Appendix J

Vessel Spill Risk Analysis

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Vessel Spill Risk Analysis For EFSEC DEIS for Vancouver Energy

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Executive Summary

The overall approach to the vessel spill analysis for the proposed Vancouver Energy facility includes:

- Determining the contingency or response planning spill volumes based on vessel type and size, and by oil cargo type;
- Determining the probability distributions of oil outflow from vessel impact accidents (collisions and groundings) based on vessel type and size, accident type, and by oil cargo type;
- Determining the effective worst-case discharges by vessel type and size, and by oil cargo type;
- Determining the probability of underway-related spillage (i.e., spills that occur while vessels are underway);
- Determining the probability of transfer-related spillage (i.e., spills that occur while vessels are loading at the facility dock); and
- Identifying risk mitigation measures that might reduce the incidence or volume of spillage.

The spill volumes identified are for application in both contingency planning for spill response and for evaluation of potential environmental impacts.

The general approach is shown in Figure 1.

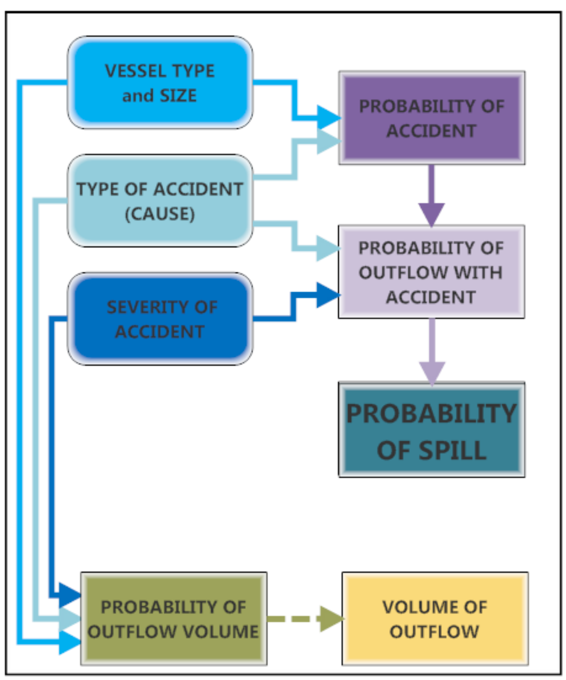

Figure 1: General Approach to Vessel Spill Analysis

Basic Assumptions on Vancouver Energy Facility Throughput

For this analysis (and the related analysis conducted for rail transport risk) the following basic assumptions have been applied:

- The overall annual throughput at the facility will average 360,000 barrels (bbl) per day across 365 days for a maximum annual throughput of 131.4 million bbl;
- Rail deliveries of crude oil to the facility will be limited to 120-car train length unit trains by the loading facilities and proposed rail infrastructure at Terminal 5;
- The maximum volume per rail tank car is assumed to be 750 bbl for air permitting purposes, though actual carloads are limited by cargo weight, which is affected by oil density, by tank car weight, which is affected by the design, and by vapor space requirements to allow for expansion of the oil and to control for buildup of volatiles;[1]
- There would be four trains per day, with a possible fifth train infrequently on some days;
- The tank vessel departures will range from 345 to a maximum of 365 annual calls due to constraints in time periods when vessels can arrive at the Columbia Bar in conditions suitable to departure without having to anchor or loiter and in consideration of potential weather closures;
- For consistency in rail inputs and vessel output a fleet mix that includes some larger vessels must be considered; and
- A fleet mix of 80% Handymax tankers (average 46,000 MDWT), 15% Aframax (average 105,000 MDWT), and 5% Suezmaz (average 165,000 MDWT) across 365 vessel calls per year, as provided by Tesoro Savage is assumed.

Terminology for Spill Volumes and Worst-Case Discharges (WCDs)

There are two distinct sets of spill volumes that need to be considered for the purposes of the Vancouver Energy EFSEC DEIS report:

- ***Regulatory:*** Volumes for contingency (spill response) planning that are dictated by regulations at the federal and state levels; and
- ***Environmental Impact/Risk Assessment:*** Volumes of spills to be evaluated for potential environmental impacts and risk assessment, which are based on distributions of spill volumes derived from outflow modeling of relevant vessels.

Within both of these two categories there are different volumes to be considered, from relatively small spills to "worst-case" discharges (WCDs). For clarity, the terminology used throughout the vessel spill analysis report is described in Table 1.

[1] In actual practice, the tank cars often do not exceed 650 to 690 bbl of cargo loading.

Table 1: Spill Volume Terminology Applied in Report				
Category	**Regulatory Contingency Planning Volumes**		**Environmental Impact/ Risk Assessment Volumes**	
	Report Term	**Basis**	**Report Term**	**Basis**
Small Spill	Average Most-Probable Discharge	US Coast Guard regulations	Small Spill	Minimum volume outflow modeling
Median Spill	n/a	n/a	Median Spill	50th percentile outflow modeling
Large Spill	Maximum Most-Probable Discharge	US Coast Guard regulations	n/a	n/a
Worst-Case Discharge	*Regulatory* Worst-Case Discharge	US Coast Guard and Ecology regulations	*Effective* Worst-Case Discharge	Maximum volume outflow modeling

The "effective" WCD is the most credible or realistic volume for a worst-case discharge based on the amount of oil that would effectively be released in the event of a vessel impact accident (collision or grounding) based on maximum possible outflow as determining by modeling. This volume does not necessarily equate to the regulatory WCD, which is the entire vessel cargo, because all of the oil would not flow out of the vessel but rather become entrapped between double hulls or other areas of the ship rather than be released to the environment. While regulatory requirements for contingency planning stipulate that response plans must be developed for the entire cargo of a vessel, the "effective" worst-case discharge is applied in this analysis for evaluating potential worst-case environmental impacts of a spill.

Volumes for Contingency and Response Planning for Vessel Spills

There are three basic discharge (spill) volumes of concern for spill response planning based on US Coast Guard (USCG) regulations:

- Average Most-Probable Discharge (AMPD)
- Maximum Most-Probable Discharge (MMPD)
- Worst-Case Discharge (WCD)

These volumes are only loosely based on the concept of probability. Small spills are more likely than very large spills or worst-case discharges. The definitions of discharge volumes by category are in Table 2.

Table 2: Definitions of Planning Volumes for Vessels		
Discharge Category	**Definition**	**Regulation**
AMPD	*Lesser* of 50 bbl or 1% of cargo during oil transfer operations to/from vessel.	33 CFR 155.1020
MMPD	2,500 bbl if oil capacity ≥ 25,000 bbl; 10% capacity if capacity < 25,000 bbl	
WCD	Discharge of vessel's entire oil cargo in adverse weather conditions. [2]	33 CFR 155.1020 WAC 173-182-030

[2] The weather conditions that will be considered when identifying response systems and equipment in a response plan for the applicable operating environment. Factors to consider include, but are not limited to, significant wave height, ice, temperature, weather-related visibility, and currents within the Captain of the Port (COTP) zone in which the systems or equipment are intended to function.

Technically, the regulatory-based WCD planning volume (as per Table 1) should be based on the vessel's cargo capacity, i.e., the amount of oil it would carry when fully loaded. But, given the draft limit of 43.0 feet in the Columbia River, there is a limit as to the actual cargo that can be accommodated in the largest tankers. Since weight (and not volume) would determine the actual draft of a fully-loaded tanker, the specific gravity of the oil is a contributing factor. The more dense the oil, the less volume can be accommodated. Since Bakken crude has a specific gravity of about 0.811 (°API 43), more barrels (a volume measure) can be accommodated than diluted bitumen. The latter is heavier with a specific gravity of 0.930 (°API 20).

Another issue involved in determining the possible cargo capacity given the 43.0-foot channel draft restriction, is the lightship (empty) weight of the vessel itself. Ironically, a smaller vessel with a lower lightship weight might actually carry more oil than a larger vessel with a heavier lightship weight when there are draft restrictions. Planning volumes by vessel type and cargo are shown in Table 3 and Table 4.

Table 3: Planning Volumes for Vancouver Energy Vessels Loaded with Bakken Crude

Vessel Type[3]	DWT	Cargo Capacity at Maximum Loaded Draft (43.0 ft)[4]	Planning Discharge Volume		
			AMPD	MMPD	Regulatory WCD Based on Draft Restriction
Oil Tanker (Handymax)	46,172	319,925 bbl	50 bbl	2,500 bbl	319,925 bbl
Oil Tanker (Aframax)	115,000	667,777 bbl	50 bbl	2,500 bbl	667,777 bbl
Oil Tanker (Aframax)	125,000	614,337 bbl	50 bbl	2,500 bbl	614,337 bbl
Oil Tanker (Aframax)	142,000	642,428 bbl	50 bbl	2,500 bbl	642,428 bbl
Oil Tanker (Suezmax)	165,000	729,560 bbl	50 bbl	2,500 bbl	729,560 bbl

Table 4: Planning Volumes for Vancouver Energy Vessels Loaded with Diluted Bitumen

Vessel Type	DWT	Cargo Capacity at Maximum Loaded Draft (43.0 ft)	Planning Discharge Volume		
			AMPD	MMPD	Regulatory WCD Based on Draft Restriction
Oil Tanker (Handymax)	46,172	319,925 bbl	50 bbl	2,500 bbl	319,925 bbl
Oil Tanker (Aframax)	115,000	667,777 bbl	50 bbl	2,500 bbl	667,777 bbl
Oil Tanker (Aframax)	125,000	614,337 bbl	50 bbl	2,500 bbl	614,337 bbl
Oil Tanker (Aframax)	142,000	648,220 bbl	50 bbl	2,500 bbl	648,220 bbl
Oil Tanker (Suezmax)	165,000	635,220 bbl	50 bbl	2,500 bbl	635,220 bbl

Probability Distributions of Oil Outflow in Vessel Impact Accidents

The largest spills from tank vessels are expected with impact accidents – groundings (bottom impact) and collisions (side impact). The oil outflow volume due to an impact accident depends on the impact type, vessel type and size, and configuration of cargo and bunker tanks on the vessel.

[3] Based on Table 5.2-1 in PDEIS.
[4] Including fresh water allowance.

Three representative double-hulled tank vessel types were analyzed with respect to theoretical oil outflow by application of the probabilistic outflow extension of the HECSALV model[5] with and without consideration of bunker fuel:

- Handymax (46,000 DWT)
- Medium-large Aframax (125,000 DWT)[6]
- Average Suezmax (165,000 DWT)[7]

Each of the vessels has 12 cargo tanks that are partially loaded based on draft-related volume restrictions (e.g., Figure 2). In addition to the cargo tanks, there are generally two bunker tanks carrying fuel oil.

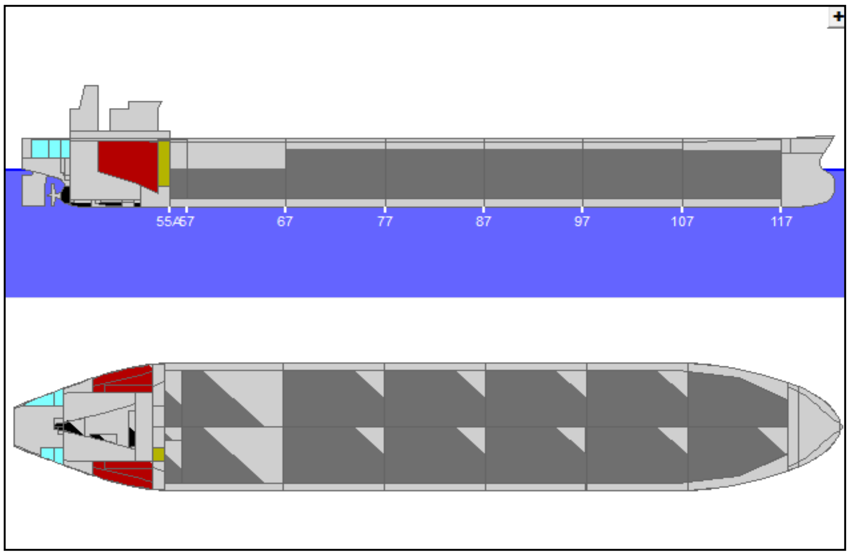

Figure 2: Partial Loading Conditions for Suezmax Tankers for 43-Ft. Draft

When an impact accident occurs and the double hulls are penetrated, one or more tanks may release oil within the hull space and/or to the environment (water), depending on the energy involved in the impact. The number of tanks involved determines the spillage volume.

The probability distributions[8] of oil outflow for tank vessels containing cargoes of Bakken crude oil are in Table 5 and Table 6 for groundings with and without consideration of damage to bunker tanks.

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[5] http://www.herbertsoftware.com/brochure/HECSALV.pdf (Described in greater detail in Appendix A.)

[6] A 125,000 DWT Aframax tanker was selected out of available model runs to be representative of the broader range of Aframax tankers, including the 105,000 DWT Aframax tanker that was suggested by the Applicant as being part of its fleet mix. The modeling of oil outflow from a 125,000 DWT versus a 105,000 DWT Aframax tanker would not be different due to the margins of error inherent in the underlying assumptions for the IMO outflow model. While the data represented from the outflow modeling is for a typical Aframax tanker of 125,000 DWT-sized vessel, the modeling outcome is also applicable to a 105,000 DWT Aframax tanker. It is also important to bear in mind that it is unlikely that the facility will have a dedicated fleet of tankers and that a 125,000 DWT tanker may well be part of the ever-changing fleet of tank vessels that calls at the facility.

[7] Slight variations in the sizes of tankers within a category would have minimal effect on the outcome of outflow modeling due to the error margins within the model in addition to variations within the tank configurations of specific tankers. These specific tankers were selected as proxies for the general size classes.

Table 5: Bakken Crude Outflow Probability Distribution: Grounding (no Bunkers)			
Percentile Spill	**Bakken Crude Oil Outflow (bbl) by Tanker Type without Bunker Fuel**		
	Handymax 46,000 DWT	**Aframax 125,000 DWT**	**Suezmax 165,000 DWT**
Probability of Outflow[9]	0.191	0.191	0.188
Mean Outflow[10]	3,881	7,975	9,208
Minimum[11]	1,050	11,863	151
10th Percentile	5,944	13,177	15,039
25th Percentile	8,001	23,731	19,297
50th Percentile	15,498	28,983	38,506
75th Percentile	27,537	55,344	68,678
90th Percentile	43,469	85,944	92,114
95th Percentile	46,677	116,544	115,695
99th Percentile	77,673	148,156	184,235
Effective WCD	89,554	171,888	184,380

Table 6: Bakken Crude Outflow Probability Distribution: Grounding (with Bunkers)			
Percentile Spill	**Bakken Crude Oil Outflow (bbl) by Tanker Type with Bunker Fuel**		
	Handymax 46,000 DWT	**Aframax 125,000 DWT**	**Suezmax 165,000 DWT**
Probability of Outflow	0.191	0.191	0.191
Mean Outflow	3,856	7.975	8,504
Minimum	1,050	11,863	151
10th Percentile	5,944	13,177	15,039
25th Percentile	8,001	23,731	19,297
50th Percentile	15,498	28,983	38,506
75th Percentile	27,537	55,344	68,678
90th Percentile	43,469	85,944	92,114
95th Percentile	46,677	116,544	115,695
99th Percentile	77,673	148,156	184,235
Effective WCD	89,554	171,888	184,380

Table 7 and Table 8 show the results for simulations of collisions involving tankers with Bakken crude oil as cargo, again with and without the consideration of bunker tank damage. In the collision simulations, there are two sets of results for Suezmax tankers. The first shows the results for damage in a collision between two Suezmax-sized vessels, which is a highly improbable event given the very low number of vessels of this size in the Columbia River. The second simulation shows the results for the collision of a Suezmax tanker with a smaller Aframax tanker, which would lead to less damage due to the lower amount of energy involved in a collision. *This is the more realistic scenario for the Columbia River and is used to estimate the "effective" WCD for this study*.

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[8] More detailed graphs of the probability distributions are shown in Appendix A.
[9] This is the probability that given an impact accident, there will be spillage of any amount.
[10] The mean or average of all potential outflow volumes including zero outflow cases.
[11] Minimum spill volume given that a spill occurs.

Table 7: Bakken Crude Outflow Probability Distribution: Collision (no Bunkers)				
Percentile Spill	Bakken Crude Oil Outflow (bbl) by Tanker Type without Bunker Fuel			
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT[12]	
			Suezmax Collision	Aframax Collision
Probability of Outflow	0.164	0.187	0.219	0.191
Mean Outflow	4,711	11,693	15,291	12,693
Minimum	2,686	3,195	1,403	3,390
10th Percentile	15,379	38,066	32,116	32,116
25th Percentile	21,511	45,846	43,532	43,532
50th Percentile	21,989	46,815	55,181	55,130
75th Percentile	43,507	89,460	98,662	55,180
90th Percentile	43,903	96,222	110,367	87,296
95th Percentile	43,985	96,228	142,477	90,686
99th Percentile	65,496	143,030	165,548	98,662
Effective WCD	87,403	189,845	220,678	110,311

Table 8: Bakken Crude Outflow Probability Distribution: Collision (with Bunkers)				
Percentile Spill	Bakken Crude Oil Outflow (bbl) by Tanker Type with Bunker Fuel			
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT	
			Suezmax Collision	Aframax Collision
Probability of Outflow	0.147	0.272	0.266	0.251
Mean Outflow	3,881	11,944	14,127	13,026
Minimum	283	1,277	1,403	1,403
10th Percentile	15,410	1,868	3,950	3,950
25th Percentile	21,448	3,101	7,718	6,692
50th Percentile	22,014	46,809	8,765	44,280
75th Percentile	35,223	51,463	55,181	55,180
90th Percentile	43,903	96,222	110,311	87,296
95th Percentile	43,966	97,719	110,397	98,662
99th Percentile	46,104	143,030	165,548	110,311
Effective WCD	66,053	189,845	220,678	110,311

With a Suezmax collision, there is a lower probability of larger spills that involve damage to more than one tank. The risk of the biggest spills in collisions goes down using a larger ship. As the ship gets larger, it has more resistance to the inner hull being penetrated in terms of the energy required.

[12] The outflow values for the Suezmax side-impact (collision) case are based on the assumption that the vessel would be hit (or itself hit) another vessel that was equal in size/weight. Given that it is unlikely that there would be more than one Suezmax tanker in the Columbia River at the same time let alone colliding with each other makes this case highly improbable. If a Suezmax were to collide with another smaller vesse, the outflow would be less.

If the tank vessel is loaded with a cargo of diluted bitumen, the volumes of outflow would be different since there would be proportionately less oil on board due to the draft restrictions. This difference would be primarily seen in groundings with bottom damage (Table 9 and Table 10).

Table 9: Diluted Bitumen Outflow Probability Distribution: Grounding (no Bunkers)

Percentile Spill	Diluted Bitumen Outflow (bbl) by Tanker Type without Bunker Fuel		
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT
Probability of Outflow	0.188	0.191	0.189
Mean Outflow	3,566	7,038	8,114
Minimum	4,441	31	1,000
10th Percentile	7,296	9,202	13,712
25th Percentile	10,976	17,297	16,756
50th Percentile	14,919	27,820	33,487
75th Percentile	24,109	52,501	60,936
90th Percentile	39,318	75,610	80,673
95th Percentile	45,356	89,951	100,486
99th Percentile	73,402	135,797	161,346
Effective WCD	84,384	151,251	163,390

Table 10: Diluted Bitumen Outflow Probability Distribution: Grounding (with Bunkers)

Percentile Spill	Diluted Bitumen Outflow (bbl) by Tanker Type with Bunker Fuel		
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT
Probability of Outflow	0.207	0.191	0.189
Mean Outflow	3,585	7,038	8,114
Minimum	4,441	31	1,000
10th Percentile	7,296	9,202	13,712
25th Percentile	10,976	17,297	16,756
50th Percentile	14,919	27,820	33,487
75th Percentile	24,109	52,501	60,936
90th Percentile	39,318	75,610	80,673
95th Percentile	45,356	89,951	100,486
99th Percentile	73,402	135,797	161,346
Effective WCD	84,384	151,251	163,390

A collision occurs if two moving objects strike each other. An allision occurs when a moving object strikes a stationary object, such as when a moving vessel strikes a pier or another vessel that is stationary. An allision would generally involve less force as one object is not moving. Estimates of side impact accidents assume that a second equally-sized vessel hits the tanker with enough force to potentially cause spillage. No simulations were conducted for allision accidents, because these incidents would generally involve less energy or force since one of the objects is stationary. Allision incidents, such as a vessel striking a dock, would be expected to result in less oil outflow. The focus of this study is worst-case discharges and other potentially large spill scenarios. Allision-related spill incidents can effectively be assumed to be similar to the smaller volume collision spills.

The results for tanker collisions involving diluted bitumen were extrapolated from the simulation results for the Bakken crude incidents based on the relatively lower amount of oil that would be on board the Suezmax tankers due to draft restrictions. The volumes for the smaller tanks would be the same as for the Bakken crude cargoes. The results are shown in Table 11 and Table 12.

Table 11: Diluted Bitumen Outflow Probability Distribution: Collision (no Bunkers)

Percentile Spill	Bakken Crude Oil Outflow (bbl) by Tanker Type without Bunker Fuel			
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT[13]	
			Suezmax Collision	Aframax Collision
Probability of Outflow	0.164	0.187	0.219	0.191
Mean Outflow	4,711	11,693	13,314	11,052
Minimum	2,686	3,195	1,222	2,952
10th Percentile	15,379	38,066	27,963	27,963
25th Percentile	21,511	45,846	37,903	37,903
50th Percentile	21,989	46,815	48,046	48,002
75th Percentile	43,507	89,460	85,905	48,045
90th Percentile	43,903	96,222	96,097	76,009
95th Percentile	43,985	96,228	124,055	78,960
99th Percentile	65,496	143,030	144,143	85,905
Effective WCD	87,403	189,845	192,144	96,048

Table 12: Diluted Bitumen Outflow Probability Distribution: Collision (with Bunkers)

Percentile Spill	Bakken Crude Oil Outflow (bbl) by Tanker Type with Bunker Fuel			
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT	
			Suezmax Collision	Aframax Collision
Probability of Outflow	0.147	0.272	0.266	0.251
Mean Outflow	3,881	11,944	12,300	11,342
Minimum	283	1,277	1,222	1,222
10th Percentile	15,410	1,868	3,439	3,439
25th Percentile	21,448	3,101	6,720	5,827
50th Percentile	22,014	46,809	7,632	38,555
75th Percentile	35,223	51,463	48,046	48,045
90th Percentile	43,903	96,222	96,048	76,009
95th Percentile	43,966	97,719	96,123	85,905
99th Percentile	46,104	143,030	144,143	96,048
Effective WCD	66,053	189,845	192,144	96,048

[13] The outflow values for the Suezmax side-impact (collision) case are based on the assumption that the vessel would be hit (or itself hit) another vessel that was equal in size/weight. Given that it is unlikely that there would be more than one Suezmax tanker in the Columbia River at the same time let alone colliding with each other makes this case highly improbable. If a Suezmax were to collide with another smaller vesse, the outflow would be less.

Effective Worst-Case Discharge Volumes

Based on the analyses above, the "effective" worst-case discharge volumes for tank vessels that would call at the proposed Vancouver Energy facility are as shown in Table 13. The regulatory WCDs are based solely on the vessel size and its maximum cargo capacity loaded to a 43.0-foot draft.

The effective WCDs are based on the outflow modeling. The incident type that would lead to each of the effective WCD volumes is explained in Table 14.

Table 13: Effective Worst Case Discharges for Environmental Impact Analysis

Tank Vessel Type/Size	Worst-Case Discharge Volume (bbl)			
	Regulatory WCD		Effective WCD	
	Bakken Crude	Diluted Bitumen	Bakken Crude	Diluted Bitumen
Handymax (46,000 DWT)	319,925	319,925	89,554	87,403
Aframax (125,000 DWT)	614,337	614,337	189,845	189,845
Suezmax (165,000 DWT)	729,560	635,220	184,380	163,390

Table 14: Explanations for Effective Worst Case Discharge Volumes

Tank Vessel Type/Size	Effective WCD Volume (bbl)		Effective WCD Incident Type		Exceptions	
	Bakken Crude	Diluted Bitumen	Bakken Crude	Diluted Bitumen	Bakken Crude	Diluted Bitumen
Handymax (46,000 DWT)	89,554	87,403	Grounding with/without bunkers	Grounding without bunkers	-	-
Aframax (125,000 DWT)	189,845	189,845	Grounding with/without bunkers	Collision without bunkers	-	-
Suezmax (165,000 DWT)	184,380	163,390	Grounding with/without bunkers	Grounding with/without bunkers	In collision with another Suezmax:[14] 220,678 bbl	In collision with another Suezmax: 192,144 bbl

The effective WCD volume for a Suezmax is based on the largest realistic scenario. The outflow values for the Suezmax side-impact (collision) case are based on the assumption that the vessel would be hit (or itself hit) another vessel that was equal in size/weight. Given that it is unlikely that there would be more than one Suezmax tanker in the Columbia River at the same time let alone colliding with each other makes this case highly improbable. If a Suezmax were to collide with smaller vessel, the outflow would be less.

Probability of Underway-Related Spillage

The probability that a WCD or any other spill might occur from a vessel while underway is dependent on a series of probabilities (Figure 3).

[14] The outflow values for the Suezmax side-impact (collision) case are based on the assumption that the vessel would be hit (or itself hit) another vessel that was equal in size/weight. Given that it is unlikely that there would be more than one Suezmax tanker in the Columbia River at the same time let alone colliding with each other makes this case highly improbable. If a Suezmax were to collide with smaller vessel, the outflow would be less.

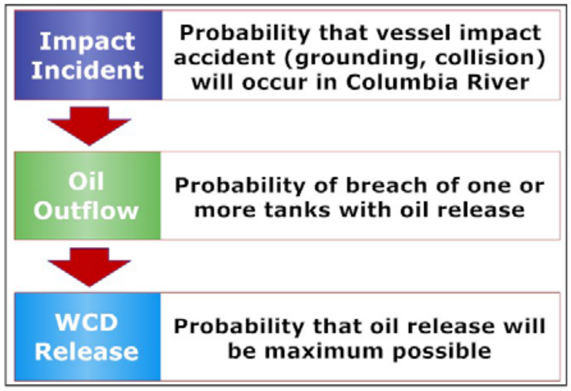

Figure 3: Series of Probabilities for Worst-Case Discharge Vessel Spill

The probabilities of WCD releases by vessel type and impact accident type are shown in Table 14. The probability of incidents is based on the data in Table 15 and Table 16.

For underway-related spills, rates of vessel accidents (i.e., collisions and groundings) and other conditions that may potentially cause a spill are based on a complex combination of factors related to characteristics of the vessels, degree of traffic, and conditions in the waterway and transit area (bathymetry, navigational issues, channel dimensions and configurations).[15] The addition of vessels to a waterway, especially if it is already somewhat congested, could increase the incidence of collision accidents among all of the vessels in the waterway.

Overall, the probability of an underway-related spill from one of the tank vessels associated with the Vancouver Energy facility is dependent on the number of vessel transits, regardless of the size of the vessel. The more transits that occur, the greater the likelihood of incidents that may lead to spillage.

Note that the terms vessel "transit", "trip", and "call" are used interchangeably in this analysis. A vessel *call* or *trip* to a port would theoretically involve two transits (i.e., a round-trip). But, since one of these transits involves an empty vessel (except for bunkers), the probability of a WCD involving crude cargo is applicable only to one of the transits.

Vancouver Energy has provided information on a tank vessel types in the fleet that may be used to transport crude oil from the facility. Projections call for 365 tank vessels (Table 15), i.e., approximately one vessel loading at the facility per day.

Table 15: Vessel Traffic per Year on the Lower Columbia River[16]

Existing Vessel Trips (Baseline 2013)		Maximum Projected Increase with Vancouver Energy		Maximum Potential Projected Increase All Other Vessels		Cumulative Projected Number Trips with Baseline		Historical Peak Vessel Trips (1999)	
All Vessels	Tank Vessels	All Vessels	Tank Vessels	All Vessels	Tank Vessels	All Vessels	Tank Vessels	All Vessels	Tank Vessels
1,457	280	365	365	1,795	326	3,617	645	2,269	n/a

The following fleet mix was provided by Tesoro Savage:

[15] The Glosten Associates et al. 2013; 2014.
[16] WorleyParsons and DNV GL Oil & Gas. 2014, based on Washington Department of Ecology VEAT data.

- 80% Handymax;
- 15% Aframax; and
- 5% Suezmax.

Vessel spill probabilities were calculated based on an assumed 365 vessel calls annually with the above vessel fleet mix. Note that any change in the fleet mix would affect the probabilities of accidents and spillage.

Historical accident statistics for tank vessel traffic[17] in the Columbia River between 1990 and 2011 (22 years) are shown in Table 16. These data were used to estimate the probability of accidents.

Table 16: Tank Vessel Accident Frequency in Columbia River (1990 – 2011)[18]

Accident Type	Incident Number	Vessel Trips	Incidents Per Trip	Trips/ Incident
Allision	9	5,288	0.00170	588
Collision	2	5,288	0.00038	2,632
Grounding	2	5,288	0.00038	2,632
Other	1	5,288	0.00019	5,263
Total	**14**	**5,288**	**0.00265**	**377**

The probabilities of WCD releases by vessel type and impact accident type are shown in Table 17, based on the fleet mix assumptions.

Table 17: Probability of Effective WCD by Vessel/Accident Type[19]

Impact Accident Type	Statistic	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT	All Tankers[20]
		80% calls	15% calls	5% calls	All Calls
Collision or Grounding	**Probability of Spill (per year)**	0.039196	0.007824	0.002617	0.049637
	Return Years for Spill	26	128	382	20
	Overall Probability WCD (per year)	0.0000547	0.0000259	0.0000011	0.0000817
	Return Years for WCD	18,282	38,610	909,091	12,240
	Effective WCD (Bakken Crude)	89,554 bbl	189,845 bbl	184,380 bbl	189,845 bbl
	Effective WCD (Diluted Bitumen)	84,384 bbl	151,121 bbl	163,390 bbl	163,390 bbl

This analysis shows that, depending on the number of tank vessels, it can be expected that that there is a spill associated with a collision or grounding once 20 years. Note that none of the incidents that occurred during 1990 – 2011 resulted in the spillage of oil.

[17] With drafts of greater than 15 feet.
[18] WorleyParsons and DNV GL Oil & Gas. 2014, based on US Coast Guard MISLE data.
[19] Fleet Mix A (365 calls): 292 Handymax, 55 Aframax, and 18 Suezmax (365 total).
[20] The effective WCD for all tankers is the largest WCD of the various tanker size categories. Likewise, the effective WCD for "any underway accident" is the largest WCD of groundings and collisions.

Hard groundings with enough bottom damage to cause spillage, are less likely to occur in the Columbia River channel than in many other locations because while the route includes some areas with rock walls, wing dams, rock jetties or nearshore outcroppings, much of the route is bounded by soft banks. There are areas of particular concern for groundings. For example in the section of River from Longview to Tongue Point, there are some rock walls and nearshore outcroppings, specifically Pillar Rock. The area from Tongue Point to the ocean side of the Columbia River Bar also presents potential hard grounding areas with several wing dams and rock jetties.

Probability of Transfer-Related Spillage

Transfer-related spill rates were calculated based on previous studies involving transfer operations (spill incidents per transfer) in Washington State and California, where transfer operations have been studied extensively as part of rulemaking,[21] and as part of an EIS-process for the BP Cherry Point Refinery North Dock.[22]

In the study conducted for Washington Ecology,[23] oil transfer rates in California were found to be 0.0134 per transfer prior to the implementation of transfer regulations in 1996. Thereafter, the rate was 0.0046 spills per transfer operation, a reduction of 34%. In Washington State, there were on average 0.0004 spills per transfer prior to 2006. With the implementation of the state's transfer regulations,[24] a similar reduction of spills as occurred in California would lead to a spill rate of 0.00026 per transfer operation.

In the course of 16 years (1995 – 2010), there were 27 transfer error incidents involving tankers in the Puget Sound.[25] One of those incidents involved bunker spillage during bunkering operations. The other 26 incidents involved the spillage of oil cargo during transfer operations. For both oil cargo transfer-error related incidents and bunker transfer-related incidents there appeared to be no issue of both bunker fuel *and* oil cargo spilling during transfers. This is because oil cargo transfer operations are generally conducted separately from bunkering operations.

At the Vancouver Energy, there are expected to be crude oil transfer operations occurring at the rate of about 360,000 bbl per day. Since the expected frequencies of transfer spills is directly related to the number of transfer operations, the fleet mix and numbers of vessel calls at the facility dock are crucial to the analysis. The more transfer operations due to the greater number of smaller vessels, the higher the frequency of transfer-related spills. An assumption of 365 transfer operations annually based on 365 vessel calls is applied to the transfer-related spill analysis.

The expected frequency of transfer-related spills is shown in Table 18.

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[21] Etkin 2006; Etkin et al. 2006.
[22] Etkin 2011; Cardno Entrix 2014.
[23] Etkin 2006.
[24] See Appendix A.
[25] Etkin 2013.

Table 18: Probability of Effective WCD Transfer-Related Spill[26]				
Statistic	**Handymax 46,000 DWT**	**Aframax 125,000 DWT**	**Suezmax 165,000 DWT**	**Total**
	80% calls	**15% calls**	**5% calls**	**100% calls**
Probability Transfer Incident/Year	0.0759	0.0143	0.0047	0.0949
Overall Probability of WCD/Year	0.00076	0.00014	0.00005	0.00095
Return Years for WCD	1,317	6,993	21,368	1,053
Effective WCD (Bakken Crude)	1,152 bbl	2,212 bbl	2,626 bbl	2,626 bbl
Effective WCD (Diluted Bitumen)	1,152 bbl	2,212 bbl	2,287 bbl	2,287 bbl

Volumes for Cargo Transfer-Related Spill Incidents

The volume of outflow for spills that might occur during cargo transfer operations at the Vancouver Energy facility (i.e., oil being transferred from the facility into tank vessels) would generally involve smaller volumes of oil than for underway-related incidents. The oil outflow probability distribution for tanker transfer errors is shown in Table 19. The outflows are based on percentages of oil cargo, which differ by vessel type. The three representative vessel types are shown. Oil transfer-related spills in Washington State have averaged 3.5 bbl with the largest having been 179 bbl.[27]

Table 19: Oil Outflow Volumes[28] *for Cargo Transfer Incidents*							
Percentile Spill	**% Outflow**	**Handymax 46,000 DWT**		**Aframax 125,000 DWT**		**Suezmax 165,000 DWT**	
		Bakken Crude (bbl)	**Diluted Bitumen (bbl)**	**Bakken Crude (bbl)**	**Diluted Bitumen (bbl)**	**Bakken Crude (bbl)**	**Diluted Bitumen (bbl)**
10th Percentile	0.000003%	0.01	0.01	0.02	0.02	0.02	0.02
25th Percentile	0.000007%	0.02	0.02	0.04	0.04	0.05	0.04
50th Percentile	0.000054%	0.17	0.17	0.33	0.33	0.39	0.34
75th Percentile	0.00054%	2	2	3	3	4	3
90th Percentile	0.004%	13	13	25	25	29	25
95th Percentile	0.008%	26	26	49	49	58	51
99th Percentile	0.18%	576	576	1,106	1,106	1,313	1,143
Effective WCD	0.36%	1,152	1,152	2,212	2,212	2,626	2,287
Regulatory WCD[29]	1 tank	26,650	26,650	53,514	53,997	60,772	52,914

Bunkering-Related Spills

The tank vessels calling at the proposed Vancouver Energy facility will periodically requiring refueling or "bunkering." Generally, bunkering operations occur at shoreline-based facilities or from bunkering barges that pull up alongside the vessels at designated anchorages.

Since no storage or vessel fueling capabilities are planned as part of the Vancouver Energy and the applicant has stated that it would not permit bunkering at the facility dock, it is assumed that bunkering

[26] Fleet Mix A (365 calls): 292 Handymax, 55 Aframax, and 18 Suezmax (365 total).
[27] Etkin 2006.
[28] Volumes are based on the outflow percentage multiplied by the cargo capacity at maximum loaded draft. This would be the volume that would be transferred into the vessel at the dock.
[29] Assumed to be the contents of a single largest cargo tank.

would occur elsewhere. Further, it is assumed that bunkering would most likely not take place in the Lower Columbia River, but rather occur at the refineries in the Puget Sound and/or California receiving crude oil shipments, or at anchorages in Puget Sound, California, Alaska, or even Hawaii, depending on the voyage of the specific vessel involved. Note that it is possible that bunkering would occur in Puget Sound even for vessels that are destined for other ports.[30] Analyses for potential bunkering-related spills were therefore not conducted in this study.

