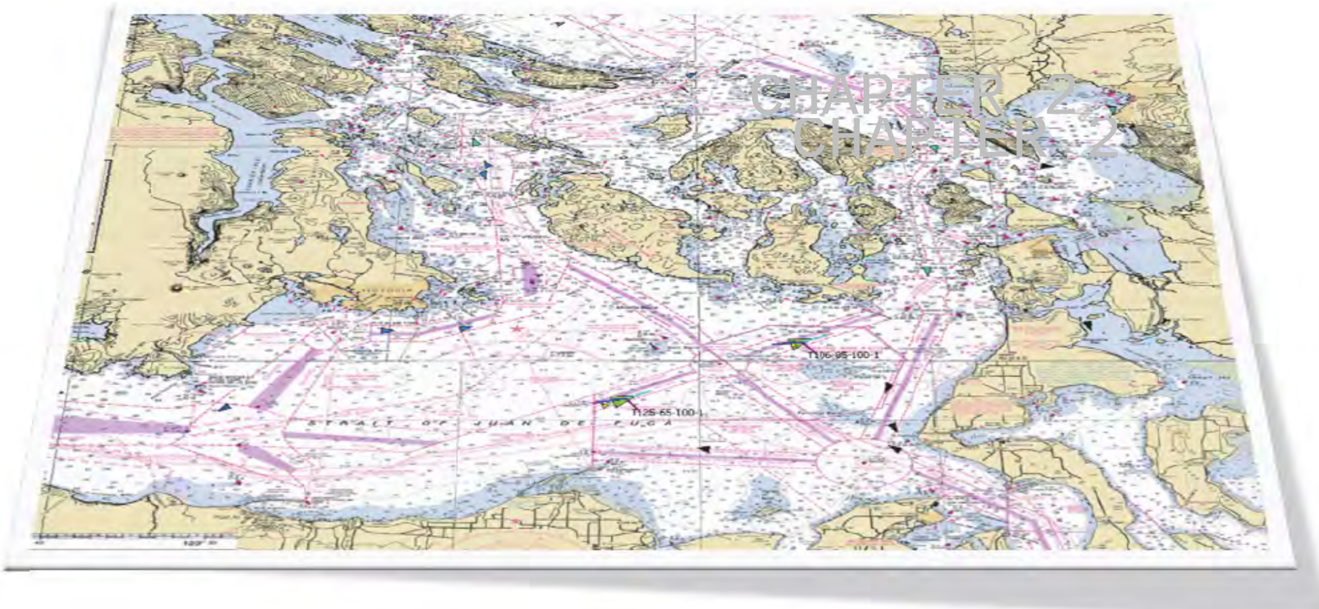
CHAPTER 9

VTRA 2010 FINAL REPORT

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



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9. BENCH MARK/SENSITIVITY SCENARIOS

Historical arrival data was obtained through the Marine Exchange Puget Sound (MXPS) regarding arrivals of tank focus vessels and cargo focus vessels. Tanker arrival data was obtained for the years 1998-2012 by the three major refinery destinations within the VTRA study area, i.e. Cherry Point, Anacortes and Ferndale. Cargo vessel Automatic Identification System (AIS) crossing line count data was obtained from 2008 – 2012 for crossing lines at the entrance of the West Strait of Juan de Fuca, the entrance of the Puget Sound and the entrance of Georgia-Strait (see Figure 103 for a depiction and general location of these crossing lines). Prior to 2008, AIS was not available or AIS was not considered a reliable data source yet.

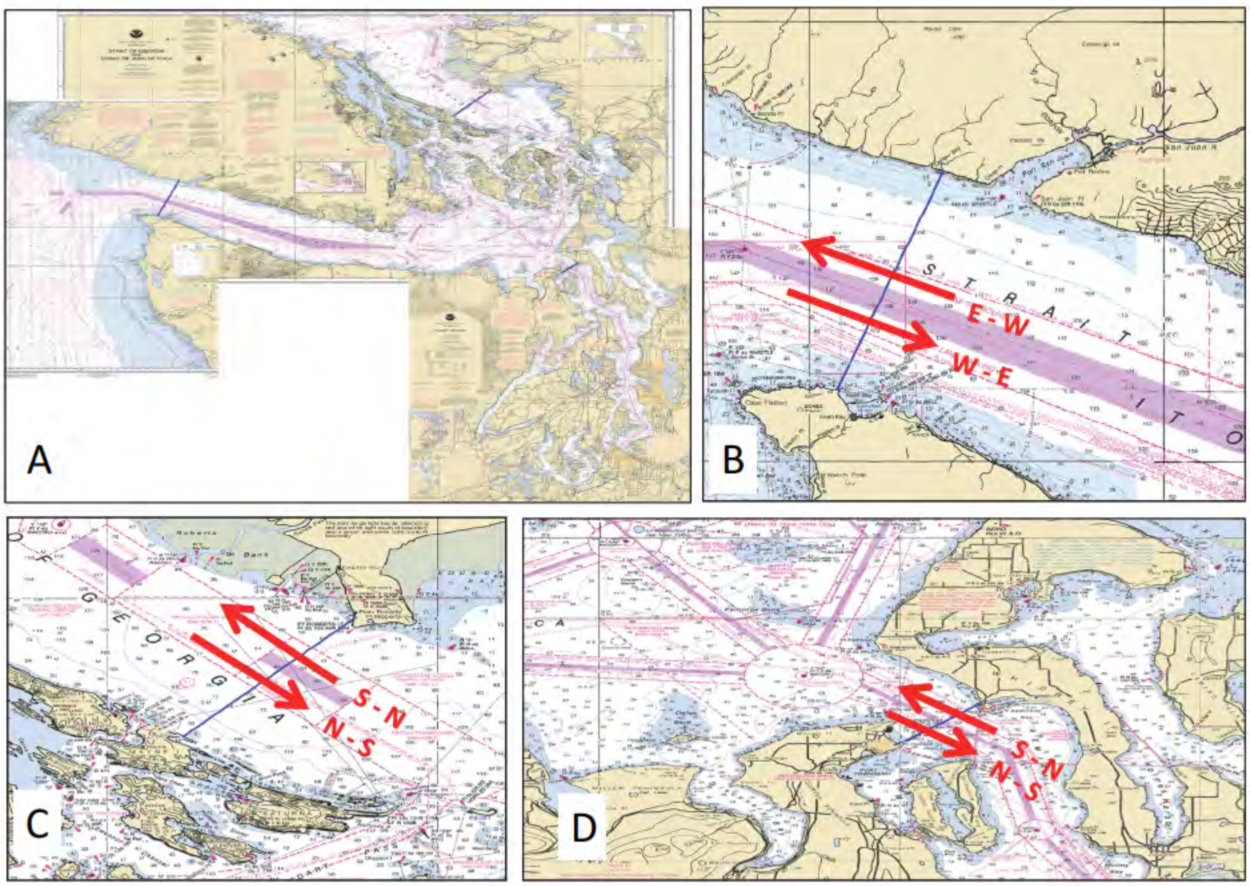


Figure 103. A: Overview of three AIS crossing definitions; B: Close-up view of crossing line at the West Strait of Juan de Fuca Entrance; C: Close-up view of crossing line at the George Strait entrance; D: Close-up view of the crossing line at the Puget Sound entrance.

An analysis was conducted on both datasets (described in more detail below) and a high and low year was selected for both data sets. High years were used to define high traffic benchmarking/ sensitivity scenarios, whereas low years were used to define low traffic benchmarking/sensitivity analyses scenarios by adding/canceling vessel transits to/from the 2010 Base Case (P) and the combined What-If Scenario (T).

The purpose of the benchmarking/sensitivity analysis is three-fold. First, to provide a robustness analysis of the VTRA 2010 Base Case (P) and Combined What-If Scenario (T) analyses results in light of historical increases or decreases in traffic. Second, the high-low scenario analyses conducted on the Base Case (P) serve as a benchmark to compare (1) delta changes in VTRA 2010 analyzed risk levels for the various What-If and RMM Scenarios against (2) delta changes in VTRA 2010 analyzed risk levels at historical traffic levels. Third, it provides context regarding changes occasioning in the background that in conjunction with proposed What-If scenario expansions further inform the potential need for risk management actions.

Modeling the High-Low levels for Tank Focus Vessels

Table 13 provides the tanker arrival count data obtained from the MXPS. Figure 104 depicts a historical trend analysis by refinery destination for the row totals by destination in Table 13. One observes from Figure 104 that tank focus vessel arrivals for the Ferndale destination have remained relatively constant whereas on average an increase of about 5 tank focus vessel arrivals per year have been observed for the Anacortes destination and on average an increase of about 10 tank focus vessels arrivals per year for the Cherry Point destination.

The base case year (2010), the selected high year for tanker arrivals (2007), and the selected low year (1998) are indicated in Figure 104. The selections of the high-low years coincide with the high (730) and low (541) years observed for distinct tank focus vessels arrivals to the Puget Sound listed in Table 13. The modeling culmination of adding high tank focus vessel levels to the VTRA 2010 Base Case (P) and the combined What-If scenario (T) in terms of vessel time exposure is depicted in the top 2 panels of Figure 105. From Figure 105 one observes that the addition of 142 tankers leads to a delta change of (+2%) in terms of vessel time exposure relative to the Base case (P) total focus vessel time exposure.

Modeling the High-Low Levels for Cargo Focus Vessels

Due to a larger number of destinations for cargo focus vessels the selection of a high-low year is more challenging. Moreover, traditional MXPS data collection efforts focus on US arrivals, not Canadian bound cargo focus vessels. To account for Canadian bound cargo focus vessel traffic AIS crossing count data was requested for the longest period that yearly AIS data was considered operationally reliable. This period was deemed to be 2008-2012. The data obtained from the MXPS is provided in Figure 106. Figure 106 also contains a rough schematic of the VTRA study waterway with its main origins and destinations identified in Figure 106 as Buoy J (1), Puget Sound (2) and Georgia Strait (3).

