BC, and model their coverage in the same manner as the coverage model that was developed for the Neah Bay rescue tug in the VTRA 2005.

The first three components DH100-RMM, HM50-RMM and SE-RMM are referred to in combination as the USCG-RMM Suite. DH100-RMM is currently being phased in by vessel owners to meet the requirements of the International Maritime Organization (IMO) Convention for the Prevention of Pollution from Ships, Annex I, Regulation 12A. The intent of the HM50-RMM is to conduct a maximum benefit type evaluation utilizing the VTRA 2015 model through the on-going implementation of 46CFR Subchapter M, which establishes safety regulations governing the inspections, standards, and safety management systems of towing vessels. The intent of including the SE-RMM is to conduct a maximum benefit type evaluation utilizing the VTRA 2015 model through increased carriage of AIS transponders by fishing and passenger vessels, changes to USCG VTS software that will allow VTS operators to display additional small vessel and recreational boat AIS data, and mandatory safety inspections for commercial fishing vessels. The effect of the SE-RMM implementation in the VTRA 2015 model evaluations is the removal of all POTENTIAL collisions in the VTRA analysis with special event vessels and the removal of the contributing effect that the presence of these special event vessels may have on other focus vessel accidents. By no means ought the implementation method of the HM50-RMM and the SE-RMM in the VTRA

2015 model, and their effectiveness evaluation, be interpreted as the manner in which the HM50-RMM and the SE-RMM are operationalized in practice.

To achieve risk reduction across the VTRA Study Area, we believe that the question "which risk mitigation measure should one implement?" is not the right question to ask, but rather it should be "which portfolio of risk mitigation measures should one implement?". Two of these trial portfolio scenario analyses were conducted utilizing the VTRA 2015 model. The first portfolio is referred to as the **5RMM** Scenario and combines the USCG RMM Suite (i.e. the DH100-RMM, HM50-RMM and the SE-RMM), with RMMs 2 through 5 (i.e. the OAE-RMM, KME-RMM, SRT-RMM and the 125-RMM). The second portfolio is referred to as the **3RMM** Scenario combining the DH100-RMM, 17-RMM and the VBRT-RMM. Four RMMs were evaluated individually: the OAE-RMM, SRT-RMM, KME-RMM and the 125-RMM. In summary, a total of six RMM Scenarios were evaluated during the VTRA 2015 Study of which two were portfolios of RMMs. All six RMM Scenarios were enacted on the combined USKMCA1600 Scenario. The POTENTIAL effectiveness of these six RMM scenarios was evaluated in the VTRA 2015 model by implementing them on top of the USKMCA1600 What-If Scenario only. As such, these analyses solely reflect POTENTIAL effectiveness evaluation of these RMMs should all maritime development projects in the USKMCA1600 Scenario come to fruition and subsequently these RMMs have been adopted.

The analyses observations evaluated using the VTRA 2015 model for the six RMM Scenarios and provided in the Executive Summary are:

Analysis Observation 12: The relative multipliers for the probabilities of at least one accident occurring in the VTRA Study Area over a 10-year period in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category are less than 1.0 for the 5RMM Portfolio Scenario (with a relative multiplier 0.86) and the 3RMM Portfolio Scenario (with a relative multiplier 0.94) enacted on the USKMCA1600 What-If Scenario, implying a lesser POTENTIAL Oil Loss evaluated for these two portfolio RMM Scenarios than evaluated for the Base Case 2015 Scenario in this particular POTENTIAL Oil Loss category. Other notable reductions are observed from Figure E-17 for the 5RMM Scenario in the 2500 m^3 or more POTENTIAL Oil Loss Category and for the 5RMM Scenario and OAE-RMM Scenario in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category.

Analysis Observation 13-A: For the 5RMM, 3RMM and OAE-RMM Scenarios, enacted on the USKMCA1600 What-If Scenario, relative multipliers with a value less than 1.0 are observed from Figure E-18 for the probabilities of at least one accident occurring within a 10-year period for the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss category for respectively, twelve, seven and six out of the fifteen waterway zones in the VTRA Study Area (implying a lesser POTENTIAL Oil loss than evaluated for the Base Case 2015 Scenario in these waterway zones for this POTENTIAL Oil Loss category than the USKMCA1600 What-If Scenario).

Analysis Observation 13-B: Overall, across all six RMM Scenarios relative multipliers less than 0.95 are evaluated for the probability of at least one accident occurring over a 10-year period in the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category from their USKMCA1600 What-If Scenario estimated probability levels in 29 out of 90 by-waterway-zone cells (i.e. 6 RMM Scenarios × 15 Waterway Zones) in Figure E-18. These 29 cells are indicated in a bold font (underlined or not) in Figure E-18. That being said, 55 out of the 90 relative multipliers in Figure E-18 are larger than one, implying larger than Base Case 2015 Scenario analysis results for these probabilities in these waterway zones, should all the terminal projects in the USKMCA1600 Scenario come to fruition, despite the six RMM Scenarios evaluated and enacted upon the USKMCA1600 Scenario.