Summary of Expected Spill Frequencies

Combining the frequencies of underway- and transfer-related spills, the overall expected frequencies of spills by volume are summarized in Table 20. The relative number of Bakken crude versus diluted bitumen spills will depend on the actual types of crude that are being transported to and handled at the facility.

Table 20: Expected Vancouver Energy Vessel Spill Frequency[31]

Spill Volume Category	Estimated Frequency of Transfer-Related (Dockside) Spills		Estimated Frequency of Underway-Related Impact Accident Spills	
	Spills Per Year	Return Years	Spills Per Year	Return Years
<1 – 9 bbl	0.07118	14	0	-
10 – 99 bbl	0.01898	53	0	-
100 – 999 bbl	0.00411	243	0.01931	52
1,000 – 9,999 bbl	0.00063	1,587	0.02972	34
10,000 – 99,999 bbl	0	-	0.00050	2,018
100,000 bbl or more	0	-	0.00000	202,467
Effective WCD	0.00095	1,053	0.00011	8,999
Bakken Crude	Effective WCD: 2,626 bbl		Effective WCD: 189,845 bbl	
Diluted Bitumen	Effective WCD:2,287 bbl		Effective WCD: 163,390 bbl	

Degree of Impact of Crude Spills

The spill volumes of a sampling of the various outflow scenarios from underway- and transfer-related spills were analyzed with respect to degree of evaporation and dispersion to estimate the amount of oil remaining. This amount of oil was then assumed spread over a typical slick thickness of 0.1 mm for fresh oil and 0.0003 mm for rainbow sheen, as shown in Table 21 for Bakken crude and in Table 22 for diluted bitumen.

[30] Etkin et al. 2015.
[31] Fleet mix: 292 Handymax, 55 Aframax, and 18 Suezmax (365 total).

Table 21: Estimated Spread of Bakken Crude Oil on Water Surface						
Spill Volume (bbl)	% Remaining After 120 hours	Volume Remaining (bbl)	Covered by Fresh Slick (0.1 mm)		Covered by Rainbow Sheen (0.0003 mm)	
			Area (sq, miles)	River Length (miles)	Area (sq, miles)	River Length (miles)
1	35%	0.35	0.0002	0.0003	0.0711	0.1016
10	35%	3.5	0.0021	0.0031	0.7111	1.0158
100	35%	35	0.02	0.03	7.11	10.16
1,000	35%	350	0.21	0.31	71.11	102
10,000	35%	3,500	2.1	3.1	711.1	1,016
20,000	35%	7,000	4.2	6.2	1,422	2,032
50,000	35%	17,500	10.5	15.5	3,555	5,080
90,000	35%	31,500	19	28	6,399	9,142
100,000	35%	35,000	21	31	7,111	10,158
190,000	35%	66,500	41	58	13,510	19,300
221,000	35%	77,350	47	68	15,714	22,449
360,000	35%	126,000	77	110	25,598	36,568
642,000	35%	224,700	138	197	45,650	65,214
730,000	35%	255,500	157	224	51,907	74,153

Table 22: Estimated Spread of Diluted Bitumen Oil on Water Surface						
Spill Volume (bbl)	% Remaining After 120 hours	Volume Remaining (bbl)	Covered by Fresh Slick (0.1 mm)		Covered by Rainbow Sheen (0.0003 mm)	
			Area (sq, miles)	River Length (miles)	Area (sq, miles)	River Length (miles)
1	75%	0.75	0.0005	0.0007	0.1524	0.2177
10	75%	7.5	0.0046	0.0066	1.5237	2.1767
100	75%	75	0.05	0.07	15.24	21.77
1,000	75%	750	0.46	0.66	152.37	218
10,000	75%	7,500	4.6	6.6	1523.7	2,177
20,000	75%	15,000	9.2	13.2	3,048	4,354
50,000	75%	37,500	23.0	33.0	7,619	10,885
90,000	75%	67,500	41	59	13,713	19,590
100,000	75%	75,000	46	66	15,237	21,767
190,000	75%	142,500	87	125	28,950	41,357
221,000	75%	165,750	102	145	33,673	48,105
360,000	75%	270,000	166	237	54,853	78,361
642,000	75%	481,500	295	422	97,821	139,744
730,000	75%	547,500	336	480	111,229	158,898

Assuming the Upper Columbia River averages about 0.7 miles in width, the extent of spread on the river was estimated in length as well. In the Lower Columbia River the spill would spread out more. In both locations, significant oil would also stick to shorelines preventing the oil from actually spreading as far as is indicated. With diluted bitumen there is the possibility that some of the oil may become submerged when it comes in contact with sediment. For a Bakken crude oil spill there is the distinct possibility that some or much of the oil would burn. While this would certainly cause public safety risks that would need to be properly managed, the end result would be less oil on the river to cause damages.

Note that in an actual spill situation the oil would be patchy and not in a continuous slick. River currents could carry the oil to greater distances with some oil adhering to shorelines, depending on the adhesive properties of the oil, the configuration of the river, and the characteristics of the shoreline.

Potential Bakken Crude Oil Spill Impacts in the Columbia River

Bakken crude oil exhibits the general properties of light oils, as detailed in Appendix B. Light oils then to have a high toxicity and low persistence due to the high proportion of lighter, more volatile hydrocarbon components that are toxic, but also evaporate or dissolve relatively quickly. Bakken crude has fewer of the heavier hydrocarbon components that tend to persist in the environment and adhere to surfaces, including shorelines, as well wildlife fur and feathers.

Bakken crude is also notably volatile and potentially flammable in a spill situation. This is the greatest concern with respect to public safety in the event of a spill. Its behavior is not unlike spilled gasoline.

Potential Diluted Bitumen Spill Impacts in the Columbia River

Diluted bitumen has a higher degree of persistence and adherence and a lower degree of toxicity, depending on the exact blend and type and proportion of diluent used. Appendix C provides more information about the properties of diluted bitumen, including the potential for submergence under some circumstances.

Vessel Spill Analysis for EFSEC DEIS for Vancouver Energy

This report addresses the risks from tank vessel traffic in the Columbia River associated with the proposed Vancouver Energy facility. The analysis briefly addresses:

- The probability of tank vessel spills associated with accidents and other causes, including spills during oil transfer operations from the facility to tank vessels;
- The potential volumes of spillage from tank vessel operations;
- The probability distribution of spill volumes from tank vessel operations;
- Spill volumes related to requirements for contingency planning (average most-probable, maximum most-probable, and worst-case discharges);
- The potential impacts of spills of Bakken crude oil and diluted bitumen from tank vessels in the Columbia River; and
- Risk mitigation measures to prevent tank vessel spills in the Columbia River.[32]

Risk Assessment Approach

For *risk assessment* purposes, the *consequences* of spills from Vancouver Energy-related vessel traffic *and* the *probabilities* of those spills need to be considered:

[1]

$$Risk = probability \cdot consequences$$
$$R_{spill} = P_{spill} \cdot C_{spill}$$
$$R_s = P_s \cdot C_s$$

Where:

R_S = spill risk
P_S = probability of spill incident
C_S = consequences of spill

As part of this, the probability of each spill volume is calculated. For example, the probability that a spill of 1,000 barrels (bbl) or a worst-case discharge will occur is estimated based on historical data analyses and various modeling.

For the tank vessels, there are a number of causes for incidents or conditions (termed accidents, *A*) that may potentially cause spillage or oil outflow (*O*). For example, a grounding of a tanker may result in a spill, but not all groundings result in spills. The term "accident" is used here, but there are other non-accidental conditions that may cause spills as well that are included in this general category, e.g., corrosion, structural problems, and equipment malfunctions.

[2]

$$P_S = P_A \cdot P_O$$

[32] Risk mitigation by effective spill response is not addressed in this report.

Where:
P_S = probability of spill incident
P_A = probability of accident (situation that could *potentially* cause oil outflow)
P_O = probability that accident results in oil outflow

For each vessel type and cause type combination, there is a potential distribution of spill volumes. The spilled volume depends on the intensity or severity of the incident cause, the capacity (K) of the source (e.g., cargo load, tank volume), and the degree of outflow. The degree of outflow depends on the characteristics of the tank, the properties of the oil, the size of the hole or orifice through which the oil flows, the flow rate, environmental factors (e.g., ambient temperature), and the duration of outflow (D).

Overall, there is a probability that an incident will result in oil spillage, and various probabilities that the spillage will be of a certain volume. Usually, there is a high probability that the spillage will be relatively small, a lower probability that the spillage will be larger, and a very low probability that there will be a worst-case discharge. The probabilistic distribution of potential volumes and the range of realistic volumes depend on the source type and cause. For example, impact accidents with vessels (e.g., groundings) are more likely to cause larger spill volumes than other factors such as structural corrosion or equipment failures. Oil transfer accidents also tend to involve smaller quantities. The spilled volume in a specific incident (*i*) is a function of a variety of factors:

[3] $$V_{S_i} = f(A_i, O_i, D_i, \frac{O_i}{D_i}, K_i)$$

Where:
i = specific spill incident
f = function
A_i = accident type (by source)
O_i = oil outflow percentage
D_i = duration of outflow (time)
K_i = capacity of source
O_i/D_i = rate of outflow

There is also a probability that an accident and resultant spill will occur in a particular geographic location (*G*). For a facility, the geographic location is fixed, though there can be spills in different parts of a large facility that may have different impacts – within a secondary containment, entering a river, entering groundwater, etc. For moving sources (railroads and vessels), there are different probabilities of occurrence in different locations along the tracks or river that need to be considered.

In addition, since the seasonal timing (*T*) of spill events (e.g., in relation to salmon spawning, bird migrations, tribal hunting or fishing) can have a significant effect on spill impacts, any seasonal impacts on spill events (e.g., more derailments during colder temperatures, or more vessel traffic at certain times) should be considered in assessing risk.

[4] $$P_S(G,T) = P_S \cdot P_G \cdot P_T$$

Where:

P_S = probability of spill incident

G = geographic location

T = seasonal timing

P_G = probability of spill occurring in specific geographic location

P_T = probability of spill occurring in specific season

In addition to volume, the impact (I_S) of a spill is dependent geographic location (G), seasonal timing (T), and oil type (J).

[5] $$I_{S_i} = f(G_i, T_i, J_i)$$

Where:

i = specific spill incident

G = geographic location

T = seasonal timing

J = oil type

The environment (E) has a general sensitivity to spills by geographic location (G), seasonal timing (T), and oil type (J). For a particular location, season, and oil type combination (G_E,T_E,J_E), the magnitude of impact is determined by the volume of spillage (V_S).

[6] $$I_{S_E} = V_S \cdot I_{G_E T_E J_E}$$

Where:

E = environment

I_{SE} = impact of spill in specific environment

V_S = volume of spillage

G_E,T_E,J_E = combination of geographic location, seasonal timing, and oil type

The factors are interrelated as shown in Figure 2. Combing the formulae together, the basic approach is:

[7]
$$R_{S_i} = P_S \cdot C_S$$
$$R_{S_i} = P_S \cdot V_S \cdot I_S$$
$$R_{S_i} = P_A \cdot P_O \cdot V_S \cdot I_S$$
$$R_{S_{GT_i}} = (P_A \cdot P_O) \cdot (P_G \cdot P_T) \cdot V_S \cdot I_{S_E}$$
$$R_{S_{GT_i}} = (P_A \cdot P_O) \cdot (P_G \cdot P_T) \cdot V_S \cdot I_{G_E T_E J_E}$$
$$R_S = \sum_{i=1}^{1=n} (P_{A_i} \cdot P_{O_i}) \cdot (P_{G_i} \cdot P_{T_i}) \cdot V_{S_i} \cdot (I_{G_E T_E J_E})_i$$

The final equation indicates that the risks (probabilities and impacts) for each incident type needs to be added together for all the different source types and scenarios. Since a completely quantitative approach will not be feasible, qualitative evaluations will need to be used in some parts of the analysis.

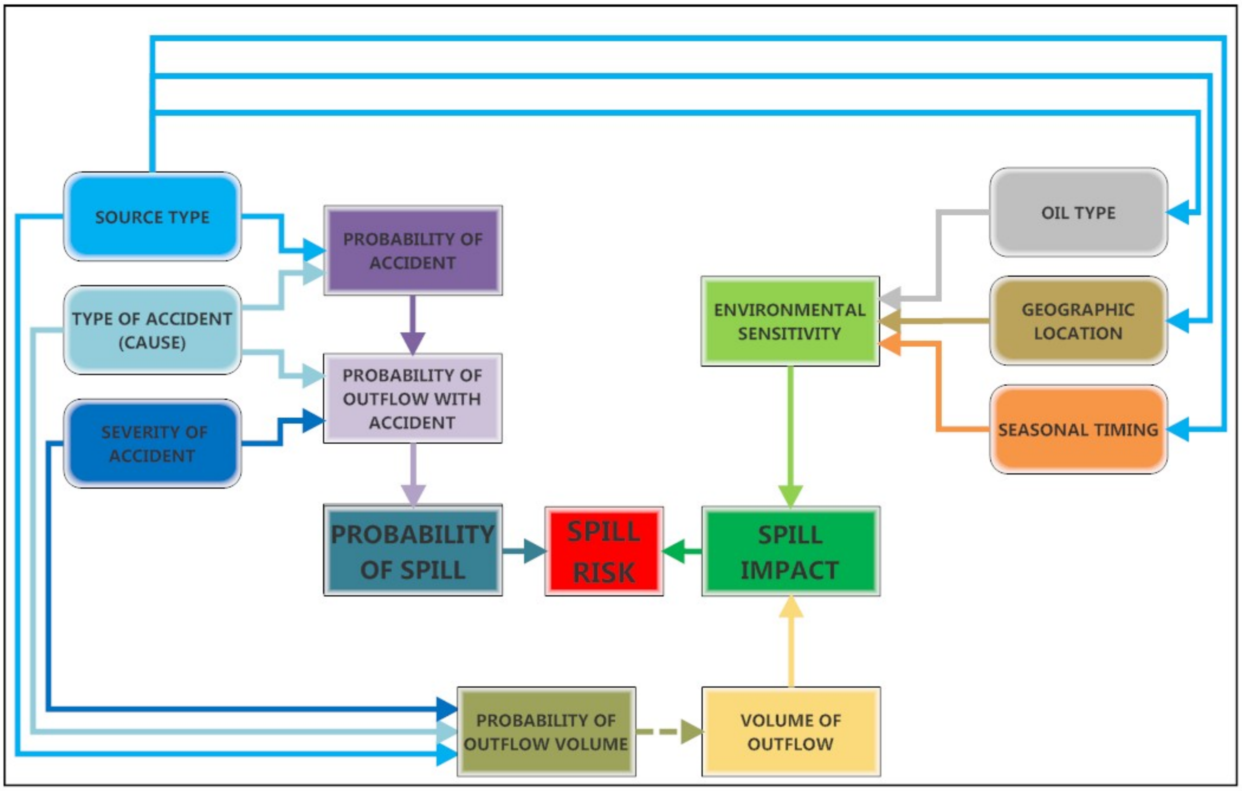

Figure 4: Probability and Consequence Factor Interrelationship in Oil Spill Risk Analysis

Vancouver Energy Vessel Spill Volume Analysis

There are two distinct set of spill volumes that need to be considered for the purposes of the Vancouver Energy EFSEC DEIS report:

- Volumes for contingency (spill response) planning, which are dictated by regulations at the federal and state levels; and
- Volumes of spills to be evaluated for potential environmental impacts and risk assessment.

Volumes for Contingency and Response Planning for Vessel Spills

There are three basic discharge (spill) volumes of concern for spill response planning based on US Coast Guard regulations:

- Average Most-Probable Discharge (AMPD)
- Maximum Most-Probable Discharge (MMPD)
- Worst-Case Discharge (WCD)

These volumes are only loosely based on the concept of probability. Small spills are more likely than very large spills or worst-case discharges. The definitions of discharge volumes by category are in Table 23.

Table 23: Definitions of Planning Volumes for Vessels		
Discharge	**Definition**	**Regulation**
AMPD	*Lesser* of 50 bbl or 1% of cargo during oil transfer operations to/from vessel.	33 CFR 155.1020
MMPD	2,500 bbl if oil capacity ≥ 25,000 bbl; 10% capacity if capacity < 25,000 bbl	
WCD	Discharge of vessel's entire oil cargo in adverse weather conditions. [33]	33 CFR 155.1020 WAC 173-182-030

Theoretically, the WCD planning volume should be based on the vessel's cargo capacity, i.e., the amount of oil it would carry when fully loaded. But, given the draft limit of 43.0 feet in the Columbia River, there is a limit as to the actual cargo that can be accommodated in the largest tankers. Since weight (and not volume) would determine the actual draft of a fully-loaded tanker, the specific gravity of the oil is a contributing factor. The more dense the oil, the less volume can be accommodated. Since Bakken crude has a specific gravity of about 0.811 (°API 43), more barrels (a volume measure) can be accommodated than diluted bitumen. The latter is heavier with a specific gravity of 0.930 (°API 20).

Another issue involved in determining the possible cargo capacity given the 43.0-foot channel draft restriction, is the lightship (empty) weight of the vessel itself. Ironically, a smaller vessel with a lower lightship weight might actually carry more oil than a larger vessel with a heavier lightship weight when there are draft restrictions. Planning volumes by vessel type and cargo are shown in Table 24 and Table 25. Loading conditions are based on the configurations shown in Figure 3 and Figure 4.

Table 24: Planning Volumes for Vancouver Energy Vessels Loaded with Bakken Crude

Vessel Type[34]	DWT	Cargo Capacity at Maximum Loaded Draft (43.0 ft)[35]	Planning Discharge Volume		
			AMPD	**MMPD**	**WCD Based on Draft Restriction**
Oil Tanker (Handymax)	46,172	319,925 bbl	50 bbl	2,500 bbl	319,925 bbl
Oil Tanker (Aframax)	115,000	667,777 bbl	50 bbl	2,500 bbl	667,777 bbl
Oil Tanker (Aframax)	125,000	614,337 bbl	50 bbl	2,500 bbl	614,337 bbl
Oil Tanker (Aframax)	142,000	642,428 bbl	50 bbl	2,500 bbl	642,428 bbl
Oil Tanker (Suezmax)	165,000	729,560 bbl	50 bbl	2,500 bbl	729,560 bbl

[33] The weather conditions that will be considered when identifying response systems and equipment in a response plan for the applicable operating environment. Factors to consider include, but are not limited to, significant wave height, ice, temperature, weather-related visibility, and currents within the Captain of the Port (COTP) zone in which the systems or equipment are intended to function.
[34] Based on Table 5.2-1 in PDEIS.
[35] Including fresh water allowance.

Table 25: Planning Volumes for Vancouver Energy Vessels Loaded with Diluted Bitumen					
Vessel Type	**DWT**	**Cargo Capacity at Maximum Loaded Draft (43.0 ft)**	**Planning Discharge Volume**		
			AMPD	**MMPD**	**WCD Based on Draft Restriction**
Oil Tanker (Handymax)	46,172	319,925 bbl	50 bbl	2,500 bbl	319,925 bbl
Oil Tanker (Aframax)	115,000	667,777 bbl	50 bbl	2,500 bbl	667,777 bbl
Oil Tanker (Aframax)	125,000	614,337 bbl	50 bbl	2,500 bbl	614,337 bbl
Oil Tanker (Aframax)	142,000	648,220 bbl	50 bbl	2,500 bbl	648,220 bbl
Oil Tanker (Suezmax)	165,000	635,220 bbl	50 bbl	2,500 bbl	635,220 bbl

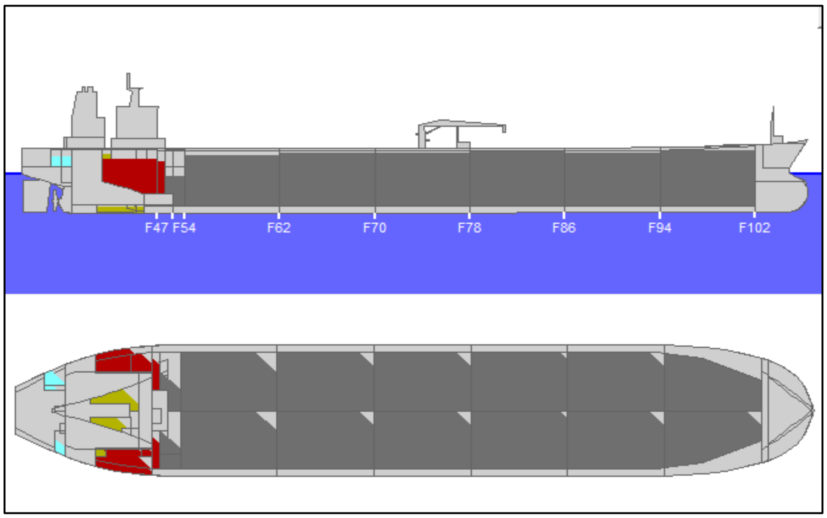

Figure 5: Partial Loading Conditions for Aframax Tankers for 43-Ft. Draft

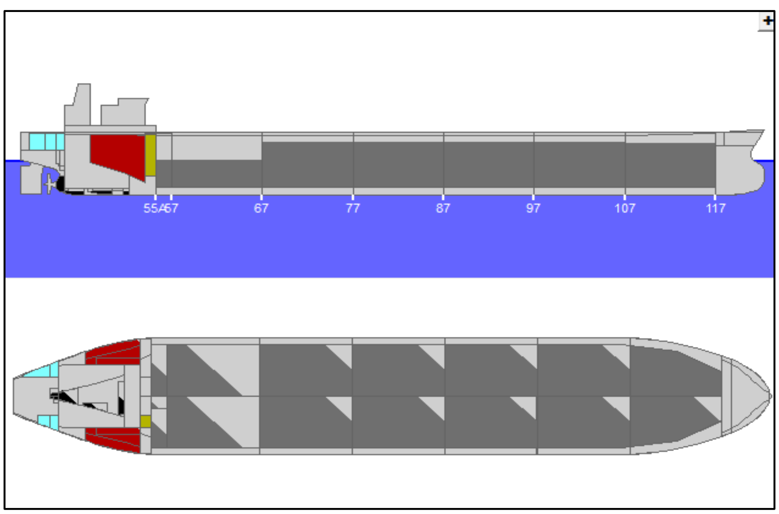

Figure 6: Partial Loading Conditions for Suezmax Tankers for 43-Ft. Draft

Basic Assumptions on Vancouver Energy Facility Throughput

For this analysis (and the related analysis conducted for rail transport risk) the following basic assumptions have been applied:

- The overall annual throughput at the facility will average 360,000 barrels (bbl) per day across 365 days for a maximum annual throughput of 131.4 million bbl;
- Rail deliveries of crude oil to the facility will be limited to 120-car train length unit trains by the loading facilities and proposed rail infrastructure at Terminal 5;
- The maximum volume per rail tank car is assumed to be 750 bbl for air permitting purposes, though actual carloads are limited by cargo weight, which is affected by oil density, by tank car weight, which is affected by the design, and by vapor space requirements to allow for expansion of the oil and to control for buildup of volatiles;[36]
- There would be four trains per day, with a possible fifth train infrequently on some days;
- The tank vessel departures will range from 345 to a maximum of 365 annual calls due to constraints in time periods when vessels can arrive at the Columbia Bar in conditions suitable to departure without having to anchor or loiter and in consideration of potential weather closures;
- For consistency in rail inputs and vessel output a fleet mix that includes some larger vessels must be considered; and
- A fleet mix of 80% Handymax tankers (average 46,000 MDWT), 15% Aframax (average 105,000 MDWT), and 5% Suezmaz (average 165,000 MDWT) across 365 vessel calls per year, as provided by Tesoro Savage is assumed.

Probability Distributions of Oil Outflow in Vessel Impact Accidents

The largest spills from tank vessels are expected with impact accidents – groundings (bottom impact) and collisions[37] (side impact). The oil outflow volume due to an impact accident depends on the impact type, vessel type and size, and configuration of cargo and bunker tanks on the vessel.

Three representative double-hulled tank vessel types were analyzed with respect to theoretical oil outflow by application of the probabilistic outflow extension of the HECSALV model[38] with and without consideration of bunker fuel:

- Handymax (46,000 DWT)
- Medium-large Aframax (125,000 DWT)[39]

[36] In actual practice, the tank cars often do not exceed 650 to 690 bbl of cargo loading.

[37] A collision occurs if two moving objects strike each other. An allision occurs when a moving object strikes a stationary object, such as when a moving vessel strikes a pier or another vessel that is stationary. An allision would generally involve less force as one object is not moving. Estimates of side impact accidents assume that a second equally-sized vessel hits the tanker with enough force to potentially cause spillage.

[38] http://www.herbertsoftware.com/brochure/HECSALV.pdf (Described in greater detail in Appendix A.)

[39] A 125,000 DWT Aframax tanker was selected out of available model runs to be representative of the broader range of Aframax tankers, including the 105,000 DWT Aframax tanker that was suggested by the Applicant as being part of its fleet mix. The modeling of oil outflow from a 125,000 DWT versus a 105,000 DWT Aframax tanker

- Average Suezmax (165,000 DWT)[40]

Each of the vessels has 12 cargo tanks that are partially loaded based on draft-related volume restrictions (e.g., Figure 7). In addition to the cargo tanks, there are generally two bunker tanks carrying fuel oil.

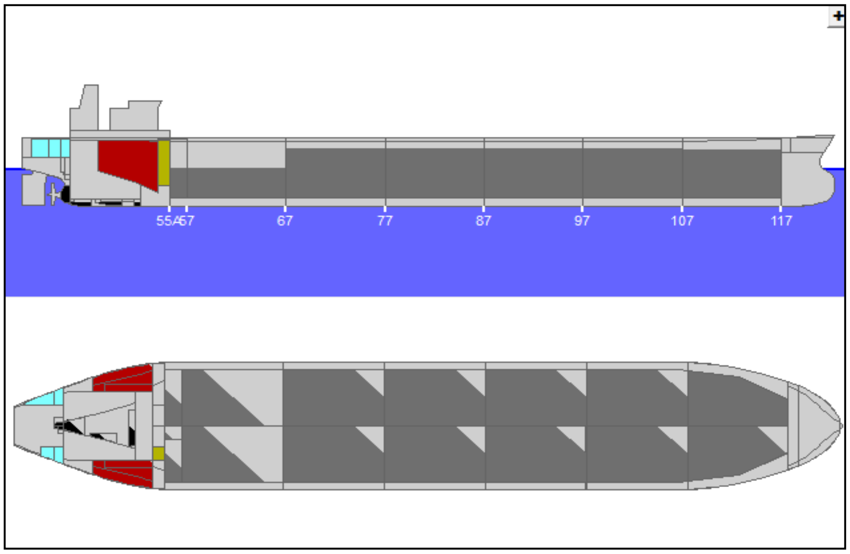

Figure 7: Partial Loading Conditions for Suezmax Tankers for 43-Ft. Draft

The probability distributions of oil outflow for tank vessels containing cargoes of Bakken crude oil are in Table 26 and Table 27 for groundings with and without consideration of damage to bunker tanks.

Table 26: Bakken Crude Outflow Probability Distribution: Grounding (no Bunkers)

Percentile Spill	Bakken Crude Oil Outflow (bbl) by Tanker Type without Bunker Fuel		
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT
Probability of Outflow[41]	0.191	0.191	0.188
Mean Outflow[42]	3,881	7,975	9,208
Minimum[43]	1,050	11,863	151
10th Percentile	5,944	13,177	15,039
25th Percentile	8,001	23,731	19,297
50th Percentile	15,498	28,983	38,506
75th Percentile	27,537	55,344	68,678

would not be different due to the margins of error inherent in the underlying assumptions for the IMO outflow model. While the data represented from the outflow modeling is for a typical Aframax tanker of 125,000 DWT-sized vessel, the modeling outcome is also applicable to a 105,000 DWT Aframax tanker. It is also important to bear in mind that it is unlikely that the facility will have a dedicated fleet of tankers and that a 125,000 DWT tanker may well be part of the ever-changing fleet of tank vessels that calls at the facility.

[40] Slight variations in the sizes of tankers within a category would have minimal effect on the outcome of outflow modeling due to the error margins within the model in addition to variations within the tank configurations of specific tankers. These specific tankers were selected as proxies for the general size classes.

[41] This is the probability that given an impact accident, there will be spillage of any amount.

[42] The mean or average of all potential outflow volumes including zero outflow cases.

[43] Minimum spill volume given that a spill occurs.

Table 26: Bakken Crude Outflow Probability Distribution: Grounding (no Bunkers)			
Percentile Spill	**Bakken Crude Oil Outflow (bbl) by Tanker Type without Bunker Fuel**		
	Handymax 46,000 DWT	**Aframax 125,000 DWT**	**Suezmax 165,000 DWT**
90th Percentile	43,469	85,944	92,114
95th Percentile	46,677	116,544	115,695
99th Percentile	77,673	148,156	184,235
Effective WCD	89,554	171,888	184,380

Table 27: Bakken Crude Outflow Probability Distribution: Grounding (with Bunkers)			
Percentile Spill	**Bakken Crude Oil Outflow (bbl) by Tanker Type with Bunker Fuel**		
	Handymax 46,000 DWT	**Aframax 125,000 DWT**	**Suezmax 165,000 DWT**
Probability of Outflow	0.191	0.191	0.191
Mean Outflow	3,856	7.975	8,504
Minimum	1,050	11,863	151
10th Percentile	5,944	13,177	15,039
25th Percentile	8,001	23,731	19,297
50th Percentile	15,498	28,983	38,506
75th Percentile	27,537	55,344	68,678
90th Percentile	43,469	85,944	92,114
95th Percentile	46,677	116,544	115,695
99th Percentile	77,673	148,156	184,235
Effective WCD	89,554	171,888	184,380

Table 28 and Table 29 show the results for simulations of collisions involving tankers with Bakken crude oil as cargo, again with and without the consideration of bunker tank damage. In the collision simulations, there are two sets of results for Suezmax tankers.

The first shows the results for damage in a collision between two Suezmax-sized vessels, which is a highly improbable event given the very low number of vessels of this size in the Columbia River.

The second simulation shows the results for the collision of a Suezmax tanker with a smaller Aframax tanker, which would lead to less damage due to the lower amount of energy involved in a collision. *This is the more realistic scenario for the Columbia River and is used to estimate the "effective" WCD for this study.*

Table 28: Bakken Crude Outflow Probability Distribution: Collision (no Bunkers)				
Percentile Spill	**Bakken Crude Oil Outflow (bbl) by Tanker Type without Bunker Fuel**			
	Handymax 46,000 DWT	**Aframax 125,000 DWT**	**Suezmax 165,000 DWT[44]**	
			Suezmax Collision	**Aframax Collision**
Probability of Outflow	0.164	0.187	0.219	0.191
Mean Outflow	4,711	11,693	15,291	12,693
Minimum	2,686	3,195	1,403	3,390
10th Percentile	15,379	38,066	32,116	32,116
25th Percentile	21,511	45,846	43,532	43,532
50th Percentile	21,989	46,815	55,181	55,130
75th Percentile	43,507	89,460	98,662	55,180
90th Percentile	43,903	96,222	110,367	87,296
95th Percentile	43,985	96,228	142,477	90,686
99th Percentile	65,496	143,030	165,548	98,662
Effective WCD	87,403	189,845	220,678	110,311

Table 29: Bakken Crude Outflow Probability Distribution: Collision (with Bunkers)				
Percentile Spill	**Bakken Crude Oil Outflow (bbl) by Tanker Type with Bunker Fuel**			
	Handymax 46,000 DWT	**Aframax 125,000 DWT**	**Suezmax 165,000 DWT**	
			Suezmax Collision	**Aframax Collision**
Probability of Outflow	0.147	0.272	0.266	0.251
Mean Outflow	3,881	11,944	14,127	13,026
Minimum	283	1,277	1,403	1,403
10th Percentile	15,410	1,868	3,950	3,950
25th Percentile	21,448	3,101	7,718	6,692
50th Percentile	22,014	46,809	8,765	44,280
75th Percentile	35,223	51,463	55,181	55,180
90th Percentile	43,903	96,222	110,311	87,296
95th Percentile	43,966	97,719	110,397	98,662
99th Percentile	46,104	143,030	165,548	110,311
Effective WCD	66,053	189,845	220,678	110,311

A collision occurs if two moving objects strike each other. An allision occurs when a moving object strikes a stationary object, such as when a moving vessel strikes a pier or another vessel that is stationary. An allision would generally involve less force as one object is not moving. Estimates of side impact accidents assume that a second equally-sized vessel hits the tanker with enough force to potentially cause spillage. No simulations were conducted for allision accidents, because these incidents would generally involve less energy or force since one of the objects is stationary. Allision incidents, such as a vessel

[44] The outflow values for the Suezmax side-impact (collision) case are based on the assumption that the vessel would be hit (or itself hit) another vessel that was equal in size/weight. Given that it is unlikely that there would be more than one Suezmax tanker in the Columbia River at the same time let alone colliding with each other makes this case highly improbable. If a Suezmax were to collide with another smaller vesse, the outflow would be less.

striking a dock, would be expected to result in less oil outflow. The focus of this study is worst-case discharges and other potentially large spill scenarios. Allision-related spill incidents can effectively be assumed to be similar to the smaller volume collision spills.

With a Suezmax collision, there is a lower probability of larger spills that involve damage to more than one tank. The risk of the biggest spills in collisions goes down using a larger ship. As the ship gets larger, it has more resistance to the inner hull being penetrated in terms of the energy required.

If the tank vessel is loaded with a cargo of diluted bitumen, the volumes of outflow would be different since there would be proportionately less oil on board due to the draft restrictions. This difference would be primarily seen in groundings with bottom damage (Table 30 and Table 31).

Table 30: Diluted Bitumen Outflow Probability Distribution: Grounding (no Bunkers)

Percentile Spill	Diluted Bitumen Outflow (bbl) by Tanker Type without Bunker Fuel		
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT
Probability of Outflow	0.188	0.191	0.189
Mean Outflow	3,566	7,038	8,114
Minimum	4,441	31	1,000
10th Percentile	7,296	9,202	13,712
25th Percentile	10,976	17,297	16,756
50th Percentile	14,919	27,820	33,487
75th Percentile	24,109	52,501	60,936
90th Percentile	39,318	75,610	80,673
95th Percentile	45,356	89,951	100,486
99th Percentile	73,402	135,797	161,346
Effective WCD	84,384	151,251	163,390

Table 31: Diluted Bitumen Outflow Probability Distribution: Grounding (with Bunkers)

Percentile Spill	Diluted Bitumen Outflow (bbl) by Tanker Type with Bunker Fuel		
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT
Probability of Outflow	0.207	0.191	0.189
Mean Outflow	3,585	7,038	8,114
Minimum	4,441	31	1,000
10th Percentile	7,296	9,202	13,712
25th Percentile	10,976	17,297	16,756
50th Percentile	14,919	27,820	33,487
75th Percentile	24,109	52,501	60,936
90th Percentile	39,318	75,610	80,673
95th Percentile	45,356	89,951	100,486
99th Percentile	73,402	135,797	161,346
Effective WCD	84,384	151,251	163,390

The results for tanker collisions involving diluted bitumen were extrapolated from the simulation results for the Bakken crude incidents based on the relatively lower amount of oil that would be on board the Suezmax tankers due to draft restrictions. The volumes for the smaller tanks would be the same as for the Bakken crude cargoes. The results are shown in Table 32 and Table 33.