Table 13. Arrival Counts of Tankers for the three major refinery destinations in the VTRA 2010 study area

ARRIVALS INTO PUGET SOUND (DISTINCT ARRIVALS, NO SHIFTS)

TOTAL TANK SECTOR	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
PETROL TANKER	487	497	543	487	493	494	451	455	471	517	476	505	427	462	441
CHEM TANKER	50	60	46	47	40	24	16	14	30	34	23	17	15	16	12
PETRO/CHEM	537	557	589	534	533	518	467	469	501	551	499	522	442	478	453
ITB/ATB	4	9	32	47	65	130	167	145	183	179	179	172	148	130	142
TOTAL TANK SECTOR	541	566	621	581	598	648	634	614	684	730	678	694	590	608	595

ARRIVALS TO EACH OF THE NORTH SOUND REFINERY AREAS

FERNDALE REFINERY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
PETROL TANKER	118	136	136	99	88	86	69	113	92	92	103	108	86	88	81
CHEM TANKER	0	0	0	0	2	0	0	0	0	0	4	2	3	2	1
PETRO/CHEM	118	136	136	99	90	86	69	113	92	92	107	110	89	90	82
ITB/ATB	0	0	0	0	0	4	12	16	17	19	15	24	26	17	21
TOTAL	118	136	136	99	90	90	81	129	109	111	122	134	115	107	103

CHERRY POINT REFINERY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
PETROL TANKER	189	189	224	167	164	213	116	196	206	243	266	205	203	197	163
CHEM TANKER	0	1	13	4	1	1	10	15	12	36	28	70	70	59	72
PETRO/CHEM	189	190	237	171	165	214	126	211	218	279	294	275	273	256	235
ITB/ATB	4	15	33	54	49	88	65	89	134	119	82	63	56	41	64
TOTAL	193	205	270	225	214	302	191	300	352	398	376	338	329	297	299

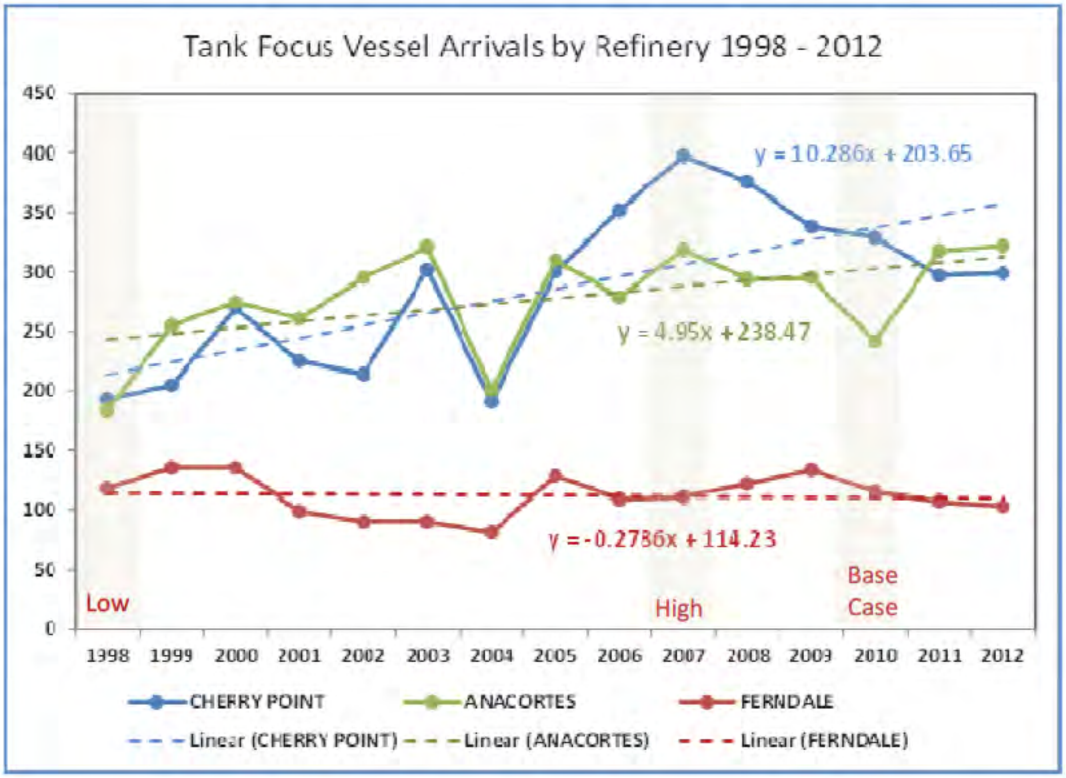
ANACORTES REFINERIES	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
PETROL TANKER	183	250	270	250	253	258	143	240	217	240	172	160	121	178	195
CHEM TANKER			1	1	24	13	19	16	22	24	29	39	33	56	42
PETRO/CHEM	183	250	271	251	277	271	162	256	239	264	201	199	154	234	237
ITB/ATB	1	5	4	10	18	50	39	54	40	55	93	96	88	84	85
TOTAL	184	255	275	261	295	321	201	310	279	319	294	295	242	318	322

SUM OF THREE AREAS	495	596	681	585	599	713	473	739	740	828	792	767	686	722	724

Next, we introduce the variable x_{12} to represent the annual cargo focus vessel traffic flow from Buoy J to the Puget Sound and x_{13} to represent the annual cargo focus vessel traffic flow from Buoy J to the Georgia Strait, etc. In other words, the variable x_{ij} represents the annual cargo focus vessel flow from origin (i) to destination (j). The sum of the variables x_{12} and x_{13} represents the total annual in-flow of cargo focus vessels to the VTRA study area at Buoy J. Considering the destinations (2) and (3) as "closed" it follows that traffic that arrives at Buoy J, must leave at Buoy J[18]. In other words:

$$x_{12} + x_{13} = x_{31} + x_{21}.$$

[18] We are assuming here that cargo focus vessel traffic that travels from Buoy J to the Georgia Strait does not leave through the Northern Passage.



TANKER CALL NUMBER HIGH-LOW ANALYSIS FROM 1998-2012

	LOW - YEAR: - #	2010	HIGH - YEAR: + #
CHERRY POINT	193 - 1998 : -136	329	398 - 2007 : +69
ANACORTES	184 - 1998 : -58	242	319 - 2007 : +77
FERNDALE	118 - 1998 : 3	115	111 - 2007 : -4
Total Change Tank FV	-191		+142

Figure 104. High-Low traffic year analysis conducted on 1998-2012 MXPS refinery arrival data in Table 13

This is called a traffic flow balance equation. Following similar reasoning a set of balance equations can be formulated (all indicated in Figure 106) from which values for the variables x_{ij} can be solved. The solution of these equations for each year is depicted in Figure 107. Observe from the solution that on balance the traffic flow from Buoy J to Puget Sound equals the traffic flow from Puget Sound to Buoy J, etc. This solution, however, does not preclude a particular vessel to travel from Buoy J to Puget Sound, next from Puget Sound to Georgia Strait and from Georgia Strait to Buoy J, or any other traffic pattern. That particular vessel would simply be part of different traffic flows. What this solution does mean, however, is that on average cargo vessel traffic flow from Buoy J to Puget Sound equals the cargo focus vessel traffic flow from the Puget Sound to Buoy J. The same applies to other paired origins and destinations.