Analysis Observation 14-A: Most of the relative multipliers, 61 out of 90 (i.e. 6 RMM Scenarios × 15 Waterway Zones), in Figure E-19 for the probability of at least one accident over a 10-year period in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss category are larger than 1.0 across the fifteen waterway zones in the VTRA Study Area, implying larger than Base Case 2015 Scenario analysis results for these probabilities in the USKMCA1600 What-If Scenario. In fact, the analysis results in Figure E-19 demonstrate relative multipliers larger than 3.0 in this POTENTIAL Oil Loss category for the Haro-Strait/Boundary Pass waterway zone and multipliers ranging from 1.5 to 2.5 for the Buoy J and West Strait of Juan de Fuca waterway zones, despite the six RMM Scenarios evaluated and enacted upon the USKMCA1600 What-If Scenario.

Analysis Observation 14-B: Overall, across all six RMM Scenarios relative multipliers less than 0.95 are evaluated for the probability of at least one accident occurring over a 10-year period in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category from their USKMCA1600 What-If Scenario estimated probability levels in 45 out of 90 by-waterway-zone cells (i.e. 6 RMM Scenarios × 15 Waterway Zones) in Figure E-19. These 45 cells are indicated in a bold font (underlined or not) in Figure E-19.

Analysis Observation 15-A: Most of the relative multipliers, 78 out of 90 (i.e. 6 RMM Scenarios × 15 Waterway Zones), in Figure E-20 for the probability of at least one accident over a 10-year period in the 2500 m^3 or more POTENTIAL Oil Loss category are larger than 1.0 across the fifteen waterway zones in the VTRA Study Area, implying larger than Base Case 2015 Scenario analysis results for these probabilities in the USKMCA1600 What-If Scenario. In fact, the analysis results demonstrate relative multipliers larger than 9.0 in this POTENTIAL Oil Loss category for the Haro-Strait/Boundary Pass waterway zone and multipliers ranging from 4.5 to 6.0 for the Buoy J, East Strait of Juan de Fuca and Southern Gulf Islands waterway zones, despite the six RMM Scenarios evaluated and enacted upon the USKMCA1600 What-If Scenario.

Analysis Observation 15-B: Overall, across all six RMM Scenarios relative multipliers less than 0.95 are evaluated for the probability of at least one accident occurring over a 10-year period in the 2500 m^3 or more POTENTIAL Oil Loss Category from their USKMCA1600 What-If Scenario estimated probability levels in 28 out of 90 by-waterway-zone cells (i.e. 6 RMM Scenarios × 15

Waterway Zones) in Figure E-20. These 28 cells are indicated in a bold font (underlined or not) in Figure E-20.

Analysis Observation 16: Should all the terminal projects in the USKMCA1600 Scenario come to fruition and either the 5RMM Portfolio Scenario or the 3RMM Portfolio Scenario be enacted thereafter, the RMM Scenario POTENTIAL Oil Loss results show a reduction below the Base Case 2015 Scenario analysis results for the 1 m^3 - 1000 m^3 POTENTIAL Oil Loss Category. The same applies to the POTENTIAL Oil Loss for the 5RMM Portfolio Scenario and the OAE-RMM Scenario in the 0 m^3 - 1 m^3 POTENTIAL Oil Loss Category. These four cells are indicated by a bold and underlined font in Figure E-21. Relative multiplier decreases of less than 0.90 are observed in the 1000 m^3 - 2500 m^3 POTENTIAL Oil Loss Category for the 5RMM Portfolio Scenario, and the OAE-RMM, 125-RMM Scenarios <u>from their USKMCA1600 What-If Scenario estimated levels</u> (these three cells being indicated in a bold only font in Figure E-21).

Analysis Observation 17: Overall, the six RMM Scenarios evaluated show VTRA Study area wide POTENTIAL Oil Loss increases ranging from 131% to 185% following their POTENTIAL enactment on the USKMCA1600 What-If Scenario. Hence, were the USKMCA1600 scenario come to effect, it would be prudent to consider implementation of risk mitigation measures beyond the six RMM Scenarios evaluated in the VTRA 2015 study to counter those POTENTIAL risk increases.