Table 32: Diluted Bitumen Outflow Probability Distribution: Collision (no Bunkers)

Percentile Spill	Bakken Crude Oil Outflow (bbl) by Tanker Type without Bunker Fuel			
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT[45]	
			Suezmax Collision	Aframax Collision
Probability of Outflow	0.164	0.187	0.219	0.191
Mean Outflow	4,711	11,693	13,314	11,052
Minimum	2,686	3,195	1,222	2,952
10th Percentile	15,379	38,066	27,963	27,963
25th Percentile	21,511	45,846	37,903	37,903
50th Percentile	21,989	46,815	48,046	48,002
75th Percentile	43,507	89,460	85,905	48,045
90th Percentile	43,903	96,222	96,097	76,009
95th Percentile	43,985	96,228	124,055	78,960
99th Percentile	65,496	143,030	144,143	85,905
Effective WCD	87,403	189,845	192,144	96,048

Table 33: Diluted Bitumen Outflow Probability Distribution: Collision (with Bunkers)

Percentile Spill	Bakken Crude Oil Outflow (bbl) by Tanker Type with Bunker Fuel			
	Handymax 46,000 DWT	Aframax 125,000 DWT	Suezmax 165,000 DWT	
			Suezmax Collision	Aframax Collision
Probability of Outflow	0.147	0.272	0.266	0.251
Mean Outflow	3,881	11,944	12,300	11,342
Minimum	283	1,277	1,222	1,222
10th Percentile	15,410	1,868	3,439	3,439
25th Percentile	21,448	3,101	6,720	5,827
50th Percentile	22,014	46,809	7,632	38,555
75th Percentile	35,223	51,463	48,046	48,045
90th Percentile	43,903	96,222	96,048	76,009
95th Percentile	43,966	97,719	96,123	85,905
99th Percentile	46,104	143,030	144,143	96,048
Effective WCD	66,053	189,845	192,144	96,048

[45] The outflow values for the Suezmax side-impact (collision) case are based on the assumption that the vessel would be hit (or itself hit) another vessel that was equal in size/weight. Given that it is unlikely that there would be more than one Suezmax tanker in the Columbia River at the same time let alone colliding with each other makes this case highly improbable. If a Suezmax were to collide with smaller vessel, the outflow would be less.

Effective Worst-Case Discharge Volumes

Based on the analyses above, the "effective" worst-case discharge volumes for tank vessels that would call at the proposed Vancouver Energy facility are as shown in Table 34. The regulatory WCDs are based solely on the vessel size and its maximum cargo capacity loaded to a 43.0-foot draft.

The effective WCDs are based on the outflow modeling. The incident type that would lead to each of the effective WCD volumes is explained in Table 35. The effective WCD volume for a Suezmax is based on the largest realistic scenario. The outflow values for the Suezmax side-impact (collision) case are based on the assumption that the vessel would be hit (or itself hit) another vessel that was equal in size/weight. Given that it is unlikely that there would be more than one Suezmax tanker in the Columbia River at the same time let alone colliding with each other makes this case highly improbable. If a Suezmax were to collide with smaller vessel, the outflow would be less

Table 34: Effective Worst Case Discharges for Environmental Impact Analysis

Tank Vessel Type/Size	Worst-Case Discharge Volume (bbl)			
	Regulatory WCD		Effective WCD	
	Bakken Crude	Diluted Bitumen	Bakken Crude	Diluted Bitumen
Handymax (46,000 DWT)	319,925	319,925	89,554	87,403
Aframax (125,000 DWT)	614,337	614,337	189,845	189,845
Suezmax (165,000 DWT)	729,560	635,220	184,380	163,390

Table 35: Explanations for Effective Worst Case Discharge Volumes

Tank Vessel Type/Size	Effective WCD Volume (bbl)		Effective WCD Incident Type		Exceptions	
	Bakken Crude	Diluted Bitumen	Bakken Crude	Diluted Bitumen	Bakken Crude	Diluted Bitumen
Handymax (46,000 DWT)	89,554	87,403	Grounding with/without bunkers	Grounding without bunkers	-	-
Aframax (125,000 DWT)	189,845	189,845	Grounding with/without bunkers	Collision without bunkers	-	-
Suezmax (165,000 DWT)	184,380	163,390	Grounding with/without bunkers	Grounding with/without bunkers	In collision with another Suezmax:[46] 220,678 bbl	In collision with another Suezmax: 192,144 bbl

Bunkering-Related Spills

The tank vessels calling at the proposed Vancouver Energy facility will periodically requiring refueling or "bunkering." Generally, bunkering operations occur at shoreline-based facilities or from bunkering barges that pull up alongside the vessels at designated anchorages.

[46] The outflow values for the Suezmax side-impact (collision) case are based on the assumption that the vessel would be hit (or itself hit) another vessel that was equal in size/weight. Given that it is unlikely that there would be more than one Suezmax tanker in the Columbia River at the same time let alone colliding with each other makes this case highly improbable. If a Suezmax were to collide with smaller vessel, the outflow would be less.

Since no storage or vessel fueling capabilities are planned as part of the Vancouver Energy and the applicant has stated that it would not permit bunkering at the facility dock, it is assumed that bunkering would occur elsewhere. Further, it is assumed that bunkering would most likely not take place in the Lower Columbia River, but rather occur at the refineries in the Puget Sound and/or California receiving crude oil shipments, or at anchorages in Puget Sound, California, Alaska, or even Hawaii, depending on the voyage of the specific vessel involved. Note that it is possible that bunkering would occur in Puget Sound even for vessels that are destined for other ports.[47]

Analyses for potential bunkering-related spills were therefore not conducted in this study.

Vessel Spill Probability

The probability of a tank vessel associated with the Vancouver Energy project having a spill will be considered in two categories:

- Underway-related spills in the Columbia River; and
- Transfer-related spills at the facility dock.

Probability of Transit-Related Spillage

The probability that a WCD or any other spill might occur from a vessel while underway is dependent on a series of probabilities (Figure 8).

For underway-related spills, rates of vessel accidents (i.e., collisions and groundings) and other conditions that may potentially cause a spill are based on a complex combination of factors related to characteristics of the vessels, degree of traffic, and conditions in the waterway and transit area (bathymetry, navigational issues, channel dimensions and configurations).[48] The addition of vessels to a waterway, especially if it is already somewhat congested, could increase the incidence of collision accidents among all of the vessels in the waterway.

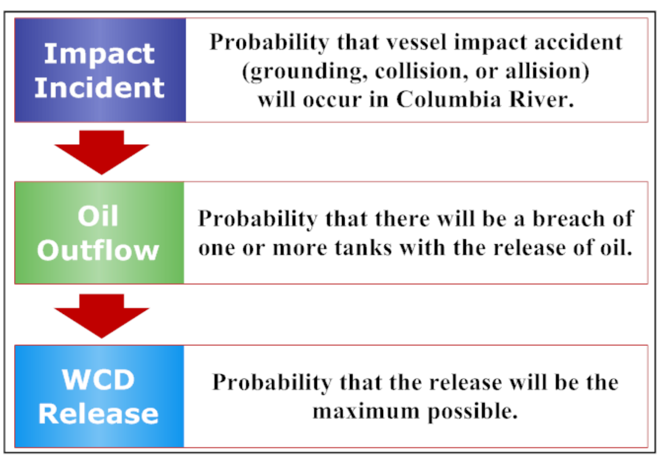

Figure 8: Series of Probabilities for Worst-Case Discharge Vessel Spill

[47] Etkin et al. 2015.
[48] The Glosten Associates et al. 2013; 2014.

Overall, the probability of an underway-related spill from one of the tank vessels associated with the Vancouver Energy facility is dependent on the number of vessel transits, regardless of the size of the vessel. The more transits that occur, the greater the likelihood of incidents that may lead to spillage.

Note that the terms vessel "transit", "trip", and "call" are used interchangeably in this analysis. A vessel *call* or *trip* to a port would theoretically involve two transits (round-trip). But, since one of these transits involves an empty vessel (except for bunkers), the probability of a WCD involving crude cargo is applicable only to one of the transits.

Vancouver Energy has provided information on a tank vessel types in the fleet that may be used to transport crude oil from the facility. Projections call for 365 tank vessels (Table 36), i.e., approximately one vessel loading at the facility per day.

Table 36: Vessel Traffic per Year on the Lower Columbia River[49]

Existing Vessel Trips (Baseline 2013)		Maximum Projected Increase with Vancouver Energy		Maximum Potential Projected Increase All Other Vessels		Cumulative Projected Number Trips with Baseline		Historical Peak Vessel Trips (1999)	
All Vessels	Tank Vessels	All Vessels	Tank Vessels	All Vessels	Tank Vessels	All Vessels	Tank Vessels	All Vessels	Tank Vessels
1,457	280	365	365	1,795	326	3,617	645	2,269	n/a

The following fleet mix was provided by Tesoro Savage:

- 80% Handymax;
- 15% Aframax; and
- 5% Suezmax.

Vessel spill probabilities were calculated based on an assumed 365 vessel calls annually with the above vessel fleet mix (Table 37). Note that any change in the fleet mix would affect the probabilities of accidents and spillage.

Table 37: Representative Tank Vessel Fleet Mixes Applied in Probability Analysis

Characteristic	Tank Vessel Size Category			Total
	Handymax MDWT 46,172 319,925 bbl	Aframax MDWT 105,000 609,709 bbl	Suezmax MDWT 165,000 729,560 bbl	
Percentage	80%	15%	5%	**100%**
Bbl/Year	105,120,000	19,710,000	6,570,000	**131,400,000**
Estimated Annual Calls	292	55	18	**365**

Historical accident statistics for tank vessel traffic[50] in the Columbia River between 1990 and 2011 (22 years) are shown in Table 38. These data were used to estimate the probability of accidents.

[49] WorleyParsons and DNV GL Oil & Gas. 2014, based on Washington Department of Ecology VEAT data.

Table 38: Tank Vessel Accident Frequency in Columbia River (1990 – 2011)[51]				
Accident Type	**Incident Number**	**Vessel Trips**	**Incidents Per Trip**	**Trips/ Incident**
Allision	9	5,288	0.00170	588
Collision	2	5,288	0.00038	2,632
Grounding	2	5,288	0.00038	2,632
Other	1	5,288	0.00019	5,263
Total	**14**	**5,288**	**0.00265**	**377**

The probabilities of WCD releases by vessel type and impact accident type are shown in Table 39.

Table 39: Probability of Effective WCD by Vessel/Accident Type[52]					
Impact Accident Type	**Statistic**	**Handymax 46,000 DWT**	**Aframax 125,000 DWT**	**Suezmax 165,000 DWT**	**All Tankers[53]**
		80% calls	**15% calls**	**5% calls**	**All Calls**
Grounding	**Probability Grounding (per year)**	0.1104	0.0207	0.0069	0.138
	Probability Oil Outflow/Spillage	0.191	0.191	0.188	0.191
	Probability WCD Release	0.002	0.006	0.001	0.009
	Probability of Spill (per year)	0.021086	0.003954	0.001297	0.026337
	Return Years for Spill	47	253	771	38
	Overall Probability WCD (per year)	0.000042	0.000024	0.000001	0.000067
	Return Years for WCD	23,712	42,155	770,891	14,925
	Effective WCD (Bakken Crude)	89,554 bbl	171,888 bbl	184,380 bbl	184,380 bbl
	Effective WCD (Diluted Bitumen)	84,384 bbl	151,251 bbl	163,390 bbl	163,390 bbl
Collision	**Probability Collision (per year)**	0.1104	0.0207	0.0069	0.138
	Probability Oil Outflow/Spillage	0.164	0.187	0.191	0.542
	Probability WCD Release	0.0007	0.0005	0.0001	0.0013
	Probability of Spill (per year)	0.01811	0.00387	0.00132	0.02330
	Return Years for Spill	55	258	759	43
	Overall Probability WCD (per year)	0.0000127	0.0000019	0.0000001	0.0000147
	Return Years for WCD	78,902	516,676	7,587,829	68,027
	Effective WCD (Bakken Crude)	89,554 bbl	189,845 bbl	163,390 bbl	189,845 bbl
	Effective WCD (Diluted Bitumen)	84,384 bbl	151,121 bbl	96,048 bbl	151,121 bbl
Collision or Grounding	**Probability of Spill (per year)**	0.039196	0.007824	0.002617	0.049637
	Return Years for Spill	26	128	382	20
	Overall Probability WCD (per year)	0.0000547	0.0000259	0.0000011	0.0000817
	Return Years for WCD	18,282	38,610	909,091	12,240
	Effective WCD (Bakken Crude)	89,554 bbl	189,845 bbl	184,380 bbl	189,845 bbl
	Effective WCD (Diluted Bitumen)	84,384 bbl	151,121 bbl	163,390 bbl	163,390 bbl

[50] With drafts of greater than 15 feet.
[51] WorleyParsons and DNV GL Oil & Gas. 2014, based on US Coast Guard MISLE data.
[52] Fleet Mix A (365 calls): 292 Handymax, 55 Aframax, and 18 Suezmax (365 total).
[53] The effective WCD for all tankers is the largest WCD of the various tanker size categories. Likewise, the effective WCD for "any underway accident" is the largest WCD of groundings and collisions.

This analysis shows that, depending on the number of tank vessels, it can be expected that that there is a spill associated with a collision or grounding once 20 years. Note that none of the incidents that occurred during 1990 – 2011 resulted in the spillage of oil.

Hard groundings with enough bottom damage to cause spillage, are less likely to occur in the Columbia River channel than in many other locations because while the route includes some areas with rock walls, wing dams, rock jetties or nearshore outcroppings, much of the route is bounded by soft banks. There are areas of particular concern for groundings. For example in the section of River from Longview to Tongue Point, there are some rock walls and nearshore outcroppings, specifically Pillar Rock. The area from Tongue Point to the ocean side of the Columbia River Bar also presents potential hard grounding areas with several wing dams and rock jetties.

Probability of Transfer-Related Spillage

Transfer-related spill rates were calculated based on previous studies involving transfer operations (spill incidents per transfer) in Washington State and California, where transfer operations have been studied extensively as part of rulemaking,[54] and as part of an EIS-process for the BP Cherry Point Refinery North Dock.[55]

In the study conducted for Washington Ecology,[56] oil transfer rates in California were found to be 0.0134 per transfer prior to the implementation of transfer regulations in 1996. Thereafter, the rate was 0.0046 spills per transfer operation, a reduction of 34%. In Washington State, there were on average 0.0004 spills per transfer prior to 2006. With the implementation of the state's transfer regulations,[57] a similar reduction of spills as occurred in California would lead to a spill rate of 0.00026 per transfer operation.

In the course of 16 years (1995 – 2010), there were 27 transfer error incidents involving tankers in the Puget Sound.[58] One of those incidents involved bunker spillage during bunkering operations. The other 26 incidents involved the spillage of oil cargo during transfer operations. For both oil cargo transfer-error related incidents and bunker transfer-related incidents there appeared to be no issue of both bunker fuel *and* oil cargo spilling during transfers. This is because oil cargo transfer operations are generally conducted separately from bunkering operations.

At the Vancouver Energy, there are expected to be crude oil transfer operations occurring at the rate of about 360,000 bbl per day. Since the expected frequencies of transfer spills is directly related to the number of transfer operations, the fleet mix and numbers of vessel calls at the facility dock are crucial to the analysis. The more transfer operations due to the greater number of smaller vessels, the higher the frequency of transfer-related spills. An assumption of 365 transfer operations annually based on 365 vessel calls is applied to the transfer-related spill analysis.

The expected frequencies of transfer-related spills are shown in Table 40.

[54] Etkin 2006; Etkin et al. 2006.
[55] Etkin 2011; Cardno Entrix 2014.
[56] Etkin 2006.
[57] See Appendix A.
[58] Etkin 2013.

Table 40: Probability of Effective WCD Transfer-Related Spill: Fleet Mix A (365 Calls)[59]				
Statistic	**Handymax 46,000 DWT**	**Aframax 125,000 DWT**	**Suezmax 165,000 DWT**	**Total**
	80% calls	**15% calls**	**5% calls**	**100% calls**
Number of Transfers/Year	292	55	18	365
Probability Transfer Incident/Year	0.0759	0.0143	0.0047	0.0949
Probability Oil Outflow/Spillage	1	1	1	1.0
Probability WCD Release	0.01	0.01	0.01	0.01
Overall Probability of WCD/Year	0.00076	0.00014	0.00005	0.00095
Return Years for WCD	1,317	6,993	21,368	1,053
Effective WCD (Bakken Crude)	1,152 bbl	2,212 bbl	2,626 bbl	2,626 bbl
Effective WCD (Diluted Bitumen)	1,152 bbl	2,212 bbl	2,287 bbl	2,287 bbl

Summary of Expected Spill Frequencies

Combining the frequencies of underway- and transfer-related spills, the overall expected frequencies of spills by volume are summarized in Table 41.

The relative number of Bakken crude versus diluted bitumen spills will depend on the actual types of crude that are being transported to and handled at the facility.

Table 41: Expected Vancouver Energy Vessel Spill Frequency[60]				
Spill Volume Category	**Estimated Frequency of Transfer-Related (Dockside) Spills**		**Estimated Frequency of Underway-Related Impact Accident Spills**	
	Spills Per Year	**Return Years**	**Spills Per Year**	**Return Years**
<1 – 9 bbl	0.07118	14	0	-
10 – 99 bbl	0.01898	53	0	-
100 – 999 bbl	0.00411	243	0.01931	52
1,000 – 9,999 bbl	0.00063	1,587	0.02972	34
10,000 – 99,999 bbl	0	-	0.00050	2,018
100,000 bbl or more	0	-	0.00000	202,467
Effective WCD	0.00095	1,053	0.00011	8,999
Bakken Crude	Effective WCD: 2,626 bbl		Effective WCD: 189,845 bbl	
Diluted Bitumen	Effective WCD:2,287 bbl		Effective WCD: 163,390 bbl	

Vessel Spill Consequences: Environmental Impacts

If a spill occurs the environmental impacts will be determined by the sensitivity of the "receiving environment" based geographic location, oil type, and season, as previously described, and the volume of oil involved. Small spills will have localized effects, but larger spills may spread from the spill site to cause more widespread impacts. On land, this can mean incursions into aquifers, streams, and small rivers. A spill on a waterway (from a vessel or at a waterfront facility) will spread in a trajectory that depends on hydrodynamics (tides and current velocity and direction) as well as wind direction and speed.

[59] Fleet Mix A (365 calls): 292 Handymax, 55 Aframax, and 18 Suezmax (365 total).
[60] Fleet mix: 292 Handymax, 55 Aframax, and 18 Suezmax (365 total).

Columbia River Estuary Spill Considerations

The Columbia River (to the west of the Bonneville Dam) is an estuary (Figure 9). To the west of Bonneville Dam there are no tidal currents that would affect the flow of oil from a spill at the facility or from a vessel.

Figure 10 shows the probability that a spill of 25,000 bbl would spread to the locations shown on the river. The highest probability for surface floating oil in the vicinity of the spill (shown by the black dot). The areas shown in bright green have a 30% chance of impact and extend about 15 miles downriver and about 10 miles upriver. Note that there is a less than 10% chance that the oil will extend to locations further away from the spill site. The actual impacts will depend on the timing of the spill with respect to tidal currents and winds at the time of the spill.

Figure 11 shows that the oil would reach these locations within 24 hours, i.e., within two tidal cycles.

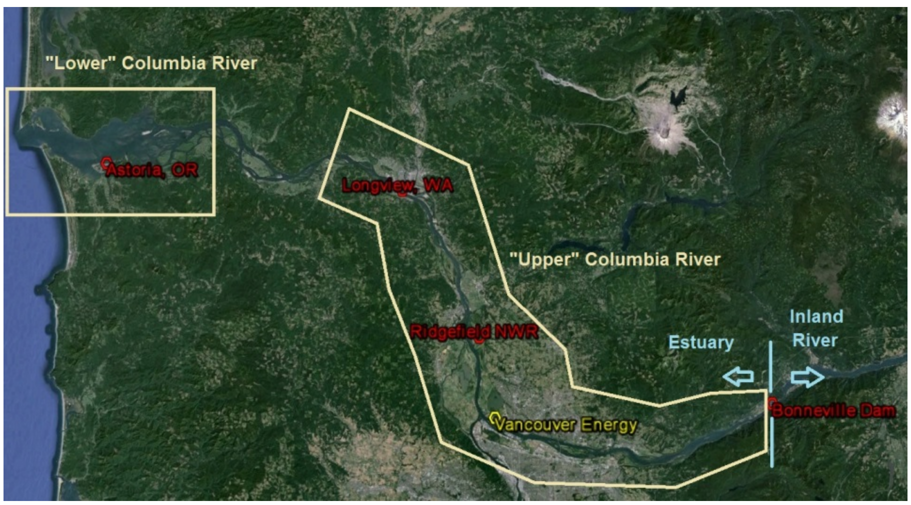

Figure 9: Columbia River Estuary/River Map

This hypothetical spill represents the 50th percentile of a collision or grounding incident with spillage for a Handymax and a smaller scenario with a larger Aframax or Suezmax of a heavy oil. The degree of spread of oil spilled in the Columbia River will depend on a number of factors:

- The volume of oil spilled;
- The type of oil spilled and its characteristics;
- The actual location of the spill; and
- The timing of the spill with respect to tidal currents, winds, and other environmental factors at the time of the spill.

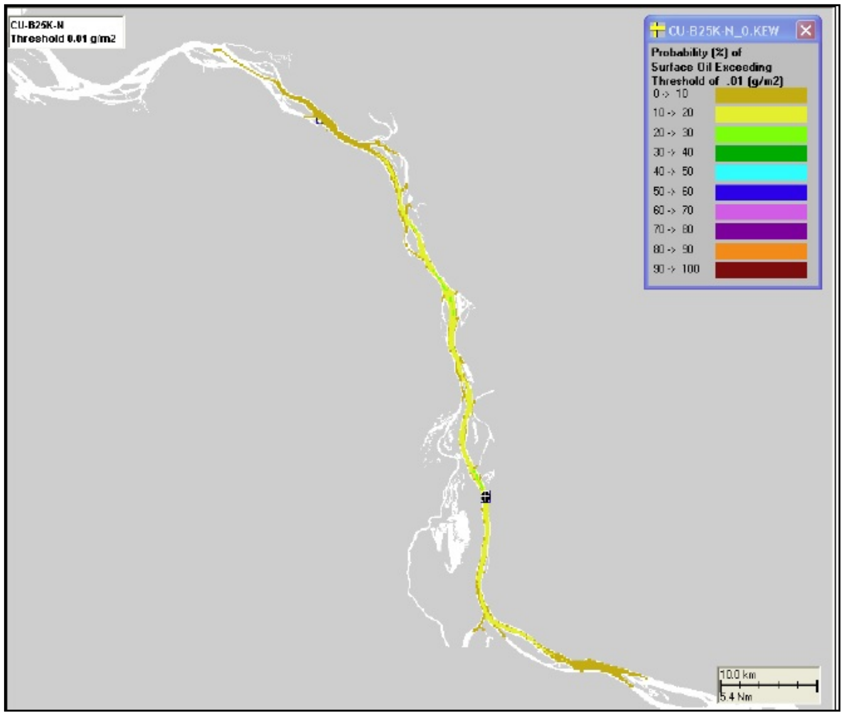

Figure 10: Upper Columbia River Bunker C Spill Probability of Surface Floating Oil[61]

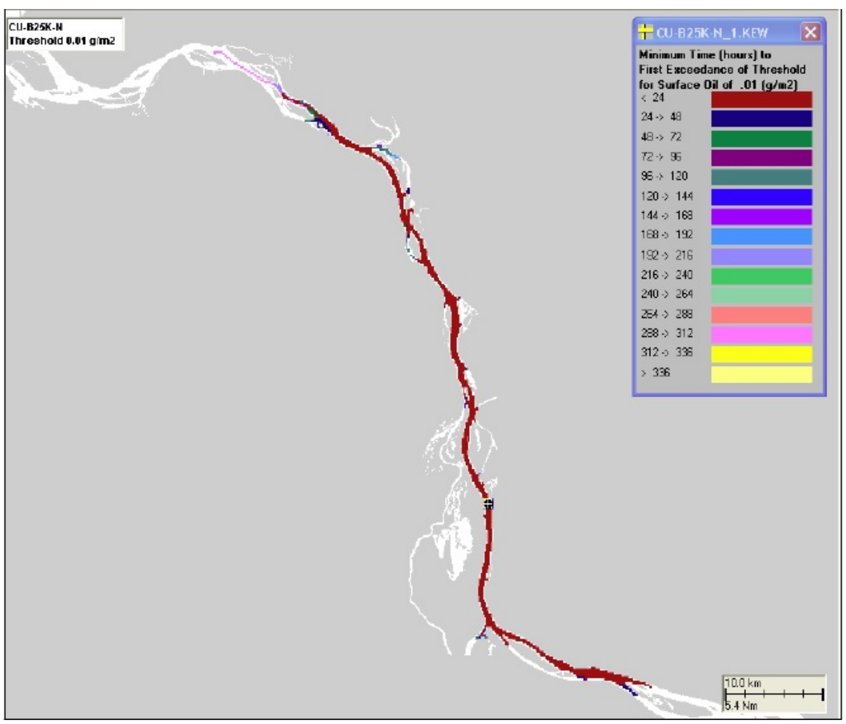

Figure 11: Upper Columbia River Bunker C Spill – Time (Hours) for Surface Spreading[62]

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[61] Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (minimum thickness for sheen). French-McCay et al. 2006e.

[62] Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2. French-McCay et al. 2006e.

If, the spill occurs in the Lower Columbia, near the mouth of the river, the tidal effects would be such that part of the mouth of the river near Baker Bay would be affected and there would also likely be oiling in other areas along the Washington and Oregon coasts, depending on winds and currents at the time of the spill (Figure 12 and Figure 13).

In the hypothetical spill example of 25,000 bbl of heavy fuel oil spilled in the Lower Columbia River, an estimated 615,000 to 1.6 million square meters (152 to 395 acres) of shoreline would be impacted. If the spill occurred in the Upper Columbia River, the shoreline oiling would be 168,000 to 321,000 square meters (42 to 79 acres). The environmental impacts to shoreline resources would depend on the specific shorelines affected, but in general, in the Upper Columbia River there would be significant areas of wetlands and mudflats affected. A spill that occurred in the Lower Columbia River would affect areas like this as well as sandy and rocky areas on the outer coast.

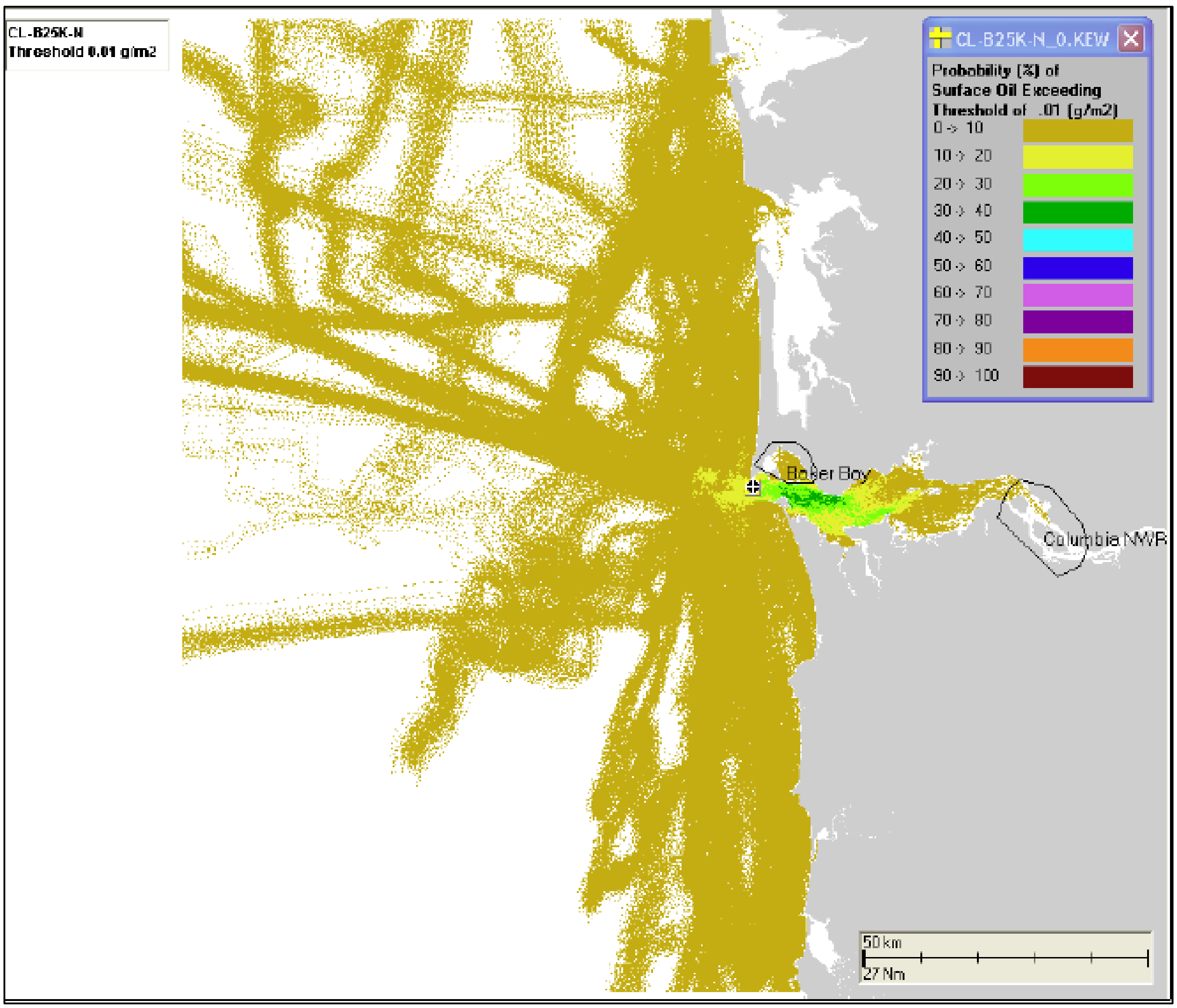

Figure 12: Lower Columbia River Spill 25,000 bbl HFO – Probability of Surface Oiling

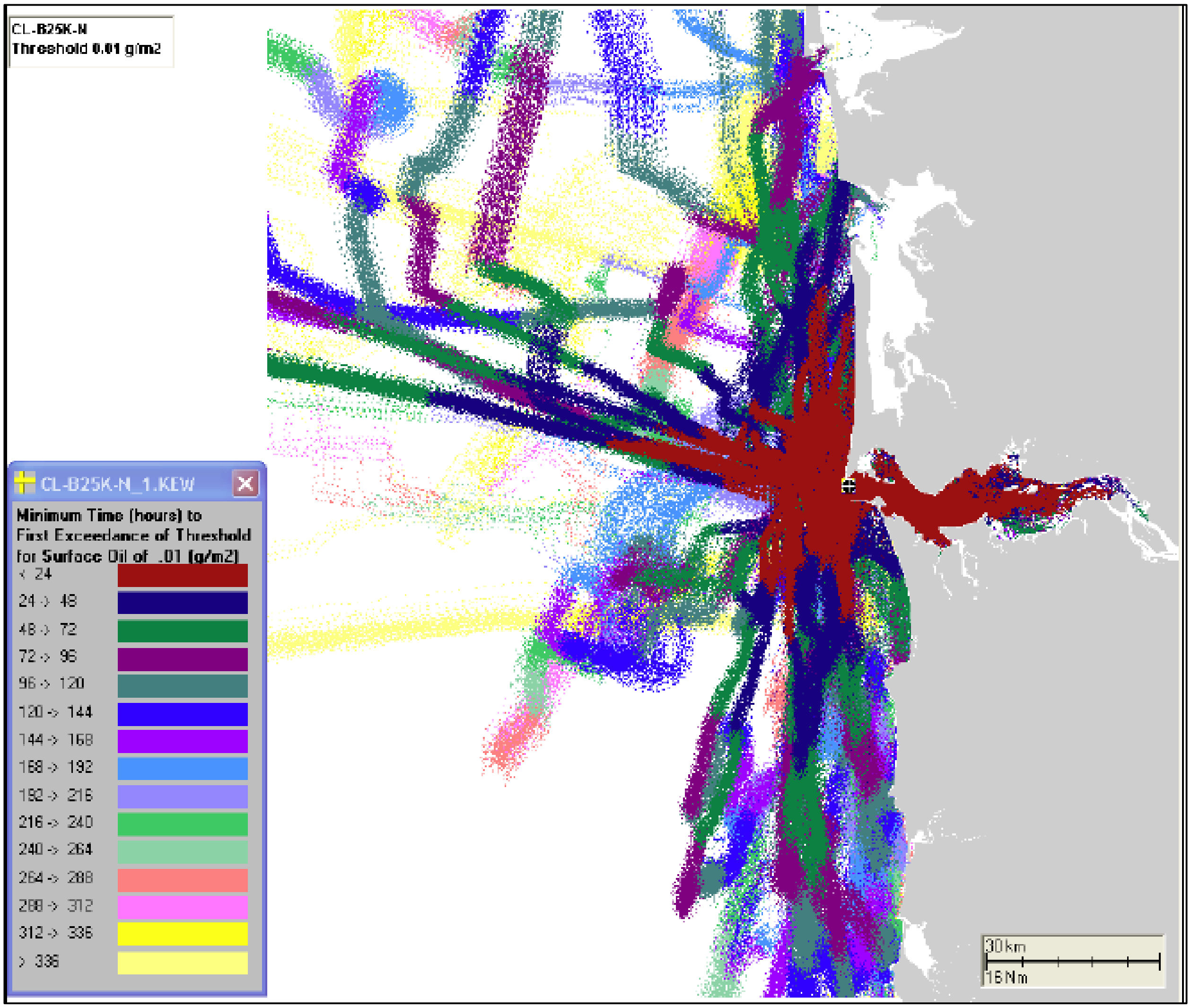

Figure 13: Lower Columbia River Spill of 25,000 bbl HFO – Time to Surface Oiling Threshold

Potential Extent of Impact from Vancouver Energy Vessel Spills

While trajectory, fate, and effects modeling for specific spill scenarios related to Vancouver Energy vessel traffic is outside the scope of the current study, it is possible to estimate the extent of spread of the oil in some sample spill scenarios based on the characteristics of the oil types (Bakken crude and diluted bitumen) and their predicted behavior. In order to extrapolate from these studies to the scenarios that may occur from tank vessels transiting from the facility, adjustments need to be made for oil type and volume. While the modeled heavy oil spills are reasonable approximations of diluted bitumen spills that might occur, the properties of Bakken crude oil are considerably different. More evaporation would occur and the solubility of the oil would create greater water column impacts.

Adjustments with respect to oil type can be made to some extent using NOAA's ADIOS2 model, which will estimate the amount of oil evaporated, dispersed, and remaining over time (e.g., Figure 14 and Figure 15).