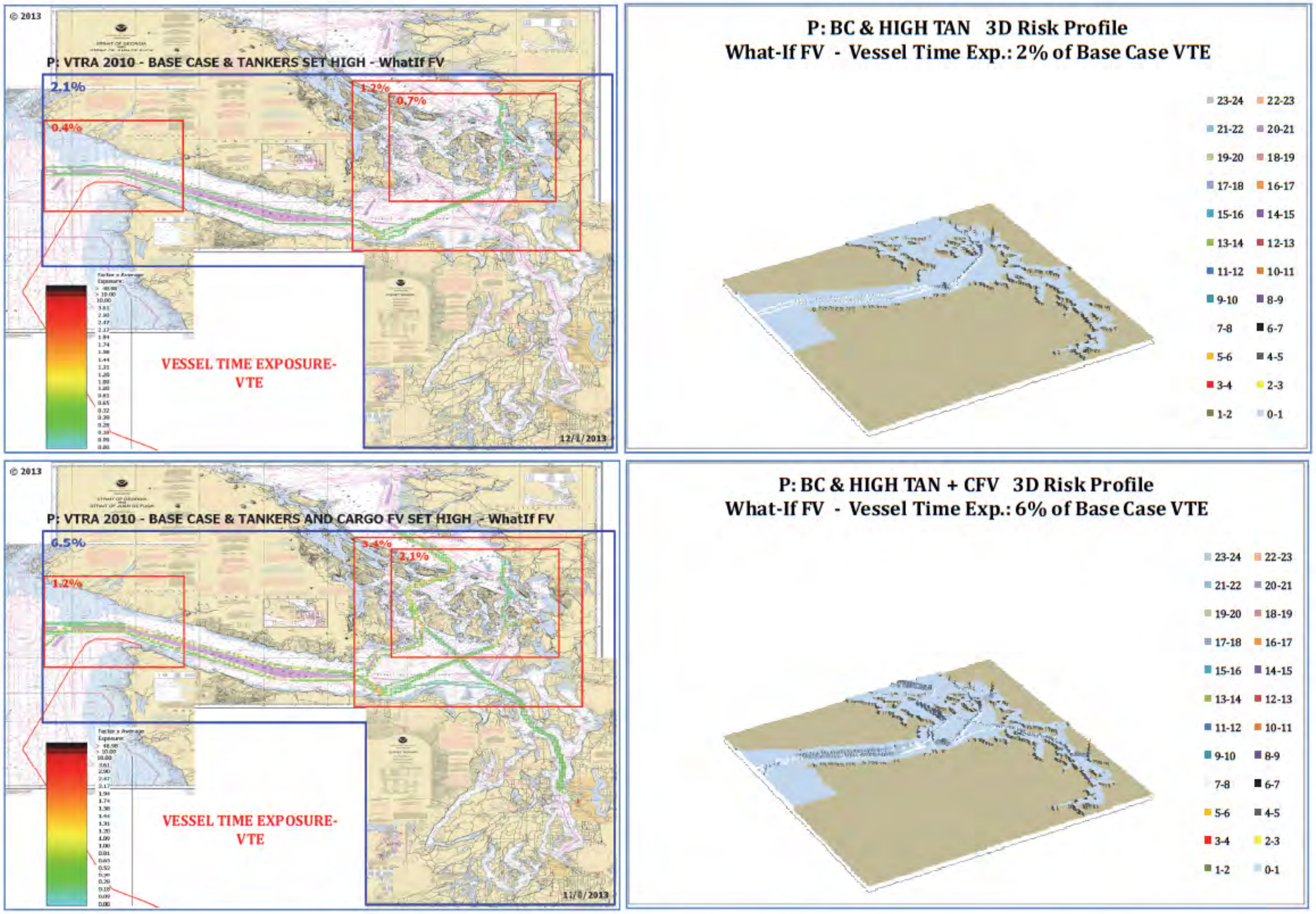
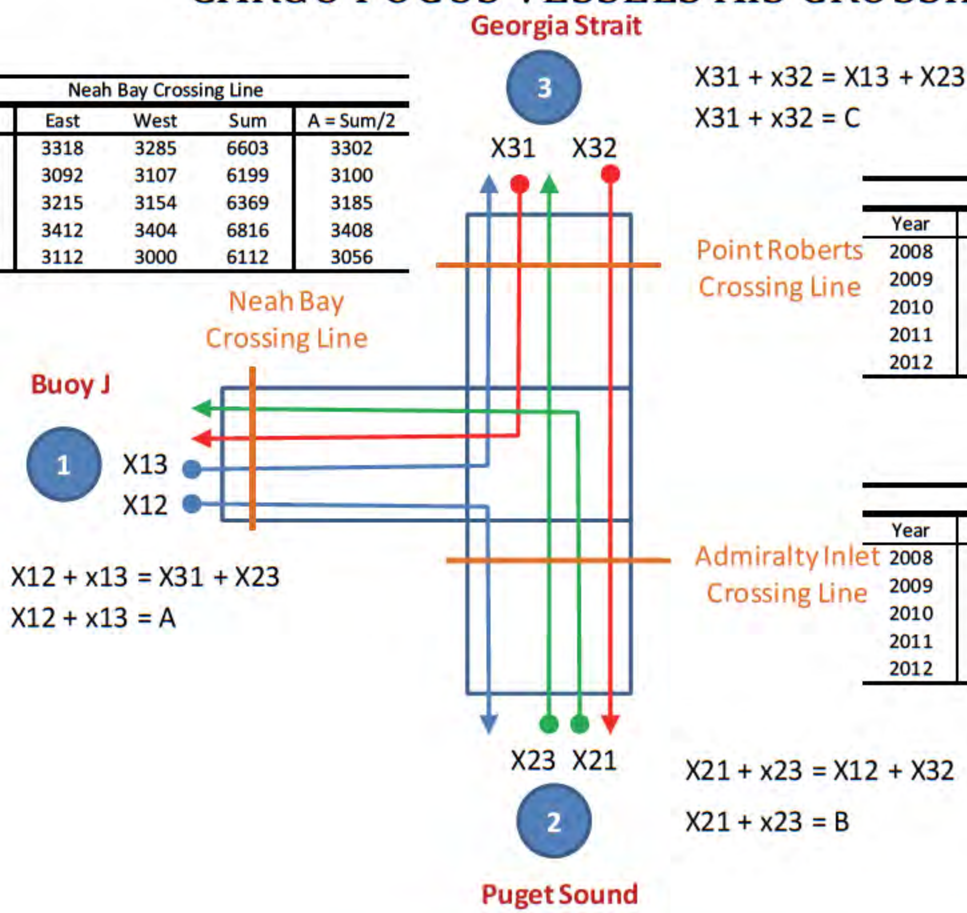


Figure 105. 2D and 3D Geographic profiles of added tanker and cargo focus vessel traffic in bench mark/sensitivity analyses enacted on the VTRA 2010 base case (P) and the combined What-If Scenario (T).

CARGO FOCUS VESSELS AIS CROSSING DATA

Neah Bay Crossing Line				
Year	East	West	Sum	A = Sum/2
2008	3318	3285	6603	3302
2009	3092	3107	6199	3100
2010	3215	3154	6369	3185
2011	3412	3404	6816	3408
2012	3112	3000	6112	3056



Point Roberts Crossing Line				
Year	North	South	Sum	C = Sum/2
2008	2377	2314	4691	2346
2009	2168	2106	4274	2137
2010	2277	2131	4408	2204
2011	2537	2451	4988	2494
2012	2405	2341	4746	2373

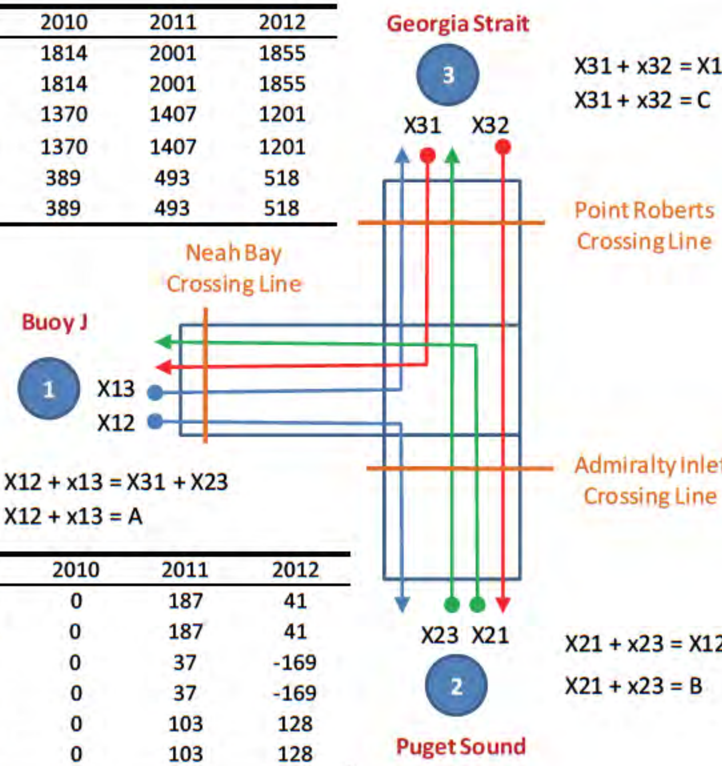
Admiralty Inlet Crossing Line				
Year	North	South	Sum	B = Sum/2
2008	2233	2242	4475	2238
2009	1945	1936	3881	1941
2010	1754	1765	3519	1760
2011	1903	1896	3799	1900
2012	1734	1702	3436	1718

Figure 106. AIS count data from 2008-2012 for Neah Bay, Admiralty Inlet and Point Roberts crossing lines depicted in Figure 103.

CARGO FOCUS VESSELS AIS CROSSING LINE ANALYSIS

		2008	2009	2010	2011	2012
x13	Bouy J - Georgia Strait	1604	1648	1814	2001	1855
x31	Georgia Strait - Bouy J	1604	1648	1814	2001	1855
x21	Puget Sound - Bouy J	1496	1451	1370	1407	1201
x12	Bouy J - Puget Sound	1496	1451	1370	1407	1201
x23	Puget Sound - Georgia Strait	742	489	389	493	518
x32	Georgia Strait - Puget Sound	742	489	389	493	518

	2008	2009	2010	2011	2012
A	3099	3099	3184	3408	3056
B	2237	1940	1759	1899	1718
C	2346	2137	2204	2494	2373



X31 + x32 = X13 + X23

X31 + x32 = C

X12 + x13 = X31 + X23

X12 + x13 = A

X21 + x23 = X12 + X32

X21 + x23 = B

		2008	2009	2010	2011	2012
x13	Bouy J - Georgia Strait	-211	-166	0	187	41
x31	Georgia Strait - Bouy J	-211	-166	0	187	41
x21	Puget Sound - Bouy J	126	81	0	37	-169
x12	Bouy J - Puget Sound	126	81	0	37	-169
x23	Puget Sound - Georgia Strait	352	100	0	103	128
x32	Georgia Strait - Puget Sound	352	100	0	103	128

Figure 107. Traffic flow analysis based on 2008-2012 AIS crossing line count data provided in Figure 106

In Figure 108 a 5-year trend analysis is presented of the cargo focus vessel traffic flow solution provided in Figure 107 for the traffic flows:

1. Buoy J to Puget Sound and vice versa
2. Puget Sound to Georgia Strait and vice versa
3. Buoy J to Georgia Strait and vice versa

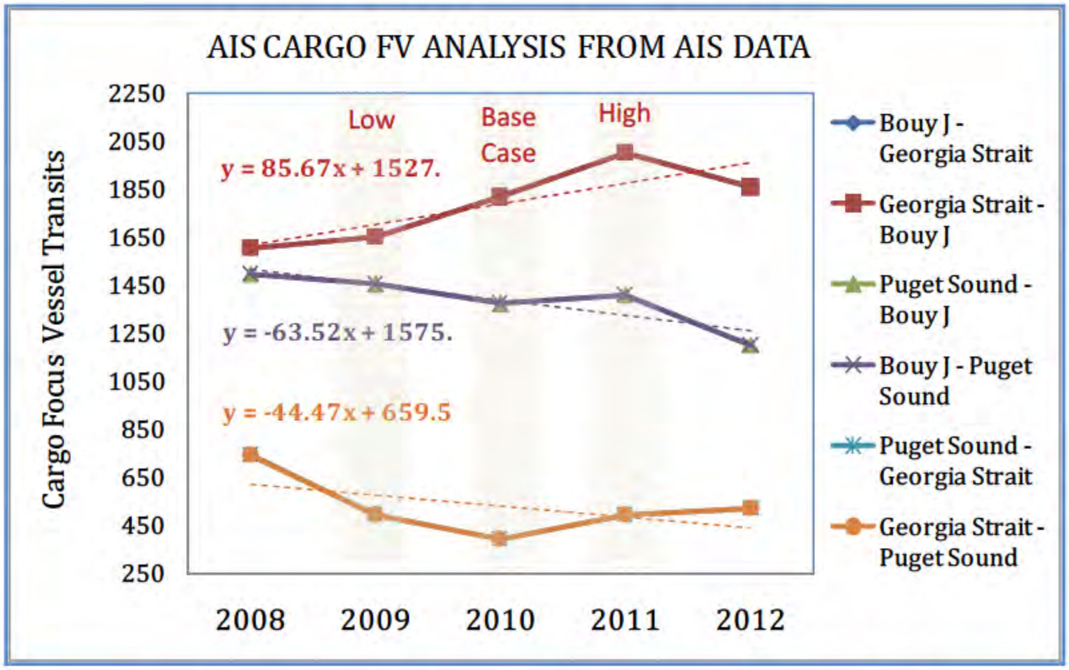
Observe from Figure 108 that the analysis results suggest that cargo focus vessel traffic between Buoy J and Puget Sound has decreased on average over the period from 2008-2012 by about 64 vessels a year, cargo focus vessel traffic between Georgia Strait and Buoy J has decreased on average by about 44 vessels year, but cargo focus vessel traffic between Buoy J and Georgia Strait has increased by about 86 vessels per year.

