Appendix E

Washington Department of Ecology

Fate and Effects Modeling

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Phase I: Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume I: Model Description, Approach, and Analysis

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EXECUTIVE SUMMARY

Oil spill fate and effects modeling and analysis was performed to evaluate the implications of spill response options being considered by the Washington State Department of Ecology in their rulemaking related to oil spill preparedness (WA State Contingency Plan Rule). The impacts of potential spills in Washington's outer coast, sound and river environments were modeled varying response options and operational timing, including use of conventional mechanical containment and recovery operations; dispersant application with concurrent mechanical containment and recovery; and *in-situ* burning with concurrent mechanical containment and recovery. US Coast Guard federal response capability standards, current Washington State standards, and potential theoretical higher response capability standards were simulated for scenarios involving spills of crude oil, bunker fuel and diesel into Washington waters (Strait of Georgia, Strait of Juan de Fuca, Inner Strait/Puget Sound, outer coast, and lower and upper Columbia River).

The modeling was performed in probabilistic mode, randomly varying location along tanker routes, spill date, and time, and so environmental conditions during and after the release among potential conditions that would occur. The model results were analyzed to estimate mean, standard deviation, and 5th, 50th and 95th percentile results for surface water and shoreline oiling, water column and sediment contamination, biological impacts (to wildlife, fish, invertebrates, and habitats), and natural resource damages (NRD) for losses of ecological services. NRD costs were based on the Washington Compensation Schedule and the US Oil Pollution Act (OPA) NRD procedures involving compensatory restoration and associated costs. Response costs and socioeconomic damages were evaluated in a companion study by D. S. Etkin (Environmental Research Consulting). The results are being incorporated into a rulemaking process and cost-benefit analysis by the Department of Ecology.

The SIMAP (Spill Impact Model Application Package) modification of the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME) model (developed by Applied Science Associates (ASA) for use by the Department of the Interior in CERCLA NRDA type A regulations and for oil spill assessments under OPA) was used for this study. This model is comprised of three-dimensional oil fate and biological effects models that access impacts and provide data to estimate NRD, response, and socioeconomic costs of spills in marine and freshwater environments. The model was run in stochastic mode to produce results and statistics for multiple model runs under various possible environmental conditions.

The model uses wind data, current data, and transport and weathering algorithms to calculate mass balance in various environmental compartments (water surface, shoreline, water column, atmosphere, sediments, etc.), surface oil distribution over time (trajectory), and concentrations of the oil components in water and sediments. Geographical data (habitat mapping and shoreline location) were obtained from existing Geographical Information System (GIS) databases based on Environmental Sensitivity Indices (ESI).

Water depth was obtained from National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) soundings databases. Hourly wind speed and direction data over a long historical period were obtained from nearby meteorological stations. Tidal and other currents were modeled based on known water heights, using a hydrodynamic model based on physical laws (i.e., conserving mass and momentum). SIMAP was used to evaluate exposure of aquatic habitats and organisms to whole oil and potentially toxic components from the fuels, resulting mortality and ecological losses.

Thirteen spill scenarios were run in stochastic mode using combinations of 6 spill locations, 3 oil types (crude, bunker C fuel, and diesel) and response combinations including protective booming, mechanical removal and dispersant use. For each scenario, the model was run numerous times, randomly sampling environmental conditions during and after the spill. For each stochastic scenario, the 5th, 50th and 95th percentile runs, in terms of environmental consequences, were examined in detail for NRDA, socioeconomic, and response costs. These 3 events were run with alternate response plans to evaluate the change in consequences resulting from different response implementations.

Specifications for the scenarios (amount, duration of release, etc.) were provided by the Department of Ecology based on Washington state planning standards, federal planning standards, and input from Stakeholders. The spill locations were along shipping routes in Washington state waters. Spill sites for each individual run were randomized along the designated route for that scenario. The oil types selected were those typically shipped (Alaska North slope crude and diesel fuel) or used to power vessels (Bunker C). The spill volumes were selected to be a relatively large spill, but of a size that would be handled primarily by the state rather than the federal government. The crude oil spills are all 65,000 bbl, while the Bunker C spills are 25,000 bbl.

The 100 runs of each of the main stochastic scenario were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are used) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling.

In the report, the results for the individual 5th, 50th, and 95th percentile runs based on shore costs are presented. Because other impact indices are not necessarily correlated with shore cost, the results for other indices may not be in increasing order from 5th to 95th percentile run by shore cost. The actual 5th, 50th and 95th percentile results for the 100 values of the index were calculated by sorting only the index being considered. These are also listed in the tables in the report, along with the mean and standard

deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. In the results where alternative response options are examined, the individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made. A base case scenario was selected for the purpose of identifying which runs in the main stochastic scenario base case were 5th, 50th and 95th percentile ordered by shoreline cleanup cost. For the Outer Coast, no response was the base case. For all the scenarios in the Straits and the Columbia River, Washington state mechanical response was the base case used to sort the runs.

Table E-1 lists the scenarios examined. All the results are summarized in tables in Volume II, organized by location and oil type. The key results and discussion are described in Sections 4-7 of Volume I. Volume I also contains a description of the model used, input data sources, assumptions, and conclusions.

Tables E-2 to E-7 summarize the estimated impacts for the main stochastic scenarios, as the mean and standard deviation of the results for the 100 runs. The mean plus or minus two standard deviations gives the range of expected impacts for 95% of spills of the volume simulated.

The percent of oil removed by mechanical recovery averages 59-85% of the spilled oil in the simulations (Table E-2). The application of dispersant reduces the amount removed mechanically only by a small amount because the mechanical response is so efficient. By the time the dispersant could be applied, the mechanical removal has removed most of the surface floating oil, or the oil has already come ashore, entrained naturally, or become too viscous to be dispersed. This indicates that the amount of equipment and the planned response times are sufficient to remove most of the oil *under ideal conditions where everything goes according to plan and where responders know where the oil is at all times*. In reality, people and equipment will not be able to meet the schedules exactly and there will not be perfect knowledge of the oil movements allowing the responders to arrive at all possible locations where oil would be transported. Thus, the percentage removed mechanically is the maximum possible given the equipment capacities, and dispersant use (assuming it is effectively applied in the assumed amounts and timing) would likely account for more of the oil removal from the water surface in an actual spill event than is reflected by these results.

Table E-3 summarizes the shoreline oiling, listing the length of shore where cleanup would occur. Comparing the scenarios of the same spill location and oil, particularly the outer coast scenarios where three scenarios were run (no removal, state removal, and state removal plus dispersant), the difference between no response and mechanical removal is very large, while adding dispersant to the state mechanical removal has little

effect on total shoreline oiled *to some degree*. However, the shoreline length heavily oiled is reduced somewhat by addition of dispersant. In some locations, such as the San Juan Islands scenarios, the areas where dispersants could be applied are far removed from the spill sites, and so the mechanical removal takes care of the surface oil before the oil reaches the dispersant application zones, or the oil is too emulsified to be dispersed by the time it enters those zones. In the outer coast scenarios, not all the oil comes ashore, and so the dispersant effect on shoreline oil is not always indicative of reduced impact.

The majority of the biological impacts are to birds, particularly to seabirds and waterfowl (diving ducks). Table E-4 summarizes the bird impacts. The bird impacts are highest for the outer coast and lower Columbia River scenarios (which include spill sites up to 3 miles off the coast), because the oil remains at sea longer than for the straits and upper Columbia River scenarios, and there are higher abundances of birds on the outer coast than in the straits. In outer coast scenario, the mechanical recovery assumed would be projected to save 100,000 birds, and adding dispersant to the mechanical removal would save 3,000 more birds on average. This is certainly an idealized situation where the mechanical cleanup would need to proceed without a hitch and with perfect knowledge of where the oil is located at all (daylight) times. In reality, the mechanical recovery would not be so efficient and the dispersant could be more effective in reducing the number of birds oiled by a spill.

Table E-5 shows that the mammal impacts are projected to be minor, with the exception of the outer coast and Columbia River scenarios. The mammals primarily impacted in the outer coast and Columbia River scenarios would be sea otters and fur seals, with lesser impacts to harbor seals and harbor porpoises. In the upper Columbia River, the mammals impacted would be mostly muskrat and mink.

Table E-6 summarizes estimated impacts to subtidal fish and invertebrates (those in the water exposed to water and submerged sediment concentrations). The outer coast scenarios have the least impacts because of the large dilution volumes involved. Addition of dispersant off the outer coast did not significantly increase the effects on fish and invertebrates. Diesel is much more readily dispersed (naturally) into the water column than crude oil, and so the impacts are projected to be much higher for diesel than for the same volume of crude oil. This is because Alaskan crude oil emulsifies rapidly, minimizing entrainment and dissolution into the water.

In the scenarios examined, use of dispersants on crude oil spilled in the straits (S2, SI or IS) increased the impacts on fish and invertebrates, while impacts to birds and shorelines were not significantly reduced because the mechanical removal was assumed to be a relatively large effort and very efficient. If the mechanical response could not be accomplished at the assumed efficiency/capacity and dispersants were used, there likely would be some reduction in the bird and shoreline impacts to counter the increase in fish and invertebrate impacts. However, in confined waters, there may not be a net benefit of dispersant use. The San Juan Islands/Rosario Strait and the inner straits/Puget Sound scenarios would be ones where the net effects of dispersant use would likely be negative even if the mechanical response capacities were not fully utilized.

The Bunker C spills were of lower volume, had low content of soluble and toxic components, and were not readily dispersed naturally into the water because of the high viscosity of the oil. For these reasons, the effects on fish and invertebrates for the Bunker C spills were very minimal in areas where there is rapid dilution, i.e., in the Straits or lower Columbia River. Impacts to fish and invertebrates for Bunker C spills offshore would also be insignificant. In the upper Columbia River, the impacts were primarily on demersal fish such as suckers, catfish and sunfishes.

Impacts to intertidal invertebrates (Table E-7) were evaluated for geoducks, soft-shell clams, razor clams, and hard clams in soft shoreline habitats (wetlands, mud flats and sand beaches). The main species affected in the straits scenarios (S1, S2, SI and IS) was the geoduck, an important fishery species. On the outer coast, the other clam species are more abundant. The impacts to clams are proportional to the shoreline area heavily oiled. Thus, removal of oil from the surface, which results in less shoreline oiled, reduced the impact to intertidal clams.