The challenge of risk management is to be location specific, taking into consideration the type and location of traffic and how it changes because of proposed traffic increases. The proposed RMM Scenarios evaluated above were in part informed by evaluated changes in risk for the five What-If Scenarios. Four of these RMM scenarios modeled individual risk mitigation measures, whereas two evaluate portfolios of RMMs. The VTRA 2015 Working Group was involved in the selection/definition of five of these RMM Scenarios, whereas the 3RMM Portfolio evaluated was defined by GW/VCU after the VTRA 2015 Working Group selection process. All six RMM Scenarios were enacted on the combined USKMCA1600 Scenario. In reality, risk mitigation measure considerations, of course, are not limited to the six RMM Scenarios evaluated during this VTRA 2015 Study.

One must realize in evaluating the VTRA 2015 RMM analysis results that risk does not necessarily disappear when mitigated locally, but tends to migrate, as demonstrated by some waterway zones experiencing increases in risk when other waterway zones see risk reductions. This is because a maritime transportation system is a dynamic system, where a small traffic perturbation can precipitate traffic behavior changes in the future. Such risk migrations are preferably avoided in a sound risk management strategy, but some may be inevitable. In addition, the VTRA 2015 maritime simulation model contains some random elements in terms of it traffic simulation for what are termed “special events”. These special events represented in the VTRA model are whale watching activities, regattas, and tribal and commercial fishing openers. Because of these random elements, some risk changes in the evaluated RMM Scenarios (and the What-If Scenarios) are a result of these random elements changing their behavior from simulation run to simulation run, see also Figure E-6A.

Considering the analysis observations in this VTRA 2015 study, we close with the more general observation that there still is a serious need for an electronic data source that is cross-boundary (US and Canadian waters) when taking a longer-term view of risk management in the VTRA study area. In this data source the vessel type should be consistently defined (and verified) beyond cargo focus vessel or tank focus vessel classifications. VTOSS was and AIS is such cross-boundary data source that could serve this purpose. However, without AIS refining the classification of vessel type in AIS data to the level that was customary in the VTOSS data, it will become increasingly difficult to further update the VTRA 2015 model solely using AIS data. While it may be possible to link vessel-identifiers recorded in AIS data to other databases to further refine vessel type classification, the recording of four to five different vessel types in AIS from the 26 different vessel types in the decommissioned VTOSS data is a step in the wrong direction from a risk modeling perspective. There is no doubt that with more vessels using AIS, however, dynamic risk modeling like the VTRA 2015 model can become more representative of actual experienced risk levels.

Moreover, with the same eye towards risk management analysis it would be equally beneficial if AIS datasets capture cargo or at a minimum cargo levels (laden, un-laden, 50% laden, etc.) and a cargo type by focus vessel. We would like to specifically call out the need for the electronic recording at a much greater consistency of the barge type and cargo content of tug-tows. Not only would studies like these benefit from the availability of such a data source, but the immediacy of having such information available could also benefit first responders responding to a spill scenario both from a response and a safety to the first responder perspective.

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A. Appendix A: Glossary and List of Acronyms

- Allision–The collision of a vessel with its intended docking berth.
- AIS – Automatic Identification System
- ATB – Articulated Tug Barge
- Ecology – The Washington Department of Ecology's Spill Prevention, Preparedness and Response Program which is the primary state organization with authority and accountability for managing oil and hazardous material spill risk state-wide. Ecology is assisting PSP in conducting the VTRA with its expertise and experience.
- EPA – Environmental Protection Agency.
- MTS – Maritime Transportation System.
- FV – Focus Vessel.
- ITB – Integrated Tug Barge.
- IV – Interacting Vessel.
- MXPS – Marine Exchange Puget Sound.
- NGO – Non-Governmental Organization.
- NPO – Non-Persistent Oil
- Study Area – The Washington waters of Puget Sound east of Cape Flattery, north of Admiralty Inlet and west of Deception Pass, and their approaches.
- GW – George Washington University is the prime subgrant awardee.
- VCU – Virginia Commonwealth University is a sub-awardee to GW.
- GW/VCU – The technical team composed of GW and VCU.
- PO – Persistent Oil.
- PSP – The Puget Sound Partnership is the Washington state agency responsible for developing a Puget Sound Action Agenda, convening a Cross Partnership Oil Spill Work Group and for coordinating work to restore and protect Puget Sound.
- PSHSC – The Puget Sound Harbor Safety Committee.
- VTRA 2010 Steering Committee – A steering committee of stakeholders advising the Puget Sound Partnership and GW/VCU over the course of this study.
- QAPP – Quality Assurance Project Plan
- USCG – US Coast Guard Sector Seattle, District 13.
- VTOSS – Vessel Traffic Operational Support System
- VTRA – Vessel Traffic Risk Assessment
- VTS – Vessel Traffic Service is the real-time marine traffic monitoring system used by the USCG, similar to air traffic control for aircraft.