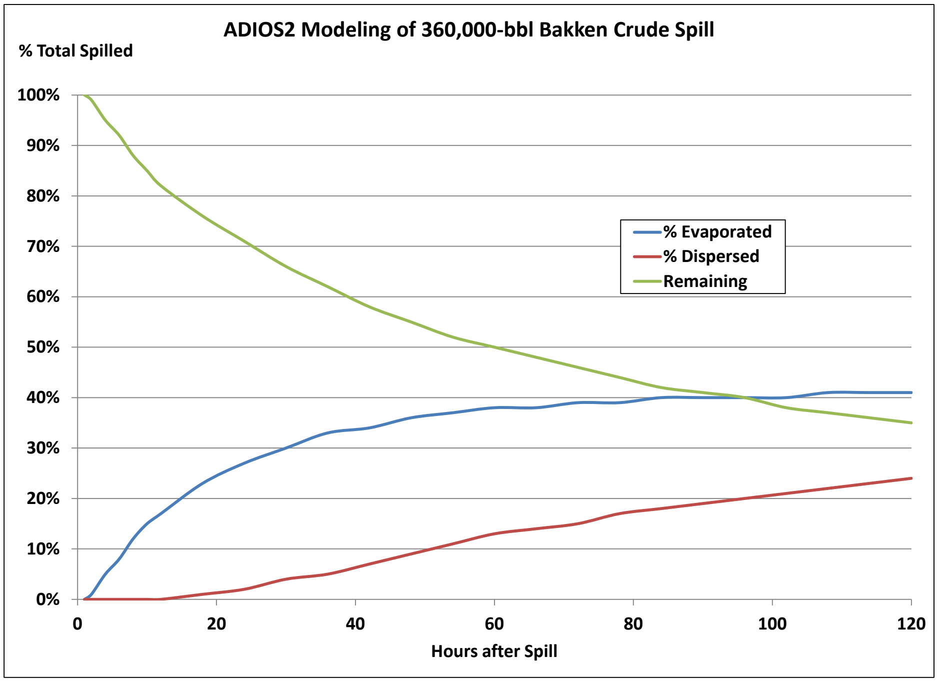

Figure 14: ADIOS2 Modeling of 360,000-bbl Bakken Crude Spill in Estuary[63]

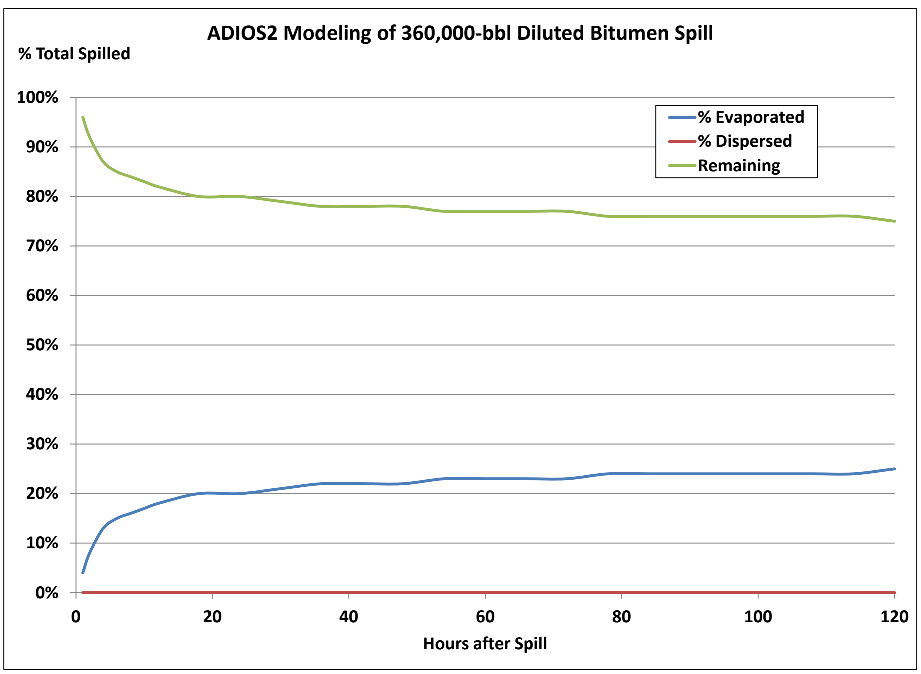

Figure 15: ADIOS2 Modeling of 360,000-bbl Diluted Bitumen Crude Spill in Estuary[64]

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[63] Assumes: 360,000 bbl Bakken crude spilled into estuarine water of 50°F with 8mph winds. Bakken characteristics based on Lac Megantic samples with °API of 41.8, density 0.827 g/cc at 50°F, viscosity 3.6 cSt at 50°F.
[64] Assumes: 360,000 bbl Cold Lake Blend (Alberta) spilled into estuary of 50°F with 8mph winds. Cold Lake Blend characteristics with °API of 22.6, density 0.927 g/cc at 50°F, viscosity 206.0 cSt at 50°F.

In addition, the extent of the spread of the oil on the water surface can be estimated based on the oil remaining after weathering and the area that would be covered with a spill of a particular volume to a typical slick thickness.

The spill volumes of a sampling of the various outflow scenarios from underway- and transfer-related spills were analyzed with respect to degree of evaporation and dispersion to estimate the amount of oil remaining. This amount of oil was then assumed spread over a typical slick thickness of 0.1 mm for fresh oil and 0.0003 mm for rainbow sheen, as shown in Table 42 for Bakken crude and in Table 43 for diluted bitumen. Assuming the Upper Columbia River averages about 0.7 miles in width, the extent of spread on the river was estimated in length as well. In the Lower Columbia River the spill would spread out more. In both locations, significant oil would also stick to shorelines preventing the oil from actually spreading as far as is indicated. With diluted bitumen there is the possibility that some of the oil may become submerged when it comes in contact with sediment. For a Bakken crude oil spill there is the distinct possibility that some or much of the oil would burn. While this would certainly cause public safety risks that would need to be properly managed, the end result would be less oil on the river to cause damages.

Table 42: Estimated Spread of Bakken Crude Oil on Water Surface

Spill Volume (bbl)	% Remaining After 120 hours	Volume Remaining (bbl)	Covered by Fresh Slick (0.1 mm)		Covered by Rainbow Sheen (0.0003 mm)	
			Area (sq, miles)	River Length (miles)	Area (sq, miles)	River Length (miles)
1	35%	0.35	0.0002	0.0003	0.0711	0.1016
10	35%	3.5	0.0021	0.0031	0.7111	1.0158
100	35%	35	0.02	0.03	7.11	10.16
1,000	35%	350	0.21	0.31	71.11	102
10,000	35%	3,500	2.1	3.1	711.1	1,016
20,000	35%	7,000	4.2	6.2	1,422	2,032
50,000	35%	17,500	10.5	15.5	3,555	5,080
90,000	35%	31,500	19	28	6,399	9,142
100,000	35%	35,000	21	31	7,111	10,158
190,000	35%	66,500	41	58	13,510	19,300
221,000	35%	77,350	47	68	15,714	22,449
360,000	35%	126,000	77	110	25,598	36,568
642,000	35%	224,700	138	197	45,650	65,214
730,000	35%	255,500	157	224	51,907	74,153

Table 43: Estimated Spread of Diluted Bitumen Oil on Water Surface

Spill Volume (bbl)	% Remaining After 120 hours	Volume Remaining (bbl)	Covered by Fresh Slick (0.1 mm)		Covered by Rainbow Sheen (0.0003 mm)	
			Area (sq, miles)	River Length (miles)	Area (sq, miles)	River Length (miles)
1	75%	0.75	0.0005	0.0007	0.1524	0.2177
10	75%	7.5	0.0046	0.0066	1.5237	2.1767
100	75%	75	0.05	0.07	15.24	21.77

Table 43: Estimated Spread of Diluted Bitumen Oil on Water Surface

Spill Volume (bbl)	% Remaining After 120 hours	Volume Remaining (bbl)	Covered by Fresh Slick (0.1 mm)		Covered by Rainbow Sheen (0.0003 mm)	
			Area (sq, miles)	River Length (miles)	Area (sq, miles)	River Length (miles)
1,000	75%	750	0.46	0.66	152.37	218
10,000	75%	7,500	4.6	6.6	1,523.7	2,177
20,000	75%	15,000	9.2	13.2	3,048	4,354
50,000	75%	37,500	23.0	33.0	7,619	10,885
90,000	75%	67,500	41	59	13,713	19,590
100,000	75%	75,000	46	66	15,237	21,767
190,000	75%	142,500	87	125	28,950	41,357
221,000	75%	165,750	102	145	33,673	48,105
360,000	75%	270,000	166	237	54,853	78,361
642,000	75%	481,500	295	422	97,821	139,744
730,000	75%	547,500	336	480	111,229	158,898

Potential Bakken Crude Oil Spill Impacts in the Columbia River

Bakken crude oil exhibits the general properties of light oils, as detailed in Appendix B. Light oils then to have a high toxicity and low persistence due to the high proportion of lighter, more volatile hydrocarbon components that are toxic, but also evaporate or dissolve relatively quickly. Bakken crude has fewer of the heavier hydrocarbon components that tend to persist in the environment and adhere to surfaces, including shorelines, as well wildlife fur and feathers.

Bakken crude is also notably volatile and potentially flammable in a spill situation. This is the greatest concern with respect to public safety in the event of a spill. Its behavior is not unlike spilled gasoline.

Potential Diluted Bitumen Spill Impacts in the Columbia River

Diluted bitumen has a higher degree of persistence and adherence and a lower degree of toxicity, depending on the exact blend and type and proportion of diluent used. Appendix C provides more information about the properties of diluted bitumen, including the potential for submergence under some circumstances.

Vessel Spill Risk Mitigation Measures in the Columbia River

The best way to mitigate risk of vessel spills in the Columbia River would be to prevent spills from occurring in the first place. Once the oil has spilled, response measures will reduce the impacts to some degree.

Tug Escorting Characteristics Applicable to Columbia River Use

Tug escorting is one methodology that has been proposed for application in the Columbia River to help prevent accidents from occurring. Tug escorts provide two main features that reduce the risk of an incident:

1. Raised situational awareness due to additional professional mariners in the operation; and

2. Ability to prevent groundings due to tug assist in emergency maneuvers.

The first feature would be recognized if not outweighed by other factors as noted above. The second feature requires room to maneuver, and as noted by the Bar Pilots above, the limited width of the river's channel does not provide this.

Existing tugs on the Columbia River are not suitable for escort duties. The existing Rescue tug stationed at Neah Bay is not close enough for practical assistance to Columbia River bound vessels. A rescue tug stationed nearer the Columbia River may have its effectiveness limited by bar crossing requirements.

The deepwater channel is typically 600 ft (182 m) wide (Figure 16).

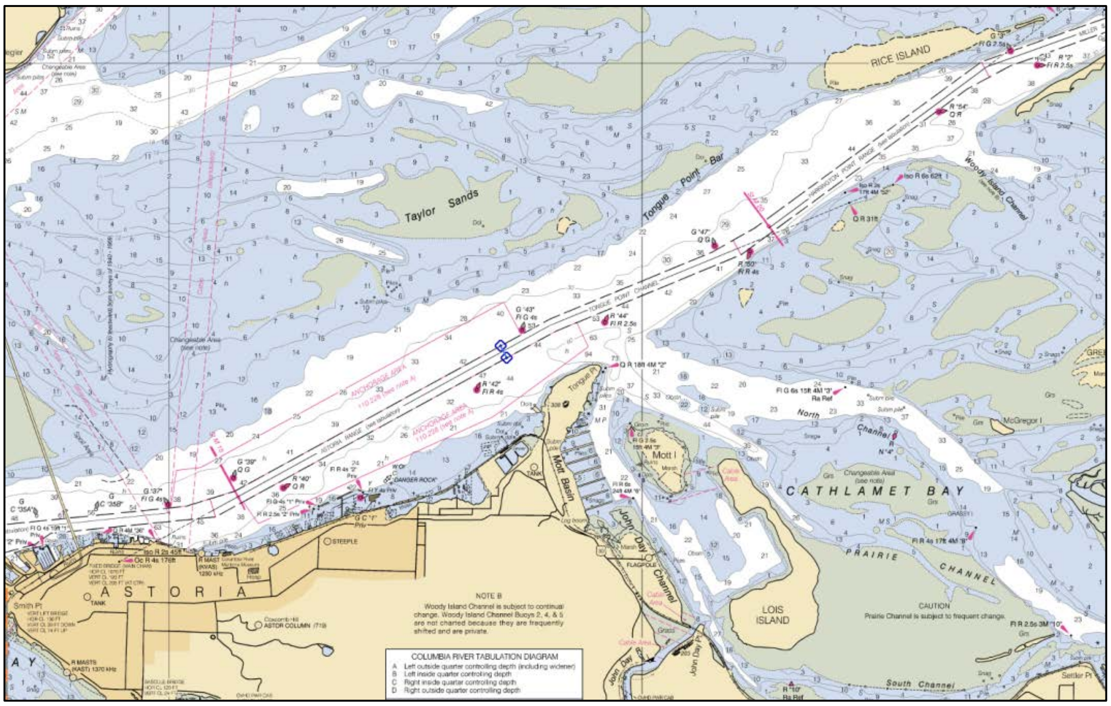


Figure 16: Columbia River deepwater channel off Astoria (from NOAA Chart 18521)

The deepwater channel crossing the bar is wider, approximately 2,675 ft. (815 m) as shown in Figure 17.

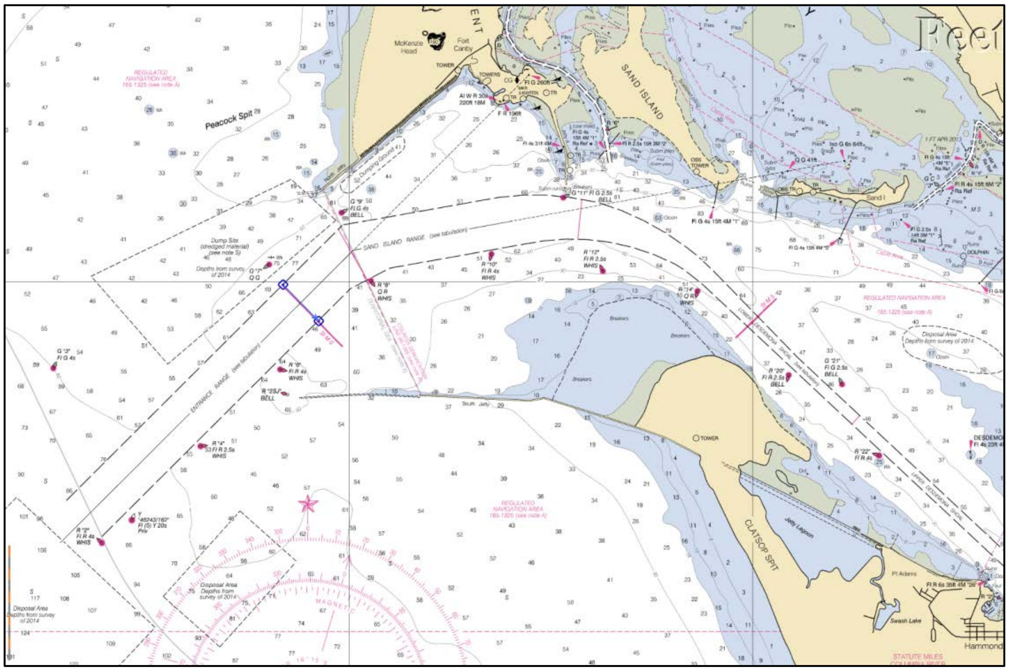


Figure 17: Columbia River deepwater channel crossing the bar (from NOAA Chart 18521)

Emergency maneuvers can be conducted by conventional and tractor tugs, as shown in Figure 18 .

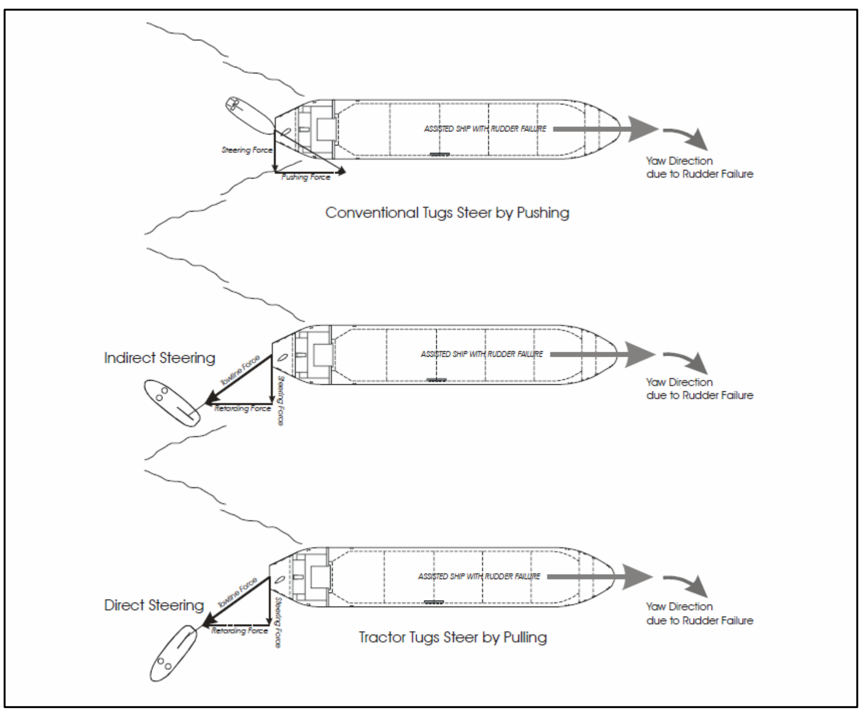


Figure 18: Emergency assist modes of Conventional and Tractor Tugs[65]

[65] The Glosten Associates, Inc. 2004. Study of Tug Escorts in Puget Sound, Prepared for State of Washington: Dept. of Ecology, 30 December 2004

Assuming the ship depicted is a Suezmax of 274 m LOA then the distance off centerline for the forward end of the tug in the Direct steering mode is about 79 m. This is about 11.5 m from the edge of a 183 m. (600 ft.) channel assuming the ship is on centerline of the channel.

In the indirect mode, the tractor tug could operate as shown in Figure 19. A powered direct mode is shown in Figure 20.

On long transits, the best results were obtained when the tractor was placed slightly off to one side of the wheel wash of the ship in an easy indirect. With the towline at about a 5 degree angle to the ship's centerline, the tug's engines are used to the force on the towline, about 3 to 5 tons. In doing so, the tug will remain in one position, providing a steady, light drag that does not adversely affect the steering of the ship, nor unduly fatigue the tug operator, so that he will be fresh in the event of a casualty. However, when the ship makes a turn, the tractor operator must return to a position directly astern of the ship to avoid having the drag of the tractor begin to oppose the ship's rudder.

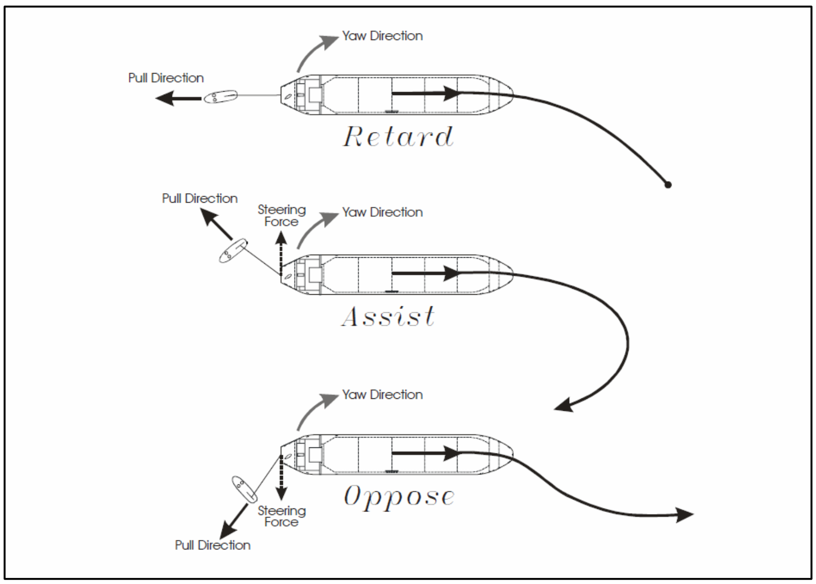


Figure 19: Retard, Assist, and Oppose Emergency Maneuvers (Indirect Mode)

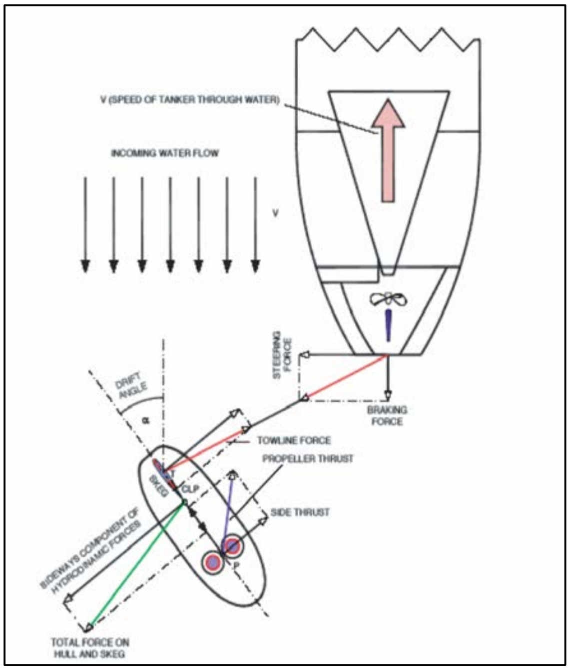


Figure 20: Powered Indirect Mode[66]

The following show Oppose and Assist emergency maneuvers for a Suezmax tanker loaded to 125,000 DWT (Figure 21 and Figure 22).

- The Rosario Straits 95th % distance is 3,370 ft (0.55 nm) off centerline.
- Calm conditions.
- Hard over rudder failure.
- Thirty seconds to failure recognition and engine shutdown.
- The tractor tug is assumed to be tethered and starts to apply corrective forces 60 seconds after the onset of the failure and is applying maximum steering forces at 90 seconds.
- The conventional tug is untethered and must maneuver into position on the tanker transom. It begins applying corrective steering forces at 120 seconds and is applying maximum forces at 150 seconds. It does not apply any forces until the speed of the tanker falls below 7 knots.

[66] Tethered Escort of tankers (Source ?, probably Enbridge Northern Gateway Project)

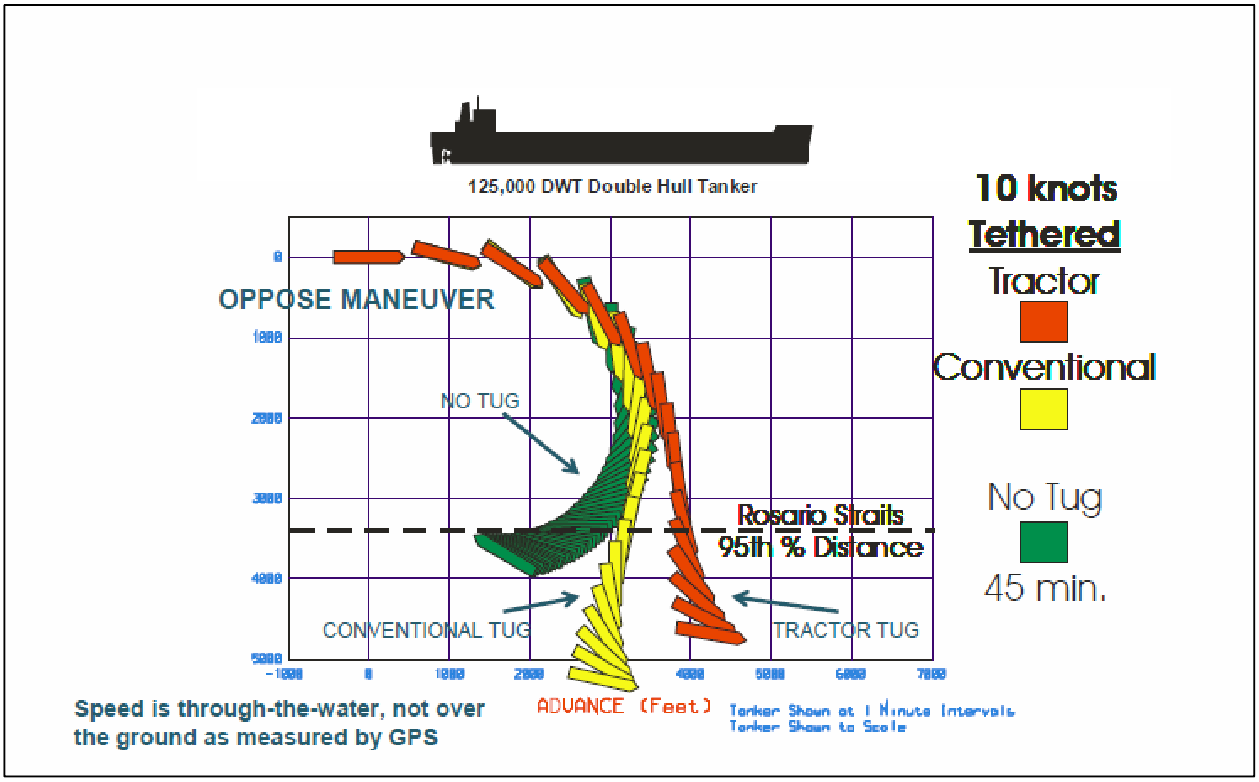


Figure 21: Simulation of Oppose Maneuver with 6,250 hp Conventional and Tractor Tug

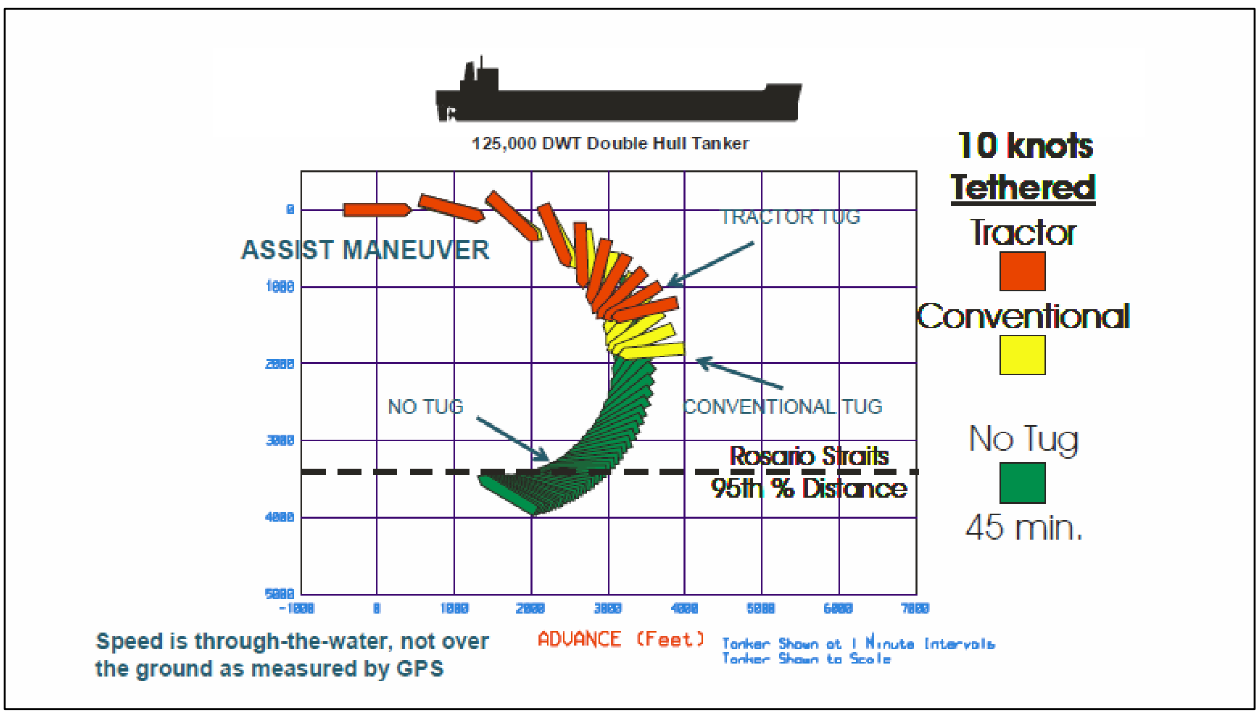


Figure 22: Simulation of Assist Maneuver with 6,250 hp Conventional and Tractor Tug

The following are examples from Full Scale Tests at 8 Knots of Arco Juneau – Lindsey Foss (Georgia Strait, 1997). The Arco Juneau was an Aframax tanker, 122K DWT, 259 m x 42.07 m x 20.73 m. (Figure 23 and Figure 24).

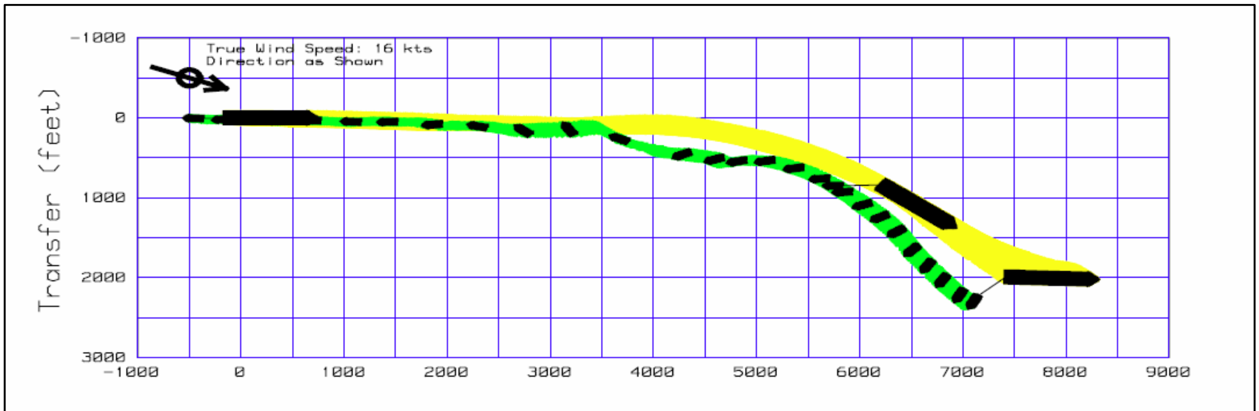


Figure 23: Test 4: Turn to Starboard from 8 Knots, 5 March 1997, Wind: 10-15 knot Seas: 1-2 feet

The tug was tethered on a long tether, 30 seconds before engine stopped, 30 seconds to order to tug to pull stern to starboard. The test took about 9 minutes and stopped when the original heading was matched. From the figure the tug appears to have operated in Direct mode. The off track distance of the tug approaches 2,500 ft. while the tanker moved 2,000 ft. off track.

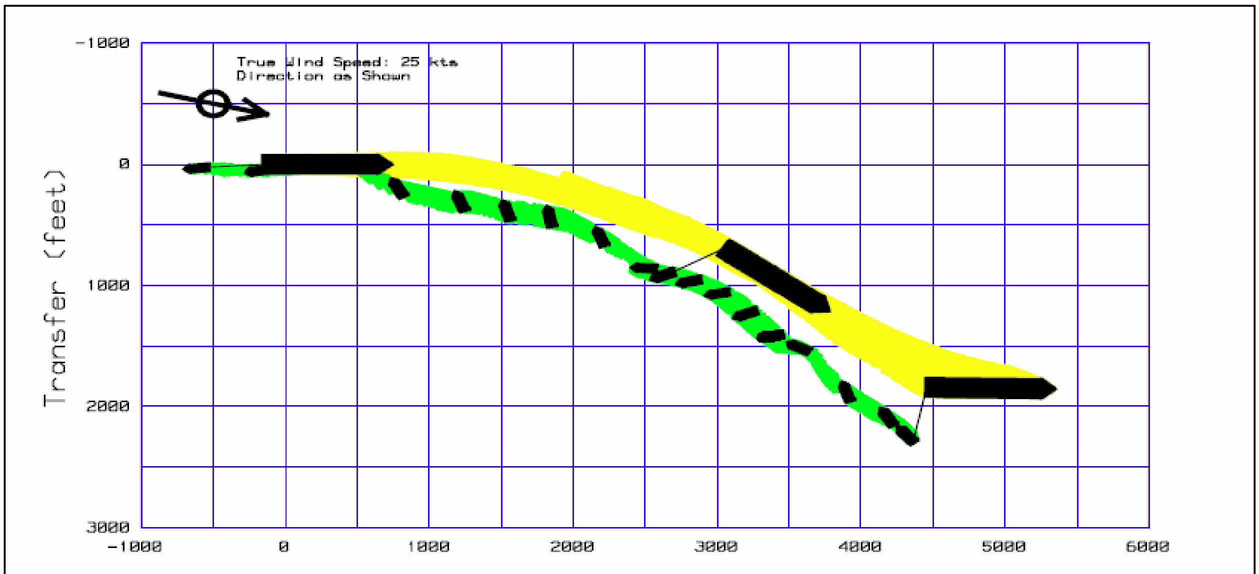


Figure 24: Test 4a: Turn to Starboard from 8 Knots, 5 March 1997, Wind: 10-15 knot Seas: 1-2 feet

From the figure the tug appears to have operated in Indirect mode. The off track distance of the tug approaches 2,250 ft. while the tanker moved 1,800 ft. off track.

Appendix A: HECSALV Model Approach

The methodology employed for estimating oil outflow for collisions and groundings was the application of an extension of HECSALV, a proprietary software of Herbert Engineering Corp. [67] HECSALV is one of the world's leading salvage and emergency response software tools. It is used by ABS and DNV-GL and the USCG and US Navy and many salvage companies. The probabilistic oil outflow model is an internal extension.

The HECSALV analysis approach utilizes the IMO distributions for side and bottom damage for tankers as modified for the Pollution Prevention and Control (POP&C) risk assessment of double-hulled Aframax tankers to estimate releases of oil based upon actual hull geometries. This approach was originally developed for assessment of alternatives to double-hull tankers for USCG.[68]

The simulation is a stepwise integration of probability distributions calculating oil outflow at each step. The damage extents used in evaluating the probability of hitting an oil tank are based upon Regulation 23 of Annex I of MARPOL (2006). The probability distributions were derived by IMO and are based upon damage records for tankers over 30,000 dwt collected by Lloyd's Register. These are modified to account for the presence of a double hull based upon the work of Zheng and Aksu (2006) implemented in the European Union POP&C project.[69] The modifications improve the modeling slightly by reducing the chance of penetration through the second skin of a double-hulled vessel.

The damage probability distributions are based upon the dimensions of the vessel under consideration. For groundings this is appropriate. For collision this does not take in to account the energy associated with the striking vessel. An underlying rationale for this assumption is that the energy of the striking ship will be consistent with existing damage records, which reflect tankers operating in waters where they have primarily encountered similarly sized vessels.

For Suezmax tankers in the Columbia River this is not likely to be true for the case of collisions, and thus the damage extents could be smaller for that vessel than reflected in the simulation. For this reason, additional simulations were conducted in which it was assumed that the Suezmax would collide with an Aframax tanker. The probability distributions for damage are based upon damage statistics for accidents where there was a hull breach, so they represent conditional probabilities given hull penetration.

IMO Guideline Oil Outflow Methodology[70]

Probabilistic analysis, whether it is for ship damage stability or oil outflow, is based on evaluating the cumulative probability of occurrence of an expected consequence (survival or quantity of outflow). It is typically formulated in terms of the following conditional probabilities:

- Probability that the ship will encounter damage;

[67] http://www.herbertsoftware.com/products/hecsalv/
[68] USCG 1992.
[69] Moore et al. 2007.
[70] *Interim Guidelines for the Approval of Alternative Methods of Design and Construction of Oil Tankers under Regulation 13F(5) of Annex I of MARPOL 73/78,* Resolution MEPC.66(37) adopted September 14, 1995. Presented as Appendix 8 in MARPOL 73/78 Consolidated Edition, 1997.

- Probability of the damage location and extent; and
- Probability of survival or expected consequences.

Evaluation of all of these probabilities would constitute a fully probabilistic evaluation for a specific vessel on a specific route.

The IMO Guidelines do not specifically deal with the probability of whether the ship will encounter damage. Instead, it is acknowledged that the risk does exist, and assumes that in fact, the vessel has been involved in a casualty event significant enough to breach at least one compartment. The methodology deals exclusively with determination of the probability of damage extent (once damage has occurred) and calculation of the resulting consequences.

The basic method is outlined below. A discussion of each aspect of the method follows the outline. The IMO Guidelines call for a "Conceptual" analysis to obtain approval for an alternative tanker concept, and a damaged stability or "Survivability" analysis for the final shipyard design. Differences in these approaches are explained in the text.

- **Step A:** Establish the Intact Load Condition: Develop models for each design. Perform full load trim and stability calculations to determine initial intact draft and GMt conditions.
- **Step B:** Assemble Damage Cases: Assemble damage cases for each possible combination of compartments by applying the damage density distribution functions included in the Guidelines, for both side and bottom damage.
- **Step C:** Compute the Oil Outflow for Each Damage Case: Both a "Conceptual" analysis and a "Survivability" analysis were performed for each model.
    - "Conceptual" Analysis: Damage equilibrium calculations are not required for the "Conceptual" analysis. This approach assumes that the vessel subjected to side damage always survives, and the vessel subject to bottom damage always remains stranded on the shelf without trim or heel.
    - "Survivability" Analysis: Calculate the survivability and equilibrium condition for each damage case. Side damage is assumed to result in a free floating vessel. Bottom damage is assumed to result in a grounded vessel unless loss of oil allows the vessel to float free.
    - For bottom damage a hydrostatic balance method is used to compute outflow. For side damage, all oil is assumed to escape from damaged tanks. (Note: For the "Survivability" analysis, all cargo on board is assumed to flow out for those cases which result in loss of the vessel.)
- **Step D:** Compute the Oil Outflow Parameters: Develop the cumulative probability of occurrence of each level of oil outflow and the associated oil outflow parameters.
- **Step E:** Compute the Pollution Prevention Index "E": The pollution prevention index "E" is computed using the formula provided in the IMO Guidelines. The design is equivalent to the reference hull, or in this case the "rule" double hull, if "E" is greater than or equal to 1.0.

Step A: Establish the Intact Condition

Hull offset, compartment offset and ship data files were developed for each design utilizing the HEC Salvage Engineering Software (HECSALV).