The natural resource damages (Table E-8) were based on estimated costs to restore equivalent resources and/or ecological services. This is the preferred method used by natural resource trustees, based on guidance in the OPA regulations. The Washington Compensation Schedule is designed for small spills, much less than the volumes considered here. Habitat Equivalency Analysis (HEA) was used to estimate the required amount of habitat (saltmarsh) restoration for NRD compensation of injuries to wildlife, fish and invertebrate species. Production by the restored habitat ultimately benefits wildlife, fish and invertebrates, and equivalency is assumed if equal production of similar species (i.e., the same general taxonomic group and trophic level) results. According to HEA-scaled calculations, the offshore crude oil scenario would be the most expensive to provide compensatory restoration because of the relatively large impact on birds. Use of dispersant in the offshore scenario reduced damages, while dispersant use increased damages (due to increase fish and invertebrate impacts) in the straits scenarios.

The changes in natural resource damages with different response alternatives are summarized in Tables E-9 to E-16. In these tables, individual runs are examined, holding spill conditions constant so comparisons can be made. In all scenarios, the difference between no mechanical removal and any of the mechanical removal capacity assumptions (state, federal or 3rd alternative) is substantial, again because the capacities were high relative to the oil spill volume and the efficiency of the response was assumed high (as planned). The state mechanical response capacities were higher than the federal, and the 3rd alternative capacities were higher than the state's, so that the damages typically were higher for the federal and lower for the 3rd alternative than for the state standards. ISB or dispersant use added to the state mechanical capacities did not incrementally reduce damages in most scenarios because the mechanical removal rates were very high, removing 59-85% of the spilled oil. (Variability in some of the results involving mechanical response was insignificant and due to the randomization routine employed to simulate natural dispersion.)

In conclusion, the model results and analysis of biological impacts indicate that the mechanical removal capacities examined are sufficient for cleaning up the spill volumes evaluated and can greatly reduce impacts to biota and shorelines. However, the simulations assume that everything goes according to plan and responders know where the oil is at all times. In reality, people and equipment will not be able to meet the schedules exactly and there will not be perfect knowledge of the oil movements allowing the responders to mechanically clean up as much oil as the results suggest. Thus, the percentage removed mechanically is the maximum possible given the equipment capacities, and dispersant use would likely account for more of the oil removal from the water surface in an actual spill event than is reflected by these results.

The model results show that dispersant use on spills up to 65,000 bbl in the offshore would not cause significant impacts to fish and invertebrates. Because a highly efficient mechanical response at the capacity standards examined would be difficult to accomplish, use of dispersants instead of mechanical removal would be unlikely to adversely affect the environment and may be more realistically achieved. However, dispersant use would likely increase impacts to fish and invertebrates in the inner straits, Puget Sound and Rosario Strait. Similar results would be likely in other confined waters, such as inside the Columbia River estuary. Thus, based on the modeling analysis, dispersant use in confined waters in the state of Washington is not suggested unless protection of sensitive shorelines and wildlife cannot be accomplished by other means.

In a second phase of this project, increasing inefficiencies in recovery capability with time were built into the response model assumptions for all three alternative capacity standards, thus, allowing the model to simulate realistic delays that commonly occur during oil spill response. The response model assumptions for Phase II were developed by Dr. D. S. Etkin and WDOE, as described in Etkin (2005b). The results of Phase II are presented in French-McCay et al. (2005b). Response costs and socioeconomic damages associated with the Phase II model outputs were evaluated in a companion study by D. S. Etkin (2005b,c, Environmental Research Consulting) and in Etkin and French-McCay (2005).

Table E-1 Oil spill modeling scenarios. [St = main stochastic scenario; MR = mechanical removal capacities assumed; DSP = dispersant included; ISB = in situ burning included]

Spill Site(s)	Oil Type	St	MR	DSP	ISB	Volume (bbl)	Abbreviation
Outer Coast: Duntz Rock NW Cape Flattery	Alaskan North Slope Crude	*	none			65,000	OC-Crud-N
		*	State			65,000	OC-Crud-R-ST
			Federal			65,000	OC-Crud-R-Fed
			3rd			65,000	OC-Crud-R-3
			State		*	65,000	OC-Crud-R-ISB
		*	State	*		65,000	OC-Crud-C-ST
			Federal	*		65,000	OC-Crud-C-Fed
			3rd	*		65,000	OC-Crud-C-3
Strait of Juan de Fuca: Neah Bay to Dungeness Spit	Bunker C		none			25,000	S1-Bunk-N
		*	State			25,000	S1-Bunk-R-ST
			Federal			25,000	S1-Bunk -R-Fed
			3rd			25,000	S1-Bunk -R-3
			State		*	25,000	S1-Bunk-R-ISB
Strait of Juan de Fuca: Neah Bay to Dungeness Spit	Diesel		none			65,000	S1-Dies-N
		*	State			65,000	S1-Dies-R-ST
			Federal			65,000	S1-Dies-R-Fed
			3rd			65,000	S1-Dies-R-3
Strait of Juan de Fuca: Shipping Lane from Neah Bay to Port Angeles	Alaskan North Slope Crude		none			65,000	S2-Crud-N
		*	State			65,000	S2-Crud-R-ST
			Federal			65,000	S2-Crud-R-Fed
			3rd			65,000	S2-Crud-R-3
			State		*	65,000	S2-Crud-R-ISB
		*	State	*		65,000	S2-Crud-C-ST
			Federal	*		65,000	S2-Crud-C-Fed
			3rd	*		65,000	S2-Crud-C-3
San Juan Islands: Rosario Strait /Georgia Strait: S end of Lopez Is. to Cherry Point	Alaskan North Slope Crude		none			65,000	SI-Crud-N
		*	State			65,000	SI-Crud-R-ST
			Federal			65,000	SI-Crud-R-Fed
			3rd			65,000	SI-Crud-R-3
		*	State			65,000	SI-Crud-C-ST
			Federal			65,000	SI-Crud-C-Fed
			3rd			65,000	SI-Crud-C-3
Inner Straits / Puget Sound: Port Angeles to the south end of Lopez Island	Alaskan North Slope Crude		none			65,000	IS-Crud-N
		*	State			65,000	IS-Crud-R-ST
			Federal			65,000	IS-Crud-R-Fed
			3rd			65,000	IS-Crud-R-3
		*	State	*		65,000	IS-Crud-C-ST
			Federal	*		65,000	IS-Crud-C-Fed
			3rd	*		65,000	IS-Crud-C-3
Lower Columbia River: 3 mi. off Columbia River to Astoria	Bunker C		none			25,000	C1-Bunk-N
		*	State			25,000	C1-Bunk-R-ST
			Federal			25,000	C1-Bunk-R-Fed
			3rd			25,000	C1-Bunk-R-3
Upper Columbia River: From Portland to Longview	Bunker C		none			25,000	C2-Bunk-N
		*	State			25,000	C2-Bunk-R-ST
			Federal			25,000	C2-Bunk-R-Fed
			3rd			25,000	C2-Bunk-R-3

Table E-2. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	-	-
OC-Crud-R-ST	65	10	45	85
OC-Crud-C-ST	59	9	42	77
S1-Bunk-R-ST	85	10	66	104
S1-Dies-R-ST	48	20	7	89
S2-Crud-R-ST	67	8	51	83
S2-Crud-C-ST	64	8	48	79
SI-Crud-R-ST	68	3	62	73
SI-Crud-C-ST	66	3	60	73
IS-Crud-R-ST	69	3	63	76
IS-Crud-C-ST	64	4	57	72
C1-Bunk-R-ST	76	11	54	98
C2-Bunk-R-ST	73	14	45	101

Table E-3. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 0.01 g/m2 (where cleanup would occur).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	97	66	-	229
OC-Crud-R-ST	33	27	-	87
OC-Crud-C-ST	33	29	-	91
S1-Bunk-R-ST	15	11	-	37
S1-Dies-R-ST	20	14	-	49
S2-Crud-R-ST	23	16	-	54
S2-Crud-C-ST	23	17	-	57
SI-Crud-R-ST	54	30	-	114
SI-Crud-C-ST	53	30	-	113
IS-Crud-R-ST	41	33	-	107
IS-Crud-C-ST	39	31	-	101
C1-Bunk-R-ST	24	21	-	67
C2-Bunk-R-ST	22	12	-	45

Table E-4. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	153,783	119,773	-	393,329
OC-Crud-R-ST	51,432	54,953	-	161,339
OC-Crud-C-ST	48,407	52,859	-	154,125
S1-Bunk-R-ST	6,916	3,042	833	12,999
S1-Dies-R-ST	10,688	5,089	510	20,865
S2-Crud-R-ST	9,598	3,619	2,361	16,835
S2-Crud-C-ST	9,264	3,357	2,549	15,978
SI-Crud-R-ST	4,904	2,911	-	10,725
SI-Crud-C-ST	4,705	2,671	-	10,046
IS-Crud-R-ST	10,363	4,098	2,166	18,559
IS-Crud-C-ST	9,844	3,746	2,351	17,336
C1-Bunk-R-ST	28,580	11,827	4,926	52,234
C2-Bunk-R-ST	306	272	-	851

Table E-5. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	40.9	31.8	-	104.6
OC-Crud-R-ST	13.7	14.6	-	42.9
OC-Crud-C-ST	12.9	14.1	-	41.0
S1-Bunk-R-ST	0.6	0.3	0.0	1.1
S1-Dies-R-ST	0.8	0.4	0.1	1.6
S2-Crud-R-ST	0.7	0.2	0.3	1.1
S2-Crud-C-ST	0.7	0.2	0.3	1.1
SI-Crud-R-ST	0.4	0.2	0.0	0.7
SI-Crud-C-ST	0.4	0.2	0.0	0.7
IS-Crud-R-ST	0.8	0.4	0.0	1.6
IS-Crud-C-ST	0.8	0.4	0.1	1.5
C1-Bunk-R-ST	4.6	2.0	0.6	8.6
C2-Bunk-R-ST	3.4	1.1	1.1	5.7

Table E-6. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	3	0	3	4
OC-Crud-R-ST	3	0	3	4
OC-Crud-C-ST	3	0	2	3
S1-Bunk-R-ST	10	6	-	21
S1-Dies-R-ST	114,144	38,077	37,990	190,298
S2-Crud-R-ST	8,669	9,481	-	27,631
S2-Crud-C-ST	21,771	16,381	-	54,532
SI-Crud-R-ST	6,752	6,090	-	18,932
SI-Crud-C-ST	10,799	8,283	-	27,366
IS-Crud-R-ST	8,736	13,767	-	36,269
IS-Crud-C-ST	41,996	25,320	-	92,636
C1-Bunk-R-ST	0	1	-	3
C2-Bunk-R-ST	3,630	4,123	-	11,877