The selected high and low year for cargo focus vessels indicated in Figure 108 coincide with the high and low year counts of cargo focus vessels at the Neah Bay crossing line (see Figure 106). Following the selection of the high-low years for cargo focus vessels, cargo focus vessel crossing line counts were separated into bulk carrier, container and other cargo focus vessel counts using their percentage contribution to the 2010 cargo focus vessel class. These contributions were evaluated utilizing the VTRA 2010 model crossing count algorithm at the three crossing lines depicted in Figure 103. Following separation into bulk carrier, container and cargo focus vessel crossing line counts for 2008 – 2012 yearly separate balance equations were solved resulting in the high-low counts by bulk carriers, container ships and cargo focus vessels listed in Figure 108.

The modeling culmination of adding high cargo focus vessel traffic levels to the VTRA 2010 base case (P) and the combined What-If scenario (T), in addition to 142 added tank focus vessel, is depicted in the bottom 2 panels of Figure 105. From Figure 105 one observes that the addition of 287 cargo focus vessels results in a delta change of about 7% - 2% = +5% in terms of vessel time exposure relative to the base case (P) total focus vessel time exposure.

Modeling added variability in arrivals of what-if focus vessels

Arrivals of What-If focus vessels were modeled in the VTRA 2010 analyses as equidistant in time as indicted in the top part of Figure 109 ensuring a specified annual number of additional arrivals per year. The Steering Committee showed an interest in analyzing the effect of this equidistant arrival assumption of the What-If focus vessel arrival pattern. To that end, a sensitivity scenario was constructed by modifying the combined What-If scenario (T) with added random variability of What-If focus vessel arrivals as depicted in the bottom part of Figure 109. Observe from the bottom part of Figure 109 that in the added arrival variability scenario What-If focus vessels arrive randomly within equidistant time intervals. This arrival pattern still assures the arrival of a specified number of arrivals annually.



BULK TRANSIT NUMBER HIGH-LOW ANALYSIS FROM 2008-2012

	LOW - YEAR: - #	2010	HIGH - YEAR: + #
Bouy J - Georgia Strait	1095 - 2009 : -63	1159	1268 - 2011 : +109
Bouy J - Puget Sound	344 - 2009 : 22	322	325 - 2011 : +3
Puget Sound - Georgia Strait	0 - 2009 : +0	0	0 - 2011 : +0
Total Change Bulk FV	-41		+112

CONTAINER TRANSIT NUMBER HIGH-LOW ANALYSIS FROM 2008-2012

	LOW - YEAR: - #	2010	HIGH - YEAR: + #
Bouy J - Georgia Strait	223 - 2009 : -85	308	332 - 2011 : +25
Bouy J - Puget Sound	812 - 2009 : +46	766	807 - 2011 : +41
Puget Sound - Georgia Strait	274 - 2009 : +52	222	258 - 2011 : +36
Total Change Container FV	+13		+102

OTHER CARGO TRANSIT NUMBER HIGH-LOW ANALYSIS FROM 2008-2012

	LOW - YEAR: - #	2010	HIGH - YEAR: + #
Bouy J - Georgia Strait	336 - 2009 : -50	386	421 - 2011 : +36
Bouy J - Puget Sound	280 - 2009 : +28	252	255 - 2011 : +3
Puget Sound - Georgia Strait	246 - 2009 : +20	226	260 - 2011 : +34
Total Change Other Cargo FV	-2		+73

Figure 108. A 5-year trend analysis of cargo focus vessel traffic flows based on 2008-2012 AIS crossing line count data provided in Figure 106. Note that only three graphs appear in the figure as vessels streams between two locations are equal in both directions.

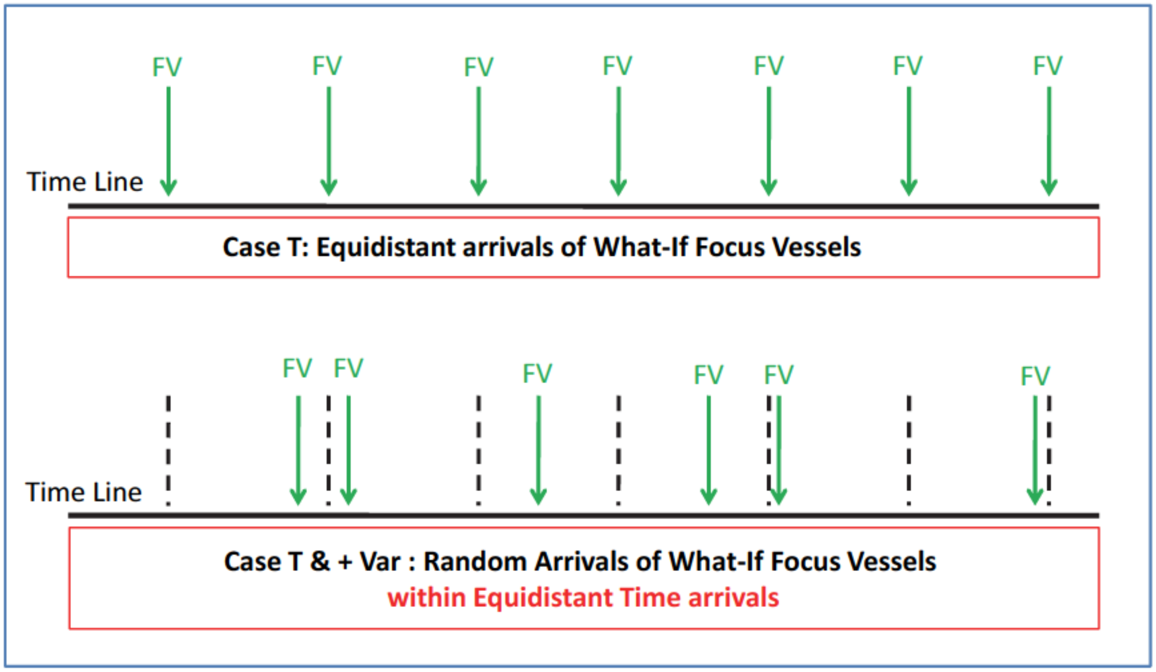


Figure 109. Equidistant arrivals of What-If focus vessels and modeling of random arrivals within equidistant time intervals to test effect of added variability in What-If focus vessel arrivals.

A distinct advantage of selecting equidistant arrivals for various What-If scenario's over random arrivals in equidistant time intervals in the VTRA 2010 What-If scenarios (Q), (R), (S) and (T) is that observed differences between scenario analyses in that case are solely the result of how the modeled Maritime Transportation System (MTS) responds to these added vessel arrivals and not the result of changes in timing of What-If Focus vessel arrival patterns from scenario to scenario (as would have been the case should the random approach within equidistant time intervals have been selected throughout the VTRA 2010 scenario analyses).

Bench marking the What-If Scenarios and the BM/Sensitivity Scenarios

Figure 110 depicts the summary analysis results of the bench mark/sensitivity scenarios enacted on the VTRA 2010 Base Case (P). The bench mark/sensitivity is evaluated for vessel time exposure, POTENTIAL accident frequency and POTENTIAL oil outflow. The delta change for each bench mark/sensitivity scenario is evaluated in terms of base case percentages and can thus be compared against the delta changes evaluated for the What-If Scenarios depicted in Figure 74. For completeness the 2010 Base Case is shown as a 0% delta change from itself in Figure 110.