B. Appendix B. Available Accident Data to the VTRA 2015 Study

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	T. FV - NO O.B.	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	T. FV - NO O.B.	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	T. FV - NO O.B.	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	T. FV - NO O.B.	US	ALLEGIANCE
33	2/11/2002	ALLISION	N 48° 07' 50.00"	W 123° 27' 12.00"	TANKER	T. FV - NO O.B.	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

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

+ 1991 Tenyo Maru Collision in > 1 m3 Spill Category

Figure B-1. Available focus vessel accident data for VTRA 2015 Model recalibration – PART I

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	T. FV - NO O.B.	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	N 48° 06' 00.00"	W 122° 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	T. FV - NO O.B.	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

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

+ 1994 Barge 101 Grounding in > 1 m3 Spill Category

Figure B-2. Available focus vessel accident data for VTRA 2015 Model recalibration – PART II

C. Appendix C. AIS Count Line Data from 2010 - 2015

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

Figure C-1. AIS Count Line date for 10 crossing lines in VTRA 2015 Study Area from 2010 - 2012.

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

Figure C-2. AIS Count Line date for 10 crossing lines in VTRA 2015 Study Area from 2013 - 2015.

D. Appendix D: Summary Tables of VTRA 2015 study area wide analysis results

<table>
<tr><th></th><th></th><th>OIL_2500_MORE</th><th>OIL_1000_2500</th><th>OIL_1_1000</th><th>OIL_0_1</th><th>TOTAL_OIL</th></tr>
<tr><td rowspan="6">VTRA '15 BASE CASE</td><td>Base Case % Potential Annual Oil Loss</td><td>42.0%</td><td>12.3%</td><td>45.3%</td><td>0.5%</td><td>100.0%</td></tr>
<tr><td>Base Case % Potenial Annual Accident Frequency</td><td>0.01%</td><td>0.01%</td><td>1.8%</td><td>98.2%</td><td>100.0%</td></tr>
<tr><td>Average potential spill size per accident (in m^3)</td><td>6,798</td><td>1,619</td><td>46.9</td><td>0.01</td><td>1.8</td></tr>
<tr><td>Probability of at least one accident in 1 year by spill size</td><td>0.05%</td><td>0.06%</td><td>7.5%</td><td>98.7%</td><td>98.8%</td></tr>
<tr><td>Probability of at least one accident in 10 year by spill size</td><td>0.50%</td><td>0.61%</td><td>54.2%</td><td>100.0%</td><td>100.0%</td></tr>
<tr><td>Probability of at least one accident in 25 years by spill size</td><td>1.24%</td><td>1.52%</td><td>85.8%</td><td>100.0%</td><td>100.0%</td></tr>
<tr><th></th><th></th><th>OIL_2500_MORE</th><th>OIL_1000_2500</th><th>OIL_1_1000</th><th>OIL_0_1</th><th>TOTAL_OIL</th></tr>
<tr><td rowspan="6">USKMCA1600</td><td>Base Case % Potential Annual Oil Loss</td><td>91.1% (+49.11%| x2.17)</td><td>20.0% (+7.71%| x1.63)</td><td>72.8% (+27.54%| x1.61)</td><td>0.5% (+0.08%| x1.17)</td><td>184.4% (+84.4%| x1.84)</td></tr>
<tr><td>Base Case % Potenial Annual Accident Frequency</td><td>0.03% (+0.02%| x2.72)</td><td>0.02% (+0.01%| x1.56)</td><td>1.9% (+0.16%| x1.09)</td><td>108.9% (+10.7%| x1.11)</td><td>110.9% (+10.9%| x1.11)</td></tr>
<tr><td>Average potential spill size per accident (in m^3)</td><td>5413 (-1385 | x0.80)</td><td>1693 (+75 | x1.05)</td><td>69.2 (+22.3 | x1.48)</td><td>0.01 (+0.00 | x1.06)</td><td>3.0 (+1.2 | x1.66)</td></tr>
<tr><td>Probability of at least one accident in 1 year by spill size</td><td>0.14% (+0.09%| x2.72)</td><td>0.10% (+0.03%| x1.56)</td><td>8.2% (+0.64%| x1.09)</td><td>99.2% (+0.48% | x1.00)</td><td>99.3% (+0.45%| x1.00)</td></tr>
<tr><td>Probability of at least one accident in 10 year by spill size</td><td>1.35% (+0.85%| x2.71)</td><td>0.95% (+0.34%| x1.55)</td><td>57.3% (+3.09%| x1.06)</td><td>100.0% (0.00%| x1.00)</td><td>100.0% (0.00%| x1.00)</td></tr>
<tr><td>Probability of at least one accident in 25 years by spill size</td><td>3.35% (+2.10%| x2.70)</td><td>2.36% (+0.84%| x1.55)</td><td>88.1% (+2.27%| x1.03)</td><td>100.0% (0.00%| x1.00)</td><td>100.0% (0.00%| x1.00)</td></tr>
</table>

Figure D-1. Summary of VTRA Study area risk metrics from USKMCA1600 Scenario to Base Case 2015.