Table E-7. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (clams).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	150	281	-	713
OC-Crud-R-ST	31	132	-	295
OC-Crud-C-ST	31	136	-	304
S1-Bunk-R-ST	257	429	-	1,115
S1-Dies-R-ST	282	445	-	1,171
S2-Crud-R-ST	198	355	-	907
S2-Crud-C-ST	185	347	-	880
SI-Crud-R-ST	1,134	716	-	2,566
SI-Crud-C-ST	1,087	648	-	2,383
IS-Crud-R-ST	506	554	-	1,615
IS-Crud-C-ST	490	578	-	1,647
C1-Bunk-R-ST	22	20	-	61
C2-Bunk-R-ST	-	-	-	-

Table E-8. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	883	685	0	2,254
OC-Crud-R-ST	298	314	0	926
OC-Crud-C-ST	80	88	0	257
S1-Bunk-R-ST	7	5	1	17
S1-Dies-R-ST	96	45	8	187
S2-Crud-R-ST	19	15	2	48
S2-Crud-C-ST	31	21	2	72
SI-Crud-R-ST	9	7	0	22
SI-Crud-C-ST	12	8	0	28
IS-Crud-R-ST	21	20	2	61
IS-Crud-C-ST	42	27	2	96
C1-Bunk-R-ST	35	15	4	66
C2-Bunk-R-ST	1	1	0	2

Table E-9. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (in millions of 2004$).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
OC-Crud-N	2,393	420	998
OC-Crud-R-ST-base	662	76	275
OC-Crud-R-Fed	731	78	280
OC-Crud-R-3	694	72	264
OC-Crud-R-ISB	816	77	271
OC-Crud-C-ST-base	671	76	272
OC-Crud-C-Fed	679	75	278
OC-Crud-C-3	698	71	266

Table E-10. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of 2004$).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
S1-Bunk-N	27	40	25
S1-Bunk-R-ST	13	4	19
S1-Bunk-R-Fed	13	5	16
S1-Bunk-R-3	6	4	12
S1-Bunk-R-ISB	13	8	3

Table E-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of 2004$).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
S1-Dies-N	139	87	79
S1-Dies-R-ST	57	84	126
S1-Dies-R-Fed	30	50	82
S1-Dies-R-3	28	34	79

Table E-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total NRDA costs (in millions of 2004$).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
S2-Crud-N	57	23	45
S2-Crud-R-ST	11	7	20
S2-Crud-R-Fed	15	11	26
S2-Crud-R-3	7	10	20
S2-Crud-R-ISB	9	6	21
S2-Crud-C-ST-base	60	18	24
S2-Crud-C-Fed	69	19	24
S2-Crud-C-3	45	18	25

Table E-13. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of 2004$).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
SI-Crud-N	43.7	29.6	15.4
SI-Crud-R-ST	2.5	13.5	5.3
SI-Crud-R-Fed	4.0	14.1	6.2
SI-Crud-R-3	2.0	12.6	4.3
SI-Crud-C-ST-base	4.8	14.5	6.4
SI-Crud-C-Fed	11.7	12.6	6.8
SI-Crud-C-3	2.1	14.8	4.3

Table E-14. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total NRDA costs (in millions of 2004$).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
IS-Crud-N	95	55	234
IS-Crud-R-ST	11	30	14
IS-Crud-R-Fed	23	23	24
IS-Crud-R-3	7	21	9
IS-Crud-C-ST-base	36	40	48
IS-Crud-C-Fed	24	21	21
IS-Crud-C-3	25	37	43

Table E-15. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
C1-Bunk-N	74	50	55
C1-Bunk-R-ST	48	22	35
C1-Bunk-R-Fed	40	26	35
C1-Bunk-R-3	40	24	33

Table E-16. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
C2-Bunk-N	0.8	0.6	0.7
C2-Bunk-R-ST	0.5	0.5	0.7
C2-Bunk -R-Fed	0.7	0.5	0.6
C2-Bunk -R-3	0.7	0.5	0.6

1. INTRODUCTION

As part of their rulemaking related to oil spill preparedness (Washington State Contingency Plan Rule), the Washington State Department of Ecology (WDOE) needs to evaluate the implications of various spill response options being considered. Oil spill fate and effects modeling and analysis was performed to estimate the impacts of potential spills in Washington's outer coast, sound and river environments, assuming various response options and operational timing, including use of conventional mechanical containment and recovery operations; dispersant application with concurrent mechanical containment and recovery; and *in-situ* burning (ISB) with concurrent mechanical containment and recovery. US Coast Guard federal response capability standards, current Washington State standards, and potential theoretical higher response capability standards were simulated for scenarios involving spills of crude oil, bunker fuel and diesel into Washington waters in 6 geographic locations: Strait of Georgia, Strait of Juan de Fuca, Inner Strait/Puget Sound, outer coast, and lower and upper Columbia River. These locations were selected to be representative of potential spill sites along transportation routes. The upper Columbia River was used to evaluate implications of spills into large rivers of similar dimensions and river flow.

In the study described herein, mechanical recovery was modeled assuming that equipment to fulfill the various response capability levels was available, in good working condition, and handled by competent, trained personnel. Mechanical recovery and storage equipment was assumed to be operating at the Effective Daily Recovery Capability (EDRC) rate. It was also assumed that if oil was on the water surface and available for recovery, personnel would be able to locate and reach that oil and recover it at the EDRC rate.

However, in an actual spill response, there are a number of reasons why such high efficiencies and recovery rates would not be realized, including logistical problems, difficulty in tracking oil, breakdowns, etc. (see Etkin et al., 2005a for additional discussion of this issue). Thus, in a second phase of this project, increasing inefficiencies in recovery capability with time were built into the response model assumptions for all three alternative capacity standards. The response model assumptions for Phase II were developed by Dr. D. S. Etkin and WDOE, as described in Etkin (2005b). The results of Phase II are presented in French-McCay *et al.* (2005b). Response costs and socioeconomic damages associated with the Phase II model outputs were evaluated in a companion study by D. S. Etkin (2005b,c, Environmental Research Consulting) and in Etkin and French-McCay (2005).

This report contains the results of the Phase I study. It was updated from an earlier draft report, submitted to WDOE in July 2004. However, the comparison of the results from Phase I with Phase II is contained in the Phase II report. Additional presentation and discussion of the Phase I results for the Outer Coast at Duntz Rock scenario is in French et al. (2005a) and Etkin et al. (2005b).

The SIMAP (Spill Impact Model Application Package) model system, comprised of three-dimensional oil fate and biological effects models, was used for this study. The modeling was performed in probabilistic (stochastic) mode, randomly varying location along shipping routes, spill date, and time, and so environmental conditions during and after the release among potential conditions that would occur. The model results were analyzed to estimate mean, standard deviation, and 5th, 50th and 95th percentile results for surface water and shoreline oiling, water column and sediment contamination, biological impacts (to wildlife, fish, invertebrates, and habitats), and natural resource damages (NRD) for losses of ecological services. NRD costs were based on the Washington Compensation Schedule and the US Oil Pollution Act (OPA) NRD procedures involving compensatory restoration and associated costs. Response costs and socioeconomic damages were evaluated in a companion study by D.S. Etkin (Environmental Research Consulting). The results are being incorporated into a rulemaking process and cost-benefit analysis by the Department of Ecology.

This report describes the approach, model, data inputs, and results of the modeling. Inputs include habitat and depth mapping, winds, currents, other environmental conditions, chemical composition and properties of the oils most likely to be spilled, specifications of the release (amount, location, etc.), toxicity parameters, and biological abundance. Model results are displayed by a Windows graphical user interface that animates the trajectory and concentrations over time. The figures included here (appendices) are snapshots taken from that output, synoptically (over time after the spill) showing the areas and volumes where oil or concentrations in the water would move if there were a spill of the assumed volume and conditions.

SIMAP was first run in stochastic mode for 13 scenarios to estimate probabilities and degrees of oil exposure for each location in the vicinity of a spill. The output of the stochastic model includes time histories of a large number of spill trajectories. These distributions are used to (1) estimate the percent of these hypothetical spills where water surface, water column, and shoreline areas will be affected by a release; (2) determine the highest exposure concentration in time and for any possible environmental condition; and (3) identify the 5th, 50th and 95th percentile results with respect to shoreline impact.

For each of the 13 main scenarios, 100 simulations were run for a given spill location (shipping route segment), oil and response scenario, varying the spill date and time, and thus the environmental conditions, for each run. The results were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (the per area portion of the costs) are related to biological impacts on shorelines. Response and socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to degree of shoreline oiling.

The results for the individual 5th, 50th, and 95th percentile runs based on shore costs were evaluated in detail. However, certain impacts, such as to waterfowl and seabirds, were more closely related to water surface oiled. Impacts to fish and invertebrates in the

subtidal zone (below the low tide level) were related to water contaminated above a threshold for effects. Intertidal zone impacts to clams were related to degree of soft (sand, mud, or wetland) shoreline oiling. Because other impact indices were not necessarily correlated with shore cost, the results for other indices were not typically in increasing order from 5th to 95th percentile run by shore cost. The actual 5th, 50th and 95th percentile results for the 100 values of the index were calculated by sorting only the index being considered. The mean and standard deviation of the 100 results were also calculated.

Further, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. When alternative response options were examined, the individual run dates and times were held constant across alternate response scenarios so inter-comparisons could be made. A base case main scenario was selected for the purpose of identifying which run dates provided 5th, 50th and 95th percentile results ordered by shoreline cleanup cost. For the Outer Coast, no response was the base case. For all the scenarios in the Straits and the Columbia River, Washington state mechanical response was the base case used to sort the runs.

It should be noted that the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model. This results in variability in the movements of oil spillets in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This results in variation in the specific water areas and shoreline locations oiled and in some cases the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported. If this uncertainty were not included in the model simulations, the oil would all move along a single trajectory path to one shoreline location down wind and down current, clearly an unrealistic event to analyze.

Table 1-1 lists the scenarios examined. The 13 main stochastic scenarios are noted, as well as which of these were the base cases. The other scenarios were run for the 5th, 50th and 95th percentile runs by altering the response assumed in the main stochastic scenario base case. Thus, only the 3 runs were examined in the alternate scenarios. Figures 1-1 and 1-2 show the hypothetical spill locations examined.