Bench marking at vessel time exposure level

Observe from the left panel of Figure 110 that when compared to the traffic levels of the VTRA 2010 Base Case (P), the addition of about 142 tank focus vessels (P & HTFV) increases vessel time

	P - RMM SCENARIO REFERENCE POINT			
	Vessel Time Exposure (VTE)	Oil Time Exposure (OTE)	Pot. Accident Frequency (PAF)	Pot. Oil Loss (POL)
P - Base Case	100%	100%	100%	100%
	CASE P BENCHMARK (BM) & SENSITIVITY ANALYSIS			
P - BC & LOW TAN + CFV	Base Case with Tankers and Cargo Focus Vessels set at a low historical year			
P - BC & LOW TAN	Base Case with Tankers set at a low historical year			
P - BC & HIGH TAN	Base Case with Tankers set at a high historical year			
P - BC & HIGH TAN + CFV	Base Case with Tankers and Cargo Focus Vessels set at a high historical year			

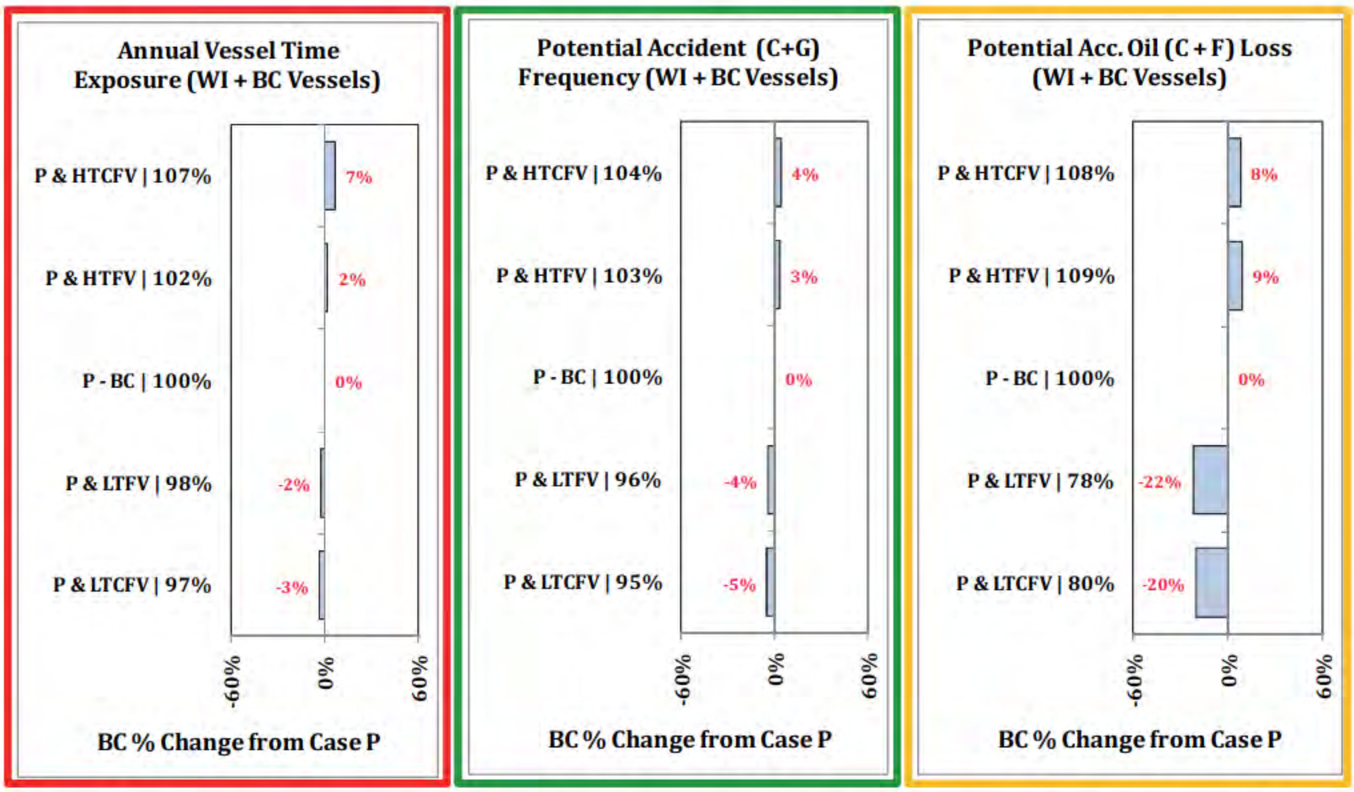


Figure 110. Summary Analysis results of BM/Sensitivity Scenario Analysis enacted on the base case (P).

exposure by a delta change of about (+2%), whereas the addition of 142 tank focus vessels and 287 cargo focus vessels (P & HTCFV) increases vessel time exposure by a delta change of (+7%). When comparing these delta changes against those observed for the What-If scenarios in the left panel of Figure 74, one observes that delta changes in vessel time exposure for the Delta Port What-if Scenario DP – 415 (+5%) and the Trans Mountain Pipeline expansion scenario KM-348 (+7%) are within the ball bark of the historical high scenario's P & HTFV and P & HTCFV delta changes. The vessel time exposure delta changes for the Gateway GW487 scenario (+13%) and

Combined What-If Scenario T (+24%) on the other hand are larger. In fact, the delta change for the Combined What-If Scenario T is about a multiplicative factor

$$(+24\%)/(+7\%) \approx 3$$

times more than the delta change in vessel time exposure for the historical high scenarios P & HTFV and P & HTCFV. Hence, it would be fair to say that increases in vessel time exposure under the GW-487 and Combined What-If (T) scenarios are significant as they are higher than the increases in vessel time exposure observed for the historical high scenarios P & HTFV and P & HTCFV.

Bench marking at POTENTIAL accident frequency level

One concludes from Figure 110 that the delta change of (+5%) in vessel time exposure by adding 287 cargo focus vessels on top of the added 142 tank focus vessels results only in a delta change of (+1%) in POTENTIAL accident frequency from P & HTFV, whereas the addition of the 142 tank focus vessels on their own results in a delta change of (+3%) in POTENTIAL accident frequency from the Base Case (P). Overall the P & HTCFV Scenario results in a delta change of (+4%) in POTENTIAL accident frequency from the Base Case (P).

Comparing the delta change in POTENTIAL accident frequency of (+4%) against the delta changes evaluated for the various What-If Scenarios in the middle panel of Figure 74 (+12%, +6% and +5%), one concludes that the VTRA 2010 analysis suggests that all three individual What-If scenarios result in higher delta changes in POTENTIAL accident frequency than the historical high scenarios P & HTFV and P & HTCFV. Therefore, these increases can be considered significant. In fact, the delta change for the Combined What-If Scenario (T) in POTENTIAL accident frequency (+18%) is about a multiplicative factor

$$(+18\%)/(+4\%) \approx 4$$

times more than the delta changes in POTENTIAL accident frequency for the historical high scenario P & HTCFV. In other words, if all three expansions scenario were to be in effect, the VTRA 2010 analysis results suggest that the delta change in POTENTIAL accident frequency from the 2010 Base Case (P) to be about a factor 4 higher than the delta change observed from the Base Case 2010 (P) year to the historical high scenario P & HTCFV.

Bench marking at POTENTIAL oil loss level

Finally, observe from Figure 110 that both the P & HTFV and P & HTCFV scenarios result both in a delta change of about (+9%) in POTENTIAL oil loss. Hence, this (+9%) increase is predominantly attributable to the addition of the 142 tank focus vessels to the VTRA 2010 Base Case (P).

Comparing the delta change in POTENTIAL oil loss of (+9%) against the delta change in POTENTIAL oil loss evaluated for the various What-If scenarios in the right panel of Figure 74

(+12%, +36%, +4%) one concludes that the VTRA 2010 analysis suggests that both the Gateway What-If expansion scenario and the Trans-Mountain Pipeline expansion scenario result in a higher delta change in POTENTIAL oil loss than the historical high scenarios P & HTFV and P & HTCFV and thus these delta changes can be considered significant. In fact, the delta change for the Combined What-If Scenario (T) in POTENTIAL oil loss is about a multiplicative factor

$$(+68\%)/(+9\%) \approx 7$$

times more than the delta changes in POTENTIAL oil loss for the historical high scenarios P & HTFV and P & HTCFV. In other words, if all three expansions scenario were to be in effect, the VTRA 2010 analysis results suggest that the delta change in POTENTIAL oil loss from the 2010 Base Case (P) to be about a factor 7 times higher than the delta change evaluated from the Base Case 2010 (P) year to historical high scenario's P & HTFV and P & HTCFV.

Bench marking the RMM Scenarios and the BM/Sensitivity Scenarios

Figure 110 depicts the summary analysis results of the bench mark/sensitivity scenarios enacted on the VTRA 2010 Base Case (P). The bench mark/sensitivity is evaluated for vessel time exposure, POTENTIAL accident frequency and POTENTIAL oil outflow. The delta change for each bench mark/sensitivity scenario is evaluated in terms of base case percentages and can thus be compared against the delta changes evaluated for the RMM Scenarios depicted in Figure 89, Figure 94 and Figure 97. For completeness the 2010 Base Case is shown as a 0% delta change from itself in Figure 110.

Bench marking at vessel time exposure level

Observe from the left panel of Figure 110 that the removal of about 191 tank focus vessels (P & LTFV) decreases vessel time exposure by a delta change of about (-2%) from the base case (P), whereas the removal of about 191 tank focus vessels and 30 cargo focus vessels (P & LTCFV) decreases vessel time exposure by a delta change of about (-3%). None of the RMM scenarios enacted on the Base Case P (left panel of Figure 89), however, result in a reduction of vessel time exposure. The RMM scenarios enacted on Case Q (Figure 94) do result in a reduction of vessel time exposure with delta changes of about (-4%) from the What-If Scenario Q – GW487 as a result of the removal of bunkering support in both RMM Scenarios Q – GW487& NB and Q – GW487 & NB & OH. Finally, observe that none of the RMM Scenario's enacted on Case T (Figure 93) results in a reduction of vessel time exposure from the Combined What-If scenario (T).[19]

[19] The RMM scenario T & 6RMM's also includes removal of bunkering support for Gateway vessels, but it subsequent decrease in vessel time exposure are offset by vessel time exposure increases as a result of the other RMM scenario's included.

Bench marking at POTENTIAL accident frequency level

Observe from the middle panel of Figure 110 that the delta change of (-2%) in vessel time exposure in case of the P & LTFV scenario translates in a delta change of about (-5%) in POTENTIAL accident frequency for the P & LTFV and P & LTCFV scenarios. From a benchmarking perspective, observe from the middle panel in Figure 89 that the RMM scenario P-BC & CONT 17KNTS results in a similar delta change in POTENTIAL accident frequency of (-4%) as the removal of about 191 tankers from the Base Case (i.e. the P & LTFV scenario). In fact, one observes from Figure 89, Figure 94 and Figure 97 that with the exception of the RMM scenario T & EC and the RMM scenario T & OW ATB, all other RMM scenarios result in larger delta change reductions in POTENTIAL accident frequency (as evaluated as delta changes from Case P, from Case Q and from Case T, respectively) than the low historical traffic scenarios P & LTFV and P & LTCFV. These delta change reductions can thus be considered significant. In fact, in case of the combined T & 6RMM scenario one observes a delta change reduction of (-29%) from Case T in POTENTIAL accident frequency, which is about a multiplicitative factor

$$(-29\%)/(-5\%) = 6$$

more risk reduction one would get in POTENTIAL accident frequency when cancelling 191 tank focus vessels and about 30 cargo focus vessels from the Base Case (P) (i.e. the P & LTCFV scenario).