<table>
<tr><th></th><th></th><th>OIL_2500_MORE</th><th>OIL_1000_2500</th><th>OIL_1_1000</th><th>OIL_0_1</th><th>TOTAL_OIL</th></tr>
<tr><td rowspan="6">VTRA '15 BASE CASE</td><td>Base Case % Potential Annual Oil Loss</td><td>42.0%</td><td>12.3%</td><td>45.3%</td><td>0.5%</td><td>100.0%</td></tr>
<tr><td>Base Case % Potenial Annual Accident Frequency</td><td>0.01%</td><td>0.01%</td><td>1.8%</td><td>98.2%</td><td>100.0%</td></tr>
<tr><td>Average potential spill size per accident (in m^3)</td><td>6,798</td><td>1,619</td><td>46.9</td><td>0.01</td><td>1.8</td></tr>
<tr><td>Probability of at least one accident in 1 year by spill size</td><td>0.05%</td><td>0.06%</td><td>7.5%</td><td>98.7%</td><td>98.8%</td></tr>
<tr><td>Probability of at least one accident in 10 year by spill size</td><td>0.50%</td><td>0.61%</td><td>54.2%</td><td>100.0%</td><td>100.0%</td></tr>
<tr><td>Probability of at least one accident in 25 years by spill size</td><td>1.24%</td><td>1.52%</td><td>85.8%</td><td>100.0%</td><td>100.0%</td></tr>
<tr><th></th><th></th><th>OIL_2500_MORE</th><th>OIL_1000_2500</th><th>OIL_1_1000</th><th>OIL_0_1</th><th>TOTAL_OIL</th></tr>
<tr><td rowspan="6">VTRA '15 US232</td><td>Base Case % Potential Annual Oil Loss</td><td>72.3% (+30.28%| x1.72)</td><td>13.2% (+0.95%| x1.08)</td><td>45.6% (+0.37%| x1.01)</td><td>0.5% (+0.04%| x1.08)</td><td>131.6% (+31.6%| x1.32)</td></tr>
<tr><td>Base Case % Potenial Annual Accident Frequency</td><td>0.02% (+0.01%| x1.61)</td><td>0.01% (+0.00%| x1.08)</td><td>1.8% (+0.00%| x1.00)</td><td>102.1% (+3.9%| x1.04)</td><td>103.9% (+3.9%| x1.04)</td></tr>
<tr><td>Average potential spill size per accident (in m^3)</td><td>7289 (+491 | x1.07)</td><td>1608 (-11 | x0.99)</td><td>47.1 (+0.3 | x1.01)</td><td>0.01 (+0.00 | x1.04)</td><td>2.3 (+0.5 | x1.27)</td></tr>
<tr><td>Probability of at least one accident in 1 year by spill size</td><td>0.08% (+0.03%| x1.60)</td><td>0.07% (+0.01%| x1.08)</td><td>7.5% (+0.02%| x1.00)</td><td>98.9% (+0.20% | x1.00)</td><td>99.0% (+0.19%| x1.00)</td></tr>
<tr><td>Probability of at least one accident in 10 year by spill size</td><td>0.80% (+0.30%| x1.60)</td><td>0.66% (+0.05%| x1.08)</td><td>54.3% (+0.09%| x1.00)</td><td>100.0% (0.00%| x1.00)</td><td>100.0% (0.00%| x1.00)</td></tr>
<tr><td>Probability of at least one accident in 25 years by spill size</td><td>1.98% (+0.74%| x1.60)</td><td>1.65% (+0.13%| x1.08)</td><td>85.9% (+0.07%| x1.00)</td><td>100.0% (0.00%| x1.00)</td><td>100.0% (0.00%| x1.00)</td></tr>
</table>

Figure D-2. Summary of VTRA Study area risk metrics from US232 What-If Scenario to Base Case 2015.