Table 1-1 Oil spill modeling scenarios. [St = main stochastic scenario; MR = mechanical removal capacities assumed; DSP = dispersant included; ISB = in situ burning included]

Spill Site(s)	Oil Type	Stochastic	MR	DSP	ISB	Volume (bbl)
Outer Coast: Duntz Rock NW Cape Flattery	Alaskan North Slope Crude	* (base)	none			65,000
		*	State			65,000
			Federal			65,000
			3rd			65,000
			State		*	65,000
		*	State	*		65,000
			Federal	*		65,000
			3rd	*		65,000
Strait of Juan de Fuca: Neah Bay to Dungeness Spit	Bunker C		none			25,000
		* (base)	State			25,000
			Federal			25,000
			3rd			25,000
			State		*	25,000
Strait of Juan de Fuca: Neah Bay to Dungeness Spit	Diesel		none			65,000
		* (base)	State			65,000
			Federal			65,000
			3rd			65,000
Strait of Juan de Fuca: Shipping Lane from Neah Bay to Port Angeles	Alaskan North Slope Crude		none			65,000
		* (base)	State			65,000
			Federal			65,000
			3rd			65,000
			State		*	65,000
		*	State	*		65,000
			Federal	*		65,000
			3rd	*		65,000
San Juan Islands: Rosario Strait /Georgia Strait: S end of Lopez Is. to Cherry Point	Alaskan North Slope Crude		none			65,000
		* (base)	State			65,000
			Federal			65,000
			3rd			65,000
		*	State			65,000
			Federal			65,000
			3rd			65,000
Inner Straits / Puget Sound: Port Angeles to the south end of Lopez Island	Alaskan North Slope Crude		none			65,000
		* (base)	State			65,000
			Federal			65,000
			3rd			65,000
		*	State	*		65,000
			Federal	*		65,000
			3rd	*		65,000
Lower Columbia River: 3 mi. off Columbia River to Astoria	Bunker C		none			25,000
		* (base)	State			25,000
			Federal			25,000
			3rd			25,000
Upper Columbia River: From Portland to Longview	Bunker C		none			25,000
		* (base)	State			25,000
			Federal			25,000
			3rd			25,000

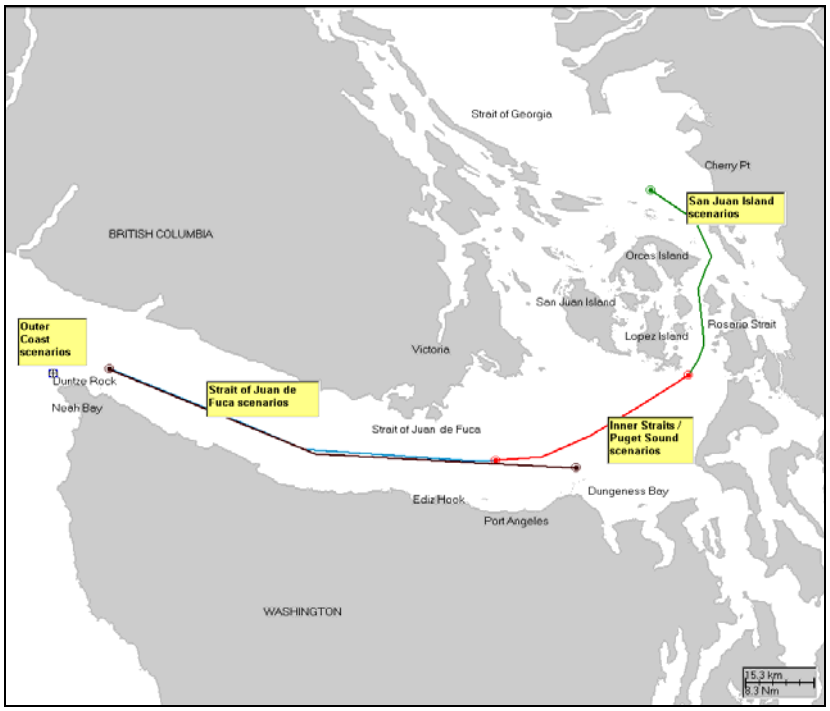

Figure 1-1. Shipping route segments where the hypothetical spills are assumed to occur: Straits and outer coast scenarios.

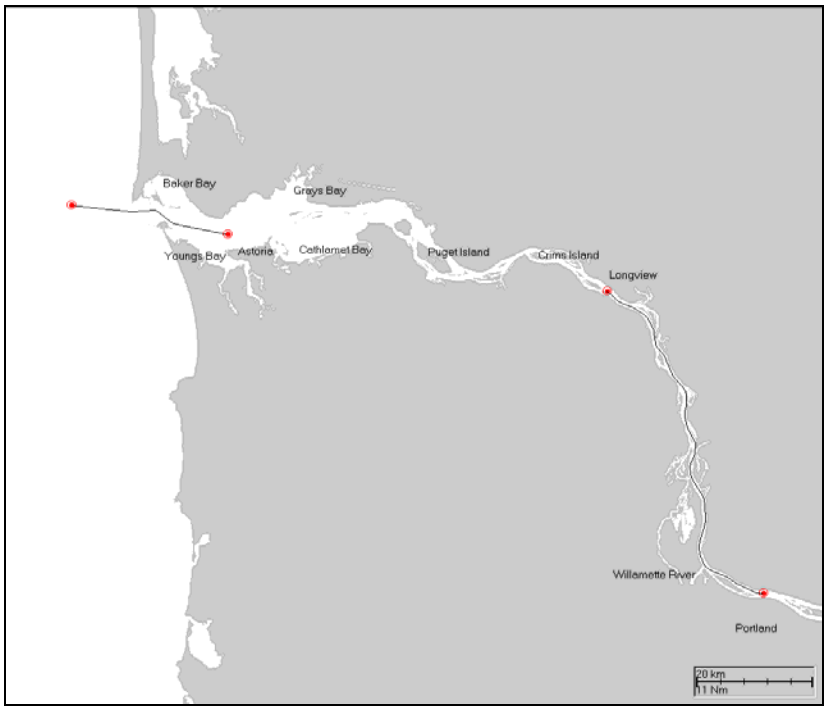

Figure 1-2. Shipping route segments where the hypothetical spills are assumed to occur: Columbia River scenarios.

In order to perform the modeling, the following input data sets were prepared for each area around where spills were simulated:

1. Shoreline location, shoreline/habitat type, and bathymetric (water depth) mapping for coastal Washington, the Vancouver Island region of British Columbia, and northern Oregon;
2. Wind data – long-term (10 year) wind record of hourly wind speed and direction;
3. Salinity and surface water temperature;
4. Current data – Tidal currents and freshwater discharge (both wet and dry seasons);
5. Oil properties and toxicity; and
6. Biological abundance.

The model results are summarized in tables of statistics describing water surface area exposed, shoreline oiled, numbers or biomass of organisms lost, and NRDA costs. Frequency distributions of model results for all runs and maps of oil exposure are also provided.

Section 2 describes the model used for this analysis. Section 3 describes the model input data sources and assumptions. Results of the physical fates model are described in Section 4. Section 5 describes the biological impact results. Estimation of economic damages (NRDA costs) based on restoration of resources and their services is in Section 6. Discussion and conclusions are in Section 7. Section 8 contains the references cited. Details of the model input data and results are in appended volumes to this main report, organized as follows. Volume II contains summary tables for all 47 scenarios. Volumes III to XXVI contain specific results for each location and oil type combination, in sets of 3 volumes: (1) model inputs, (2) results for stochastic model scenarios, and (3) results for alternate response scenarios.

2. SIMAP MODEL DESCRIPTION

The analysis was performed using the model system developed by Applied Science Associates (ASA) called SIMAP (Spill Impact Model Analysis Package). SIMAP includes (1) an oil physical fates model, (2) interfacing to a hydrodynamics model for simulation of currents, (3) a biological effects model, (4) an oil physical, chemical and toxicological database, (5) environmental databases (winds, currents, salinity, temperature), (6) geographical data (in a GIS), (7) a biological database, (8) a response module to analyze effects of response activities, (9) graphical visualization tools for outputs, and (10) exporting tools to produce text format output.

SIMAP originated from the oil fates and biological effects submodels in the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME), which ASA developed in the early 1990s for the US Department of the Interior for use in Natural Resource Damage Assessment (NRDA) regulations under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). The NRDAM/CME (Version 2.4, April 1996) was published as part of the CERCLA type A NRDA Final Rule (Federal Register, May 7, 1996, Vol. 61, No. 89, p. 20559-20614). The technical documentation for the NRDAM/CME is in French et al. (1996a,b,c). This technical development involved several in-depth peer reviews, as described in the Final Rule.

While the NRDAM/CME was developed for simplified natural resource damage assessments of small spills in the United States, SIMAP is designed to evaluate fates and effects of both real and hypothetical spills in marine, estuarine and freshwater environments worldwide. SIMAP may be run in stochastic mode to evaluate a distribution of spill results, rather than just a single result for a specific hind-cast. Additions and modifications to prepare SIMAP were made to increase model resolution, allow modification and site-specificity of input data, allow incorporation of temporally varying current data, evaluate subsurface releases and movements of subsurface oil, track multiple chemical components of the oil, enable stochastic modeling, and facilitate analysis of results. The consideration of the impacts of subsurface oil is important, particularly in the evaluation of impacts on aquatic organisms. Surface floating oil primarily impacts wildlife and intertidal biota, and not aquatic biota in subtidal habitats. At higher wind speeds than about 12 knots (or at lower wind speeds if dispersant is applied), oil will entrain into the water column, unless it has become too viscous to do so after weathering and the formation of mousse. Once oil is entrained in the water in the form of small droplets, monoaromatics (MAHs) and polynuclear aromatic hydrocarbons (PAHs) dissolve into the water column. The dissolved MAHs and PAHs are the most bioavailable and toxic portion of the oil. The dissolution rate is very sensitive to the droplet size (because it involves mass transfer across the surface area of the droplet), and the amount of hydrocarbon mass dissolved is a function of the mass entrained and droplet size distribution. These are in turn a function of soluble hydrocarbon content of the oil, the amount of evaporation of these components before entrainment, oil viscosity (which increases as the oil weathers and emulsifies), oil surface tension (which may be reduced by surfactant dispersants), and the energy in the system (the higher the energy the smaller

the droplets). Large droplets (greater than a few hundred microns in diameter) resurface rapidly, and so dissolution from those is also inconsequential. Dispersant application facilitates the entrainment of oil into the water in a smaller size distribution than would occur naturally, with the median droplet size about 20 μm (Lunel, 1993a,b).