In fact it is noteworthy, that under the T & 6RMM scenario we have for the delta change reduction in POTENTIAL accident frequency from the base case (P)

$$89\%-100\%=(-11\%),$$

whereas for the low historical scenarios P & LTFV and P & LTCFV we observe delta change reductions of (-4%) and (-5%) from the base case (P). In other words, the VTRA 2010 analysis results suggest that under the risk mitigation scenario T & 6RMM the delta change in POTENTIAL accident frequency is about a multiplicative factor

$$(-11\%)/(-4\%) \approx 3 \text{ and } (-11\%)/(-5\%) \approx 2$$

LOWER than the delta change in the POTENTIAL accident frequency observed for the historical low scenarios P & LTFV and P & LTCFV!

Bench marking at POTENTIAL oil loss level

Observe from the right panel of Figure 110 that reductions in POTENTIAL accident frequency in cases P & LTFV and P & LTCFV lead to delta changes of (-22%) and (-20%) in POTENTIAL oil loss, respectively. Thus these reductions in POTENTIAL oil loss primarily result from the removal of 191 tank focus vessels. The difference in the relative larger delta change reduction of POTENTIAL oil loss when removing 191 tankers (-22%) compared to the delta change increase (+9%) when adding 142 tankers to the VTRA 2010 base case is explained by canceled tank focus vessels following different route patterns than the fictitious tank focus vessels that were added to the VTRA 2010 Base Case for the bench mark/sensitivity analysis purposes.

From a benchmarking perspective, note that the removal of about 191 tank focus vessels and 30 cargo focus vessels from the Base Case (P & LTCFV) results in a similar delta change reduction in POTENTIAL oil loss (-22%) as the delta change reduction (-24%) evaluated for RMM scenario T-GW-KM-DP & EH[20] from the combined What-If scenario (T). In fact, the RMM scenario T & 6RMM's results in a delta change of (-44%) reduction in POTENTIAL oil loss, with translates to a multiplicative factor

$$(-44\%)/(-22\%) = 2.$$

Hence, the VTRA 2010 analysis results suggest that the risk reduction one would get in case of the T & 6RMM's is double the risk reduction one would get from removing 191 tank focus vessels and 30 cargo focus vessels from the Base Case (P).

Other benchmarking comparisons can be made by comparing Figure 110 to Figure 89, Figure 94 and Figure 97.

By waterway zone analysis results of BM/Sensitivity scenarios enacted on base case (P)

Figure 111 provides a by waterway zone comparison of changes in terms of POTENTIAL accident frequency and POTENTIAL oil outflow for the high BM/sensitivity analysis scenario P & HTCFV[21] and low BM/Sensitivity analysis scenario P & LTCFV[22]. One observes from the top left panel in Figure 111 that under the P & HTCFV Scenario the largest absolute increase (+1.8%) in POTENTIAL accident frequency is observed in the Guemes waterway zone. The largest relative waterway multiplicative factor (× 1.28), however, is observed for the Buoy J waterway zone. From the bottom left panel in Figure 111 it follows that under the P & LTCFV Scenario the largest absolute reduction (-1.1%) in POTENTIAL accident frequency is observed in the Guemes and Saddlebag waterway zones. This translates for the Saddlebag waterway zone into the smallest relative waterway multiplicative factor (× 0.62). Hence, 38% of the POTENTIAL accident frequency in the Base Case (P) in the Saddlebag waterway zone is removed through the removal of 191 tank focus vessels and 30 cargo focus vessels.

One observes from the top right panel in Figure 111 that under the P & HTCFV Scenario the largest absolute increase (+4.2%) in POTENTIAL oil loss is observed in the Guemes waterway zone. The largest relative waterway multiplicative factor (× 1.62), however, is observed for the Buoy J waterway zone. From the bottom right panel in Figure 111 it follows that under the P & LTCFV Scenario the largest absolute reduction (-6.7%) in POTENTIAL oil loss is observed for the

[20] Case T & EH assumes the availability of +1 escort for all focus vessels in the green area depicted in Figure 88.
[21] That is, with the addition of 142 tank focus vessels and 287 cargo focus vessels on top of the base case (P)
[22] That is, with the removal of 191 tank focus vessels and 30 cargo focus vessels from the base case (P)

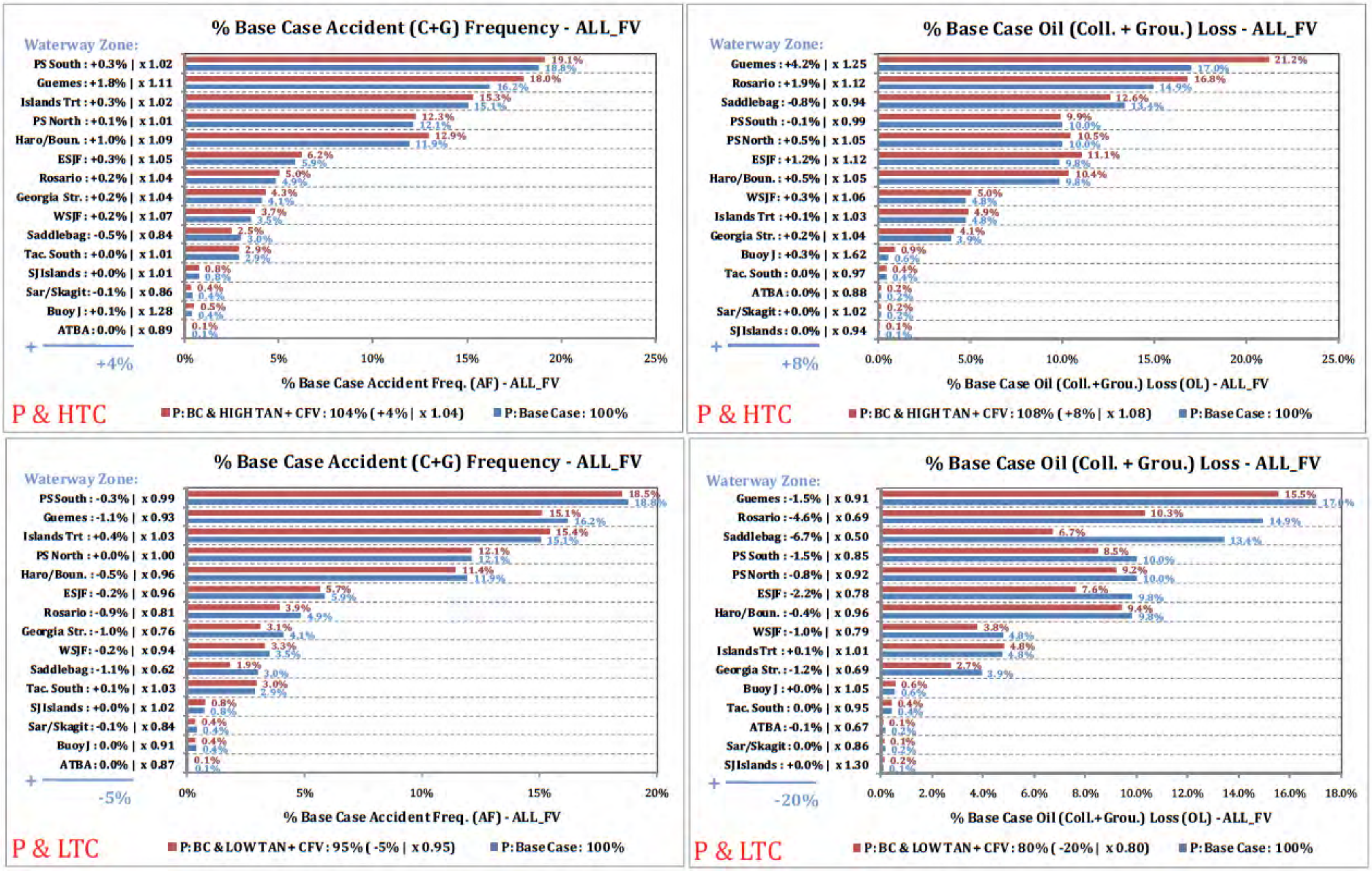


Figure 111. Waterway zone POTENTIAL accident frequency. and oil outflow results comparison of high and low Scenarios enacted on base case (P). For a detailed explanation of output format see Page 97.