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%
		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 KM348	Base Case % Potential Annual Oil Loss	57.5% (+15.46%| x1.37)	17.7% (+5.42%| x1.44)	45.6% (+0.31%| x1.01)	0.5% (-0.01%| x0.98)	121.2% (+21.2%| x1.21)
	Base Case % Potenial Annual Accident Frequency	0.02% (+0.01%| x1.95)	0.02% (+0.01%| x1.37)	1.8% (-0.01%| x1.00)	99.3% (+1.1%| x1.01)	101.1% (+1.1%| x1.01)
	Average potential spill size per accident (in m^3)	4771 (-2028 | x0.70)	1708 (+89 | x1.06)	47.4 (+0.5 | x1.01)	0.01 (0.00 | x0.97)	2.2 (+0.4 | x1.20)
	Probability of at least one accident in 1 year by spill size	0.10% (+0.05%| x1.95)	0.08% (+0.02%| x1.37)	7.5% (-0.03%| x1.00)	98.8% (+0.06% | x1.00)	98.9% (+0.06%| x1.00)
	Probability of at least one accident in 10 year by spill size	0.97% (+0.47%| x1.95)	0.83% (+0.22%| x1.36)	54.1% (-0.15%| x1.00)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)
	Probability of at least one accident in 25 years by spill size	2.41% (+1.16%| x1.94)	2.07% (+0.55%| x1.36)	85.7% (-0.12%| x1.00)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)

Figure D-3. Summary of VTRA Study area risk metrics from KM348 What-If Scenario to Base Case 2015.

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%
		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 CA 1020	Base Case % Potential Annual Oil Loss	41.4% (-0.63%| x0.99)	13.6% (+1.33%| x1.11)	71.4% (+26.12%| x1.58)	0.5% (+0.07%| x1.16)	126.9% (+26.9%| x1.27)
	Base Case % Potenial Annual Accident Frequency	0.01% (+0.00%| x1.10)	0.02% (+0.00%| x1.11)	1.9% (+0.14%| x1.08)	105.0% (+6.83%| x1.07)	107.0% (+7.0%| x1.07)
	Average potential spill size per accident (in m^3)	6081 (-717 | x0.89)	1620 (+2 | x1.00)	68.5 (+21.6 | x1.46)	0.01 (+0.00 | x1.08)	2.2 (+0.3 | x1.19)
	Probability of at least one accident in 1 year by spill size	0.05% (+0.01%| x1.10)	0.07% (+0.01%| x1.11)	8.1% (+0.57%| x1.08)	99.1% (+0.34% | x1.00)	99.1% (+0.32%| x1.00)
	Probability of at least one accident in 10 year by spill size	0.55% (+0.05%| x1.10)	0.68% (+0.07%| x1.11)	57.0% (+2.74%| x1.05)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)
	Probability of at least one accident in 25 years by spill size	1.37% (+0.12%| x1.10)	1.68% (+0.16%| x1.11)	87.8% (+2.03%| x1.02)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)

Figure D-4. Summary of VTRA Study area risk metrics from CA1020 What-If Scenario to Base Case 2015.

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%
		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
USKMCALN2250	Base Case % Potential Annual Oil Loss	96.4% (+54.37%| x2.29)	20.2% (+7.99%| x1.65)	86.9% (+41.64%| x1.92)	0.7% (+0.26%| x1.56)	204.3% (+104.3%| x2.04)
	Base Case % Potenial Annual Accident Frequency	0.03% (+0.02%| x2.81)	0.02% (+0.01%| x1.58)	2.0% (+0.28%| x1.16)	114.9% (+16.7%| x1.17)	117.0% (+17.0%| x1.17)
	Average potential spill size per accident (in m^3)	5545 (-1253 | x0.82)	1692 (+73 | x1.05)	77.8 (+30.9 | x1.66)	0.01 (+0.00 | x1.34)	3.2 (+1.4 | x1.75)
	Probability of at least one accident in 1 year by spill size	0.14% (+0.09%| x2.81)	0.10% (+0.04%| x1.58)	8.6% (+1.12%| x1.15)	99.4% (+0.67% | x1.01)	99.4% (+0.63%| x1.01)
	Probability of at least one accident in 10 year by spill size	1.40% (+0.90%| x2.80)	0.96% (+0.35%| x1.58)	59.5% (+5.27%| x1.10)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)
	Probability of at least one accident in 25 years by spill size	3.45% (+2.21%| x2.78)	2.39% (+0.87%| x1.57)	89.5% (+3.73%| x1.04)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)

Figure D-5. Summary of VTRA Study area risk metrics from USKMCALN2250 Scenario to Base Case 2015.

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%
		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
USKMCA1600-5RMM	Base Case % Potential Annual Oil Loss	83.3% (+41.25%| x1.98)	12.9% (+0.66%| x1.05)	35.2% (-10.12%| x0.78)	0.1% (-0.34%| x0.26)	131.4% (+31.4%| x1.31)
	Base Case % Potenial Annual Accident Frequency	0.03% (+0.01%| x2.28)	0.01% (+0.00%| x1.04)	1.4% (-0.35%| x0.80)	82.9% (-15.3%| x0.84)	84.3% (-15.7%| x0.84)
	Average potential spill size per accident (in m^3)	5901 (-897 | x0.87)	1646 (+27 | x1.02)	45.3 (-1.6 | x0.97)	0.00 (-0.01 | x0.30)	2.8 (+1.0 | x1.56)
	Probability of at least one accident in 1 year by spill size	0.11% (+0.06%| x2.28)	0.06% (+0.00%| x1.04)	6.1% (-1.43%| x0.81)	97.5% (-1.25% | x0.99)	97.6% (-1.19%| x0.99)
	Probability of at least one accident in 10 year by spill size	1.13% (+0.64%| x2.28)	0.63% (+0.02%| x1.04)	46.6% (-7.61%| x0.86)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)
	Probability of at least one accident in 25 years by spill size	2.81% (+1.57%| x2.27)	1.57% (+0.05%| x1.04)	79.2% (-6.65%| x0.92)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)