Thus, the fate of MAHs and PAHs in surface oil is primarily volatilization to the atmosphere, rather than to the water. If wind speeds exceed 12 knots, entrainment of the surface oil into the water becomes significant. Dispersant application can also facilitate entrainment into the water column. If oil is entrained before it has weathered and lost the lower molecular weight aromatics to the atmosphere, dissolved MAHs and PAHs in the water can reach concentrations where they can affect water column organisms or bottom communities (French McCay and Payne, 2001).

Below are brief descriptions of the fates and effects models implemented in SIMAP. Detailed descriptions of the algorithms and assumptions in the model are in published papers (French McCay 2002, 2003, 2004). The model has been validated with more than 20 case histories, including the *Exxon Valdez* and other large spills (French and Rines, 1997; French McCay, 2003, 2004; French McCay and Rowe, 2004) as well as test spills designed to verify the model (French et al., 1997).

2.1 Physical Fates Model

The three-dimensional physical fates model estimates distribution (as mass and concentrations) of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments. Oil fate processes included are spreading (gravitational and by shearing), evaporation, transport, randomized dispersion, emulsification, entrainment (natural and facilitated by dispersant), dissolution, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and semi-soluble aromatics to suspended sediments, sedimentation, and degradation.

Oil is a mixture of hydrocarbons of varying physical, chemical, and toxicological characteristics. Thus, oil hydrocarbons have varying fates and impacts on organisms. In the model, oil is represented by component categories, and the fate of each tracked separately. The “pseudo-component” approach (Payne et al., 1984, 1987; French et al., 1996a; Jones 1997; Lehr et al. 2000) is used, where chemicals in the oil mixture are grouped by physical-chemical properties, and the resulting component category behaves as if it were a single chemical with characteristics typical of the chemical group.

The most toxic components of oil to aquatic organisms are low molecular weight aromatic compounds (monoaromatic and polynuclear aromatic hydrocarbons, MAHs and PAHs), which are both volatile and soluble in water. Their acute toxic effects are by narcosis, where toxicity is related to the octanol-water partition coefficient (K_{ow}), a measure of hydrophobicity. The more hydrophobic the compound, the more toxic, but the less soluble and so the less exposure there is to aquatic organisms. Compounds of

log(K_{ow})>5.6 are considered insoluble and so unavailable to aquatic biota (French McCay, 2002). Thus, impact is the result of a balance between bioavailability (exposure) and toxicity once exposed. French McCay (2002) contains a full description of the oil toxicity model in SIMAP.

Because of these considerations, the SIMAP fates model focuses on tracking the lower molecular weight aromatic components divided into chemical groups based on volatility, solubility, and hydrophobicity. In the model, the oil is treated as eight components (defined in Table 2-1). Six of the components (all but the two non-volatile residual components) evaporate at rates specific to the pseudo-component. Solubility is strongly correlated with volatility, and the solubility of aromatics is higher than aliphatics of the same volatility, with the MAHs the most soluble, the 2-ring PAHs semi-soluble, and the 3-ring PAHs slightly soluble Mackay et al. (1992a,b,c,d). Both the solubility and toxicity of the non-aromatic hydrocarbons are much less than for the aromatics and dissolution (and water concentrations) of non-aromatics is safely ignored. Thus, dissolved concentrations are calculated only for each of the three soluble aromatic pseudo-components.

Table 2-1. Definition of four distillation cuts and the eight pseudo-components in the model (monoaromatic hydrocarbons, MAHs; benzene + toluene + ethybenzene + xylene, BTEX; polynuclear aromatic hydrocarbons, PAHs).

Characteristic	**Volatile and and Highly Soluble**	**Semi-volatile and Soluble**	**Low Volatility and Slightly Soluble**	**Residual (non-volatile and insoluble)**
Distillation cut	1	2	3	4
Boiling Point (^{o}C)	< 180	180 - 265	265 - 380	>380
Molecular Weight	50 - 125	125 - 168	152 - 215	> 215
Log(K_{ow})	2.1-3.7	3.7-4.4	3.9-5.6	>5.6
Aliphatic pseudo-components: Number of Carbons	volatile aliphatics: C4 – C10	semi-volatile aliphatics: C10 – C15	low-volatility aliphatics: C15 – C20	non-volatile aliphatics: > C20
Aromatic pseudo-component name: included compounds	MAHs: BTEX, MAHs to C3-benzenes	2 ring PAHs: C4-benzenes, naphthalene, C1-, C2-naphthalenes	3 ring PAHs: C3-, C4-naphthalenes, 3-4 ring PAHs with log(K_{ow}) < 5.6	$\geq$4 ring aromatics: PAHs with log(K_{ow}) > 5.6 (insoluble)

This number of components provides sufficient accuracy for the evaporation and dissolution calculations, particularly given the time frame (minutes) over which dissolution occurs from small droplets and the rapid resurfacing of large droplets (see discussion above). The alternative of treating oil as a single compound with empirically-derived rates (e.g., Mackay et al, 1980; Stiver and Mackay, 1984) does not provide

sufficient accuracy for impact analyses because the impacts to water column organisms are caused by MAHs and PAHs, which have specific properties that differ from the other volatile and soluble compounds. Use of more pseudo components does not improve accuracy, as the major constituents of concern are well characterized (sufficiently similar in properties within the pseudo-component group of chemicals) by the modeled component properties used in SIMAP. The model has been validated both in predicting dissolved concentrations and resulting toxic effects, supporting the adequacy of the use of this number of pseudo-components (French McCay, 2003).

The lower molecular weight aromatics dissolve from the whole oil and are partitioned in the water column and sediments according to equilibrium partitioning theory (French et al., 1996a; French McCay 2004). The residual fractions in the model are composed on non-volatile and insoluble compounds that remain in the "whole oil" that spreads, is transported on the water surface, strands on shorelines, and disperses into the water column as oil droplets or remains on the surface as tar balls. This is the fraction that composes black oil, mousse, and sheen.

The schematic in Figure 2-1 shows oil fate processes simulated in the model in open water. The algorithms are described in French McCay (2004). Lagrangian elements (spillets) are used to simulate the movements of oil components in three dimensions over time. Surface floating oil, subsurface droplets, and dissolved components are tracked in separate spillets. Transport is the sum of advective velocities by currents input to the model, surface wind drift, vertical movement according to buoyancy, and randomized turbulent diffusive velocities in three dimensions. The vertical diffusion coefficient is computed as a function of wind speed in the wave-mixed layer. The horizontal and deeper water vertical diffusion coefficients are model inputs.

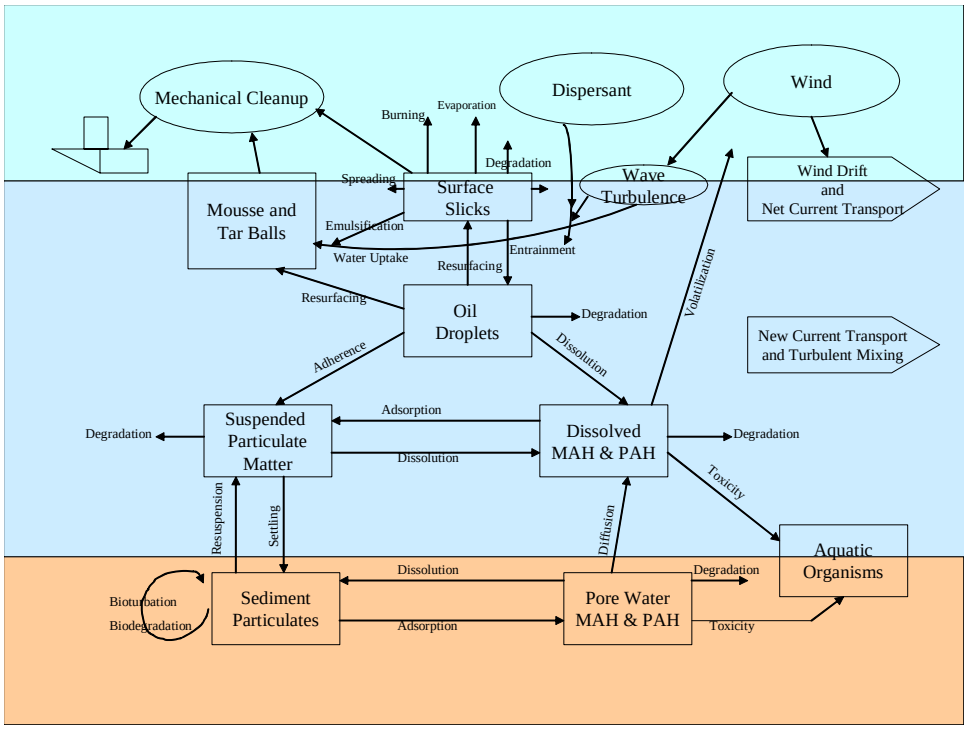

Figure 2-1. Simulated oil fates processes in open water

The oil (whole and as pseudo-components) separates into different phases or parts of the environment, i.e., surface slicks; emulsified oil (mousse) and tar balls; oil droplets suspended in the water column; dissolved lower molecular weight components (MAHs and PAHs) in the water column; oil droplets adhered and hydrocarbons adsorbed to suspended particulate matter in the water; hydrocarbons on and in the sediments; dissolved MAHs and PAHs in the sediment pore water; and hydrocarbons on and in the shoreline sediments and surfaces. The physical fates model creates output files recording the distribution of a spilled substance in three-dimensional space and time. The quantities recorded are:

- area covered by oil and thickness on the water surface ("swept area");
- volumes in the water column at various concentrations of dissolved aromatics;
- volumes in the water column at various concentrations of total hydrocarbons in suspended droplets;
- total hydrocarbon concentrations and dissolved aromatic concentrations in surface sediment;
- lengths and locations of shoreline impacted and volume of oil ashore in each segment.

The dissolved aromatic hydrocarbon concentration in the water column is calculated from the mass in the Lagrangian elements, as follows. Concentration is contoured on a three-dimensional Lagrangian grid system. This grid (of 200 X 200 cells in the horizontal and 5 vertical layers) is scaled each time step to just cover the volume occupied by aromatic particles, including the dispersion around each particle center. This maximizes the resolution of the contour map at each time step and reduces error caused by averaging

mass over large cell volumes. Distribution of mass around the particle center is described as Gaussian in three dimensions, with one standard deviation equal to twice the diffusive distance ($2D_xt$ in the horizontal, $2D_zt$ in the vertical, where D_x is the horizontal and D_z is the vertical diffusion coefficient, and t is particle age). The plume grid edges are set at one standard deviation out from the outer-most particle. These data are used by the biological effects model to evaluate exposure, toxicity and impacts.