Consistent with the IMO Guidelines, oil outflow calculations were carried out assuming the vessel is initially at a mean draft equal to its scantling load line, with zero trim and zero heel. To establish the density of the cargo oil, load cases were developed based upon the tankers full load departure condition, assuming all cargo tanks 98% full and departure consumables. Calculations assume the vessel is floating in seawater with a specific gravity of 1.025.

Step B: Assemble Damage Cases

The probability of the damage location and extent has been statistically estimated from surveys of past damage. This compilation of damage statistics continues today and is being coordinated by the IMO. The general framework of current and pending probabilistic regulations allow them to be updated with improved damage statistics as the data becomes available. As part of this effort damage statistics for tankers have been collected for IMO by the classification societies. These statistics are based upon 52 collisions and 63 groundings involving tankers above 30,000 metric tons deadweight capacity, but are also used for regulatory assessment of smaller vessels. This data is used as the basis for the damage probabilities in the proposed IMO Guidelines under Regulation 13F. The side damage and bottom damage distributions as specified in the IMO Guidelines and as applied in this report are presented in figures below.

Damage statistics are generally presented as graphs of probability density distributions. The area under the probability density histogram or curve between two points on the horizontal axis is the probability that the quantity will fall within that range. The density distribution scales are normalized by ship length for location and longitudinal extent, by ship breadth for transverse extent and transverse extent, and by ship depth for vertical location and vertical extent. Statistics for location, extent, and penetration are developed separately for side and bottom damage cases.

For side damage, the probability of a given longitudinal location, longitudinal extent, transverse penetration, vertical location and vertical extent is the product of the probability of the location, by the probability of the length, by the probability of the transverse extent of damage, by the probability of the vertical location, by the probability of the vertical extent of damage. Similarly, bottom damage includes evaluation of the longitudinal location of damage, longitudinal extent, vertical penetration, transverse location and transverse extent.

The histogram data and the probability density functions developed from them represent "marginal" distributions. That is, location, extent and penetration are presented independently. It is expected that there will be some correlation; however, correlated statistics are unavailable. This is a conservative assumption, as correlated statistics will tend to reduce the likelihood of concurrent application of extreme extents, and therefore reduce the projected oil outflow.

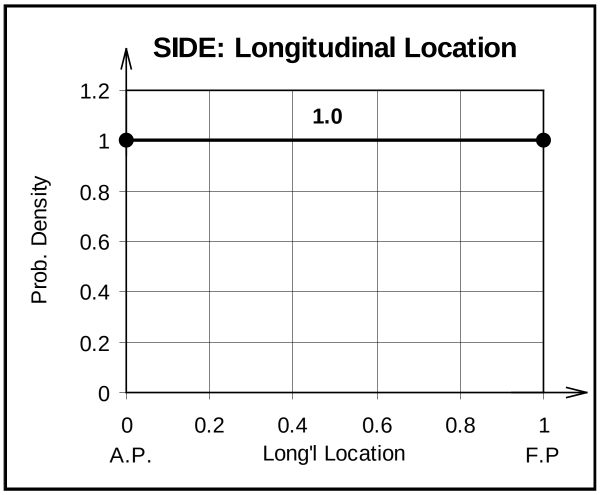


Figure 25: Side Damage Longitudinal Section

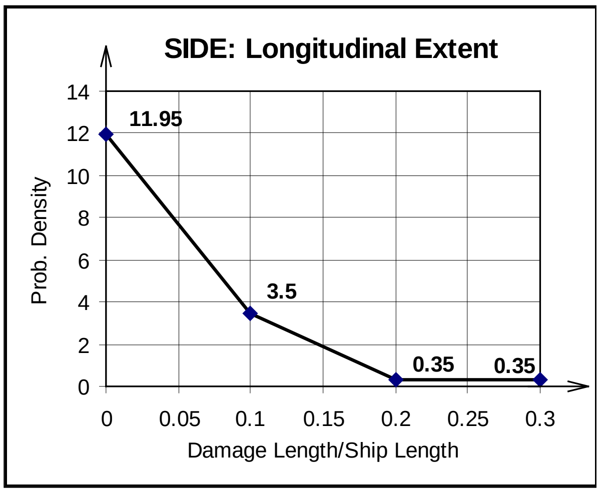


Figure 26: Side Damage Longitudinal Extent

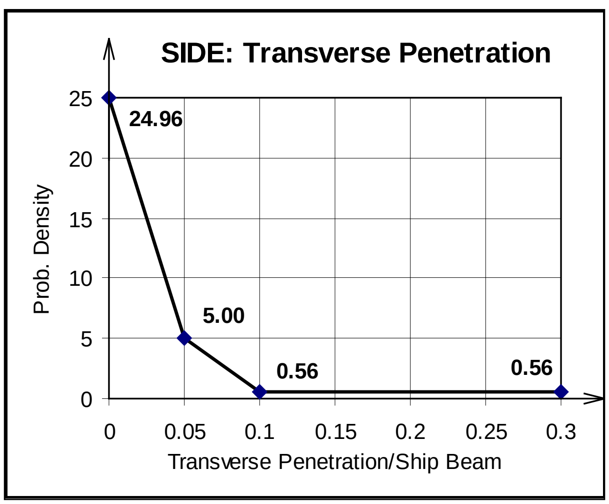


Figure 27: Side Damage Transverse Penetration

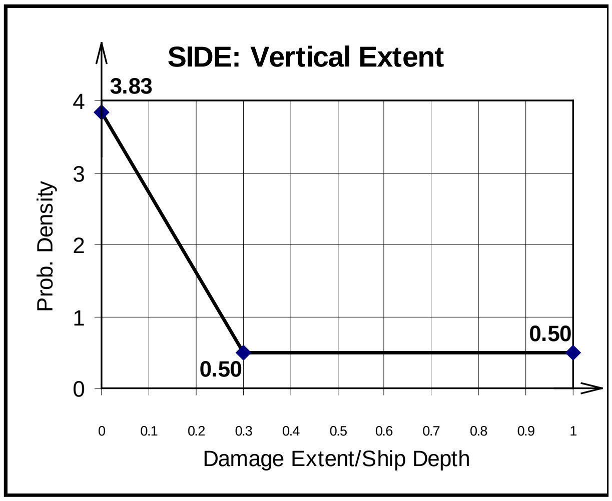


Figure 28: Side Damage Vertical Extent

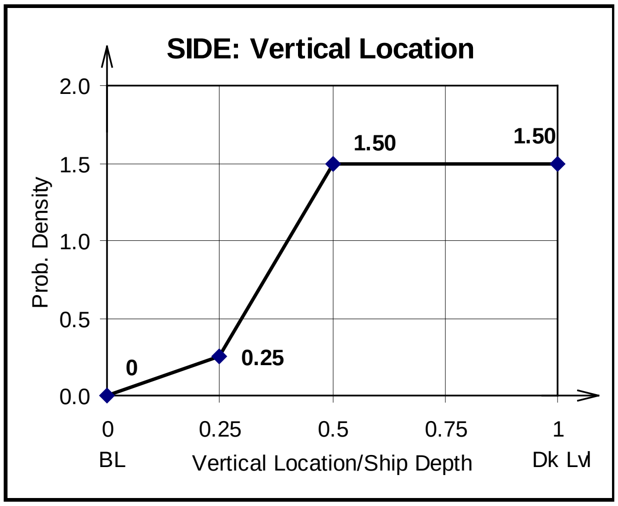


Figure 29: Side Damage Vertical Location

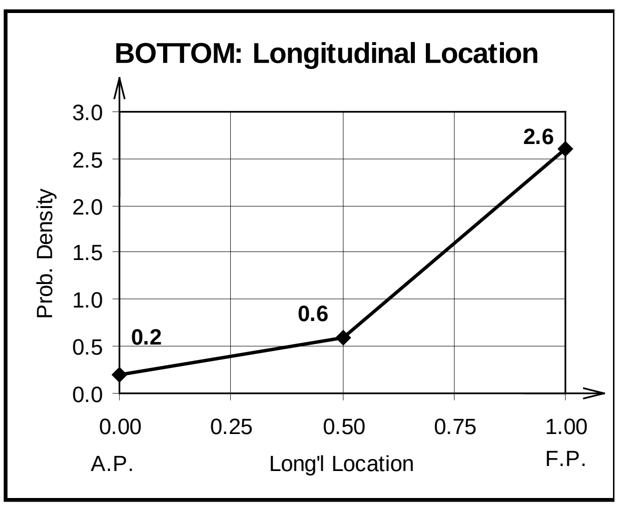


Figure 30: Bottom Damage Longitudinal Section

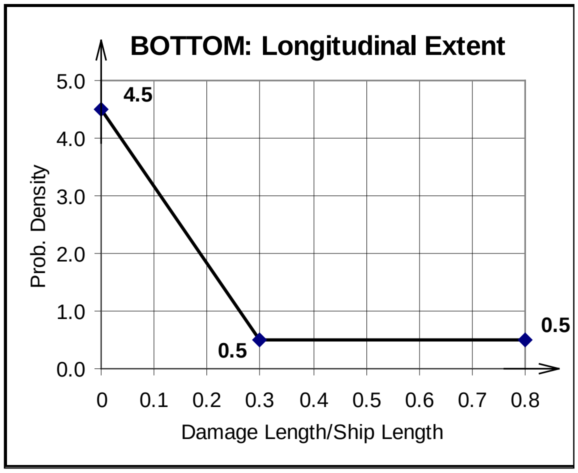


Figure 31: Bottom Damage Longitudinal Extent

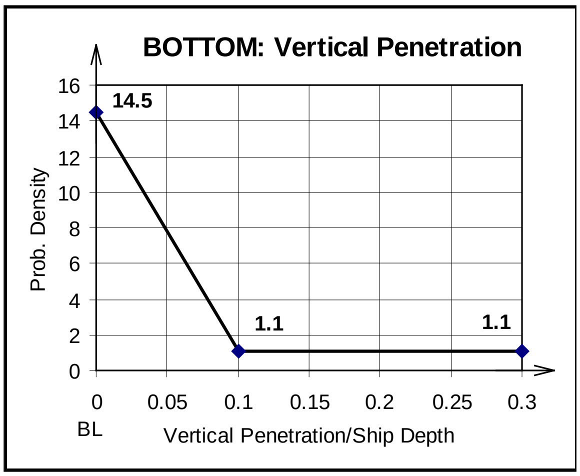


Figure 32: Bottom Damage Vertical Penetration

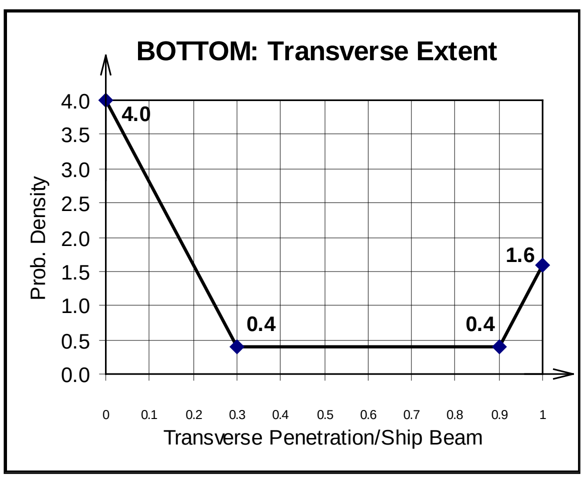


Figure 33: Bottom Damage Transverse Extent

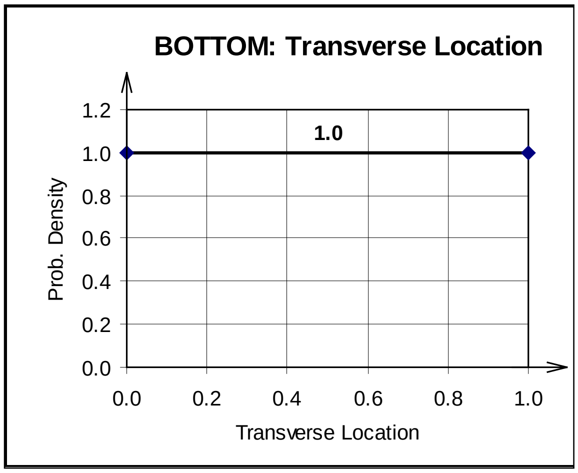


Figure 34: Bottom Damage Transverse Location

Based on the damage extents and locations covered by the density functions, a complete set of compartment groupings is developed. Each compartment group represents those tanks which can be breached from a given combination of damage location, length and penetration.

Application of the probability density functions for damage extent and location to these groupings provides the probability of occurrence of each damage incident. The cumulative probability of occurrence of all the damage incidents defined in this way is 1.0.

Compartment groupings and associated probabilities are developed by applying the distribution functions against the vessel compartmentation. This was performed using the HEC software package HECSALV.

Compartment groupings were developed by "stepping" through the vessel at the following increments. HEC performed the calculations on behalf of IMO to determine the outflow parameters for the reference ships presented in the IMO Guidelines. These same increments were applied when developing the outflow parameters for those reference ships.

For Side Damage:

- Longitudinal location at .01L
- Longitudinal length at .01L
- Transverse extent at .001B
- Vertical location at .01D
- Vertical extent at .01D

For Bottom Damage:

- Longitudinal location at .01L

- Longitudinal length at .01L
- Vertical extent at .001D
- Transverse extent at .01B
- Transverse location at .01B

Step C: Compute Oil Outflow

Computing the Equilibrium Condition for Each Damage Case

For the “Survivability” analysis only, calculations are run on each tank grouping (each damage incident). The analysis is performed using HEC Salvage Engineering Software (HECSALV), which has capabilities for evaluating both free-floating and stranded damaged conditions.

For each damage case, calculations are performed to determine the equilibrium condition and residual stability in the fully loaded condition. For free floating damage conditions, the damaged GZ curve is developed by performing iterative calculations at a series of heel angles until displacement and trim are in equilibrium. Heeling arms are developed at 10 degree increments using the "lost buoyancy" approach. Intermediate GZ values are developed by cubic spline interpolation.

Survivability for free-floating damaged conditions is based on a comparison with the MARPOL'73 criterion. These limits are as follows:

Equilibrium Heel Angle: Maximum 25 degrees if the deck edge is immersed. Otherwise, a maximum of 30 degrees.

Righting Arm: Maximum residual righting lever of at least 0.1 meters.

Range of Positive Stability: Range of positive stability beyond the equilibrium heel angle of at least 20 degrees.

Progressive Downflooding: Downflooding points such as overflows and air pipes for all non-breached compartments shall not be immersed at the equilibrium waterline.

Note: Critical downflooding points limiting the equilibrium heel angle are the ballast tank overflows, which are taken as 600 mm above the main deck at side.

For bottom damage cases, stranding calculations are carried out based on a depth of water equal to the intact drafts. The HECSALV software has capabilities for evaluating strandings on one pinnacle, two pinnacles, or a shelf. For the analyses of strandings in this study, it is assumed that the vessel was stranded on a shelf extending over 80% of the length of the vessel. If the vessel is found to be free-floating due to outflow of oil, free-floating calculations are performed and the results are applied in lieu of the stranding calculations. If, due to outflow, one end of the vessel lifts off the shelf, single point contact is assumed at the other end of the shelf and iterative calculations are performed to determine the final trimmed waterline. It is assumed that the vessel is aground over her full beam, and that the ground contact restricts heeling of the vessel.

Computing the Oil Outflow for Each Damage Case

"Conceptual" Analysis: With this approach, the vessel is assumed to survive all incidents. The outflow for each side damage case is simply the sum of the volumes of oil carried in each damaged oil tank. For bottom damage, the outflow is based on a pressure balance calculation, assuming the vessel remains aground with zero trim and heel.

"Survivability Analysis": Once the equilibrium condition has been determined, the quantity of oil outflow can be calculated. If the damage case fails to meet damage stability survivability criteria, the ship is assumed lost and 100% of all cargo oil on board is taken as "outflow". For side damage cases which survive, all the oil is assumed to flow out of breached tanks. For bottom damage cases, oil is assumed to flow out of breached tanks into the sea (or double bottom "capture" tanks) until hydrostatic pressure equilibrium is achieved. The computed oil outflows for all affected tanks are summed to determine total outflow for that particular damage case.

For oil outflow estimation purposes the top of the damage is chosen to be at the inboard, bottom of the tank, at the aft bulkhead for tanks forward of amidships and at the forward bulkhead for tanks aft of amidships.

In its final equilibrium condition, each breached compartment is assumed to be in free communication with the sea. At the damage opening, the internal pressure exerted by the oil and flooded water and inert gas pressure within the tank will equal the external pressure exerted by the sea water. It is assumed that the inert gas system exerts a positive pressure of .05 bar as specified in the "Guidelines".

Consistent with the "Guidelines", for bottom damage cases it is assumed that the flooded volume of the double bottoms would retain a 50:50 ratio of oil:seawater. The "capture" of oil by the double bottom tanks applies only if a cargo oil tank immediately above the damaged double bottom is also breached.

Step D: Compute the Oil Outflow Parameters

Once all possible damage combinations have been evaluated, they are placed in descending order as a function of oil outflow. A running sum of probabilities is computed, beginning at the minimum outflow damage case and proceeding to the maximum outflow damage case. This "cumulative probability" can then be plotted against oil outflow (see Figure 35).

The cumulative probability of oil outflow plot provides a picture of a vessel's ability to resist oil spillage when damaged. On the sample plot, Figure 35, the oil outflow corresponding to a cumulative probability of 0.8 is 30,000 m3. This means that in 80% of all collisions or groundings, the outflow will not exceed 30,000 m3. It therefore follows that 20% of all damage incidents will have outflows in excess of 30,000 m3. (Note: Figure 35 is for illustrative purposes only, and does not represent the outflow characteristics of the subject vessels.)

Independent oil outflow tables are developed for side and bottom (grounding) damage. The three outflow parameters (the probability of zero outflow, mean outflow and extreme outflow) are then computed as explained below. Bottom damage calculations are run for 0.0m, 2m and 6m (or one-half the draft, whichever is less) tidal changes, and combined by applying weighing factors of 40%, 50% and 10%

respectively. The side damage and bottom damage results are combined by applying weighing factors of 40% and 60% respectively.

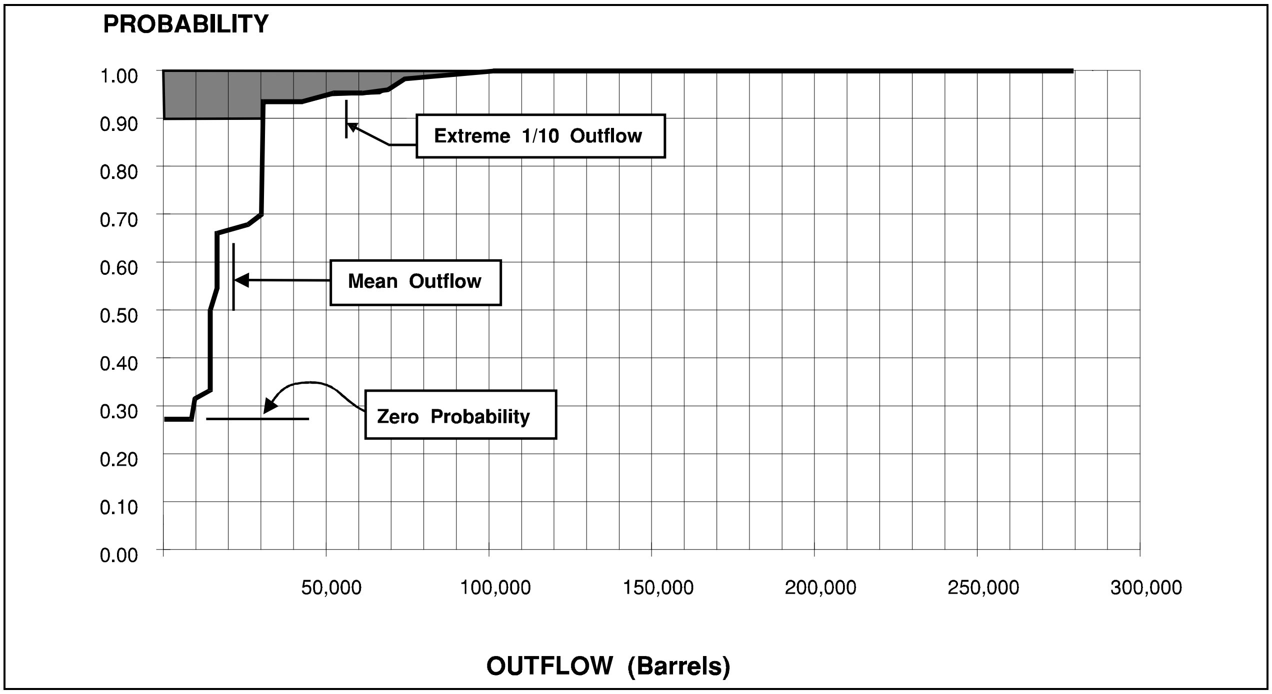


Figure 35: Cumulative Probability of Oil Outflow

The three oil outflow parameters are labeled in Figure 35 and described below.

Probability of Zero Outflow: This parameter represents the probability that no oil will be released into the environment. For the vessel depicted in Figure 35, the probability of zero outflow is 0.28. That is, there will be no oil outflow in 28% of all casualties. Conversely, 72% of all collisions or strandings will result in some level of oil outflow.

Mean Outflow: The sum of the products of each damage case probability and the computed outflow for that damage case yields the mean (expected value) of oil outflow.

Extreme (1/10) Outflow: This value represents the "worst case" spill scenario, and is a weighted average of the upper 10% of all casualties. The products of each damage case probability with a cumulative probability between 0.90 and 1.0 and its corresponding oil outflow are summed, and the result divided by 0.10.

Step E: Compute the Pollution Prevention Index "E"

The oil pollution prevention index "E" is computed in accordance with paragraph 4.2 of the *Guidelines*. To attain equivalency to the double hull reference "rule" design, the index "E" must be greater than or equal to 1.0.

$$E = \frac{(0.5)(P_O)}{P_{OR}} + \frac{(0.4)(0.01 + O_{MR})}{0.01 + O_M} + \frac{(0.1)(0.025 + O_{ER})}{0.025 + O_E}$$

where:

P_O = parameter for probability of zero outflow for the alternative design

O_M = mean oil outflow parameter for the alternative design. This equals the mean oil outflow divided by the total cargo oil capacity at 98% tank filling.

O_E = extreme oil outflow parameter for the alternative design. This equals the extreme oil outflow divided by the total cargo oil capacity at 98% tank filling.

P_{OR}, O_{MR} and O_{ER} are the corresponding parameters for the reference or "rule" double hull design of the same cargo oil capacity.

USCG OPA Double Hull Equivalency Determinations: Oil Outflow Analysis

U.S. Department of Transportation
United States Coast Guard

Memorandum

Subject: OPA 90 DOUBLE HULL EQUIVALENCY DETERMINATIONS: OIL OUTFLOW ANALYSIS METHODOLOGY

Date: August 6, 2001
9070/1
16703/NVIC 10-94
16703/M16000.7/D.6

From: G-MSE-2

To: Memo to File

Reply to Attn. of: G-MSE-2
J. Person
J. Sirkar

1. This memo documents the oil outflow analysis methodology we will accept for making OPA 90 double hull equivalency determinations. A double hull equivalency is normally requested only when a double hull tank vessel built prior to June 30, 1990, (that is, a "pre OPA 90" double hull) does not fully comply with the OPA 90 double hull dimensions specified in 33 CFR 157.10d.

2. The premise behind a double hull equivalency determination is that we allow a trade-off of the negative consequences of an undersized double bottom or side dimension for the benefits of an oversized double bottom or side dimension, provided both the following conditions are satisfied: (1) The overall oil outflow performance ("E") of the as-built vessel is equal or better than that of a reference (or "rule") comparably sized "post OPA 90" double hull tank vessel, and (2) The probability of zero outflow performance ("P_0") of the vessel is equal or better than that of a reference (or "rule") comparably sized "pre OPA 90" double hull.

3. Both "E" and "P_0" should be calculated using the methodology contained in IMO Resolution MEPC.66(37), "Interim Guidelines for the Approval of Alternative Methods of Design and Construction of Oil Tankers Under Regulation 13F(5) of Annex I of MARPOL 73/78". To meet the 2 conditions noted in above paragraph 2., the reference (or "rule") double hull(s) that should be used are described below.

   a. For comparing the overall oil outflow performance (E") of the as-built vessel to that of the "rule" double hull, the "rule" double hull should be an equivalent sized tank vessel with the same cargo capacity as the as-built double hull, and internal cargo tank compartmentation consistent with the appropriately interpolated reference double hull as defined in the above mentioned MEPC.66(37), but having double hull dimensions conforming to the requirements in 33 CFR 157.10d(c)(1)(i) or (ii) and 157.10d(c)(2)(i) or (ii), as appropriate for the DWT. That is, the double side and double bottom dimensions of the "rule" double hull should conform to that of a "post OPA 90" vessel.

SUBJ: OPA 90 DOUBLE HULL EQUIVALENCY DETERMINATIONS: OIL OUTFLOW ANALYSIS METHODOLOGY

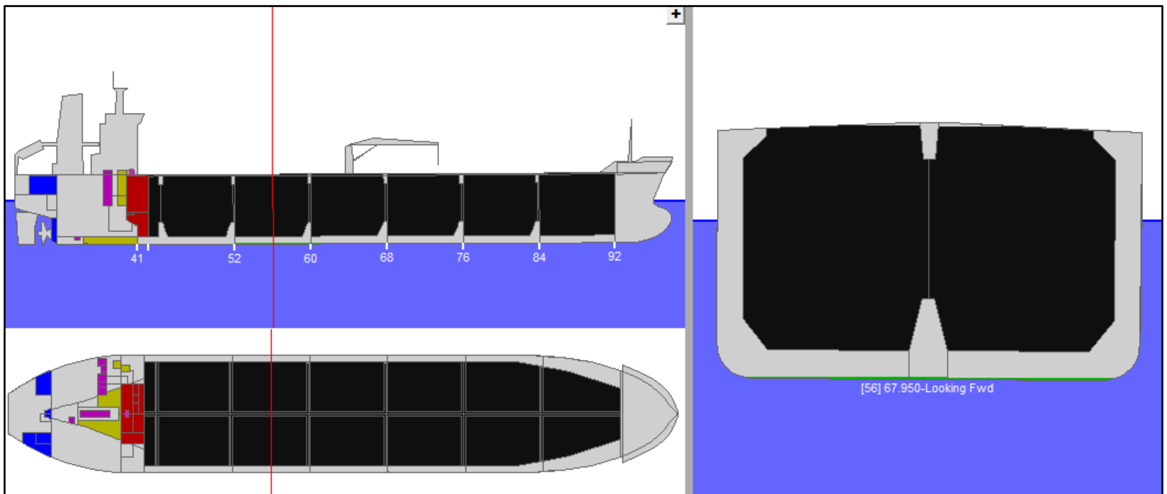
b. For comparing the probability of zero oil outflow ("P_0") of the as-built vessel to that of the "rule" double hull, the "rule" double hull should be an equivalent sized tank vessel with the same cargo capacity as the as-built double hull, but having double hull dimensions conforming to the requirements in 33 CFR 157.10d(c)(1)(iii) and 157.10d(c)(2)(iii). That is, the double side and double bottom dimensions of the "rule" double hull should conform to that of a "pre OPA 90" vessel.

4. A related matter is verification of the vessel's double hull dimensions to those used in the oil outflow analysis that form the basis of the double hull equivalency determination. The consistency of these dimensions must be demonstrated to the satisfaction of the cognizant Coast Guard Officer-in-Charge, Marine Inspection (OCMI) at the vessel's next Tank Vessel Examination.

H. PAUL COJEEN

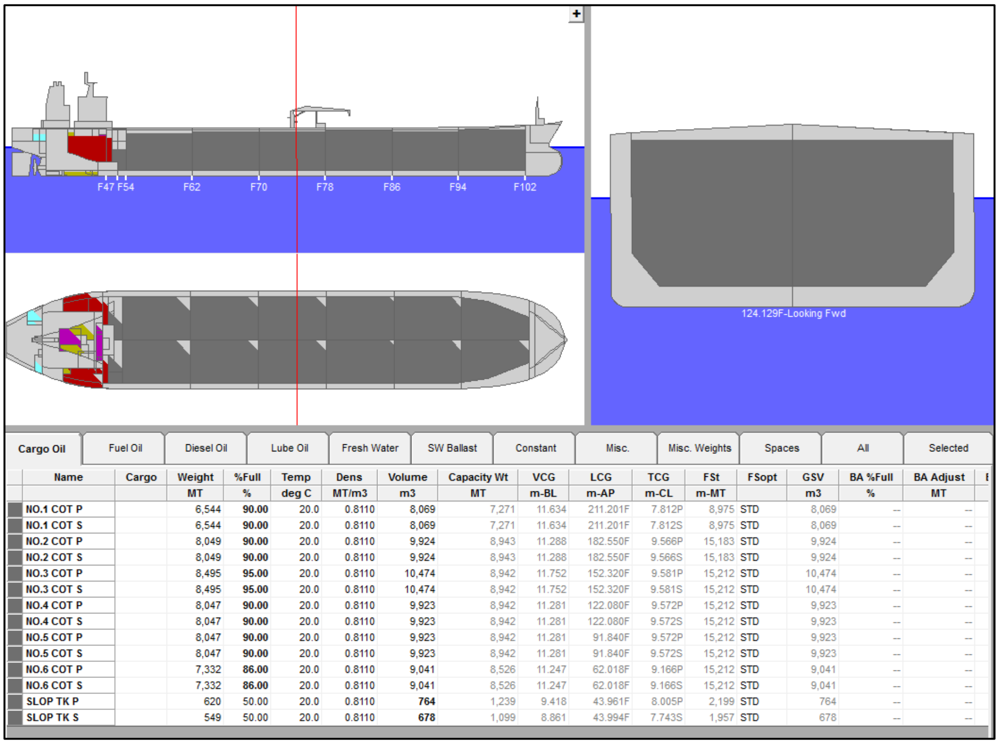
Ship Models for Oil Outflow Conditional Probability Distributions

The ship models used in the outflow conditional probability analyses are shown in Figure 36 through Figure 39.



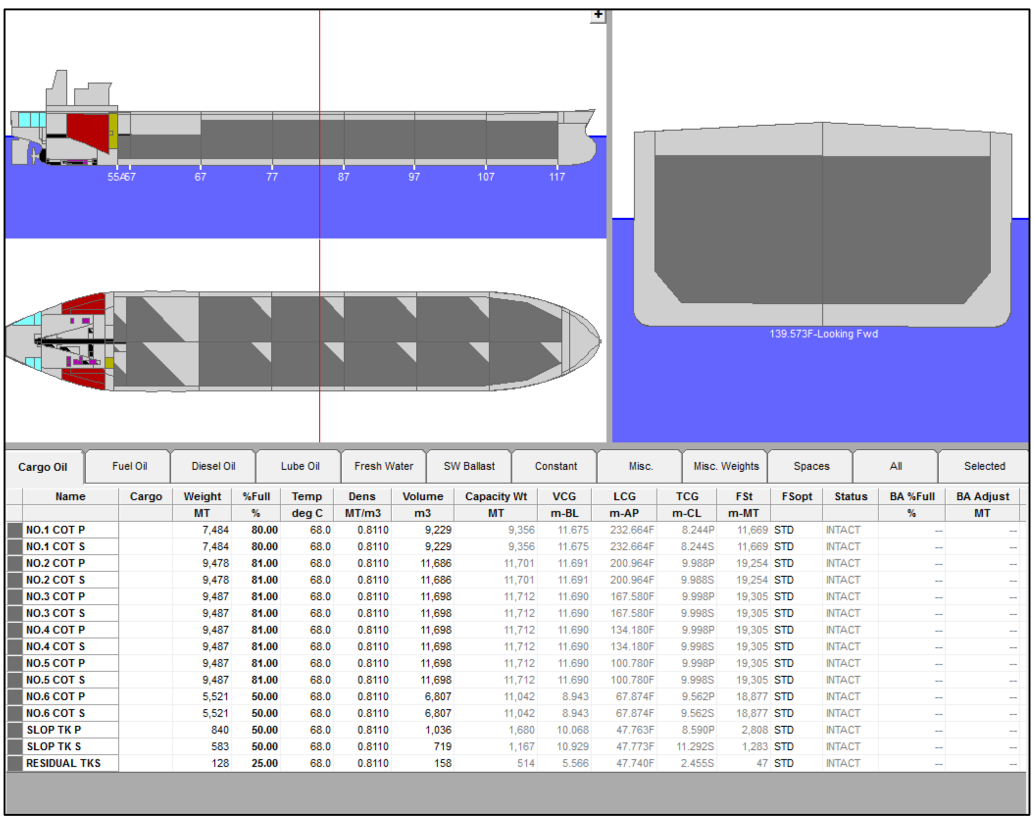
Name	Cargo	Weight	%Full	Temp	Dens	Volume	Capacity Wt	VCG	LCG	TCG	FSt	FSopt	Aft	Fwd
		MT	%	deg C	MT/m3	m3	MT	m-BL	m-AP	m-CL	m-MT		m-AP	m-AP
NO.1 COT P		2,644	98.00	20.0	0.8110	3,260	2,698	11.000	151.273	5.124P	676	STD	141.650	163.350
NO.1 COT S		2,644	98.00	20.0	0.8110	3,260	2,698	11.000	151.273	5.124S	676	STD	141.650	163.350
NO.2 COT P		3,698	98.00	20.0	0.8110	4,560	3,774	10.644	130.850	6.938P	1,525	STD	120.450	141.650
NO.2 COT S		3,698	98.00	20.0	0.8110	4,560	3,774	10.644	130.850	6.938S	1,525	STD	120.450	141.650
NO.3 COT P		3,781	98.00	20.0	0.8110	4,662	3,858	10.639	109.786	7.082P	1,636	STD	99.250	120.450
NO.3 COT S		3,781	98.00	20.0	0.8110	4,662	3,858	10.639	109.786	7.082S	1,636	STD	99.250	120.450
NO.4 COT P		3,781	98.00	20.0	0.8110	4,662	3,858	10.639	88.586	7.082P	1,636	STD	78.050	99.250
NO.4 COT S		3,781	98.00	20.0	0.8110	4,662	3,858	10.639	88.586	7.082S	1,636	STD	78.050	99.250
NO.5 COT P		3,767	98.00	20.0	0.8110	4,645	3,844	10.667	67.405	7.060P	1,630	STD	56.850	78.050
NO.5 COT S		3,767	98.00	20.0	0.8110	4,645	3,844	10.667	67.405	7.060S	1,630	STD	56.850	78.050
NO.6 COT P		3,250	98.00	20.0	0.8110	4,008	3,317	11.279	47.037	6.606P	1,420	STD	36.650	56.850
NO.6 COT S		3,250	98.00	20.0	0.8110	4,008	3,317	11.279	47.037	6.606S	1,420	STD	36.650	56.850
SLOP P		462	98.00	20.0	0.8110	570	471	11.927	34.894	5.997P	205	STD	33.200	36.650
SLOP S		462	98.00	20.0	0.8110	570	471	11.927	34.894	5.997S	205	STD	33.200	36.650

Figure 36: Handymax (174m x 32.2m x 18.9m, 50,000 dwt)



Name	Cargo	Weight	%Full	Temp	Dens	Volume	Capacity Wt	VCG	LCG	TCG	FSt	FSopt	GSV	BA %Full	BA Adjust
		MT	%	deg C	MT/m3	m3	MT	m-BL	m-AP	m-CL	m-MT		m3	%	MT
NO.1 COT P		6,544	90.00	20.0	0.8110	8,069	7,271	11.634	211.201F	7.812P	8,975	STD	8,069	--	--
NO.1 COT S		6,544	90.00	20.0	0.8110	8,069	7,271	11.634	211.201F	7.812S	8,975	STD	8,069	--	--
NO.2 COT P		8,049	90.00	20.0	0.8110	9,924	8,943	11.288	182.550F	9.566P	15,183	STD	9,924	--	--
NO.2 COT S		8,049	90.00	20.0	0.8110	9,924	8,943	11.288	182.550F	9.566S	15,183	STD	9,924	--	--
NO.3 COT P		8,495	95.00	20.0	0.8110	10,474	8,942	11.752	152.320F	9.581P	15,212	STD	10,474	--	--
NO.3 COT S		8,495	95.00	20.0	0.8110	10,474	8,942	11.752	152.320F	9.581S	15,212	STD	10,474	--	--
NO.4 COT P		8,047	90.00	20.0	0.8110	9,923	8,942	11.281	122.080F	9.572P	15,212	STD	9,923	--	--
NO.4 COT S		8,047	90.00	20.0	0.8110	9,923	8,942	11.281	122.080F	9.572S	15,212	STD	9,923	--	--
NO.5 COT P		8,047	90.00	20.0	0.8110	9,923	8,942	11.281	91.840F	9.572P	15,212	STD	9,923	--	--
NO.5 COT S		8,047	90.00	20.0	0.8110	9,923	8,942	11.281	91.840F	9.572S	15,212	STD	9,923	--	--
NO.6 COT P		7,332	86.00	20.0	0.8110	9,041	8,526	11.247	62.018F	9.166P	15,212	STD	9,041	--	--
NO.6 COT S		7,332	86.00	20.0	0.8110	9,041	8,526	11.247	62.018F	9.166S	15,212	STD	9,041	--	--
SLOP TK P		620	50.00	20.0	0.8110	764	1,239	9.418	43.961F	8.005P	2,199	STD	764	--	--
SLOP TK S		549	50.00	20.0	0.8110	678	1,099	8.861	43.994F	7.743S	1,957	STD	678	--	--

Figure 37: Aframax (239m x 44m x 21m, 125,000 dwt)



Name	Cargo	Weight	%Full	Temp	Dens	Volume	Capacity Wt	VCG	LCG	TCG	FSt	FSopt	Status	BA %Full	BA Adjust
		MT	%	deg C	MT/m3	m3	MT	m-BL	m-AP	m-CL	m-MT			%	MT
NO.1 COT P		7,484	80.00	68.0	0.8110	9,229	9,356	11.675	232.664F	8.244P	11,669	STD	INTACT	--	--
NO.1 COT S		7,484	80.00	68.0	0.8110	9,229	9,356	11.675	232.664F	8.244S	11,669	STD	INTACT	--	--
NO.2 COT P		9,478	81.00	68.0	0.8110	11,686	11,701	11.691	200.964F	9.988P	19,254	STD	INTACT	--	--
NO.2 COT S		9,478	81.00	68.0	0.8110	11,686	11,701	11.691	200.964F	9.988S	19,254	STD	INTACT	--	--
NO.3 COT P		9,487	81.00	68.0	0.8110	11,698	11,712	11.690	167.580F	9.998P	19,305	STD	INTACT	--	--
NO.3 COT S		9,487	81.00	68.0	0.8110	11,698	11,712	11.690	167.580F	9.998S	19,305	STD	INTACT	--	--
NO.4 COT P		9,487	81.00	68.0	0.8110	11,698	11,712	11.690	134.180F	9.998P	19,305	STD	INTACT	--	--
NO.4 COT S		9,487	81.00	68.0	0.8110	11,698	11,712	11.690	134.180F	9.998S	19,305	STD	INTACT	--	--
NO.5 COT P		9,487	81.00	68.0	0.8110	11,698	11,712	11.690	100.780F	9.998P	19,305	STD	INTACT	--	--
NO.5 COT S		9,487	81.00	68.0	0.8110	11,698	11,712	11.690	100.780F	9.998S	19,305	STD	INTACT	--	--
NO.6 COT P		5,521	50.00	68.0	0.8110	6,807	11,042	8.943	67.874F	9.562P	18,877	STD	INTACT	--	--
NO.6 COT S		5,521	50.00	68.0	0.8110	6,807	11,042	8.943	67.874F	9.562S	18,877	STD	INTACT	--	--
SLOP TK P		840	50.00	68.0	0.8110	1,036	1,680	10.068	47.763F	8.590P	2,808	STD	INTACT	--	--
SLOP TK S		583	50.00	68.0	0.8110	719	1,167	10.929	47.773F	11.292S	1,283	STD	INTACT	--	--
RESIDUAL TKS		128	25.00	68.0	0.8110	158	514	5.566	47.740F	2.455S	47	STD	INTACT	--	--

Figure 38: Suezmax (264m x 46m x 23.6m, 165,000 dwt)

Bottom Damage (Grounding) Simulation Results

The results for simulations of bottom damage (i.e., from groundings) are in Figure 39 and Figure 40. Note that the results are shown in cubic meters (m^3). One cubic meter is the equivalent of 6.2898 barrels (bbl).