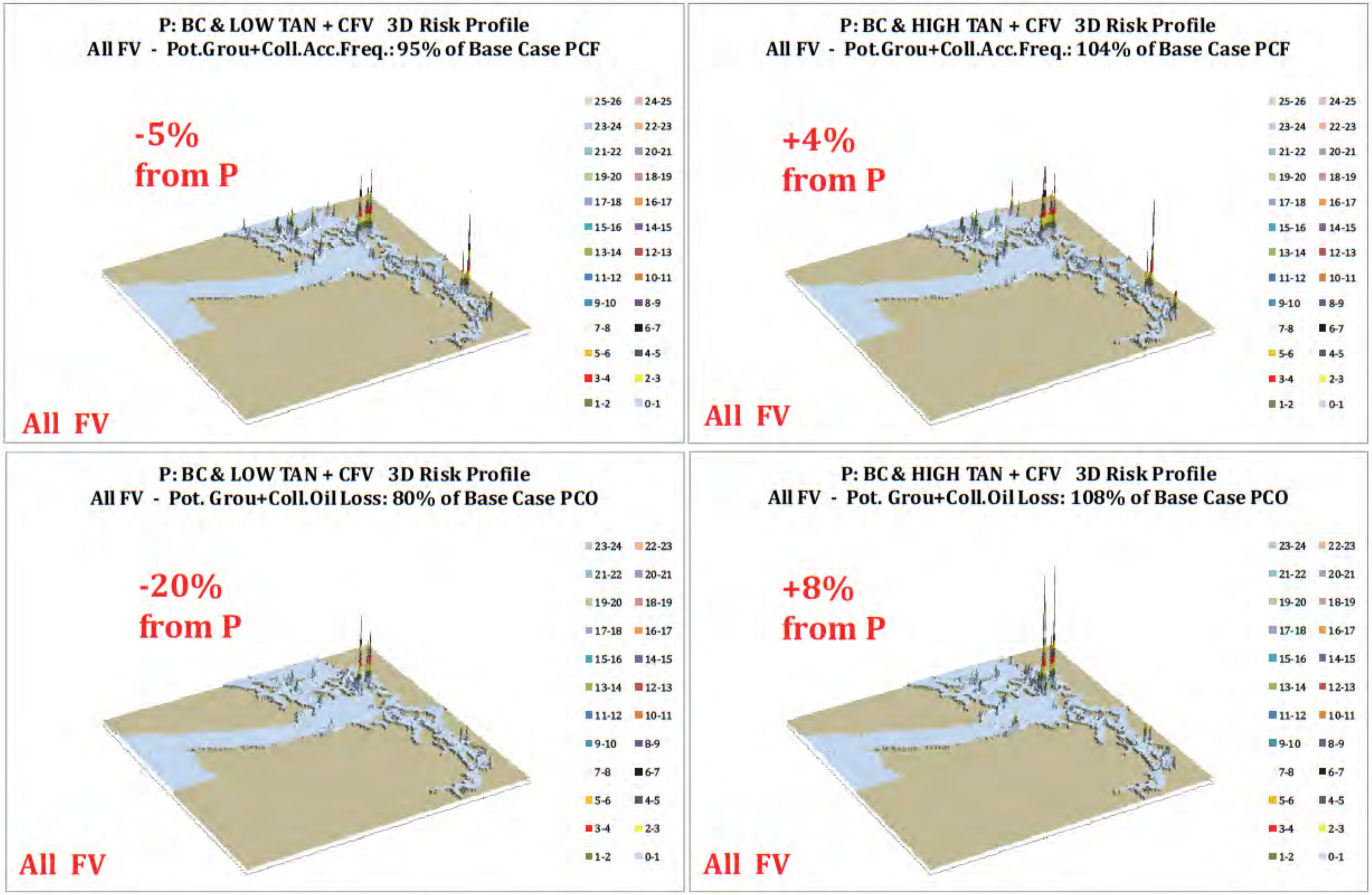


Figure 112. Geographic profiles of POTENTIAL accident frequency and oil outflow for high and low Scenarios enacted on base case (P)

Saddlebag waterway zone. This translates for the Saddlebag waterway zone into the smallest relative waterway multiplicative factor ($\times$ 0.50). Hence, 50% of the POTENTIAL oil loss in the Base Case (P) in the Saddlebag waterway zone is removed through the removal of 191 tank focus vessels and 30 cargo focus vessels from the base case.

Summary of BM/Sensitivity Scenarios Results enacted on combined What-If scenario (T)

Figure 113 depicts the summary analysis results for the bench mark/sensitivity scenarios enacted on the Combined What-If Scenario (T). The sensitivity is evaluated in terms of vessel time exposure, accident frequency and oil outflow. The delta change for each bench mark/sensitivity scenario is evaluated in terms of base case percentages from Case T and for completeness the Combined What-If Scenario (T) is shown as a 0% delta change from itself.

Observe from Figure 113 that the addition of about 142 tank focus vessels in terms of base case percentages now results in a delta change of (+3%) in vessel time exposure (T & HTFV), whereas the addition of 142 tank focus vessels and 289 cargo focus vessels results in a delta change of (+6%). Next, one concludes from Figure 113 and Figure 110 that the 3% additional increase of vessel time exposure by adding 142 tank focus vessels now (T & HTFV) results in a delta change of (+6%) in POTENTIAL accident frequency whereas when added to the Base Case (P) a delta change of (+3%) (P & HTFV) was evaluated. Observe from Figure 113 and Figure 110 that the addition of the 142 tank focus vessels and 289 cargo focus vessels to the base case (P & HTCFV) resulted in a delta change of (+8%) in POTENTIAL oil outflow, but when added to the combined What-If Scenario (T) results in a delta change of (+17%). On the other hand, while the removal of 191 tank focus vessels and 30 cargo focus vessel resulted in Case P & LTCFV in a delta change of (-20%) in POTENTIAL oil outflow, the same removal of tank focus vessels and cargo focus vessel from the Combined What-If scenario results in a delta change reduction of (-27%). Hence, overall one observes a larger sensitivity of analyses results with respect to traffic level changes in the Combined What-If Scenario (T) than in the base case (P). We attribute this larger sensitivity to Case T experiencing a larger amount of overall focus vessel traffic than the base case (P)[23].

Finally, one observes from Figure 113 that the added variability of What-If focus vessel arrivals in Case T & Var results in a lower POTENTIAL accident frequency (-3%) and a lower POTENTIAL oil outflow (-10%) than observed in the Combined What-If Scenario Case T. Please note that the delta change in vessel time exposure for the T & Var scenario equals (-1%) indicating a larger delay in focus vessel transits than when assuming equidistant traffic arrivals (see Figure 109).

[23] The vessel time exposure (VTE) in the Combined What-If Scenario (T) is about 24% higher than that of the 2010 base case (P).

	CASE T - REFERENCE POINT			
	Vessel Time Exposure (VTE)	Oil Time Exposure (OTE)	Pot. Accident Frequency (PAF)	Pot. Oil Loss (POL)
T - GW - KM - DP	+25% | 125%	+59% | 159%	+18% | 118%	+68% | 168%
	CASE T BENCHMARK (BM) & SENSITIVITY ANALYSIS			
T - LOW TAN + CFV	Case T with Tankers and Cargo Focus Vessels set at a low historical year			
T - LOW TAN	Case T with Tankers set at a low historical year			
T - GW - KM - DP & VAR	Case T with additional variability in timing of What-If Focus Vessel arrivals			
T - HIGH TAN	Case T with Tankers set at a high historical year			
T - HIGH TAN + CFV	Case T with Tankers and Cargo Focus Vessels set at a high historical year			

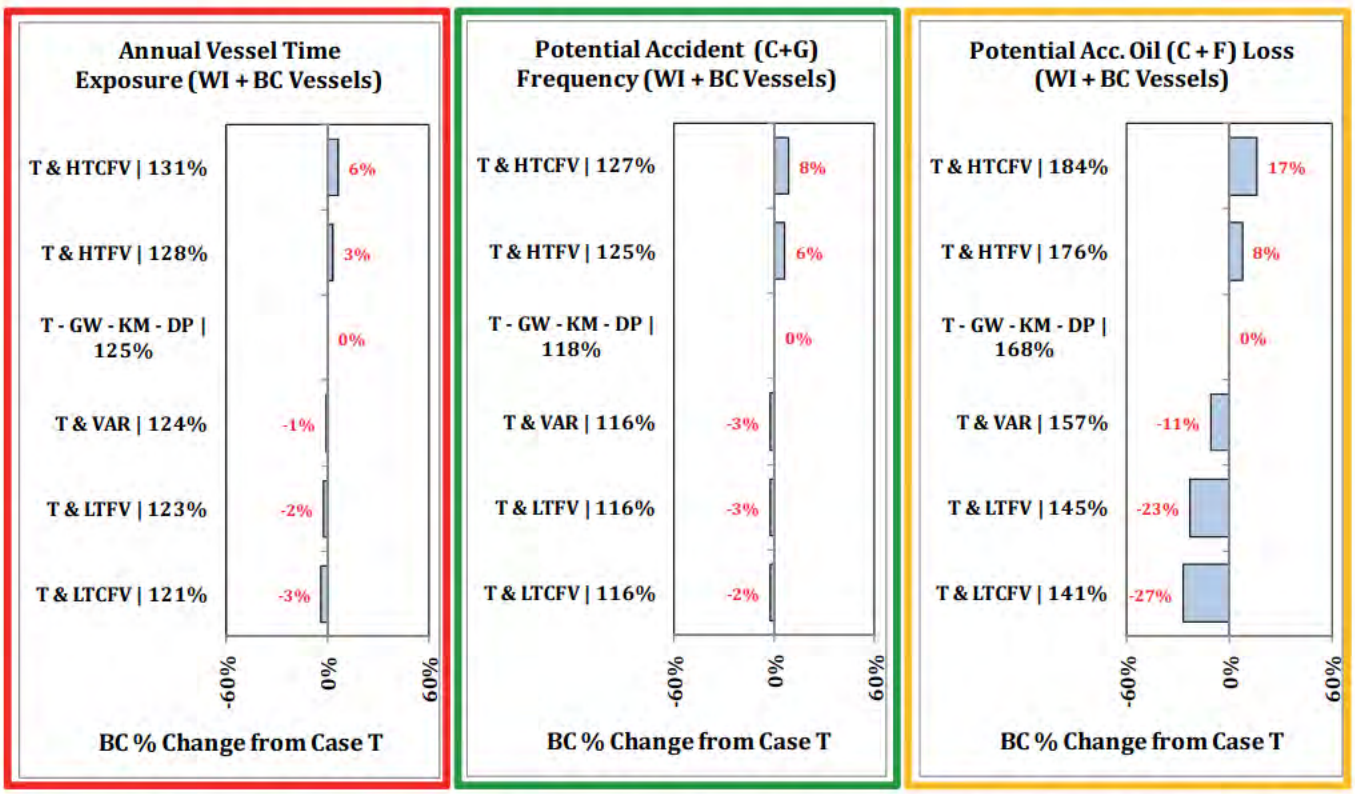


Figure 113. Summary Analysis results of BM/Sensitivity Analysis enacted on the Combined What-If Case (T).