2.2 Biological Effects Model

The biological exposure model estimates the area, volume or portion of a stock or population affected by surface oil, concentrations of oil components in the water, and sediment contamination. The biological effects model estimates losses resulting from acute exposure after a spill (i.e., losses at the time of the spill and while acutely toxic concentrations remain in the environment) in terms of direct mortality and lost production because of direct exposure or the loss of food resources from the food web. Losses are estimated by species or species group for fish, invertebrates (i.e., shellfish and non-fished species) and wildlife (birds, mammals, sea turtles). Lost production of aquatic plants (microalgae and macrophytes) and lower trophic levels of animals are also estimated.

The area potentially affected by the spill is represented by a rectangular grid with each grid cell coded as to habitat type. The habitat grid is also used by the physical fates model to define the shoreline location and type, as well as habitat and sediment type. A habitat is an area of essentially uniform physical and biological characteristics that is occupied by a group of organisms that are distributed throughout that area. A contiguous grouping of habitat grid cells with the same habitat code represents an ecosystem in the biological model. The density of fish, invertebrates and wildlife, and rates of lower trophic level productivity, are assumed constant for the duration of the spill simulation and evenly distributed across an ecosystem. While biological distributions are known to be highly variable in time and space, data are generally not sufficient to characterize this patchiness. Oil is also patchy in distribution. The patchiness is assumed to be on the same scale so that the intersection of the oil and biota is equivalent to overlays of spatial mean distributions.

Mobile fish, invertebrates and wildlife are assumed to move at random within each ecosystem during the simulation period. This is a reasonable assumption for the period of the simulation (generally a few weeks). Benthic organisms may also remain stationary on or in the bottom. Planktonic stages, such as pelagic fish eggs, larvae, and juveniles (i.e., young-of-the-year during their pelagic stage(s)), move with the currents.

Habitats include open water, wetland, sea grass, macroalgal (kelp) bed and shoreline environments. Habitat types are defined by depth, proximity to shoreline(s), bottom/shore type, dominant vegetation type, and the presence of invertebrate reefs. With respect to proximity to shoreline(s), habitats are designated as landward or seaward. Landward portions are the near-shore rivers, estuaries and inlets. The seaward portion is the more oceanic or main part of the water body. This designation allows different

biological abundances to be simulated in landward and seaward zones of the same habitat type (e.g., open water with sand bottom).

2.2.1 Wildlife

In the model, surface slicks (or other floating forms such as tar balls) of oils and petroleum products impact wildlife (birds, marine mammals). For each of a series of surface spillets, the physical fates model calculates the location and size (radius of circular spreading spillet) as a function of time. The area swept by a surface spillet in a given time step is calculated as the quadrilateral area defined by the path swept by the spillet diameter. This area is summed over all time steps for the time period the spillet is present on the water surface and separately for each habitat type where the oil passes. Spillets sweeping the same area of water surface at the same time are superimposed. The total area swept over a threshold thickness by habitat type is multiplied by the probability that a species uses that habitat (0 or 1, depending upon its behavior) and a combined probability of oiling and mortality. This calculation is made for each surface-floating spillet and each habitat for the duration of the model simulation.

A portion of the wildlife in the area swept by the slick over a threshold thickness is assumed to die, based on probability of encounter with the slick multiplied by the probability of mortality once oiled. The probability of encounter with the slick is related to the percentage of the time an animal spends on the water or shoreline surface. The probability of mortality once oiled is nearly 100% for birds and fur-covered mammals (assuming they are not successfully treated) and much lower for other wildlife. The products of the two probabilities for various wildlife behavior groups are in Table 2-2. Estimates for the probabilities are derived from information on behavior and field observations of mortality after spills (reviewed in French et al., 1996a). The threshold is 10 micron (~10g/m^2) thick oil, based on data and calculations in French et al. (1996a). The wildlife mortality model has been validated with more than 20 case histories, including the *Exxon Valdez* and other large spills, verifying that these values are reasonable (French and Rines, 1997; French McCay 2003, 2004; French McCay and Rowe, 2004).

Area swept is calculated for the habitats occupied by each of the behavior groups of wildlife listed in Table 2-2. Species or species groups are assigned to behavior groups to evaluate their loss. Wildlife mortality is directly proportional to abundance per unit area and the percent mortalities in Table 2-2.

Table 2-2. Combined probability of encounter with oil and mortality once oiled, if present in the area swept by oil exceeding a threshold thickness. Area swept is calculated for the habitats occupied.

Wildlife Group	Probability	Habitats Occupied
Dabbling waterfowl	99%	Intertidal and landward subtidal
Nearshore aerial divers	35%	Intertidal and landward subtidal
Surface seabirds	99%	All intertidal and subtidal
Aerial seabirds	5%	All intertidal and subtidal
Wetland wildlife (waders and shorebirds)	35%	Wetlands, shorelines, seagrass beds
Cetaceans	0.1%	Seaward subtidal
Furbearing marine mammals	75%	All intertidal and subtidal
Pinnipeds, manatee, sea turtles	1%	All intertidal and subtidal
Surface birds in seaward only	99%	All seaward intertidal and subtidal
Surface diving birds in seaward only	35%	All seaward intertidal and subtidal
Aerial divers in seaward only	5%	All seaward intertidal and subtidal
Surface birds in landward only	99%	All landward intertidal and subtidal
Surface diving birds in landward only	35%	All landward intertidal and subtidal
Aerial divers in landward only	5%	All landward intertidal and subtidal
Surface diving birds in water only	35%	All subtidal
Aerial divers in water only	5%	All subtidal

2.2.2 Fish and Invertebrates

In the model, aquatic biota (e.g., fish, invertebrates) are affected by dissolved aromatic concentrations in the water or sediment. This rationale is supported by the fact that soluble aromatics are the most toxic constituents of oil (Neff *et al.*, 1976; Rice *et al.*, 1977; Tatem *et al.*, 1978; Neff and Anderson, 1981; Malins and Hodgins, 1981; National Research Council, 1985, 2002; Anderson, 1985; French McCay 2002). Exposures in the water column are short in duration. Therefore, effects there are the result of acute toxicity. In the sediments, exposure may be both acute and chronic, as the concentrations may remain elevated for longer periods of time.

The model evaluates mortality and sublethal effects of dissolved aromatic concentrations in the water or sediment. Mortality is a function of duration of exposure – the longer the duration of exposure, the lower the effects concentration (see review in French McCay, 2002). At a given concentration after a certain period of time, all individuals which will die have done so. The LC50 is the lethal concentration to 50% of exposed organisms. The incipient LC50 ($LC50_\infty$) is the asymptotic LC50 reached after infinite exposure time (or long enough that that level is approached, Figure 2-2). Percent mortality is a log-normal function of concentration, with the LC50 the center of the distribution.

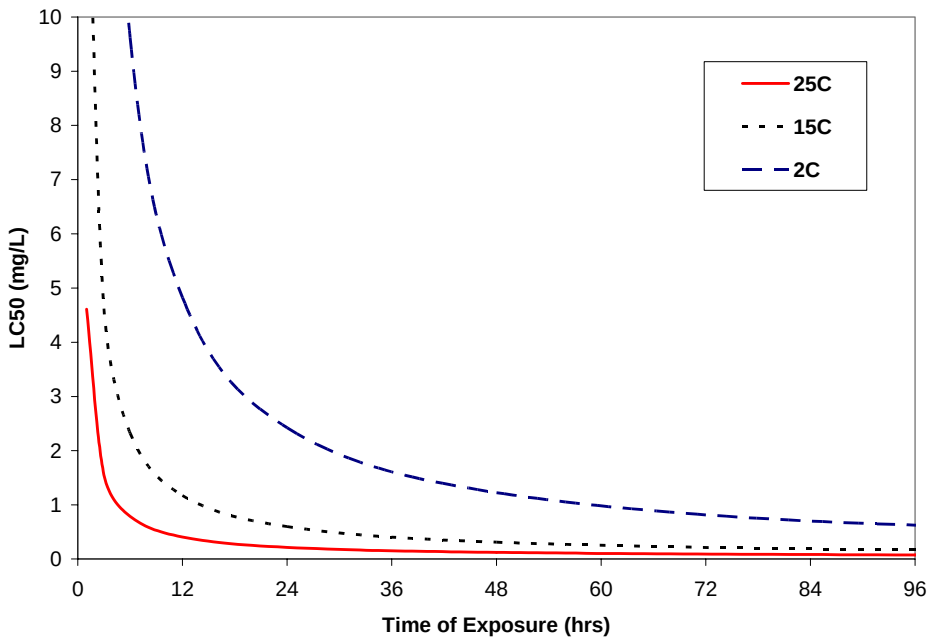

Figure 2-2. LC50 of dissolved PAH mixtures from oil, as a function of exposure duration and temperature.

The oil toxicity model in SIMAP utilizes the accepted toxic units approach for organic compounds whose primary acute effect is narcosis, which include MAHs and PAHs. The acute toxic effects of narcotic chemicals are additive (Swartz et al., 1995; French et al., 1996a; DiToro et al., 2000; DiToro and McGrath, 2000; French McCay, 2002). The approach is being used by the US Environmental Protection Agency (EPA) in the development of PAH water and sediment quality criteria (DiToro et al., 2000; DiToro and McGrath, 2000). French McCay (2002) provides estimates of $LC50_\infty$ for MAH and PAH mixtures in fuel and crude oils for spills under different environmental conditions. Figure 2-2 plots LC50s for total dissolved PAHs for species of average sensitivity under turbulent conditions ($LC50_\infty$ = 50 μg/L) for a range of exposure durations and temperatures. The $LC50_\infty$ for 95% of species fall in the range 6-400 μg/L (ppb). This oil toxicity model has been validated using laboratory oil bioassay data (French McCay, 2002).

In SIMAP, $LC50_{\infty}$ for the dissolved aromatic mixture of the spilled oil is input to the model. For each of a series of aquatic biota behavior groups, the model evaluates exposure duration, and corrects the LC50 for time of exposure and temperature to calculate mortality (Figure 2-2). The oil toxicity model is described in detail in French McCay (2002).