Figure D-6. Summary of VTRA Study area risk metrics from 5RMM Scenario to Base Case 2015.

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%
		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
USKMCA1600 - 3RMM	Base Case % Potential Annual Oil Loss	91.6% (+49.55%| x2.18)	19.6% (+7.36%| x1.60)	37.2% (-8.10%| x0.82)	0.6% (+0.14%| x1.31)	149.0% (+49.0%| x1.49)
	Base Case % Potenial Annual Accident Frequency	0.03% (+0.02%| x2.69)	0.02% (+0.01%| x1.53)	1.6% (-0.17%| x0.91)	104.1% (+5.8%| x1.06)	105.7% (+5.7%| x1.06)
	Average potential spill size per accident (in m^3)	5519 (-1279 | x0.81)	1694 (+75 | x1.05)	42.5 (-4.4 | x0.91)	0.01 (+0.00 | x1.24)	2.6 (+0.7 | x1.41)
	Probability of at least one accident in 1 year by spill size	0.13% (+0.08%| x2.68)	0.09% (+0.03%| x1.53)	6.8% (-0.68%| x0.91)	99.0% (+0.29% | x1.00)	99.1% (+0.27%| x1.00)
	Probability of at least one accident in 10 year by spill size	1.33% (+0.83%| x2.67)	0.93% (+0.32%| x1.53)	50.7% (-3.49%| x0.94)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)
	Probability of at least one accident in 25 years by spill size	3.30% (+2.06%| x2.66)	2.31% (+0.79%| x1.52)	83.0% (-2.86%| x0.97)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)

Figure D-7. Summary of VTRA Study area risk metrics from 3RMM Scenario to Base Case 2015.

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%
		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
USKMCA1600-OAE	Base Case % Potential Annual Oil Loss	91.8% (+49.79%| x2.19)	17.6% (+5.35%| x1.44)	71.4% (+26.15%| x1.58)	0.5% (-0.01%| x0.98)	181.3% (+81.3%| x1.81)
	Base Case % Potenial Annual Accident Frequency	0.03% (+0.02%| x2.71)	0.02% (+0.01%| x1.38)	1.8% (+0.07%| x1.04)	94.3% (-3.9%| x0.96)	96.2% (-3.8%| x0.96)
	Average potential spill size per accident (in m^3)	5486 (-1313 | x0.81)	1680 (+61 | x1.04)	71.1 (+24.2 | x1.52)	0.01 (+0.00 | x1.02)	3.4 (+1.6 | x1.89)
	Probability of at least one accident in 1 year by spill size	0.14% (+0.09%| x2.71)	0.08% (+0.02%| x1.38)	7.8% (+0.29%| x1.04)	98.5% (-0.25% | x1.00)	98.6% (-0.22%| x1.00)
	Probability of at least one accident in 10 year by spill size	1.34% (+0.85%| x2.70)	0.84% (+0.23%| x1.38)	55.6% (+1.43%| x1.03)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)
	Probability of at least one accident in 25 years by spill size	3.33% (+2.08%| x2.68)	2.10% (+0.58%| x1.38)	86.9% (+1.08%| x1.01)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)

Figure D-8. Summary of VTRA Study risk metrics from OAE-RMM Scenario to Base Case 2015.

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%
		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
USKMCA1600-SRT	Base Case % Potential Annual Oil Loss	91.7% (+49.70%| x2.18)	19.5% (+7.27%| x1.59)	71.4% (+26.12%| x1.58)	0.6% (+0.16%| x1.35)	183.3% (+83.3%| x1.83)
	Base Case % Potenial Annual Accident Frequency	0.03% (+0.02%| x2.72)	0.02% (+0.01%| x1.52)	1.9% (+0.15%| x1.09)	108.8% (+10.6%| x1.11)	110.7% (+10.7%| x1.11)
	Average potential spill size per accident (in m^3)	5453 (-1345 | x0.80)	1694 (+76 | x1.05)	68.0 (+21.1 | x1.45)	0.01 (+0.00 | x1.22)	3.0 (+1.2 | x1.65)
	Probability of at least one accident in 1 year by spill size	0.14% (+0.09%| x2.72)	0.09% (+0.03%| x1.52)	8.1% (+0.63%| x1.08)	99.2% (+0.48% | x1.00)	99.3% (+0.45%| x1.00)
	Probability of at least one accident in 10 year by spill size	1.35% (+0.85%| x2.71)	0.93% (+0.32%| x1.52)	57.2% (+3.01%| x1.06)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)
	Probability of at least one accident in 25 years by spill size	3.34% (+2.10%| x2.69)	2.30% (+0.78%| x1.52)	88.0% (+2.22%| x1.03)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)