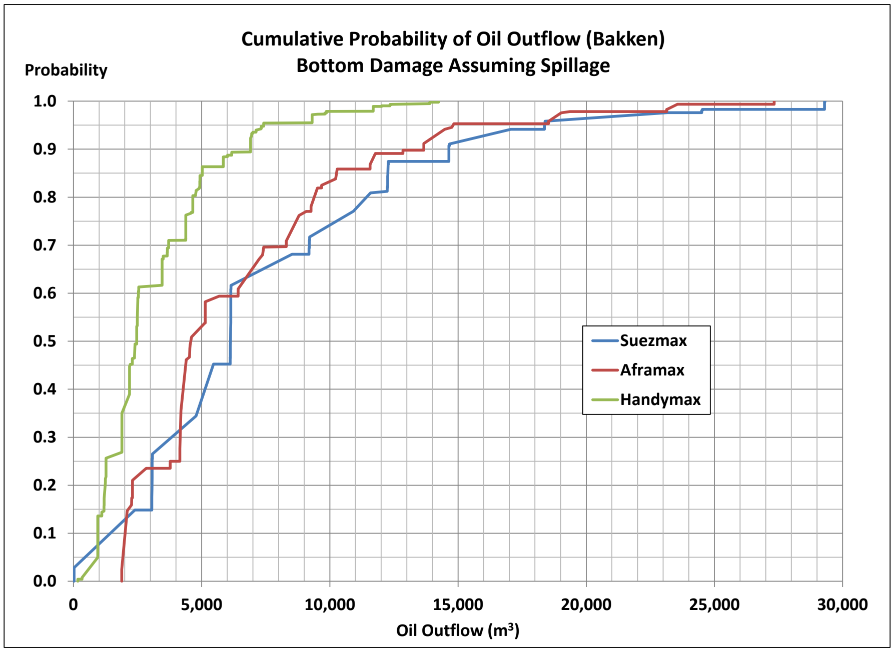


Figure 39: Cumulative Probability of Bakken Outflow with Bottom Damage

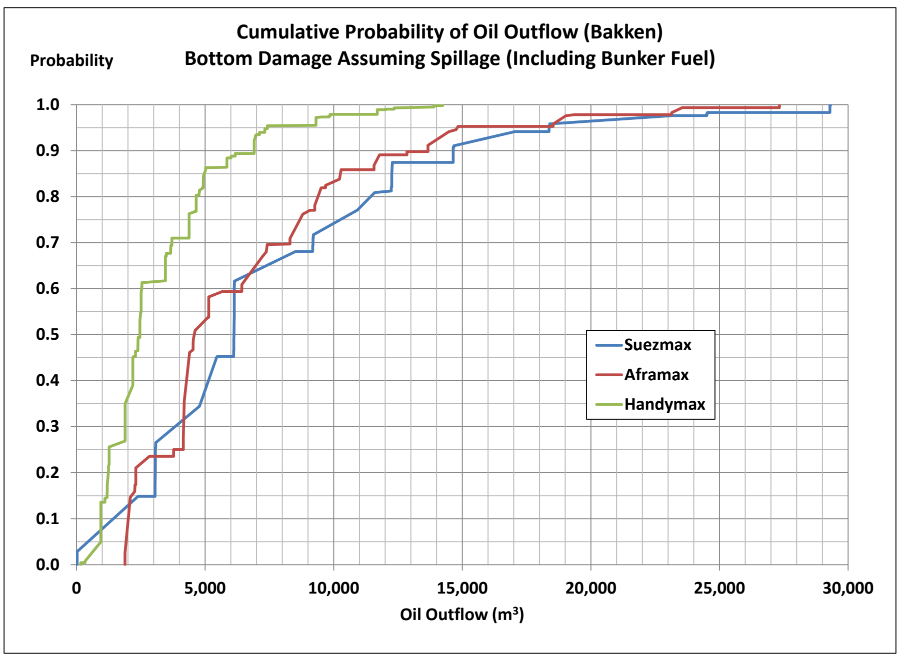


Figure 40: Cumulative Probability of Bakken/Bunker Outflow with Bottom Damage

Outflow for diluted bitumen cargo is shown in Figure 41.

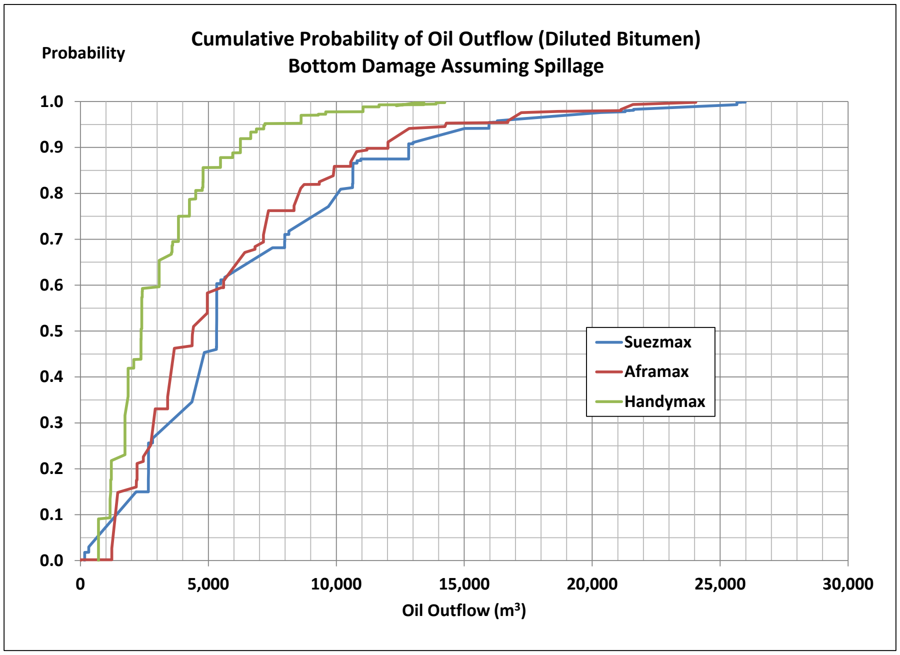


Figure 41: Cumulative Probability of Diluted Bitumen Outflow with Bottom Damage

Side Damage (Collision) Simulation Results

The results for simulations of collisions are shown in Figure 42 and Figure 43. The Suezmax results are shown as "Suezmax", which assumes that a Suezmax tanker collides with a similar-sized vessel, and "Suezmax Smaller Collision", which assumes that it collides with a smaller Aframax tanker.

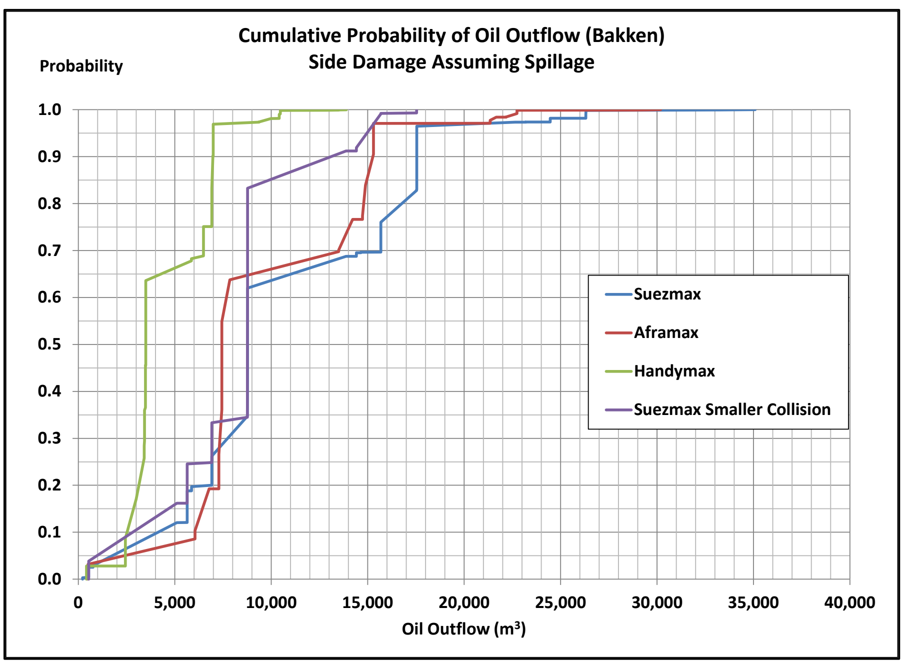


Figure 42: Cumulative Probability of Bakken Outflow with Collision

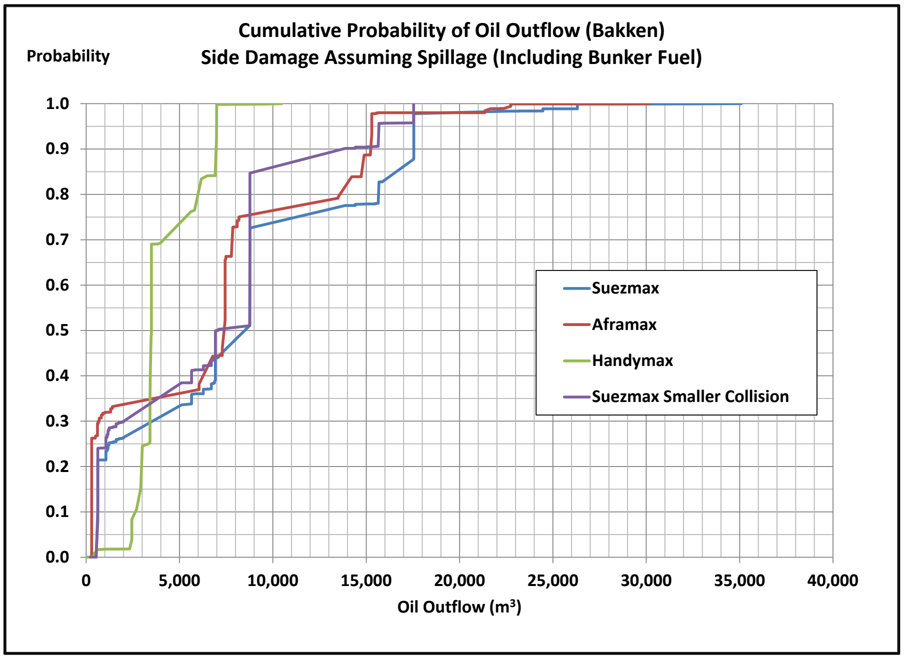


Figure 43: Cumulative Probability of Bakken/Bunker Fuel Outflow with Collision

Appendix B: Bakken Crude Oil Properties[71]

Basic Properties of Bakken Crude

The characteristics of Bakken crude and the way in which to classify it for the purposes of regulations related to transport and handling, and for preparing for spill responses and potential public health and safety issues has been a matter of considerable disagreement.

Bakken crude has a low viscosity and flows much more like diesel or gasoline than a crude oil. It has been described as looking like “two-stroke oil mixed with gasoline.”

Bakken crude oil, or North Dakota sweet crude, exhibits the properties shown in Table 44. In the table, Bakken crude is compared with West Texas Intermediate crude, which is often used as a “standard” crude oil for comparison purposes.

Table 44: Properties of Bakken Crude (North Dakota Sweet Crude)[72]

Test	Unit	Results	
		North Dakota Sweet	West Texas Intermediate[73]
Carbon Residue	%	0.54	1.69
Density	°API	42.1	39
Hydrogen Sulfide (H_2S)	ppm	<1	<1
Metals – Nickel – Pitch	ppm	7.8	28
Metals – Nickel – Whole	ppm	0.6	3
Metals – Vanadium – Pitch	ppm	6.6	42
Metals – Vanadium – Whole	ppm	0.4	5.2
Organic Chlorides – Naphtha	ppm	<1	-
Organic Chlorides – Whole	ppm	<1	<1
Pour Point	degrees F	<-27.4	<-27.4
Reid Vapor Pressure (RVP)	psia	5.94	4.86
SALT	lb/MB	63.4	64.3
Sulfur	%	0.0955	0.428
TAN E[74]	mg KOH/g	<0.1	0.4
Viscosity (SSU) @ 100°F		33.7	37.9
Viscosity (SSU) @ 60°F		37.7	45.6
Viscosity (SSU) @ 80°F		35.3	41.1

[71] From Etkin et al. 2015.
[72] Results based on North Dakota sweet sample (Lab Reference US320-0060054) taken 14 January 2014 and WTI sample (Lab Reference US320-0054517) taken 1 March 2013 as reported on www.caplinepipeline.com.
[73] West Texas Intermediate crude has traditionally been used as a benchmark against which the properties of other crudes are measured (Miller et al. 2010).
[74] Total Acid Number. The units are in milligrams of potassium hydroxide (KOH) per gram.

Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)

Samples of Bakken crude oil that spilled in the Lac-Mégantic incident in Quebec were analyzed for benzene, toluene, ethylbenzene, and xylene (BTEX) content for the Transportation Safety Board of Canada with the results shown in Table 45.[75] These natural constituents of crude oil are the most toxic and soluble components. They readily enter soil and groundwater during accidental spills. BTEX compounds are classified as priority pollutants by Environment Canada and the USEPA. The results indicate that the BTEX compositions of the Bakken crude samples are comparable to typical crude oils, such as West Texas Intermediate crude. The levels of BTEX compounds measured at the site of the Lac-Mégantic incident were reported to be well above recommended exposure limits in the portions of the derailment site that were extensively contaminated with the spilled crude oil.

Table 45: BTEX Testing Conducted on Lac-Mégantic Incident Bakken Crude Samples

Analyte	Analytical Results (ppm)[76]					Comparison	
	Sample 1	Sample 2	Sample 3	Sample 4	Average	Gasoline	WTI Crude[77]
Benzene	1,850	1,720	1,800	1,470	**1,663**	49,000	1,380
Toluene	3,170	2,870	2,920	2,770	**2,933**	250,000	2,860
Ethylbenzene	850	768	789	852	**815**	30,000	1,120
m/p-Xylene	3,500	3,300	3,310	2,890	**3,250**	-	4,290
o-Xylene	1,660	1,560	1,620	1,500	**1,585**	-	-

Alkane and Aromatic Profiles

Testing conducted at Louisiana State University for NOAA has provided further detail on the hydrocarbon profiles (alkanes and aromatics) for Bakken crude (Table 46). These are other components of oil that have a bearing on toxicity. Polycyclic aromatic hydrocarbons (PAHs) are also persistent in the environment.

Table 46: Bakken Crude Oil Testing Conducted at Louisiana State University[78]

Alkane Profile		Aromatics (PAH) Profile	
Alkane Analyte	Concentration (mg/Kg)	Aromatic Analyte	Concentration (mg/Kg)
nC-10 Decane	2,600	**Naphthalene**	750
nC-11 Undecane	2,600	**C1-Naphthalenes**	1,600
nC-12 Dodecane	2,600	**C2-Naphthalenes**	2,000
nC-13 Tridecane	2,500	**C3-Naphthalenes**	1, 400
nC-14 Tetradecane	2,400	**C4-Naphthalenes**	690
nC-15 Pentadecane	2,000	**Fluorene**	130
nC-16 Hexadecane	1,800	**C1-Fluorenes**	340
nC-17 Heptadecane	1,700	**C2-Fluorenes**	390
Pristane	960	**C3-Fluorenes**	300

[75] *Transportation Safety Board of Canada Laboratory Report LP148/2013*.
[76] Parts per million. Samples are from different tank cars involved in the derailment and spill.
[77] West Texas Intermediate crude.
[78] Data provided by NOAA.

Table 46: Bakken Crude Oil Testing Conducted at Louisiana State University[78]

Alkane Profile		Aromatics (PAH) Profile	
Alkane Analyte	**Concentration (mg/Kg)**	**Aromatic Analyte**	**Concentration (mg/Kg)**
nC-18 Octadecane	1,500	**Dibenzothiophene**	53
Phytane	770	**C1-Dibenzothiophenes**	170
nC-19 Nondecane	1,300	**C2-Dibenzothiophenes**	220
nC-20 Eicosane	1,300	**C3-Dibenzothiophenes**	160
nC-21 Heneicosane	1,100	**Phenanthrene**	290
nC-22 Docosane	1,000	**C1-Phenanthrenes**	680
nC-23 Tricosane	940	**C2-Phenanthrenes**	660
nC-24 Tetracosane	890	**C3-Phenanthrenes**	400
nC-25 Pentacosane	600	**C4-Phenanthrenes**	200
nC-26 Hexacosane	510	**Anthracene**	6.1
nC-27 Heptacosane	350	**Fluoroanthene**	4.2
nC-28 Octocosane	300	**Pyrene**	8.9
nC-29 Nonacosane	250	**C1-Pyrenes**	68
nC-30 Tricontane	230	**C2-Pyrenes**	94
nC-31 Hentriacontane	150	**C3-Pyrenes**	96
nC-32 Dotriacontane	120	**C4-Pyrenes**	54
nC-33 Tritriacontane	100	**Naphthobenzothiophene**	11
nC-34 Tetratriacontane	90	**C1-Naphthobenzothiophenes**	48
nC-35 Pentatriacontane	92	**C2-Naphthobenzothiophenes**	37
Total Alkanes	**30,752**	**C3-Naphthobenzothiophenes**	22
		Benzo (a) Anthracene	5.5
		Chrysene	36
		C1-Chrysene	100
		C2-Chrysene	100
		C3-Chrysene	54
		C4-Chrysene	19
		Benzo (b) Fluoroanthene	2.3
		Benzo (k) Fluoroanthene	1.6
		Benzo (e) Pyrene	6.6
		Benzo (a) Pyrene	1.0
		Perylene	0.92
		Indeno (1,2,3 – cd) Pyrene	0.20
		Dibenzo (a,h) Anthracene	1.3
		Benzo (g,h,i) Perylene	1.2
		Total Aromatics	11,203

Bakken Crude Volatility and Flammability

The property of greatest concern for Bakken crude is its volatility. Concern about the volatility of Bakken crude followed the July 6, 2013 accident in Lac-Mégantic, Quebec, Canada, in which a train derailed near the center of a town causing an explosion that resulted in the deaths of 47 people.

Even if volatility is the major concern, measuring it and classifying crude oils with respect to potential for flammability is not straightforward. The Reid Vapor Pressure (RVP),[79] which is often used to measure volatility, or how quickly a petroleum product or fuel evaporates, varies from one sample to another. According to ASTM Standard D-323, an RVP of less than 26 psi is considered "low volatility". In five different samples of North Dakota sweet crude taken on five different dates roughly one year apart, the RVP varied from 5.94 psia[80] to a high of 9.70 psia, a difference of nearly 39%. Other properties, such as density (°API) varied by less than 0.5% between sampling dates.[81]

In Capline Pipeline tests of a large number of crudes,[82] RVP varied from a low of 0.623 psia for UK Foinaven crude to a high of 10.0 psia for Nigerian Forcados/Oco Condensate Blend. Bakken crude (North Dakota sweet) falls into the middle.

The presence of increasing amounts of dissolved gases and other light ends (methane, ethane, propane, butanes, and pentanes) increases the crude oil's vapor pressure, lowering its flashpoint and lowering its initial boiling point. According to an American Fuel & Petrochemical Manufacturers (AFPM)[83] study, Bakken crude oil is within the norm with respect to the hazard characteristics of a light crude oil. The AFPM study had results as in Table 47. The survey showed maximum RVPs of 15.4 psia, considerably higher than those in the Capline testing.

Table 47: AFPM Survey of Bakken Crude Oil Characteristics[84]

Characteristic	Reported Values	Hazmat Transportation Regulatory Implications
Flashpoint	Range: -74.2° F – 122°F	Bakken crude oils meet the criteria for Packing Group I, II, or III flammable liquids or as combustible liquids.[85]
Initial Boiling Point	Range: 35.96°F – 152.42°F	Bakken crude oils with an initial boiling point of 35ºC or less meet criteria for Packing Group I flammable liquids; others for Packing Group II or III flammable liquids or combustible liquids according to flashpoint.
Vapor Pressure at 50°C (122°F)	Maximum: 16.72 psia	All Bakken crude oils have a vapor pressure below 43 psia at 50ºC and must be transported as liquids.
Reid Vapor Pressure at 38°C (100.4°F)	Maximum:15.4 psia	Not used by the regulations; confirm the vapor pressure at 50ºC is well below the above 43psia limit and Bakken crude oils must be transported as liquids.

[79] RVP is defined as the absolute vapor pressure exerted by a liquid at 100°F as determined by the test method ASTM D-323.
[80] psia = pounds per square inch (absolute).
[81] Based on data from www.caplinepipeline.com.
[82] www.caplinepipeline.com.
[83] AFPM 2014.
[84] Wybenga 2014.
[85] The Bakken crude data submitted included only one sample that qualified as a combustible liquid, which had a lower risk than other flammable liquids.

Table 47: AFPM Survey of Bakken Crude Oil Characteristics[84]		
Characteristic	**Reported Values**	**Hazmat Transportation Regulatory Implications**
Rail tank car pressures on delivery	Maximum:11.3 psig	Demonstrates that Bakken crude may be safely transported in DOT Specification 111 tank cars.[86]
Flammable gas content	Maximum:12.0 liquid volume %	None; with the vapor pressures of all Bakken crudes oils examined not exceeding a vapor pressure of 43 psia at 50ºC, all Bakken crude oils examined must be transported as liquids.
Hydrogen sulfide content in vapor space	Most H_2S concentrations below OSHA STEL; one reported maximum level of 23,000 ppm	None when low values are experienced; additional hazard communication to warn of the presence of H2S when inhalation hazard levels are encountered.[87]
Corrosivity	NACE B+ or B++	Data and experience indicate that Bakken crude oil does not corrode steel at a rate of ¼ inch per year or more so that Bakken crude oil is not a corrosive liquid.

American Petroleum Institute (API) analyzed more than 200 samples of Bakken and other types of crude, primarily West Texas Intermediate (WTI) crude, which is often used as a "standard" oil for comparison, and reported the results as shown in Table 48. The overall conclusion of this analysis was that Bakken crude oil is "very similar to other light crudes."

Table 48: Crude Oil Data Properties: Bakken Oil Compared with Other Light Crudes[88]				
Characteristic	**Value**	**Other Light Crudes**	**Bakken Crude**	**API Conclusion**
Vapor Pressure PSI (ASTM D6377)	**Average**	7.24	11.81	There is no practical difference in vapor pressures.
	Maximum	1.43	3.60	
	Minimum	11.46	15.37	
Sulfur Weight % (ASTM D4294)	**Average**	0.14	0.10	There is no practical difference in sulfur weight.
	Maximum	0.01	0.02	
	Minimum	0.64	0.25	
API Gravity (ASTM D5002)	**Average**	40.36	42.66	Gravity is as expected for light crude.
	Maximum	34.40	38.60	
	Minimum	46.90	47.07	
Initial Boiling Point °F (ASTM D86)[89]	**Average**	101.94°F (PG II)	91.96°F (PG I)	Initial boiling points solidly within range of Hazard Class 3.
	Maximum	83.40°F (PG I)	79.10°F (PG I)	
	Minimum	182.80°F (PG II)	150.80°F (PG II)	

[86] §179.201-1 provides summary specifications for DOT-111 rail tank cars. Earlier DOT 111's were designed to a 240 psig burst pressure whereas later designs are designed to a minimum burst pressure of 500 psig. Based on §179.15(b)(2)(ii) the minimum pressure relief valve settings for tank cars with a minimum burst pressure of 240 psig is 35 psig and for 500 psig designs the minimum setting is 75 psig.

[87] See §172.327.

[88] API 2014.

[89] PG = "packing group". Packing Group (PG) I has an initial boiling point of 95°F or less; PG II has a flash point of 73°F or less and an initial boiling point of greater than 95°F. PG I encompasses substances that pose a high hazard level; PG II encompasses substances that have a medium hazard level.

The API analyses indicate that Bakken crude is a Class 3 flammable liquid, which means that it has a flash point of not more than 141°F. The average flash point of light crudes is 101.94°F, whereas the flash point for Bakken crude is somewhat lower at 91.96°F.

The analyses indicate also that Bakken crude is classified as Packing Group I (PG I), except at the minimum measurements for those samples for which the initial boiling point is 150.8°F. Other light crudes are classified as Packing Group II (PG II), except for those that have a maximum initial boiling point of 83.40°F. The PG I classification encompasses substances that pose a high hazard level; PG II encompasses substances that have a medium hazard level.

API maintains that Reid Vapor Pressure (RVP) is not a good indicator of flammability based on preliminary analyses of simulations using the Fire Effects on Tank Cars (AFFTAC) Model.[90] The API Crude Oil Physical Properties Ad Hoc Group is considering if other crude oil properties are more appropriate in the selection of rail tank cars for transport (e.g., ignitability, flammability, light-end volumetric percent).

A more reliable and accurate measure of volatility is the analysis of distillation assays. Table 49 shows a comparison between the assay of Bakken crude and those for West Texas Intermediate (WTI) crude and Louisiana Light Sweet (LLS) crude. According to this type of assay, Bakken crude has twice as much volatile light-end components as WTI, and 1.7 times as much as LLS.

Table 49: Crude Oil Assays – Bakken vs. Other Light Crudes[91]

Assay Components		Bakken	West Texas Intermediate	Louisiana Light Sweet
API Gravity	**Degrees (°API)**	>41	40.0	35.8
Sulfur	**Weight %**	<0.2	0.33	0.36
Distillation Yield	**Volume %**			
Light Ends	**C1 – C4**	3	1.5	1.8
Naphtha	**C5 – 330°F**	30	29.8	17.2
Kerosene	**330 – 450°F**	15	14.9	14.6
Diesel	**450 – 680°F**	25	23.5	33.8
Vacuum Gas Oil	**680 – 1,000°F**	22	22.7	25.1
Vacuum Residue	**1,000+°F**	5	7.5	7.6
Total		**100**	**100**	**100**

Relative Viscosity of Bakken Crude

The viscosities of some common substances in comparison with Bakken crude are shown in Table 50. Bakken crude has a low viscosity and flows easily. It resembles dark coffee with respect to its color and tendency to flow.

[90] API 2014.
[91] Hill et al. 2011.

Table 50: Viscosity of Bakken Crude Compared with Common Substances[92]	
Liquid	**Viscosity (cSt)**
Water	1
Bakken Crude[93]	6.5
Kerosene	10
SAE 10 Motor Oil	100
Glycerin or Castor Oil	1,000
Corn Syrup	10,000
Molasses	100,000
Peanut Butter	1,000,000

[92] From Crude Oil & Response Considerations presented in May 2014 at EPA Region 10 Emergency Management Program Northwest Area Committee/Regional Response Team Meeting, Boise, Idaho.
[93] At 77°F, Bakken has a viscosity of 6.505. At 104°F, its viscosity is lower at 4.7.

Appendix C: Diluted Bitumen Properties[94]

The properties vary by location and by season. Diluted bitumen is a petroleum product produced by mixing bitumen (a highly viscous or solid asphaltic material) with light petroleum compounds (e.g., gas condensate or gas range oil), which are the diluent. Typically, the ratio of bitumen to diluent is 70:30 or 30% diluent. There is a heavier form of diluted bitumen called "railbit", which has only 15% diluent in the mixture. Diluted bitumen is considered to be a heavy crude, but varies considerably from other conventional heavy crudes. Diluted bitumen has been transported via pipeline into Washington for some time, but the transport by rail tank car is a relatively new phenomenon. There are also tank barges that carry heated bitumen.

Basic Properties of Diluted Bitumen and Related Oils

Bitumen is the heavy crude oil that remains in the geologic formation after in situ biodegradation processes occur in regions of Alberta, Canada.

In order to move bitumen efficiently through transmission pipelines, other petroleum products Diluted bitumen is created by adding naphtha-based oils including natural gas condensate. While approximately 75wt%[95] of the condensate has a low boiling point of 399.2°F, the overall boiling point of the diluted bitumen product remains high at 975.2°F. This is important because it means a small fraction <20wt% will evaporate rapidly during a spill, but the remaining fraction will not. The slower evaporation of the remaining fraction reduces the potential air quality issues for responders and the public. "Synbit" is made by diluting bitumen by using synthetic crude oil ("syncrude") from refineries. Like "dilbit", synbit maintains a high boiling point for the majority of the material.

Diluted bitumen (dilbit and synbit) that is transported through pipelines must meet certain specifications for viscosity, density, and acidity. In order to meet these specifications, the bitumen requires diluent by lighter oils, 30% for dilbit and 50% for synbit by volume.

Properties of diluted bitumen products are summarized in Table 51.

Table 51: Selected Physical Properties and Chemical Data for Diluted Bitumen Products[96]

Name	Density (kg/m^3)	Sulfur (wt%)	Sediment (ppmw)	Light Ends[97] Volume %	BTEX Volume %
Condensate Blends					
Access Western Blend	922.9 ± 4.6	3.94 ± 0.09	89 ± 8	24.1 ± 1.7	1.20 ± 0.15
Borealis Heavy Blend	927.4 ± 5.2	3.67 ± 0.29	94 ± 27	24.1 ± 1.7	0.99 ± 0.09
Christina Dilbit Blend	924.9 ± 5.2	3.88 ± 0.09	88 ± 41	22.8 ± 2.2	1.12 ± 0.17
Cold Lake	927.7 ± 5.0	3.78 ± 0.08	94 ± 42	20.4 ± 1.5	1.06 ± 0.17
Peace River Heavy	930.5 ± 4.7	5 ± 0.1	97 ± 30	22.4 ± 1.1	1.02 ± 0.09
Statoil Cheecham Blend	928.8 ± 4.5	3.81 ± 0.09	169 ± 99	24.1 ± 2.3	1.06 ± 0.14
Western Canadian Select	928.1 ± 4.3	3.50 ±0.07	284 ± 23	18.3 ± 1.3	0.83 ± 0.12

[94] From Etkin et al. 2015.
[95] Percent by weight.
[96] Government of Canada 2014, and Crude Quality Inc., 2013. www.crudemonitor.ca/home.php, accessed September 2013.
[97] Light Ends compromise the sum of all butanes through decanes, inclusive.

Table 51: Selected Physical Properties and Chemical Data for Diluted Bitumen Products[96]					
Name	**Density (kg/m^3)**	**Sulfur (wt%)**	**Sediment (ppmw)**	**Light Ends[97] Volume %**	**BTEX Volume %**
Blends Other than Condensate					
Borealis Heavy Blend	927.4 ± 5.2	3.67 ± 0.29	94 ± 27	24 ± 1.7	0.99 ± 0.09
Statoil Cheecham Blend	928.8 ± 4.5	3.81 ± 0.09	169 ± 99	24.1 ± 2.3	1.06 ± 0.13
Long Lake Heavy	932.6 ± 3.6	3.21 ± 0.16	18	15.9 ± 1.2	0.94 ± 0.10
Statoil Cheecham Synbit	930.5 ± 4.2	3.07 ± 0.09	71 ± 11	13.4 ± 1.3	0.76 ± 0.09
Surmont Heavy Blend	936.1 ± 3.8	3.08 ± 0.11	101 ± 42	11.3 ± 0.9	0.59 ± 0.09
Suncor Synthetic H	936.5 ± 2.2	3.07 ± 0.09	39	10.4 ± 1.0	0.44 ± 0.08
Albian Heavy Synthetic	938.7 ± 3.5	2.46 ± 0.23	784 ± 229	23.3 ± 1.4	0.94 ± 0.14

In combining the diluent (e.g., condensate) with the bitumen, it does not create a two-phase mixture of bitumen and diluent. The resulting mixture is a new, cohesive blended product.