Movements of biota, either active or by current transport, are accounted for in determining time and concentration of exposure. Lagrangian elements are used to represent schools or groups of animals. The elements move or remain stationary according to the behavior of the animal type, and concentration and duration of exposure are recorded. Exposures are integrated over space and time by habitat type (open water, reef, or wetland in offshore or nearshore waters) to calculate a total percentage killed. The behavior groups, representing species or stages within species, are:

1) planktonic (move with currents),
2) demersal and stationary (on the bottom exposed to near bottom water),
3) benthic (in the sediments and stationary),
4) demersal fish and invertebrates (on the bottom exposed to near bottom (within 1 m) water and moving slowly),
5) small pelagic fish and invertebrates (moving randomly and slowly in the water column), and
6) large pelagic fish and invertebrates (moving randomly and rapidly in the water column).

Mortality is calculated as percent loss in specified areas. This is translated into the equivalent area of 100% loss. That area is divided by the total area of habitat available in the region of interest to estimate a percentage of the population in the area affected. The percent mortality of the exposure group is multiplied by abundance at the time exposed and in the habitat type to calculate the species' mortality as numbers or biomass (kg).

Lost production of lower trophic level plants and animals (not explicitly modeled as individual species) is also integrated in space and over time using EC50s, the effective concentration to reduce growth to 50% of normal, to parameterize a log-normal function of the same form as the mortality function. Total production loss (g dry weight) is summed over time and space. Production losses of lower trophic levels are typically very small because of their short generation times and quick recovery after a spill. They have not been measured in the field because the impact is less than natural variability.

2.2.3 Validation of the Biological Effects Model

The biological effect model has been validated using simulations of over 20 spill events where data are available for comparison (French and Rines, 1997; French McCay, 2003, 2004; French and Rowe, 2004). In most cases (French and Rines, 1997; French McCay, 2004; French and Rowe, 2004) only the wildlife impacts could be verified because of limitations of the available observational data. However, in the *North Cape* spill

simulations, both wildlife and water column impacts (lobsters) could be verified (French McCay, 2003).

2.2.4 Quantification of Fish and Invertebrate Impacts as Lost Production

The biomass (kg) of animals killed represents biomass that had been produced before the spill. In addition, if the spill had not occurred, the killed organisms would have continued to grow until they died naturally or to fishing. This lost future (somatic) production is estimated and added to the direct kill. The total impact is the total production foregone. The loss is expressed in present day (i.e., present year) values using a 3% annual discount rate for future losses. Restoration should compensate for this loss. The scale of restoration needed is equivalent to production lost when both are expressed in values indexed to the same year, i.e., the present year.

Interim losses are sustained in future years (pending recovery to baseline abundance) resulting from the direct kill at the time of the spill. Interim losses potentially include:

- Lost future uses (ecological and human services) of the killed organisms themselves;
- Lost future (somatic) growth of the killed organisms (i.e., production foregone, which provides additional services);
- Lost future reproduction, which would otherwise recruit to the next generation.

The approach used here for estimating natural resource damages is that the injury includes the direct kill and its future services, plus the lost somatic growth of the killed organisms, which would have provided additional services. Because the impact on each species, while locally significant, is relatively small compared to the scale of the total population in the area, it is assumed that density-dependent changes in survival rate are negligible, i.e., changes in natural and fishing mortality of surviving animals do not compensate for the killed animals during the natural life span of the animals killed.

It is also assumed that the impacts were not large enough to significantly affect future reproduction and recruitment in the long term. It is assumed that sufficient eggs will be produced to replace the lost animals in the next generation. The numbers of organisms affected, while locally significant, are relatively small portions of the total reproductive stock. Given the reproductive strategy of the species involved to produce large numbers of eggs, of which only a few survive, it is assumed that density-dependent compensation for lost reproduction occurs naturally.

The services provided by the injured organisms are measured in terms of production, i.e., biomass (kg wet weight) directly lost or not produced. Among other factors, services of biological systems are related to the productivity of the resources, i.e., to the amount of food produced, the usage of other resources (as food and nutrients), the production and recycling of wastes, etc. Particularly in aquatic ecosystems, the rate of turnover (production) is a better measure of ecological services than standing biomass (Odum, 1971). Thus, the sum of the standing stock killed (which resulted from production

previous to the spill) plus lost future production is a more appropriate scaler, as opposed to standing stock alone (as number or kg), for measuring ecological services.

This method was developed and used previously in the injury quantification for the *North Cape* spill of January 1996 (French McCay et al., 2001, 2003a). The procedure makes use of the population model in SIMAP. Injuries are calculated in three steps:

1. The direct kill is quantified by age class using a standard population model used by fisheries scientists.
2. The net (somatic) growth normally to be expected of the killed organisms is computed and summed over the remainder of their life spans (termed lifetime production).
3. Future interim losses are calculated in present day values using discounting at a 3% annual rate.

The normal (natural in local waters) survival rates per year and length-weight by age relationships are used to construct a life table of numbers and kg for each annual age class. Lifetime production is estimated as the sum of the net (somatic) growth normally to be expected of the killed individual over the remainder of its life span. The age-class specific weight gain per year times percent expected to be left alive by the end of that year is summed over all years to calculate total lifetime production. Growth in future years is discounted 3% annually. Equations for these calculations are in French McCay et al. (2003a).

It should be noted that compensation is needed for lost production of each of the individual species injured, and that losses are additive. Restoration for a prey species killed will compensate for that prey killed and all the services that prey would have provided in the future to its predators and other resources. The predators that would eat that prey but were directly killed were produced before the spill from *different* prey individuals as food. Thus, the predator's production loss must be compensated in addition to the prey animals directly killed. This may be accomplished by providing additional prey production to compensate for the direct predator loss.

Discounting at 3% per year is included to translate losses in future years (interim loss) to present-day values. The discounting multiplier for translating value n years after the spill to present value is calculated as $(1+d)^{-n} = 1/(1+d)^{n}$, where d=0.03. Thus, the losses in future years have a discounted value in the present. In this report, all discounting is calculated based on the number of years from the year of the spill. The present day is considered the year of the spill.

2.3 Stochastic Modeling

2.3.1 Approach

In order to determine the consequences of hypothetical spills on ecological resources, multiple scenarios and conditions need to be evaluated to estimate the probability and likely amount of oil reaching each site of concern. The stochastic oil fates model in SIMAP is used to determine the range of distances and directions oil spills are likely to travel from a particular site, given historical wind and current speed and direction data for the area. To sample the universe of possible environmental conditions, long-term wind and current data are compiled. For each model run used to develop the statistics, the spill date is randomized, which provides a probability distribution of wind and current conditions during the spill. The stochastic oil fates model performs a large number of simulations for a given spill site, varying the spill time, and thus the wind and current conditions, for each run. Output of the model is the time histories of the spill trajectories. These distributions are used to estimate the percent of these hypothetical spills where water surface, water column, sediments, and shoreline areas will be affected by a release from a spill at a given site, as well as the amount of oil exposure for each of the model runs.

The stochastic oil fates model quantifies, in space and over time, for each individual model run:

- oil thickness (microns or g/m^2) on water surface,
- oil thickness (microns or g/m^2) on shorelines,
- subsurface oil droplet concentration, as total hydrocarbons ($\mu g/L = mg/m^3 \sim ppb$),
- dissolved aromatic concentration in water ($\mu g/L = mg/m^3 \sim ppb$),
- total hydrocarbon loading on sediments (g/m^2), and
- dissolved aromatics concentration in sediment pore water ($\mu g/L = mg/m^3 \sim ppb$).

The results are summarized by mapping of each of these exposure measures onto the habitat grid as:

- the time of first exceedance of the threshold,
- maximum exposure (thickness or concentration) at any time after the spill, and
- an integrated dose measure of g/m^2-hours for floating oil and sediments or ppb-hrs for concentrations.

The results of multiple model runs are also evaluated to develop the following indicators of possible exposure for each location and for each of the components listed above:

- Probability of exposure (probability that a threshold thickness or concentration will be exceeded at each location at any time following the spill).
- Time (hours) before potential first exceedance of the threshold at each location.
- Worst case maximum exposure (thickness, volume or concentration) at any time after the spill, at a given location (i.e., maximum peak exposure for all the model runs), calculated as follows. For each individual run (for each spill date run), the maximum amount over all time after the spill is saved for each location in the model grid. Then

the runs are evaluated to determine the greatest or highest amount possible at each location.

- Mean expected maximum exposure (thickness, volume or concentration) at any time after the spill, at a given location (i.e., mean peak exposure of all model runs), calculated as follows. For each individual run (for each spill date run), the maximum amount over all time after the spill is saved for each location in the model grid. The runs are evaluated to determine the mean expected peak exposure (mean exposure for all runs) at each location.

The SIMAP graphical user interface produces maps of these statistics, both for individual runs and summarizing all runs. Mapped geographical data of resources (biological and human use) may be compared when overlaid with model results. The results are also tabulated by location (grid cell) and habitat or shore type. Impacts by habitat or shoreline type are tabulated for each of several ranges of exposure conditions (thickness, mass loading (g/m^2) or concentration intervals).

The stochastic modeling outputs provide a distribution of spill results, which may be summarized by statistics such as mean and standard deviation. The results are ordered into a probability density function (PDF) such that the 50th (median) and other percentile spill dates-times are identified. Individual runs may be evaluated in greater detail to characterize the impacts of events of that probability in terms of weather conditions and fate. The worst case exposure described above is the maximum case of the model runs performed (e.g., 99th percentile if 100 runs are made). The 95th percentile run is a better indicator of the extreme case because the maximum run result is sensitive to the number of runs performed and so highly variable.

A PDF of a particular exposure measure, such as area swept by oil, may be scaled to estimate an impact that is proportional to the exposure measure, such as percentage or number of waterfowl in the area of interest which are oiled, by running the biological exposure model to estimate the impact for specific runs (e.g., the 5th, 50th and 95th percentile runs) and developing a regression of the impact estimates (e.g., waterfowl oiled) as a function of the exposure measure (e.g., area swept by oil). This approach was used in the analysis of model results in this study. The impact on each biological resource was evaluated as proportional to the exposure measure by which the resource is most affected (such as surface area swept for waterfowl and seabirds, water column volume where dissolved aromatic concentration exceeds the threshold for effects for fish, etc.). The exposure included was only that in habitats occupied by the species group.

Table 2-3 lists biological resource categories and the exposure measures used to develop linear regressions for each group. For each resource category, 6 model runs were used in the regression: the 5th, 50th and 95th percentile runs based on shoreline costs and the 5th, 50th and 95th percentile runs based on water surface area swept by oil. The individual runs were for specific spill dates, using the abundances for the appropriate season. As impacts are proportional to pre-spill abundance, the results were corrected to be for an annual mean abundance using the ratio of annual mean to seasonal abundance before the regression slope and intercept were calculated. The regression slopes and intercepts were

then used to estimate the impacts for all 100 runs of the stochastic model scenarios. The regressions were also used to estimate the biological impacts for all runs of the alternative response scenarios.