Figure D-9. Summary of VTRA Study risk metrics from SRT-RMM Scenario to Base Case 2015.

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%
		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
USKMCA1600-KME	Base Case % Potential Annual Oil Loss	91.5% (+49.50%| x2.18)	19.5% (+7.28%| x1.59)	72.7% (+27.46%| x1.61)	0.6% (+0.16%| x1.35)	184.4% (+84.4%| x1.84)
	Base Case % Potenial Annual Accident Frequency	0.03% (+0.02%| x2.72)	0.02% (+0.01%| x1.52)	1.9% (+0.17%| x1.10)	109.6% (+11.4%| x1.12)	111.6% (+11.6%| x1.12)
	Average potential spill size per accident (in m^3)	5454 (-1344 | x0.80)	1693 (+75 | x1.05)	68.7 (+21.9 | x1.47)	0.01 (+0.00 | x1.21)	3.0 (+1.2 | x1.65)
	Probability of at least one accident in 1 year by spill size	0.14% (+0.09%| x2.71)	0.09% (+0.03%| x1.52)	8.2% (+0.69%| x1.09)	99.2% (+0.51% | x1.01)	99.3% (+0.48%| x1.00)
	Probability of at least one accident in 10 year by spill size	1.35% (+0.85%| x2.70)	0.93% (+0.32%| x1.52)	57.5% (+3.28%| x1.06)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)
	Probability of at least one accident in 25 years by spill size	3.33% (+2.09%| x2.69)	2.31% (+0.79%| x1.52)	88.2% (+2.41%| x1.03)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)

Figure D-10. Summary of VTRA Study risk metrics from KME-RMM Scenario to Base Case 2015.

		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
VTRA '15 BASE CASE	Base Case % Potential Annual Oil Loss	42.0%	12.3%	45.3%	0.5%	100.0%
	Base Case % Potenial Annual Accident Frequency	0.01%	0.01%	1.8%	98.2%	100.0%
	Average potential spill size per accident (in m^3)	6,798	1,619	46.9	0.01	1.8
	Probability of at least one accident in 1 year by spill size	0.05%	0.06%	7.5%	98.7%	98.8%
	Probability of at least one accident in 10 year by spill size	0.50%	0.61%	54.2%	100.0%	100.0%
	Probability of at least one accident in 25 years by spill size	1.24%	1.52%	85.8%	100.0%	100.0%
		OIL_2500_MORE	OIL_1000_2500	OIL_1_1000	OIL_0_1	TOTAL_OIL
USKMCA1600-125	Base Case % Potential Annual Oil Loss	106.6% (+64.58%| x2.54)	17.8% (+5.55%| x1.45)	72.4% (+27.08%| x1.60)	0.6% (+0.10%| x1.21)	197.3% (+97.3%| x1.97)
	Base Case % Potenial Annual Accident Frequency	0.03% (+0.02%| x2.85)	0.02% (+0.01%| x1.41)	1.9% (+0.14%| x1.08)	108.1% (+9.9%| x1.10)	110.1% (+10.1%| x1.10)
	Average potential spill size per accident (in m^3)	6063 (-735 | x0.89)	1665 (+46 | x1.03)	69.2 (+22.4 | x1.48)	0.01 (+0.00 | x1.10)	3.3 (+1.4 | x1.79)
	Probability of at least one accident in 1 year by spill size	0.14% (+0.09%| x2.84)	0.09% (+0.03%| x1.41)	8.1% (+0.59%| x1.08)	99.2% (+0.46% | x1.00)	99.2% (+0.43%| x1.00)
	Probability of at least one accident in 10 year by spill size	1.41% (+0.91%| x2.83)	0.86% (+0.25%| x1.41)	57.0% (+2.84%| x1.05)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)
	Probability of at least one accident in 25 years by spill size	3.49% (+2.25%| x2.81)	2.14% (+0.62%| x1.41)	87.9% (+2.10%| x1.02)	100.0% (0.00%| x1.00)	100.0% (0.00%| x1.00)

Figure D-11. Summary of VTRA Study risk metrics from 125-RMM Scenario to Base Case 2015.