Floating/Non-Floating Properties of Diluted Bitumen

Group V oils that are heavier (more dense) than freshwater will sink into water with a density of 1.0. According to laboratory and mesoscale weathering experiments, diluted bitumen products have physical properties much aligned with a range of intermediate fuel oils and other heavy crude oils. Generally, depending on the initial blend and state of weathering, diluted bitumen products are not characterized as non-floating oils.[98]

Even Group III and IV oils can become neutrally or negatively buoyant (i.e., sink) in freshwater or saltwater through various mechanisms, especially if the oil comes in contact with sediment in a high-energy setting (i.e., in nearshore surfzone areas).[99]

Diluted bitumen's potential for sinking after weathering – i.e., losing its light fractions to evaporation – was the impetus for a series of tank test studies on the behavior of diluted bitumen when spilled into freshwater[100] or brackish[101] marine waters.[102]

Mesoscale weathering experiments done in Gainford, Alberta[103] showed that Cold Lake and Access Western Blend diluted bitumen blends exhibited properties typical of a heavy, "conventional" crude oil as they weathered but in no instance was any oil observed to have sunk after 10 days of weathering on 20 ppt brackish water under varied physical conditions. The physical properties of weathering oil measured during those tests showed that diluted bitumen spilled into fresh, brackish, or saltwater will stay on the water surface for days unless another mechanism mixes it into the water column, as would be the case for most Group III and IV oils. Only after extensive weathering, or mixing with suspended particulate material, may some portion of weathered dilbit become submerged or sink.

98 Polaris Applied Sciences 2013.
99 National Research Council 1999.
100 SL Ross 2010.
101 Water that has 0.05–3% dissolved salts compared with <0.05% for freshwater and 3–5% for seawater.
102 Witt O'Brien's et al. 2013.
103 Witt O'Brien's et al. 2013.

In another series of studies conducted by the Government of Canada on two diluted bitumen products that represented the highest volume transported by pipeline in Canada during 2012–2013 – Access Western Blend and Cold Lake Blend, the researchers concluded:[104]

- Like conventional crude oil, both diluted bitumen products floated on saltwater (free of sediment), even after evaporation and exposure to light and mixing with water.
- When fine sediments were suspended in the saltwater, high-energy wave action mixed the sediments with the diluted bitumen, causing the mixture to sink or be dispersed as floating tarballs.[105]
- Under conditions simulating breaking waves, where chemical dispersants have proven effective with conventional crude oils, a commercial chemical dispersant (Corexit 9500) had quite limited effectiveness in dispersing diluted bitumen (dilbit).
- Application of fine sediments to floating diluted bitumen was not effective in helping to disperse the products.
- The two diluted bitumen products display some of the same behaviors as conventional petroleum products (i.e. fuel oils and conventional crude oils), but also some key differences, notably for the rate and extent of evaporation.

The four major factors that have a bearing on whether spilled oil, including diluted bitumen, will float, become neutrally buoyant (suspended in the water column), or sink are:

- Density of the oil, which may change with weathering (evaporation).
- Salinity of the water (i.e., density of the water relative to the oil).
- Amount of sediment in the water.
- Turbidity of the water (stirring up sediment and breaking oil into smaller droplets).

As long as the oil is less dense than the water, it will float. It may temporarily become submerged in the water column if broken into smaller droplet in turbulent water, but in those cases it will refloat under more calm water conditions. If the oil becomes heavier than the water, either by becoming attached to sediment particles, or, less commonly, by having enough of the lighter ends evaporate to increase the density, it will become neutrally buoyant or sink.

Since salt and brackish[106] water (e.g., water in estuaries) is heavier than freshwater, it takes more of an increase in density to cause oil to sink in salt or brackish water than in freshwater, where the density of water is 999.97 kg/m^3 – or essentially 1,000 kg/m^3 or 1.0 g/ml. Seawater is denser than freshwater and has an average density of 1.025 g/m^3, though it may be as high as 1.028 g/m^3. Brackish water in estuaries varies in density between 1.0 to 1.025 g/m^3. For this reason, a heavy oil with a density of 1.01 g/m^3 would float in seawater but sink in a freshwater lake, or in an estuary.

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[104] Government of Canada 2014.

[105] The use of the term "tarball" follows convention in the literature and refers to the consistency of floating, heavily-weathered oil. It does not describe the chemical composition of the product.

[106] Brackish water has 0.05–3% dissolved salts compared with <0.05% for freshwater and 3–5% for seawater.

When oil mixes with sediment particles (e.g., sand in the surf zone of a beach), the combinations of sediment and oil – called "oil-mineral aggregates" (OMA) – can become heavier than water to cause sinking. OMA formation is more likely to occur in the following situations:

- The oil is in fine droplets.
- There is a large sediment load in the water column.
- There is a lot of turbulence in the water, which increases the number of smaller oil droplets, stirs up sediment from the bottom, and increases the likelihood of contact between the oil droplets and sediment particles.

OMA sinking is more likely to occur in freshwater than salt or brackish water because of the greater likelihood that the density of the OMA will be higher than the water density. The OMA density has to be somewhat higher to sink in salt or brackish water.

If diluted bitumen were to spill into a freshwater or estuarine system, as would occur in inland areas of Washington State, or the Columbia River, it would undergo the processes shown in Figure 44.

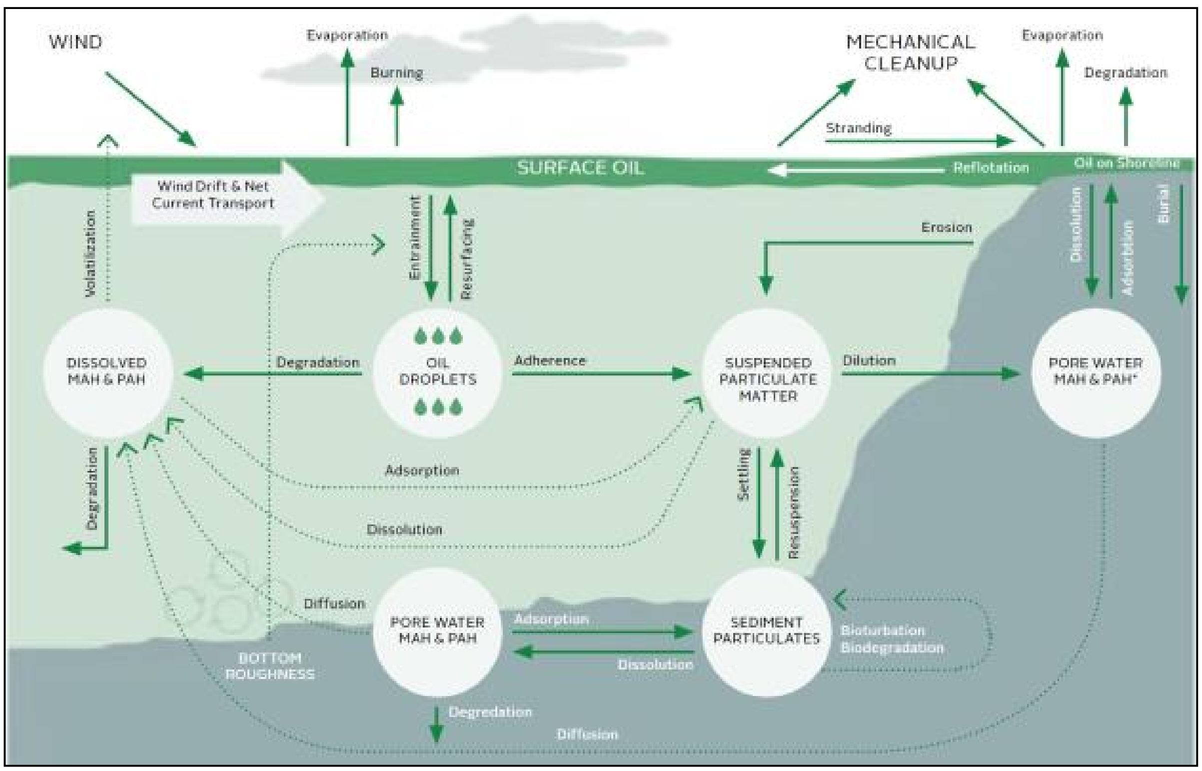

Figure 44: Simulated Oil Fate Processes in Lakes and Rivers[107]

Given that there may be sediment in the river, stream, or lake, it is possible for the diluted bitumen to create OMAs and sink. This would be most likely in a shallower stream with a rapid current, high

[107] From: http://gatewaypanel.review-examen.gc.ca/clf-nsi/dcmnt/rcmndtnsrprt/rcmndtnsrprtvlm2chp6-eng.html. MAH refers to monocyclic aromatic hydrocarbons (such as benzene, toluene, ethylbenzene, and xylene – combined, BTEX) and PAH refers to the lighter polycyclic aromatic hydrocarbons. These compounds are both volatile and relatively soluble in water.

sediment load, and turbulent waters that stir up the bottom sediment and break the oil into smaller droplets.

In marine waters, the oil would undergo similar processes, but it is less likely that the oil would sink due to the salinity of the water causing an increase in the density of the water.

Weathering as Cause of Diluted Bitumen Sinking

Theoretically, if enough of the light ends of an oil evaporate, the overall density of the oil would increase, perhaps enough to cause the density to be more than that of freshwater or even saltwater (Figure 45). The phenomenon of "evapo-sinking" has been proposed as an explanation for the sinking of some of the spilled oil during the Macondo MC-252 (Deepwater Horizon) spill in the Gulf of Mexico.[108]

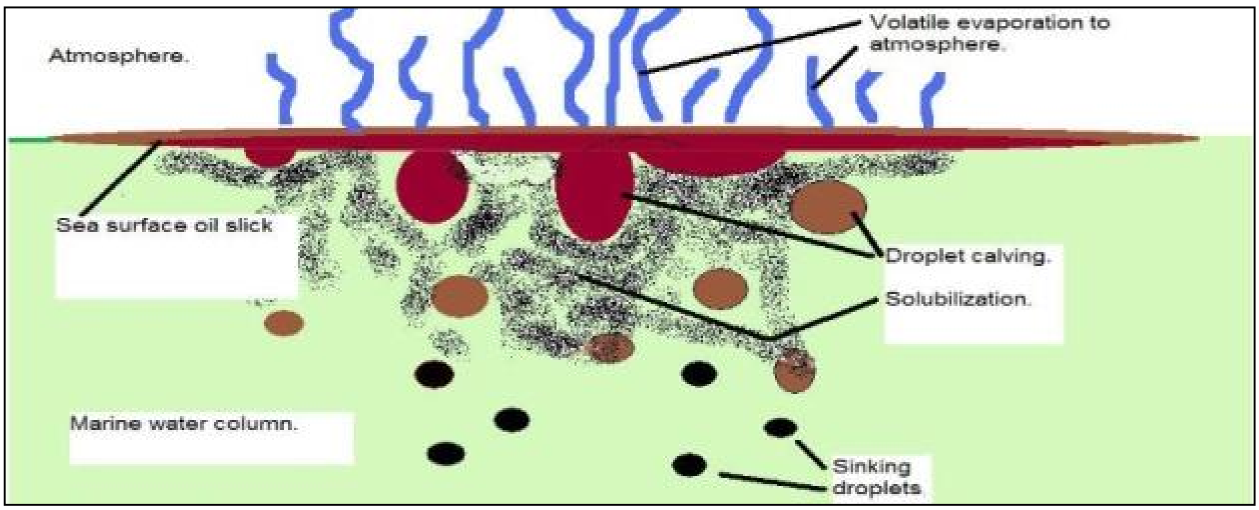

Figure 45: Evaporation/Dissolution from a Sea Surface Slick[109]

There is anecdotal evidence that this evaporative sinking phenomenon can occur, e.g., the Lake Wabamun spill in Alberta in which 185,000 gallons of heavy fuel oil spilled from 40 rail tank cars into a freshwater lake after a derailment in 2005.[110] There is also evidence that this phenomenon may have explained the sinking of Bunker C (heavy fuel oil with a density of 0.967) spilled from the USNS Potomac in 1977.[111]

When spilled into water, lighter hydrocarbon fractions of the entire diluted bitumen blend begin to evaporate. As lighter fractions evaporate, the viscosity of the weathered diluted bitumen would increase, and evaporation of remaining lighter fractions would be progressively inhibited.

Evaporative studies of diluted bitumen blends (e.g., Cold Lake) have shown that the first few hours of exposure to air results in the rapid loss of portions of the diluent with resulting increases in density and viscosity. Evaporative loss rates are affected by air temperature, oil surface area and thickness on the water surface, and wind conditions.[112] But, the studies also showed that because of the minimal light-end

[108] Thibodeaux 2013.
[109] Thibodeaux et al. 2011.
[110] Fingas et al.
[111] Michel and Galt 1995.
[112] Brown and Nicholson, 1991; SLRoss 2010a.

content of the diluted bitumen, the final evaporative loss of diluted bitumen was similar to ANS crude. The diluted bitumen exhibited an 8% volume loss through evaporation. This corresponds to an 8% increase in density. In freshwater, this may cause the oil to become heavier than water. It is unlikely to cause submergence in marine waters or even most estuarine waters, however.

Shoreline or Ground Impacts of Diluted Bitumen Spills

Oil spilled onto ground or onto shorelines, including river banks, will tend to spread, move downslope, evaporate, and penetrate into substrates. Ambient temperature, substrate grain sizes, substrate saturation (water), and additional components on or in substrate such as organic matter, vegetation, roots, and snow will affect the rate of penetration into substrates. Oil penetration into substrate is a function of oil viscosity (affected by temperature and emulsion, if stranded after being on water) and effective permeability (measured relative to the viscosity of the stranded oil).[113] One study found that diluted bitumen will spread and penetrate less into sand than the comparable crudes in the event of a spill.[114]

Table 52 shows oil penetration and the evaporative loss of Cold Lake bitumen blend that had been artificially weathered for 24 hours from four types of shoreline material at 50°F. Evaporative loss for stranded diluted bitumen was highest on mixed sediment in low energy conditions, reaching 9.5% by the end of 48 hours after application.

Table 52: Summary of Cold Lake Bitumen Blend Evaporation in Sediments[115]

Site Type	Sediment Characteristics			Evaporation		Substrate Penetration
	% Shell Fragments	Sorting	Sand	Hours	%	
Low energy mixed sediment	10 – 60%	Wide variation; all sizes up to 4 cm	Top 3” of shore at mid-tide point	8	2.5	Low water retention, resulted in high oil permeability
				15	5	
				24	7.2	
				36	8.8	
				48	9.5	
High energy mixed sediment	10%	Wide variation of well-rounded rock sizes; 10 cm to 5 mm	Small amount	8	2	
				15	3	
				24	3.8	
				36	4.5	
				48	4.7	
Low energy sand sediment	-	Well sorted sandy shore	Tidal flat sandy beach	8	1	High penetration at top 1 mm; below 1 mm wet sediment has low oil permeability
				15	2	
				24	3.4	
				36	4	
				48	4.6	
Low energy estuary sand sediment	-	Well sorted sandy shore	Fine sediment, sand from estuary beach	8	0.8	
				15	1	
				24	1.8	
				36	2.1	
				48	2.2	

[113] Etkin et al. 2007, 2008a, 2008b; Witt O’Brien’s et al. 2014.
[114] Tsaprailis et al. 2013.
[115] Witt O’Brien’s et al. 2013, as derived from Brown et al. 1992.

Appendix D: Department of Ecology Oil Transfer Rules

Department of Ecology adopted new oil transfer rules[116] to prevent spills when oil is transferred over water. These rules require submission of an Advance Notice of Oil Transfer (ANT) by the delivering facility (fixed or mobile) or vessel which is transferring over 100 gallons of bulk oil to a non-recreational vessel or facility. The ANT must be submitted 24 hours prior to the transfer for facilities, and as required by local USCG Captain of the Port requirements for vessels.[117] As a Class 1 facility[118], BP Cherry Point must follow specific rules with regard to oil transfer operations.

Designating the Person-In-Charge (PIC)

All owners and operators of Class 1, 2, and 3 facilities and vessels transferring oil in bulk on or over state waters must designate a "person in charge" (PIC) who is responsible for supervising the oil transfer. All personnel involved in the transfer must be sufficiently trained to ensure a safe transfer. All Class 1 and 2 facilities must also be trained and certified as required in chapter 173-180 WAC and carry proof of this certification while participating in an oil transfer.

Pre-Transfer Conference

Under the rules, a face-to-face conference between the receiving and delivering PICs must occur prior to the oil transfer. The PICs must be able to communicate in English during this pre-transfer conference. The PICs must discuss and approve the pre-transfer plan, the contents of the Document of Inspection (DOI), the procedures for communicating soundings, changing over tanks, topping off, shift changes, and emergency shutdown, as well as possible impacts of predicted weather and/or sea conditions. If applicable, the conference will identify the point-of-transfer watch and deck-rover watch on the vessel. The PICs may conduct this conference via radio if weather conditions make moving from vessel to facility or vessel to vessel unsafe.

Pre-Loading or Cargo Transfer Plan

A pre-load or cargo transfer plan must be completed prior to the pre-transfer conference. At a minimum, the plan must include:

- Identification, location, and capacity of the vessel's tanks receiving oil (if applicable);
- Level and type of liquid in all bunker or cargo oil tanks prior to the oil transfer;
- Planned final "ullage", or the depth of space above the free surface of the oil, and planned final "innage", or the difference from the surface of the oil to the tank bottom;
- Planned final% of each tank to be filled;
- Sequence in which the tanks will be filled; and

[116] See WAC chapters 173-184-100, 173-180-215, and 173-180-210 for details.
[117] The preferred method for submission of the ANT is via an internet web-based form which satisfies both Ecology and USCG reporting requirements for the advance notice of oil transfer. Facilities and vessels using this system must first register via state's SecureAccess Washington online system at https://secureaccess.wa.gov/. This system will ensure protection of proprietary transfer information. After registration has been approved, ANTs may be submitted at https://secureaccess.wa.gov/ecy/ants.
[118] The Class 1 category applies to large, fixed shore-side facilities such as refineries, refueling terminals, and oil pipelines. This definition includes facilities that transfer to tank vessels and pipelines.

- The facility or vessel's procedures to regularly monitor all receiving tank levels and valve alignments during the transfer operation.

Communication between PICs

The facility PIC must ensure continuous, two-way voice communication between the delivering and receiving PICs throughout all phases of the transfer operation. The facility PIC must ensure that two portable intrinsically safe communication devices are available for use during the transfer. An air horn must be available for emergency shutdown signals and all personnel involved in the oil transfer must know and use English phrases and hand signals indicating STOP, HOLD, WAIT, FAST, SLOW, and FINISH.

Safe Transfer Operational Requirements

All oil transfer operations at Class 1 and 2 facilities must be conducted according to the facility's Ecology-approved operations manual. All transfer connections must be made using appropriate materials. All persons involved in an oil transfer must have the means to contain and recover any drips or leaks from connections within the oil transfer system. Deliverers providing oil to vessels without fixed containment must use automatic back pressure shutoff valves and provide adequate portable containment for each tank vent on the vessel.

Before the transfer starts the PICs must verify that the Document of Inspection (DOI) is signed by both PICs; the available capacity in the receiving tank(s) is (are) greater than the volume of oil to be transferred; all valves are properly aligned; and an emergency shutdown system is in place and is operable. Once the transfer starts, the PICs must ensure the tanks designated in the pre-transfer plan are receiving oil at the planned rate. If a shift change occurs, the relieving PIC must notify the person in charge at the other end of the transfer and sign the DOI. The delivering PIC must refuse to start or continue an oil transfer if the receiving PIC has not provided complete information as required by the Document of Inspection or refuses to correct deficiencies identified in the pre-transfer conference; does not comply with the operations manual or does not respond to identified concerns; and/or refuses to discuss the pre-load plan and oil transfer rate.

Work Hours

Facility personnel with oil transfer duties may NOT work more than 16 hours in any 24-hour period; or more than 40 hours in any 72-hour period. The exception would include working in an emergency or to respond to a spill. A covered vessel's personnel when bunkering must comply with the 1990 Oil Pollution Act work hours or the Standards for Training and Certification of Watchkeepers rest hours. The owner or operator of a vessel engaged in bunkering and Class 1, 2, or 3 facilities must maintain work hour records demonstrating compliance with the above work hour restrictions.

Oil Transfer Equipment Requirements

All Class 1, 2, 3, and 4 facilities' oil transfer hoses and/or piping used in oil transfer operations must meet the following criteria:

- Must be well supported to avoid crushing or excessive strain.
- Flanges, joints, hoses, and piping must be visually checked for cracks and leakage prior to transferring oil.

- Must be in good condition and not have any loose covers, cracks, kinks, bulges, soft spots, or other defects that penetrate the hose reinforcement layer.
- Hoses or piping must not be permitted to chafe on the dock or vessel or be in contact with any other surface that might damage the hoses or piping.
- All hoses and loading arms must be long enough to allow the vessel to move to the limits of its moorings without placing excessive strain on the oil transfer equipment.
- Hose ends must be tightly closed with properly secured flanges when they are moved into position for connection and also immediately after they are disconnected. Residue in the hose or loading arm must be drained either into the vessels tanks or into suitable shore receptacles before they are moved away from the point of connection.

Oil Transfer Equipment Testing

Annual tests of all oil transfer equipment such as pumps, valves, piping, manifolds, connections, and hoses are required. These tests must be done in accordance with the manufacturer's recommendations and industrial standards – or through procedures identified under federal regulations. For facilities, the design, construction, and repair records for storage tanks, pipelines, and all oil transfer equipment testing and repair records must be kept for the life of the equipment. Inspection, maintenance, and repair records for pumps, valves, manifolds, and other ancillary equipment used in oil transfers must be kept for ten years.

Beyond the regulations, there are a large number of recommendations that have been made by Ecology regarding safe bulk oil transfer operations, as shown in Table 53.

Table 53: Recommendations on Bulk Oil Transfer Operations

Reference Number	Recommendation[119]
2000-007	Ensure that the revised mooring studies for {tank ship operator's} tankers at the {regulated facility operator's} Ferndale pier incorporate current speeds (in excess of 1 knot) and directions that were recorded by {environmental consultant} in May 1999 under contract with {regulated facility operators}. If necessary, undertake additional current monitoring study, in cooperation with Tosco, to determine the maximum probable current that will be experienced at the {regulated facility operator's} Ferndale pier and to determine the frequency and intensity of tideline passages at the pier.
2000-008	Work with {regulated facility operator}, {regulated facility operator}, National Oceanic and Atmospheric Administration (NOAA) and Ecology to develop tidal current prediction factors for the Cherry Point and Ferndale facilities.
2000-009	Revise company maintenance procedures to require inspections of the winch brakes prior to each mooring operation, and include checks derived from the {manufacturer's} winch manual. Ensure that these checks are documented and that any problems noted are addressed quickly.
2000-010	Revise company procedures to ensure that there are at least two qualified persons on duty on deck specifically dedicated to tending the ship's mooring during transfer operations. These two persons should work together to ensure that the safety-critical mooring system is properly adjusted for the prevailing conditions.

[119] The recommendations made by the Washington State Department of Ecology to ship operators, regulated facility operators, Classification Societies, industry associations, equipment manufacturers and government agencies following investigations of spills that occurred during ship bulk oil transfer operations. (http://www.ecy.wa.gov/programs/spills/prevention/measures/bulkoilrec.html)

Table 53: Recommendations on Bulk Oil Transfer Operations	
Reference Number	**Recommendation**[119]
2000-011	Review the mooring winch maintenance system for the company, ensure that maintenance is occurring in accordance with the established schedule. Regularly audit maintenance logs to ensure continued adherence to the schedule.
2000-012	Ensure that results of annual brake testing are readily available to those responsible for tending the ship's moorings.
2000-013	Revise company procedures to ensure that any permanent modifications to safety-critical systems, including mooring winches and brakes, are carefully considered and reviewed by company management prior to implementation. Ensure that any such modifications are documented in accordance with the company's Safety Management System (SMS).
2000-014	Ensure that the company's Safety Management System (SMS) fully complies with Section 10.2.4 of the International Safety Management (ISM) Code.
2000-015	Ensure that the revised mooring studies for {tank ship operator's} tankers at the Ferndale pier incorporate current speeds (in excess of 1 knot) and directions that were recorded by {environmental consultant} in May 1999 under contract with {regulated facility operators}. If necessary, undertake additional current monitoring study, in cooperation with {tank ship operator}, to determine the maximum probable current that will be experienced at the {regulated facility operator's} Ferndale pier and to determine the frequency and intensity of tideline passages at the pier.
2000-016	Work with {regulated facility operator}, National Oceanic and Atmospheric Administration (NOAA), {tank ship operator} and Ecology to develop tidal current prediction factors for the Cherry Point and Ferndale facilities.
2000-017	Review the role of the pollution control representative. Ensure the pollution control representative is given adequate authority (and management support) to require a transfer shut-down should he/she detect an unsafe condition.
2000-018	Review the work hours of the pollution control representative in light of their role. Consider the use of more than one pollution control representative during transfers exceeding 12 hours, so that a continuous oversight presence is maintained on deck.
2000-019	Cooperate with the Seattle Office of the National Weather Service by regularly providing weather observations (automated or manual) to forecasters on duty.
2000-020	Consider the installation of permanent tidal current monitoring equipment at the pier. Should such an installation be undertaken, work with the National Oceanic and Atmospheric Administration (NOAA) to provide the agency real-time access to the data.
2000-021	Review the company's process for accepting tanker mooring arrangements, ensure that the process adequately reviews the mooring arrangements in light of environmental conditions likely to occur at {regulated facility operator's} facilities.
2000-022	Work with {regulated facility operator}, {regulated facility operator}, {tank ship operator} and Ecology to develop tidal current prediction factors for the Cherry Point and Ferndale facilities.
2000-023	Work with NOAA, {regulated facility operator}, {tank ship operator} and Ecology to develop tidal current prediction factors for the Cherry Point and Ferndale facilities.
2000-024	Work with {regulated facility operator}, {regulated facility operator}, {tank ship operator} and National Oceanic and Atmospheric Administration (NOAA) to develop tidal current prediction factors for the Cherry Point and Ferndale facilities.
2001-024	Ensure that the guidance contained in the publication "Prevention of Oil Spillages Through Cargo Pumproom Sea Valves" is fully incorporated into company operating and maintenance procedures.

Table 53: Recommendations on Bulk Oil Transfer Operations

Reference Number	Recommendation[119]
2001-025	Ensure that all valves along potential discharge routes involving the loading of dirty ballast and line flushing using the stripping pump are examined aboard the {ship}, found to be operating properly, and providing a tight seal when seated.
2001-026	Ensure that all transfers at facilities happen in full compliance with the facility's operating requirements (a requirement of Washington State law and regulation).
2001-027	Ensure that all Persons-in-Charge (PICs) complete the Declaration of Inspection (DOI), not as a matter of routine, but as an important check on transfer readiness (thus ensuring compliance with 33 CFR 156.130 [Code of Federal Regulations]).
2001-028	Ensure that oncoming watchstanders during transfer operations read and sign the Declaration of Inspection (DOI) and meet with the facility Person-in-Charge (PIC) before assuming the watch.
2001-029	Ensure compliance with your procedures for oil transfers aboard your fleet by conducting regular spot-checks.
2001-030	Incorporate International Safety Guide for Oil Tankers & Terminals (ISGOTT) guidelines for communicating to and coordinating with the facility with regard to ballast operations into your procedures.
2001-031	Ensure, to the maximum extent possible, that all transfers across the dock at your facility happen in full compliance with your operating requirements (a requirement of Washington State law and regulation)
2001-032	Ensure that all Persons-in-Charge (PICs) complete the Declaration of Inspection (DOI), not as a matter of routine, but as an important check on transfer readiness (thus ensuring compliance with 33 CFR 156.130 [Code of Federal Regulations]).
2001-033	Incorporate International Safety Guide for Oil Tankers & Terminals (ISGOTT) guidelines for communicating to and coordinating with the vessel with regard to ballast operations into your procedures, and require an explicit exchange of information with vessel Persons-in-Charge (PICs) with regard to facility policy requiring that sea suction and overboard discharge valves be secured (and sealed as appropriate) while at the facility dock (thus prohibiting the loading of ballast water via the ship's cargo system while at the dock).
2001-034	Require that facility Persons-in-Charge (PICs) learn what the watch rotation is aboard the vessel during the pre-transfer conference with the vessel PIC, and actively request that each vessel watchstander meet with the facility PIC to review and sign the Declaration of Inspection (DOI) at scheduled shift changes.
2002-004	Ensure that mates standing cargo watches implement standing orders and cargo orders from the Chief Mate, and understand the importance of monitoring the levels in all tanks, even those that are supposed to be static.
2002-005	Ensure that Chief Mates regularly monitor compliance with standing orders and cargo orders and take prompt corrective action when deviations are noted.
2002-006	Work with {classification society} to determine a cause for the tank coating failure in the port slop tank and ensure that other {ships} in {ship operator's} fleet are not experiencing similar failure and associated deep corrosion pitting.
2002-007	Ensure that the {ship's} cathodic protection system is functioning correctly and adequately.
2002-008	Consider modifying company procedures to require regular checks of slop tanks to determine the location of the oil water interface (and thus the volume of oil versus water in the tanks). Ensure that the results of such checks are recorded.

Table 53: Recommendations on Bulk Oil Transfer Operations	
Reference Number	**Recommendation**[119]
2002-009	Ensure that personnel conducting cargo tank inspections (generally Chief Mates) are properly trained to recognize the signs and symptoms (including early signs) of tank coating failure. Consider working closely with {Classification Society}to accomplish such training.
2002-010	Consider modifying company cargo tank inspections to require more specific documentation of the observations made by personnel (generally Chief Mates) that conduct such inspections.
2002-011	Modify the procedures for checking segregated ballast tanks for oil contamination to ensure that such checks do not result in personnel making confined space entry without the appropriate confined space entry precautions.
2002-012	Ensure that each of the required checks of segregated ballast tanks for oil contamination (on initial discharge and before stripping per the Chief Mate's cargo orders) is logged distinctly and for each individual tank.
2002-013	Work with Sheridan to determine a cause for the tank coating failure in the port slop tank aboard the {ship} and ensure that other {ships} in {ship operator's} fleet, classed by {Classification Society}, are not experiencing similar failure and associated deep corrosion pitting.
2002-014	If there were special circumstances that apparently contributed to the failure of the tank coating and subsequent corrosion pitting aboard {ship}, share the findings of the investigation with other tank vessel operators classed by {Classification Society}, and if appropriate, with other International Association of Classification Societies (IACS) members.
2002-015	Consider the mooring systems on their vessels to be critical safety systems as defined in International Safety Management (ISM) Code Section 7 "The Company should establish procedures for the preparation of plans and instructions for key shipboard operations concerning the safety of the ship and the prevention of pollution. The various tasks involved should be defined and assigned to qualified personnel." ATC's policy/procedures should cover the entire mooring system - including the maintenance, inspection, and replacement of the mooring lines, in line with industry standards for their specific equipment.
2002-016	Review company policy/procedures for monitoring weather forecasts and environmental conditions while at berth, ensure that forecasts, predictions and conditions are monitored regularly, and that adequate emphasis is placed on taking early steps to prepare the ship for high winds, seas and current.
2002-017	Ensure Masters effectively utilize night orders to address special precautions that may be necessary in light of anticipated environmental conditions.
2002-018	Review company policy/procedures for tending mooring lines during inclement weather.
2002-019	Ensure that all company vessels have an up-to-date mooring analysis for the berths they frequent, and that such analyses contain the best information obtainable regarding currents, winds and seas.
2002-020	Take an active role to ensure adequate vessel mooring security at their dock. The {regulated facility operator} facility is located in an area vulnerable to wind and wave action at their docks and the potential for associated dynamic loading should be fully accounted for in any mooring analysis. Mooring analyses submitted by vessel operators should be carefully reviewed by facility engineers and marine terminal personnel before they are approved.
2002-021	Consider installing mooring load measurement devices on your docks. This equipment is available and has been installed at a number of large tanker berths. Should the loads become high or the lines become slack, the terminal operator can advise the ship.
2002-022	Review company policy/procedures for monitoring weather forecasts and conditions at the dock and ensure adequate emphasis is placed on taking early steps to prepare for high winds and seas.

Table 53: Recommendations on Bulk Oil Transfer Operations	
Reference Number	**Recommendation**[119]
2002-023	Ensure dock operators are trained to understand the importance of their role in communicating information that may have bearing on safety decisions made by vessel personnel.
2002-024	Consider installing equipment to provide weather, current and wave observations at the dock to the National Weather Service on a real-time basis.
2002-025	Consider providing vessels docking at facility handouts on potential wind/sea state effects peculiar to the dock.
2002-026	Field modifications of equipment should not be made. The covers on the emergency disconnect were duct-taped closed.
2002-040	Ensure that {marine loading arm (MLA) coupler manufacturer}provides a comprehensive list of inspection and preventive maintenance items for the Nos. 3 and 4 MLA couplers as well as the Nos. 1 and 2 couplers provided by {MLA coupler manufacturer} The list should include the appropriate torque values for all bolts that require periodic inspection for tightness.
2002-041	Ensure that all the appropriate marine terminal procedures are modified to reference the use of the new positive hydraulic shut-off valves and E-clips located on the couplers.
2002-042	Ensure that all the appropriate marine terminal procedures sufficiently emphasize that the design of the {marine loading arm (MLA) coupler manufacturer} QCDC (quick connect/disconnect) couplers requires full rotation of the actuator collar to ensure proper (and continuous) seal.
2002-043	Investigate the {marine loading arm (MLA) coupler manufacturer} coupler release of March 1, 1990 at the {refinery/terminal} in New Jersey to determine if there are similarities to the {regulated facility operator} coupler release that require notification of other facilities utilizing {marine loading arm (MLA) coupler manufacturer} hydraulically-actuated QCDC (quick connect/disconnect) couplers of similar design.
2002-044	Review the {marine loading arm (MLA) coupler manufacturer}QCDC (quick connect/disconnect) coupler manuals supplied to facilities utilizing these couplers and ensure that all inspection and preventive maintenance items are clearly stated. Include torque values for all bolts that require periodic inspection for tightness.
2002-045	Investigate the {regulated facility manufacturer}conclusion that the locking washers on the four bolts holding the clamp cylinder bracket to the coupler “had lost much of their spring.” Should the conclusion show merit, ensure that other facilities with similar QCDC (quick connect/disconnect) couplers are properly notified to inspect and/or replace those locking washers.
2002-046	Review the prevention measures undertaken on the {marine loading arm (MLA) coupler manufacturer} QCDC (quick connect/disconnect}couplers installed at {regulated facility operator} for potential application to similar {MLA coupler manufacturer} QCDC (quick connect/disconnect) couplers installed at other facilities.
2002-047	Review the {marine loading arm (MLA) manufacturer} ISO 9001 quality control system to ascertain how the {MLA coupler manufacturer}QCDC (quick connect/disconnect) couplers were installed without the over-center lock indicators, why replacement indicators were not subsequently ordered and installed, and why the opening of {regulated facility operator's} No. 4 MLA coupler during an installation and commissioning hydrotest under {MLA manufacturer} supervision was not documented.
2003-022	Modify {tank barge operator} written policies and procedures and any standard company Declaration of Inspection (DOI) to ensure the method for line clearing is part of the standard communication checklist used by the Persons-in-Charge (PICs) during the pre-transfer conference.
2003-023	Communicate details of this incident and its causes to personnel throughout the {regulated facility operator} fleet.

Table 53: Recommendations on Bulk Oil Transfer Operations	
Reference Number	**Recommendation[119]**
2003-024	Modify {regulated facility operator} written policies and procedures and the standard company Declaration of Inspection (DOI) to ensure the method for line clearing is part of the standard communication checklist used by the Persons-in-Charge (PICs) during the pre-transfer conference.
2003-025	Ensure that company policies and procedures contain standards for investigating and analyzing each spill occurrence that occurs at the facility, with an eye toward lessons-learned that can be used to prevent future spills.
2003-026	Through training, ensure that all appropriate company personnel view the dock/barge or dock/ship transfer process as a single operational system that requires good communication between all personnel with a stake in a safe and spill-free transfer process.
2003-027	Communicate details of this incident and its causes to personnel throughout the {regulated facility operator} facility.
2004-012	Update company's pre-load planning form to include the following items to ensure {tank barge operator} tankermen have a clear understanding of the planned load sequence and planned finish ullages: 1.Tank Fill Sequence; 2.Total tank capacity; 3.Starting sounding or ullage; 4.Planned final sounding or ullage
2004-013	Develop company policy that directs Tankermen to avoid topping off two different products simultaneously.
2005-001	Ensure that employees responsible for maintenance and calibration of tank level indicators, automatic shut-down systems, and overfill alarm systems aboard barges operated by {tank barge operator}are fully familiar with the systems and have received training from the manufacturer on how to properly undertake those tasks; or, have a certified manufacturer's technician conduct all maintenance and calibration operations on the tank level indicators, automatic shut-down systems, and overfill alarm systems aboard barges operated by {tank barge operator}.
2005-002	Develop procedures that ensure that plans for all required systems installed aboard vessels operated by {tank barge operator} are prepared and provided to the U.S. Coast Guard for review in accordance with federal requirements.
2005-003	Develop procedures that ensure that all proposed safety system modifications made aboard vessels operated by {tank barge operator} are fully reviewed and documented, and are submitted to the U.S. Coast Guard for review in accordance with federal requirements.
2005-004	If not already accomplished, prepare and submit plans for the {manufacturer} tank level alarm system as currently installed aboard the {tank barge} to the U.S. Coast Guard for review, with special attention given to the rewiring of the alarm system portable alarm unit (PAU) to an external power source.
2005-005	Provide protection from physical damage to the exposed, un-armored tank level alarm sensor unit cables located in hazardous zones aboard the {tank barge} and other {tank barge operator} tank barges fitted with similar equipment.
2005-006	If one is not currently in place or under development, develop a Crew Endurance Management System for {tank barge operator} personnel that takes into consideration the impact of travel time and varying scheduled work hours on {tank barge operator} personnel (specifically, tankermen).
2005-007	In developing the risk-based tank barge manning procedure (see U.S. Coast Guard Recommendation #4 {in the full report}), ensure that the potential for reduced alertness in tankermen conducting night time oil transfers is given adequate weight. Specifically, consider utilizing two tankermen for all night time transfers (those occurring between 2100 and 0700) as a way of ensuring both personal safety and the safety of the oil transfer.