By waterway zone analysis results of BM/Sensitivity scenarios enacted on combined case (T)

Figure 114 provides a by waterway zone comparison of changes in terms of POTENTIAL accident frequency and POTENTIAL oil loss for the high BM/sensitivity analysis scenario T & HTCFV[24] and

[24] That is, with the addition of 142 tank focus vessels and 287 cargo focus vessels on top of the Combined What-If Scenario (T)

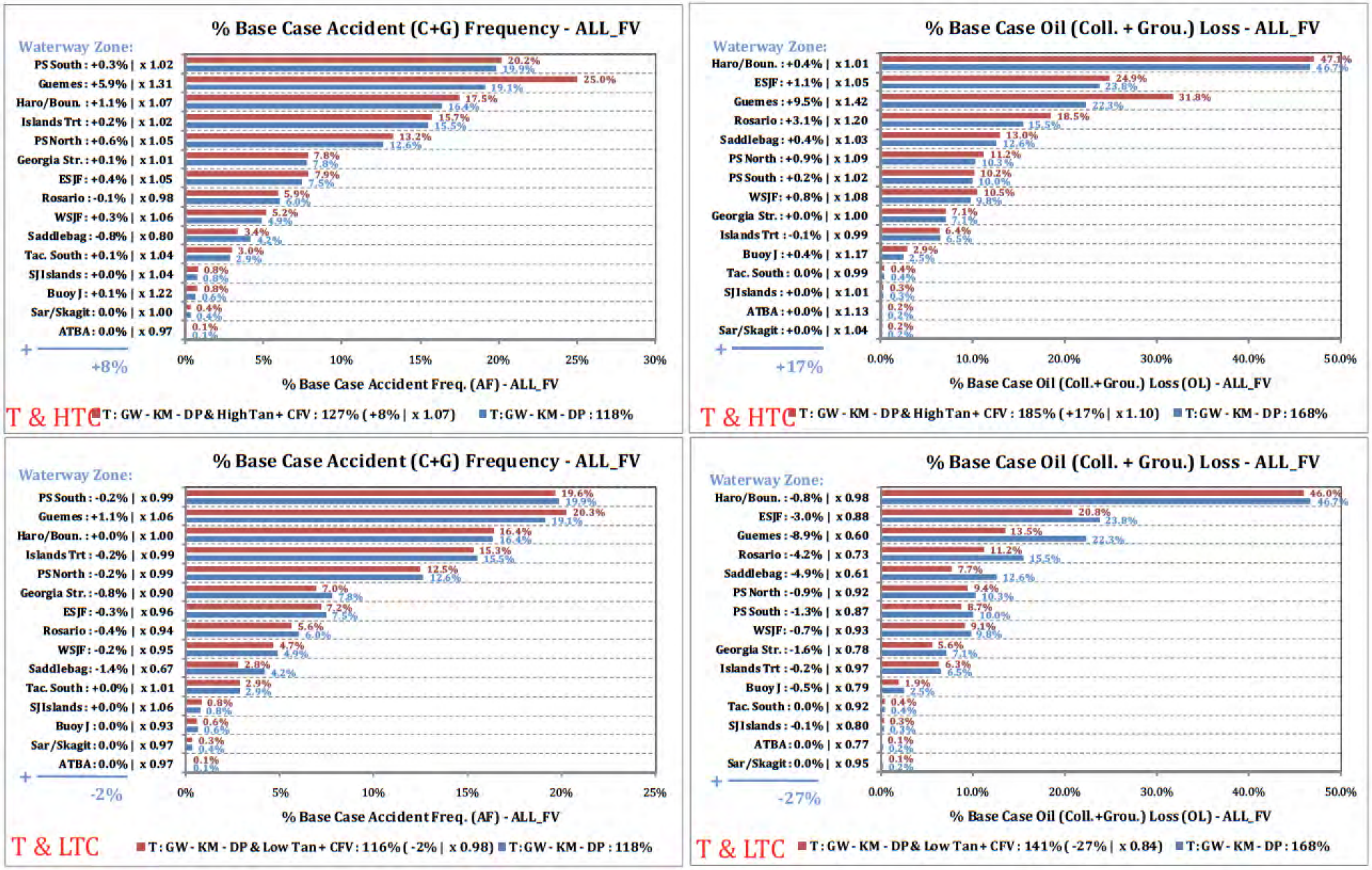


Figure 114. Waterway zone POTENTIAL accident frequency. and oil outflow results comparison of high and low Scenarios enacted on Combine Case (T). For a detailed explanation of output format see Page 97.

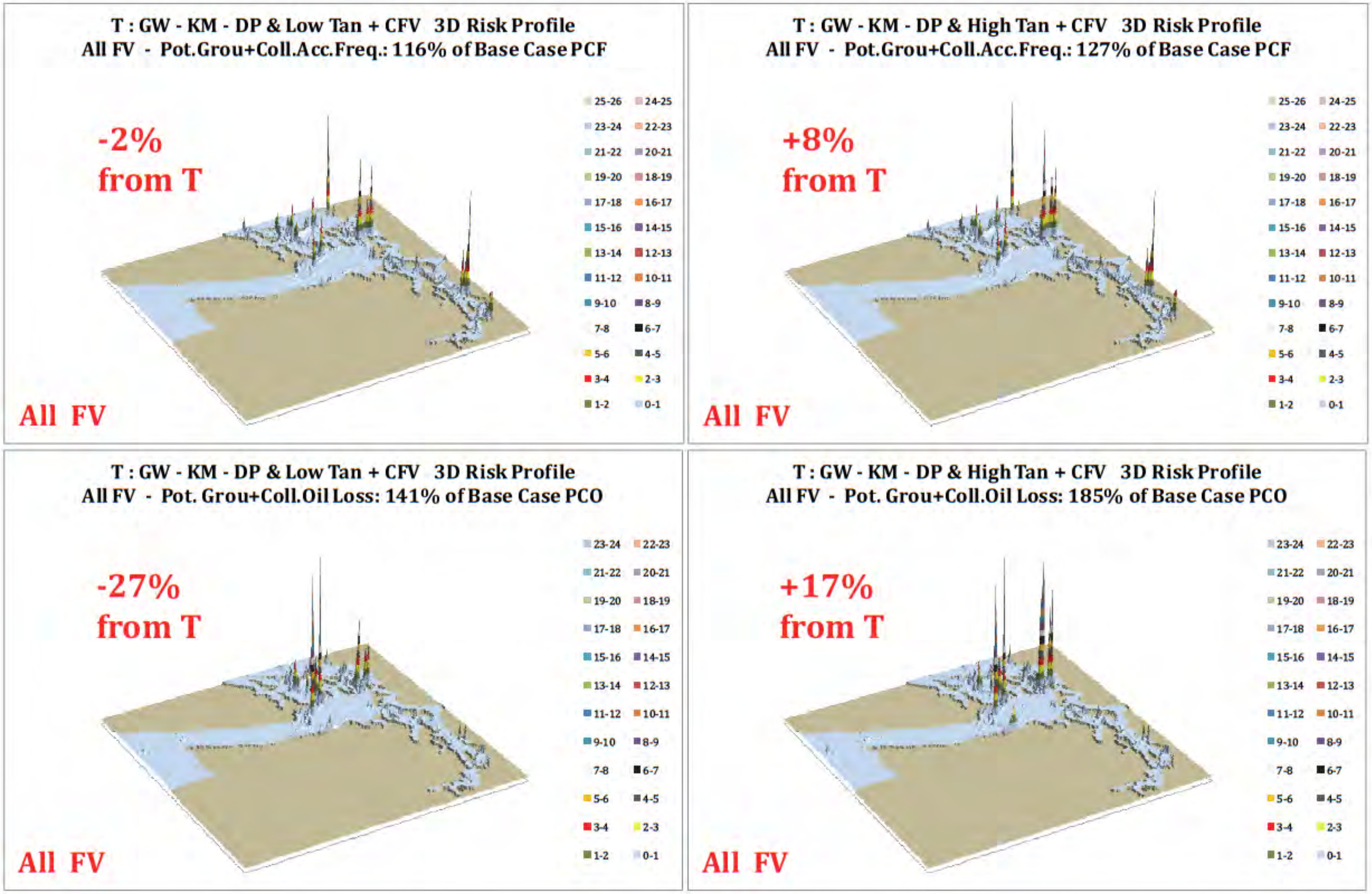


Figure 115. Geographic profiles of POTENTIAL accident frequency and oil outflow for high and low Scenarios enacted on combined case (T)

low BM/Sensitivity analysis scenario T & LTCFV[25]. One observes from the top left panel in Figure 114 that under the T & HTCFV Scenario the largest absolute increase (+5.9%) in POTENTIAL accident frequency is observed in the Guemes waterway zone compared to the (+1.8%) in case of the P & HTCFV Scenario (see top left panel in Figure 111). This translated here for the Guemes waterway zone into the largest relative waterway multiplicative factor (× 1.31). From the bottom left panel in Figure 111 it follows that under T & LTCFV the largest absolute reduction (-1.4%) in POTENTIAL accident frequency is observed in the Saddlebag waterway zone. This translates for the Saddlebag waterway zone smallest relative waterway multiplicative factor (× 0.67). Hence, 33% of the POTENTIAL accident frequency in the Combined What-If Scenario T in the Saddlebag waterway zone is removed through the removal of 191 tank focus vessels and 30 cargo focus vessels from the Combined What-If scenario (T).

One observes from the top right panel in Figure 114 that under T & HTCFV the largest absolute increase (+9.5%) in POTENTIAL oil loss is observed in the Guemes waterway zone compared to the (+4.2%) in case P & HTCFV (see top right panel in Figure 111). From the bottom right panel in Figure 114 it follows that under P & LTCFV the largest absolute reduction (-8.9%) in POTENTIAL oil outflow is observed now in the Guemes waterway zone. This translates for the Guemes waterway zone into the smallest relative waterway multiplicative factor (× 0.60). Hence, 40% of the POTENTIAL accident frequency in the Combined What-If Scenario T in the Guemes waterway zone is removed through the removal of 191 tank focus vessels and 30 cargo focus vessels.

[25] That is, with the removal of 191 tank focus vessels and 30 cargo focus vessels from the Combined What-If Scenario (T)