Table 53: Recommendations on Bulk Oil Transfer Operations	
Reference Number	**Recommendation**[119]
2005-008	Revise the company's Oil Transfer Procedures to emphasize the requirement that the {tank barge operator} Declaration of Inspection be filled out, in lieu of or in addition to, the facility-supplied Declaration of Inspection, in cases where the facility-supplied Declaration of Inspection does not include a line item requiring testing of the tank level indicators, automatic shut-down systems, and overfill alarm systems aboard the barge.
2005-009	Undertake a thorough review of response boat placement aboard tank barges operated by {tank barge operator} to ensure that deployment in time to meet State contingency planning standards is assured under foreseeable oil spill scenarios.
2005-010	Emphasize the dangers of complacency during oil transfers to crews by publicizing lessons-learned from this spill throughout the company's fleet.
2005-011	In order to maximize the potential for systematic improvement resulting from this spill, undertake a joint effort with {regulated facility operator}, the U.S. Coast Guard, Ecology and the {industry association} to publicize lessons learned from this spill, with emphasis on the importance of properly installing, maintaining, servicing, inspecting, testing and using tank level alarm systems and indicators.
2005-012	Extend the lessons-learned as a result of post-spill examination of the response to the spill at the {regulated facility operator} facility at Point Wells, as outlined above, to other oil terminals operated by {regulated facility operator}. Specifically, apply the improvements to the response boat inspection, testing, and maintenance program to all facilities operated by {regulated facility operator}.
2005-013	Develop procedures to exercise oil spill response vessels, in water, for a period of time that maintains drive train functionality; and which complies with any manufacturers' recommendations regarding periodic operation.
2005-014	Undertake a review of {regulated facility operator}oil terminals to determine at which facilities pre-booming of transfers is safe and feasible, and, if feasible, under what conditions.
2005-015	Revise facility Declaration of Inspections to cover testing tank level indicators, automatic shut-down systems, and overfill alarm systems, if installed.
2005-016	Share the lessons-learned as a result of this spill at oil terminals operated by {regulated facility operator}.
2005-017	In order to maximize the potential for systematic improvement resulting from this spill, undertake a joint effort with {tank barg operator}, the U.S. Coast Guard, Ecology and the {industry association} to publicize lessons learned from this spill, with emphasis on the importance of properly installing, maintaining, servicing, inspecting, testing and using tank level alarm systems and indicators.
2005-018	Review the {manufacturer} tank level alarm system as currently installed aboard the {tank barge}, with special attention to the potential for damage to the exposed, un-armored tank level alarm sensor unit cables located in hazardous zones, and to the potentially compromised intrinsic protection of the system resulting from the rewiring of the alarm system portable alarm unit (PAU) to an external power source.
2005-019	Undertake a review of the inspection history of the {tank barge} to determine how the original installation of the {manufacturer} tank level alarm system and how the alarm portable alarm unit (PAU) power supply modification were accomplished without the submission of plans. In addition, determine how the system was inspected annually for a period of seven and six years, respectively, without the lack of documentation being corrected.

Table 53: Recommendations on Bulk Oil Transfer Operations	
Reference Number	**Recommendation**[119]
2005-020	Ensure that the testing of the tank level indicators, automatic shut-down systems, and overfill alarm systems are adequately emphasized during inspections of tank barges. Give consideration to the adoption of additional procedures by which inspectors would more positively verify the critical set points of such systems.
2005-021	Undertake a review of inspection procedures for domestic tank barges to determine if adequate guidance regarding the scope and depth of pre-inspection preparation and review of vessel documents is in place. Specifically, ensure that procedures require a thorough review of vessel documentation prior to annual inspections and the reporting of any documentation discrepancies noted during such review.
2005-022	Undertake a review of the training provided to inspectors tasked with inspecting the domestic tank vessel fleet to ensure they are provided with the knowledge-base to determine when safety-critical systems have been modified in a way that merits further examination by the U.S. Coast Guard.
2005-023	Undertake a review of oil transfers occurring in Washington State waters and give consideration to requiring automatic shut-down devices at regulated oil facilities and to requiring that tank barges loading at those facilities be equipped to activate those devices.
2005-024	Undertake a review of oil transfers occurring in Washington State waters and give consideration to requiring a second tankerman during night time transfers (those occurring between 2100 and 0700) as a way of ensuring both personal safety and the safety of the oil transfer.
2005-025	Share the lessons-learned from this spill throughout the U.S. Coast Guard.
2005-026	In order to maximize the potential for systematic improvement resulting from this spill, undertake a joint effort with {regulated facility operator}, {tank barge operator}, Ecology and the {industry association} to publicize lessons learned from this spill, with emphasis on the importance of properly installing, maintaining, servicing, inspecting, testing and using tank level alarm systems and indicators.
2005-027	Undertake a review of oil transfers occurring in Washington State waters and give consideration to requiring pre-booming of regulated oil facilities where safe and feasible, and, if feasible, under what conditions.
2005-028	Undertake a review of oil transfers occurring in Washington State waters and give consideration to requiring automatic shut-down devices at regulated oil facilities and to requiring that tank barges loading at those facilities be equipped to activate those devices.
2005-029	Undertake a review of oil transfers occurring in Washington State waters and give consideration to requiring a second tankerman during night time transfers (those occurring between 2100 and 0700) as a way of ensuring both personal safety and the safety of the oil transfer.
2005-030	Undertake a review of the feasibility of conducting frequent inspections of bulk oil transfer operations to ensure compliance with vessel and facility procedures, as well as state and federal requirements. Identify potential sources of additional funding to allow the Program to undertake such inspections while maintaining the Program’s core activities at current levels.
2005-031	Develop procedures to ensure that all response vessels and equipment used by regulated oil facilities are regularly inspected, tested, and maintained.
2005-032	Review State contingency planning standards and clarify requirements for initial boom deployment timing (e.g. will having containment boom in the water during the first hour suffice, or will having the boom secured in a systematic manner to intercept oil be the standard for defining “deployment”).

Table 53: Recommendations on Bulk Oil Transfer Operations	
Reference Number	**Recommendation**[119]
2005-033	In order to maximize the potential for systematic improvement resulting from this spill, undertake a joint effort with {tank barge operator}, {regulated facility operator}, the U.S. Coast Guard, and the {industry association} to publicize lessons learned from this spill, with emphasis on the importance of properly installing, maintaining, servicing, inspecting, testing and using tank level alarm systems and indicators.
2005-034	Emphasize the dangers of complacency during oil transfers to member companies and their personnel by publicizing lessons-learned from this spill throughout the {industry association} membership.
2005-035	In order to maximize the potential for systematic improvement resulting from this spill, undertake a joint effort with {tank barge operator}, {regulated facility operator}, the U.S. Coast Guard, and Ecology to publicize lessons learned from this spill, with emphasis on the importance of properly installing, maintaining, servicing, inspecting, testing and using tank level alarm systems and indicators.
2005-036	Develop a procedure under which your tug crews handling single-hull tank barges and the tankermen-PICs (Persons-in-Charge) of such barges work together to visually inspect all available external hull areas in the cargo block prior to loading cargo. Require that the result of the inspection be logged.
2005-037	Assign two tankermen, or a tankerman and tankerman's assistant, to a tank barge for loading operations at night to assist with topping off operations and inspecting the surrounding water for possible oil spills.
2005-038	Consider specifically requiring that all single-hulled tank barges be visually inspected over all available external hull areas in the cargo block before loading operations commence.
2005-039	Consider prioritizing the pre-booming of single-hulled tank barges prior to loading operations. If pre-booming is not feasible due to safety or environmental conditions, make the completion of a visual inspection of all available external hull areas in the cargo block a condition of the transfer.
2005-040	Consider specifically requiring that all single-hulled tank barges be visually inspected over all available external hull areas in the cargo block before loading operations commence.
2005-041	Consider prioritizing the pre-booming of single-hulled tank barges prior to loading operations. If pre-booming is not feasible due to safety or environmental conditions, make the completion of a visual inspection of all available external hull areas in the cargo block a condition of the transfer.
2005-042	Work with {tug boat operator} to help them develop criteria and procedures for use when they are approaching a berth with tank barges under less-than-ideal environmental conditions.
2005-043	Work with {tug boat operator} to develop clear guidance for required communication between their tug crews and barge tankermen-PICs (Persons-in-Charge).
2005-044	Develop a procedure under which your tankermen-PICs (Persons-in-Charge) and the crews of the tugs handling single-hull tank barges work together to visually inspect all available external hull areas in the cargo block prior to loading cargo. Make this procedure a requirement of all companies contracted to handle your single-hull tank barges. Require that the result of the inspection be logged.
2005-045	Emphasize the dangers of complacency during oil transfers to crews by publicizing lessons-learned from this spill throughout the company's fleet.
2005-046	Work with {tank barge company} to develop criteria and procedures for use when your tug crews are approaching a berth with a tank barge under less-than-ideal environmental conditions.
2005-047	Work with {tank barge company} to develop clear guidance for required communication between your tug crews and tank barge tankermen-PICs (Persons-in-Charge).

Table 53: Recommendations on Bulk Oil Transfer Operations	
Reference Number	**Recommendation[119]**
2005-048	Develop a procedure under which your tug crews handling single-hull tank barges and the tankermen-PICs (Persons-in-Charge) of such barges work together to visually inspect all available external hull areas in the cargo block prior to loading cargo. Require that the result of the inspection be logged.
2005-049	Emphasize the dangers of complacency during oil transfers to crews by publicizing lessons-learned from this spill throughout the company's fleet.
2005-050	Consider specifically requiring that all single-hulled tank barges be visually inspected over all available external hull areas in the cargo block before loading operations commence.
2005-051	Consider prioritizing the pre-booming of single-hulled tank barges prior to loading operations. If pre-booming is not feasible due to safety or environmental conditions, make the completion of a visual inspection of all available external hull areas in the cargo block a condition of the transfer.
2005-052	Consider specifically requiring that all single-hulled tank barges be visually inspected over all available external hull areas in the cargo block before loading operations commence.
2005-053	Consider prioritizing the pre-booming of single-hulled tank barges prior to loading operations. If pre-booming is not feasible due to safety or environmental conditions, make the completion of a visual inspection of all available external hull areas in the cargo block a condition of the transfer.
2000-007	Ensure that the revised mooring studies for {tank ship operator's} tankers at the {regulated facility operator's} Ferndale pier incorporate current speeds (in excess of 1 knot) and directions that were recorded by {environmental consultant} in May 1999 under contract with {regulated facility operators}. If necessary, undertake additional current monitoring study, in cooperation with Tosco, to determine the maximum probable current that will be experienced at the {regulated facility operator's} Ferndale pier and to determine the frequency and intensity of tideline passages at the pier.
2000-008	Work with {regulated facility operator}, {regulated facility operator}, National Oceanic and Atmospheric Administration (NOAA) and Ecology to develop tidal current prediction factors for the Cherry Point and Ferndale facilities.

Pre-Booming Regulations for Oil Transfer Operations

According to WAC 173-184-115 (Rate A Pre-Booming and Alternative Measures Requirements):

(1) The Rate A[120] deliverer must pre-boom oil transfers when it is safe and effective to do so. When pre-booming is not safe and effective, the deliverer must meet the alternative measure requirements found in subsection (7) of this section.

(2) The determination of safe and effective must be made prior to starting a transfer, or if conditions change, during a transfer. This safe and effective determination must use the following threshold values:

> (a) Transfers at a class 1 facility must use the class 1facility's values found in the facility's operations manual.[121]

> (b) Transfers that do not occur at class 1 facilities must use the values found in the vessel's approved report submitted in accordance with WAC 173-184-130, the *Safe and Effective Threshold Determination Report*.[122]

[120] Rate A: Oil transfer operations at a rate over five hundred gallons per minute.
[121] See WAC 173-180-420.

(3) When it is not safe and effective or when conditions develop during a pre-boomed transfer that requires removal of the boom, the Rate A deliverer must report this finding to Ecology and meet the alternative measures found in subsection (7) of this section. The Ecology Boom Reporting form must be used for this purpose, and submitted by e-mail or facsimile prior to the transfer and/or immediately when conditions have changed.

(4) If multiple oil transfers are occurring simultaneously with a single vessel and one product transferred is not appropriate to pre-boom, then that portion of the transfer where it is unsuitable to pre-boom must meet the alternative measures found in subsection (7) of this section.

(5) For the purposes of this section, the deliverer must be able to quickly disconnect all boom in the event of an emergency.

(6) Rate A pre-booming requirements.

(a) In order to pre-boom transfers, the deliverer must have access to boom four times the length of the largest vessel involved in the transfer or two thousand feet, whichever is less. The deliverer must deploy the boom such that it completely surrounds the vessel(s) and facility/terminal dock area directly involved in the oil transfer operation, or the portion of the vessel and transfer area that provides for maximum containment of any oil spilled.

(i) The boom must be deployed with a minimum stand-off of five feet away from the sides of a vessel measured at the waterline. This stand-off may be modified for short durations needed to meet a facility or ship's operational needs.

(ii) The deliverer must check the boom positioning periodically and adjust the boom as necessary throughout the duration of the transfer and specifically during tidal changes and significant wind or wave events.

(b) In addition to pre-booming, the deliverer must have the following recovery equipment available on-site:

(i) Containers suitable for holding the recovered oil and oily water;

(ii) Non-sparking hand scoops, shovels, and buckets; and

(iii) Enough sorbent materials and storage capacity for a seven barrel oil spill appropriate for use on water or land.

(c) For pre-boomed transfers: Within one hour of being made aware of a spill the deliverer must be able to complete deployment of the remaining boom should it be necessary for containment, protection, or recovery purposes.

(7) Rate A alternative measures. Rate A deliverers must use these alternative measures when it is not safe and effective to meet the pre-booming requirements:

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[122] See Appendices D and E.

(a) To meet the alternative measures requirements the deliverer must have access to boom four times the length of the largest vessel involved in the transfer or two thousand feet, whichever is less.

(b) In addition to the boom, the deliverer must have the following recovery equipment available on-site:

(i) Containers suitable for holding the recovered oil and oily water;

(ii) Non-sparking hand scoops, shovels, and buckets; and

(iii) Enough sorbent materials and storage capacity for a seven barrel oil spill appropriate for use on water or land.

(c) The deliverer must have the ability to safely track an oil spill in low visibility conditions. The tracking system must be on-scene within thirty minutes of being made aware of the spill.

(d) For alternative measures: Within one hour of being made aware of a spill the deliverer must be able to completely surround the vessel(s) and facility/terminal dock area directly involved in the oil transfer operation or the portion of the vessel and transfer area that provides for maximum containment of any oil spilled.

(e) For alternative measures: Within two hours of being made aware of a spill, the deliverer must have the following:

(i) Additional boom four times the length of the largest vessel involved in the transfer or two thousand feet, whichever is less, available for containment, protection, or recovery; and

(ii) A skimming system must be on-site. The skimming system must be in stand-by status and be capable of fifty barrels recovery and one hundred barrels of storage.

Appendix E: Washington State Oil Transfer Study

Synopsis

The Vessel Oil Transfer Rule (WAC 317-40) and the oil transfer requirements of the Facility Standards Rule (WAC 173-180A) stipulate that preventive booming (pre-booming) must occur during oil transfer operations. Since oil booms do not contain oil effectively in higher current velocities[123], in 2006, Washington Department of Ecology requested an analysis of the currents in the locations in which oil transfers typically occur in open waters and in port/dockside areas, including those at the state's refineries.

Methodology

Because currents are dynamic, changing in space, magnitude, and direction over time, it is not possible to come up with an estimate of one current velocity and direction for each location. Using current and wind data that has already been extensively developed for the waters of the Lower Columbia River for previous studies for Department of Ecology, Environmental Research Consulting (ERC) and Applied Science Associates, Inc. (ASA) analyzed current velocity and direction using six months of current data at 10-minute intervals from 1 January 2003 – 30 June 2003 (sampling 12 spring-neap tidal cycles) for each oil transfer location specified by Ecology, including those listed in Table 54.[124]

Table 54: Refinery Oil Transfer Locations in Washington State

City of Transfer	Name
Longview	Port of Longview (10 Port Way, Longview)
Vancouver	Tesoro West Coast (2211 St. Francis Lane, Vancouver)
Vancouver	Port of Vancouver (3103 Lower River Road, Vancouver)
Vancouver	Valero (5420 Fruit Valley Road, Vancouver)
Kalama	Port of Kalama (380 West Marine Drive, Kalama)

For each location, the current velocity data were analyzed to determine:

- Peak current speed at any time step;
- Average time for current speeds > 1.0 kts;
- Average time for current speeds > 1.5 kts;
- %age of time that currents exceed 1.5 kts; and
- Probability frequency distributions[125] of current velocities (velocities < 0.7 kts[126]; velocities >0.7 but <1.0 kts; velocities >1.0 kts, in 0.1 kt intervals above 1.0 kts up to 1.5 kts; >1.5 kts)

Wind data were analyzed to determine whether wave heights[127] exceed boom capacities in each location.

[123] The "critical velocity" of booms is generally 0.5 meters per second (m/s) or 1 knot (kt) when the current is hitting the boom in a *perpendicular* fashion. The critical current velocity increases with the angle at which the current hits the boom. Booms can be positioned to take advantage of this phenomenon to increase the ability of the boom to contain oil in higher velocity situations.

[124] The hydrodynamics methodologies used to analyze the currents are described in detail in Etkin et al., 2006 and 2007.

[125] Frequency of each current velocity over the course of six months of current data including spring and neap tides.

[126] Research indicates that booms *begin* to experience entrainment (oil moving under the boom) at 0.7 kts.

ERC analyzed the current data above to determine for each location:

- The likelihood of booming failure (Figure 46) and the degree of entrainment that might occur based on the currents;
- The likelihood of splashover failures based on wave height in various locations;
- The best booming configurations to overcome or compensate for increased current velocities where possible based on the latest research on booming in fast-water currents, as developed by the US Coast Guard Research & Development Center (USCG 1999, 2001a, 2001b, and 2003) and others; and
- Other likely issues with booms (*e.g*., drainage failure with large spills of heavy oils).

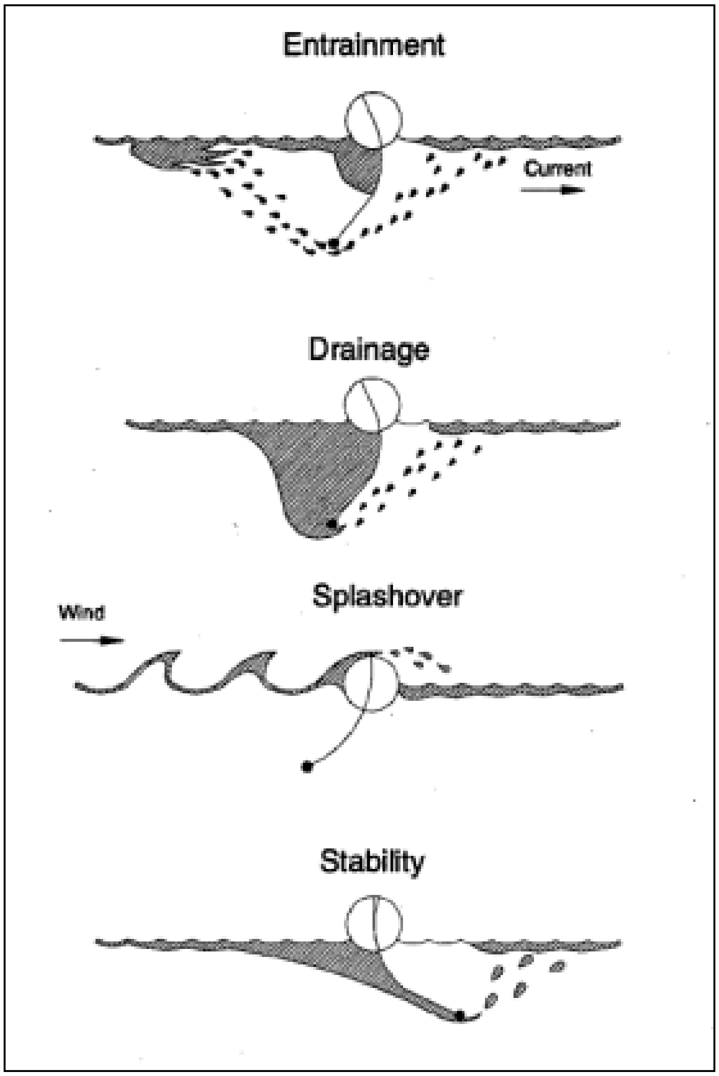

Figure 46: Modes of Boom Failure[128]

[127] Wind-affected wave heights determine the degree of "splashover" for booms. Boom splashover can be compensated for by using specific booms types made for different wave heights.
[128] US Coast Guard, 1999.

Results

Current analysis results are shown in Table 55 and Table 56.

Table 55: Summary of Current Analysis Results for Refinery Locations

Common Name	Peak Current (kts)	Hrs at >1 kt	Hrs at >1.5 kts	% Time >1.5 kts
Port of Longview (10 Port Way, Longview)	1.84	10.56	1.15	4.8%
Tesoro West Coast (2211 St. Francis Lane, Vancouver)	1.19	3.87	0	0%
Port of Vancouver (3103 Lower River Road, Vancouver)	1.48	11.66	0	0%
Valero (5420 Fruit Valley Road, Vancouver)	1.12	1.51	0	0%
Port of Kalama (380 West Marine Drive, Kalama)	1.98	14.33	2.89	12.0%

Table 56: Detailed Data on Refinery Locations with Higher Current Speeds

Location Name	% Time at Current Speed (kts)							
	0.7	1	1.1	1.2	1.3	1.4	1.5	>1.5
Port of Longview	26.7%	23.5%	10.5%	10.4%	8.6%	6.6%	3.3%	4.8%
Tesoro West Coast	32.2%	51.6%	13.1%	3.0%	0.0%	0.0%	0.0%	0.0%
Port of Vancouver	16.2%	35.2%	12.0%	13.2%	13.6%	8.3%	1.5%	0.0%
Valero	40.3%	53.5%	6.2%	0.1%	0.0%	0.0%	0.0%	0.0%
Port of Kalama	4.5%	19.5%	9.1%	10.3%	10.6%	10.1%	7.5%	12.0%

Booms will lose some oil through entrainment at the "critical velocity" of 1.0 knots (or 0.5 meters per second), though this loss can begin to start occurring at about 0.7 knots, depending on boom configuration, boom type, the manner in which the boom is deployed and anchored, and boom condition. Losses differ somewhat by oil type[129] and the angle at which the boom is situated with respect to the direction of the current[130]. While there is no one formula that predicts exactly how much oil will be lost through entrainment based on current speed, it is possible to estimate potential oil loss based on empirical data, such as those shown in Figure 47. Losses may be considerably higher than this.

Wind records and modeling data from previous work conducted for Ecology indicates that wave height would not be a factor in creating splashover losses for booms at any of the locations, provided that the correct type of boom is used based on the location. In locations where the wave height does not exceed one foot, booms that fit the "rivers/canals environment" classification of the US Coast Guard 2001 Oil Spill Removal Organization Guidelines[131] should be deployed. These guidelines stipulate the type of boom required in terms of strength, buoyancy, height, and capability of operation in waves, as shown in Table 57. For locations in which wave height reaches a maximum of three feet, booms meeting the "inland environment" boom specifications should be deployed. For locations in which wave heights exceed three feet and reach a maximum of six feet, booms meeting the "oceans environment" boom specifications should be deployed.

[129] Oil entrainment losses are higher with lighter oils (Fingas 2001).
[130] With a boom encircling a vessel during an oil transfer operation, this angle will be different at the many sections of the boom and sides of the vessel.
[131] Defined in 33 CFR 155.1020

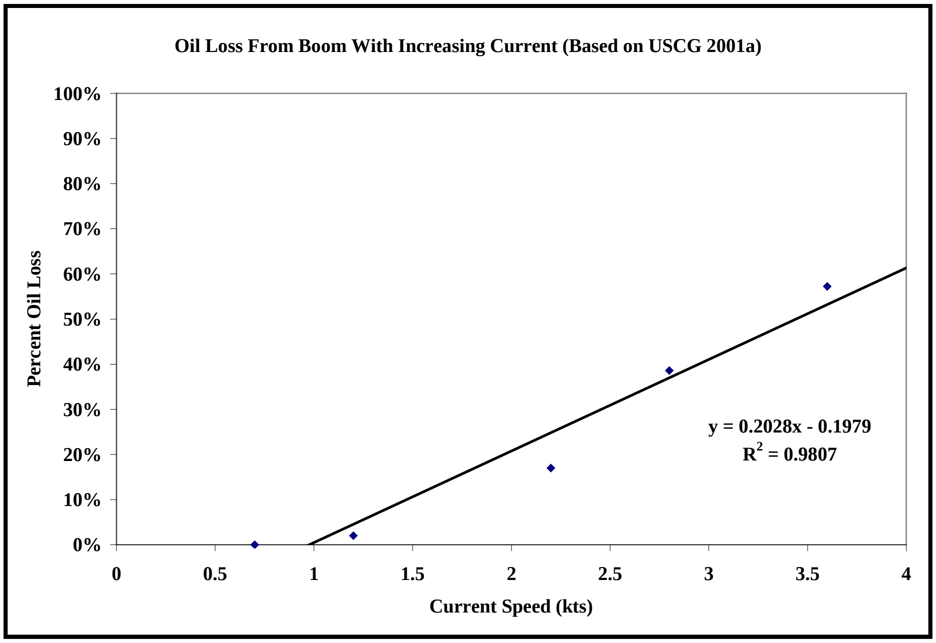

Figure 47: Entrainment Loss from Boom with Increasing Current Speed[132]

Table 57: Minimum Boom Specifications by Wave Height[133]

Boom Specifications	Operating Environment/Maximum Wave Height (feet)	
	Rivers/Canals	Inland
	1 foot	3 feet
Boom height (draft + freeboard)	6 – 18 inches	18 – 42 inches
Reserve buoyancy to weight ratio	2:1	2:1
Total tensile strength	4,500 lbs.	15,000 – 20,000 lbs.
Skirt fabric tensile strength	200 lbs.	300 lbs.
Skirt fabric tear strength	100 lbs.	100 lbs.

Critical accumulation occurs with heavier oils that are not likely to become entrained in the water, but that will begin to accumulate at the edge of the boom and are swept under the boom when sufficient oil builds up. This would tend to happen at current velocities reaching the critical velocity of 1.0 knots, but may also occur at lower velocities if there is sufficient oil.[134] In the event of a large oil release into a contained area during an oil transfer, it would be essential to initiate oil removal operations in the form of vacuum truck and/or skimmer deployment as quickly as possible. With oil containment within the pre-positioned boom, relatively high rates of oil removal (75 – 90%)[135] may be achieved in calm waters with prompt initiation of removal operations.

It is essential that appropriate booming techniques and boom types are used when pre-booming vessels during oil transfer operations to provide the best protection against oil escaping containment. Pre-

[132] Based on USCG 2001a.
[133] Based on *US Coast Guard 2001 Oil Spill Removal Organization Guidelines*
[134] Fingas 2001.
[135] Based on historical oil spill data in ERC's oil spill databases.

positioned oil removal equipment would increase the ability of responders to quickly remove oil that does enter the containment area or escapes containment. For the rare occasions in which currents do exceed 0.7 knot, the options are to postpone transfer operations, or to adopt “fast-water” booming strategies. In rivers and estuaries where the currents exceed 0.7 to 1 knot, booms are usually put into booms are often used in a *deflection* mode at various angles to the current so that the critical velocity is not exceeded and oil is not lost. The appropriate deflection angles are shown in Table 58.

Table 58: Deflection Angles and Critical Current Velocities

Deflection Angle	Velocity of Perpendicular Current Before Critical Velocity is Reached[136]	
	Meters per second (m/s)	Knots
90º	0.5	1.0
75º	0.5	1.0
60º	0.6	1.2
45º	0.7	1.4
35º	0.9	1.7
15º	1.9	3.7

Wind loads are generally not significant in high-current areas, but the loads created by wind-induced currents can affect the performance of containment booms, so the effect of wind must be included. The wind drift current is related to wind velocity as shown in Table 59.

Table 59: Wind Drift of Oil Related to Wind Velocity

Wind Velocity		Wind Drift of Current[137]	
Knots	Meters per second	Knots	Meters per second
10	19.40	0.35	0.68
20	38.80	0.70	1.36
30	58.20	1.05	2.04
40	77.60	1.40	2.72

The speed of water past a boom can be calculated using vector analysis. Each vector is represented by a line that has a direction and magnitude. The effect of the wind is determined by multiplying the wind velocity times 0.035 (or 3.5%). The two vectors can then be added to determine the overall speed of the water past the boom. The wind drift and current impacts on water movement depends both on relative speed and the direction each are moving. Wind drift and current velocity can enhance or counteract each other depending on their relative directions (Figure 48).

[136] The velocity of the current that would be encountered if the boom were perpendicular to the current. (meters per second X 1.94 = knots). Source: Fingas, M. 2001.

[137] 1Wind drift of velocity = 3.5% of wind velocity (US Coast Guard. 2001.).

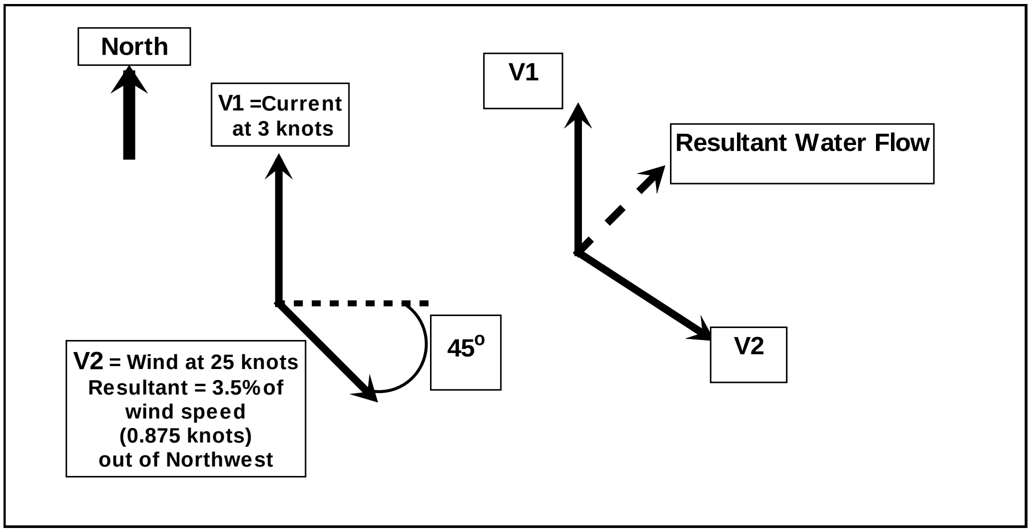

Figure 48: Wind and Current Vector Relationship Example

The vectors for the wind and current and their relation to one another and resultant water flow are shown in the above figure. Using geometrical equations, the vectors can be broken down into their north-south direction (y) and east-west direction (x) components.

For the example, the calculations are done as follows:

Y direction (North-South):

$$V1(y) = 3knots$$
$$V2(y) = -\cos(45°) \cdot 0.875 = 0.62$$
$$V1(y) - V2(y) = 2.38knots$$

X direction (East-West):

$$V1(x) = 0$$
$$V2(x) = -\sin(45°) \cdot 0.875 = 0.62$$

The length of the resultant vector (which corresponds to the water flow speed) is:

$$V(result) = \sqrt{(V1^2 + V2^2)}$$
$$V(result) = \sqrt{[(0.62)^2 + (2.38)^2]} = 2.46knots$$
$$Angle = \tan^{-1}(2.38 / 0.62) = 3.8knots(75° NE)$$

There are a number of booming strategies that can effectively and fairly easily be employed in current speeds up to 3 or 4 knots and in medium (1- to 3-foot) to high (3- to 6-foot) waves, as shown in Table 60.

Table 60: Technology Ratings for Oil Containment/Recovery Systems in High Currents[138]

Technology	Highest Effective Current (kts)	Effectiveness in Waves	Effectiveness in Shallow Water (2 ft)	Ease of Deployment	Comments
Booming Strategies					
Cascade	4	< 1 Foot (Calm)	Yes	Fair	Short sections independently moored to shore.
Deflection	4	< 1 Foot (Calm)	Yes	Fair/Good	Longer sections with shore tiebacks downstream.
Chevron (closed)	3	1 - 3 Feet	Yes	Good	Quick to deploy because uses fewer anchor points.
Chevron (open)	3	1 - 3 Feet	Yes	Good	Allows for vessel traffic between openings.
Double Boom	3	1 - 3 Feet	Yes	Fair	Improved containment but hard to keep separated properly
Boom Deflectors	4	1 - 3 Feet	Yes	Good	Deflectors used to keep boom at angle without anchors.
Boom (Specialized)					
Fast Sweep (V-Shaped)	1.5	3 - 6 Feet	No	Good	Net across foot of boom keeps in V-shape.
Horizontal Oil Boom	2.5	1 - 3 Feet	No	Fair	Two booms connected by net and filter fabric.
Holes In Lower Draft	2	1 - 3 Feet	No	Good	Larger draft with relief holes in lower skirt to reduce drag.

[138] Adapted from US Coast Guard. 1999.

Table 60: Technology Ratings for Oil Containment/Recovery Systems in High Currents[138]					
Technology	**Highest Effective Current (kts)**	**Effectiveness in Waves**	**Effectiveness in Shallow Water (2 ft)**	**Ease of Deployment**	**Comments**
Net In Foot Of Boom	1.3	3 - 6 Feet	No	Good	Short vertical net at foot of boom.
Foam 6” x 6”, Two Tension Lines	4	< 1 Foot (Calm)	Yes	Very Good	Typical fast water diversion boom with upper and lower tension
External Tension Line Foam	2	1 - 3 Feet	No	Fair	High stability, limited reserve buoyancy.
Shell High Current “Boom”	3	< 1 Foot (Calm)	Yes	Poor	Rigid aluminum perforated incline plane structure, diversion system.

The recommended strategies for booming in fast water in *tidal* river and canal environments in which the current changes direction and the depth is greater than the typical boom skirt depth and for small streams and creeks are as in Table 61.

Table 61: Tidal Rivers/Canals Fast Current Response Tactics	
Spill Scenario Situation	**Recommended Response Tactics[139]**
Current speed dependent **Vessel traffic dependent**	Single diversion boom • Current <2 knots, use 12-inch boom skirt • Current >2 knots, use boom skirt ≤ 6 inches
Current > 2 knots	Cascading diversion boom Use short skirts, short boom lengths and sufficient overlap
Collection areas available on both sides of river	Chevron booms: open for vessel traffic; closed if no traffic
Currents less than 2 knots; river wide	Single diversion boom Exclusion boom for sensitive areas Encircle and divert to collection area
Sufficient room to maneuver	Skimmers for collection
No vessels available	Boom vane Flow diverters
Special conditions	Air and water jets
Isolated areas	Sorbents and pom-pom

[139] Additional information available in US Coast Guard, 1999.

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