For intertidal biota, the impacts were estimated directly from the habitat area oiled by > 100 g/m^2 of oil. The affected area was multiplied by density (biomass per unit area) in the habitat to estimate the impact.

Table 2-3. Biological resource types and exposure measure by which the resource is most affected.

Resource	**Exposure Measure**
Waterfowl	Water surface area swept by > 10 g/m^2 of oil and wetland area oiled by > 100 g/m^2
Seabirds	Water surface area swept by > 10 g/m^2 of oil
Raptors	Water surface area swept by > 10 g/m^2 of oil (nearshore and wetland)
Cetaceans	Water surface area swept by > 10 g/m^2 of oil (open waters only)
Pinnipeds (seals)	Water surface area swept by > 10 g/m^2 of oil
Other mammals	Water surface area swept by > 10 g/m^2 of oil (nearshore and wetland)
Wading birds	Wetland and soft shoreline area oiled by > 100 g/m^2
Shorebirds	Wetland and soft shoreline area oiled by > 100 g/m^2
Fish and invertebrates in water or on bottom, plankton	Volume exposed above the threshold for potential effects (>1 ppb dissolved PAH concentration)
Benthic biota (in the sediments)	Sediment concentrations (>1 ppb dissolved aromatic concentration in pore water)

The stochastic modeling approach described above has been used to estimate potential impacts as part of contingency planning, ecological risk assessments, net environmental benefit, and cost-benefit analyses (French et al, 1999; French McCay et al. 2002, 2003b, 2004a). The strength of the approach is that the range of possible environmental conditions is sampled randomly, providing an unbiased, quantitative estimate of the distribution of expected impacts.

3. MODEL INPUT DATA

3.1 Geographical and Model Grid

For geographical reference, SIMAP uses a rectilinear grid to designate the location of the shoreline, the water depth (bathymetry), and the shore or habitat type. The grid is generated from a digital coastline using the ESRI Arc/Info compatible Spatial Analyst program. The cells are then coded for depth and habitat type. Note that the model identifies the shoreline using this grid. Thus, in model outputs, the coastline map is only used for visual reference; it is the habitat grid that defines the actual location of the shoreline in the model.

The digital shoreline, shore type, and habitat mapping for the Strait of Juan de Fuca to Strait of Georgia (including Puget Sound) were obtained from the Washington State ShoreZone Inventory (Nearshore Habitat Program, Washington State Department of Natural Resources). The digital shoreline, shore type, and habitat mapping for the outer coast of Washington and the Columbia River were obtained from Environmental Sensitivity Index (ESI) Atlas database compiled for the area by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA). Shore type data for Vancouver Island and the Northern Strait of Georgia were obtained from the Government of British Columbia, Ministry of Sustainable Resource Management (http://srmwww.gov.bc.ca/dss/coastal/mris/coast2.htm).

Model grids were constructed for each spill location (i.e., shipping route segment), sized just large enough to include areas where oil would be transported after a spill. The grids were divided into as many cells as possible (within memory limits of the computer for the model code) to obtain the maximum resolution. The gridded habitat type data are shown in Section B.2 of Volumes III, VI, IX, XII, XV, XVIII, XXI, and XXIV. The grid scale resolution and dimensions are indicated in Section E of each volume.

As noted in Section 2, within a grid, habitats are designated as landward or seaward. Landward portions are the rivers, estuaries and inlets. The seaward portion is the more oceanic or main part of the water body. This designation allows different biological abundances to be simulated in landward and seaward zones of the same habitat type (e.g., open water with sand bottom). The biological database is coded to landward or seaward by species (see French et al., 1996a, c).

Ecological habitat types (Table 3-1) are broadly categorized into two zones: intertidal and subtidal. Intertidal habitats are those above spring low water tide level, with subtidal being all water areas below that level. Intertidal areas may be extensive, such that they are wide enough to be represented by an entire grid cell at the resolution of the grid. These are typically either mud flats or wetlands, and are coded 20 (seaward mudflat), 21 (seaward wetland), 50 (landward mudflat) or 51 (landward wetland). All other intertidal habitats are typically much narrower than the size of a grid cell. Thus, these fringing intertidal types (indicated by F in Table 3-1) have typical (for the region, French et al., 1996a) widths associated with them in the model. Boundaries between land and water

are fringing intertidal habitat types. On the waterside of fringing intertidal grid cells, there may be extensive intertidal grid cells if the intertidal zone is extensive. Otherwise, subtidal habitats border the fringing intertidal.

Table 3-1. Classification of habitats. Seaward (Sw) and landward (Lw) system codes are listed. (Fringing types indicated by (F) are only as wide as the intertidal zone in that province. Others (W = water) are a full grid cell wide and must have a fringing type on the land side.)

Habitat Code (Sw,lw)	Zone	Ecological Habitat	F or W
1,31	Intertidal	Rocky Shore	F
2,32		Gravel Beach	F
3,33		Sand Beach	F
4,34		Fringing Mud Flat	F
5,35		Fringing Wetland (Saltmarsh)	F
6,36		Macrophyte Bed	F
7,37		Mollusk Reef	F
8,38		Coral Reef	F
9,39	Subtidal	Rock Bottom	W
10,40		Gravel Bottom	W
11,41		Sand Bottom	W
12,42		Silt-mud Bottom	W
13,43		Wetland (Subtidal of Saltmarsh)	W
14,44		Macroalgal (Kelp) Bed	W
15,45		Mollusk Reef	W
16,46		Coral Reef	W
17,47		Seagrass Bed	W
18,48	Intertidal	Man-made, Artificial	F
19,49		Ice Edge	F
20,50		Extensive Mud Flat	W
21,51		Extensive Wetland (Saltmarsh)	W

The intertidal habitats were assigned based on the shore types in the Washington State ShoreZone Inventory and ESI Atlases. These data were gridded using the ESRI Arc/Info compatible Spatial Analyst program. Open water areas were defaulted to sand bottom, as open water bottom type has no influence on the model results. Where data are missing, shore types are defaulted as in Table 3-2. Habitats inside bays, inlets and estuaries were designated as landward, and open coastal water as seaward.

Table 3-2. Default fringing intertidal habitat type, given adjacent subtidal or extensive intertidal habitat type.

Subtidal or Extensive Intertidal Habitat	Fringing Intertidal Habitat
Seagrass Bed (47)	Sand Beach (33)
Subtidal Sand Bottom (41)	Sand Beach (33)
Extensive Mudflat (50)	Fringing Mudflat (34)
Extensive Wetland (51)	Fringing wetland (35)

Depth data for the offshore and coastal waters were obtained from Hydrographic Survey Data supplied on CD-ROM by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center. Hydrographic survey data consist of large numbers of individual depth soundings. The depth soundings were interpolated into the model grid for each area, by averaging all soundings falling within a cell. The gridded depth data are shown in Section B.3 of Volumes III, VI, IX, XII, XV, XVIII, XXI, and XXIV.

3.2 Environmental Data

The model uses hourly wind speed and direction for the time of the spill and simulation. A long term wind record (>10 year) is sampled at random to develop a probability distribution of environmental conditions that might occur at the time of a spill. Several wind data sets were available for the state of Washington waters. Data for the nearest wind station were used for each location. Wind station data are described in Section E of Volumes III, VI, IX, XII, XV, XVIII, XXI, and XXIV.

Surface water temperature varies by month, based on data for Washington waters in French et al. (1996b), as described in Section E of Volumes III, VI, IX, XII, XV, XVIII, XXI, and XXIV. The air immediately above the water is assumed to have the same temperature as the water surface, this being the best estimate of air temperature in contact with floating oil.

Salinity is assumed to be the mean value for the location of the spill site, based on data compiled in French et al. (1996b)., as listed in Section E of Volumes III, VI, IX, XII, XV, XVIII, XXI, and XXIV. The salinity value assumed in the model runs has little influence on the fate of the oil, as salinity is used to calculate water density (along with temperature), which is used to calculate buoyancy, and none of the oils evaluated have densities near that of the water.

Suspended sediment is assumed 10 mg/l, a typical value for coastal waters (Kullenberg, 1982). The sedimentation rate is set at 1 m/day. These default values have no significant affect on the model trajectory. Sedimentation of oil and PAHs becomes significant at about 100 mg/L suspended sediment concentration. There is no indication that high

suspended sediment concentrations would occur in any of the areas where spills were simulated.

The horizontal diffusion (randomized mixing) coefficient is assumed as 1 m^2/sec. The vertical diffusion (randomized mixing) coefficient is assumed 0.0001 m^2/sec. These are reasonable values for coastal waters based on empirical data (Okubo and Ozmidov, 1970; Okubo, 1971) and modeling experience.

3.3 Currents

3.3.1 Tidal and Other Currents

Currents have significant influence on the trajectory and oil fate, and are critical data inputs. Wind-driven, tidal and background currents are included in the modeling analysis. The local surface wind drift is calculated within the oil spill model (as described in the next section). The tidal currents and background (other than tidal) currents are input to the oil fates and biological effects models from a current file that is prepared for this purpose.

3.3.1.1 Strait of Juan de Fuca, Outer Coast and Columbia River Scenarios

For the Strait of Juan de Fuca, outer coast and Columbia River scenarios, current data were generated using ASA's boundary fitted coordinate hydrodynamic model (BFHYDRO) which produces applicable hydrodynamic data sets suitable for use in the SIMAP model system. The hydrodynamic model's governing equations and validation are described in detail in Spaulding (1984), Muin (1993), Muin and Spaulding (1997a, b), Spaulding et al. (1999a), and Sankaranarayanan and Spaulding (2003). The boundary-fitted grid is a mesh of quadrilateral cells of varying size and included angles, which is capable of handling variable geometry and flow regimes. The boundary fitted coordinate system in BFHYDRO uses general curvilinear coordinates to map the model grid to the shoreline of the water body being studied. It also allows enormous versatility in grid sizing so that many of the smaller features may be resolved, along with the larger, without being penalized by an excessive grid size (number of cells).

The boundary-fitted method uses a set of coupled quasi-linear elliptic transformation equations to map an arbitrary horizontal multi-connected region from physical space to a rectangular mesh structure in the transformed horizontal plane. The 3-dimensional conservation of mass and momentum equations, with approximations suitable for estuaries (Muin and Spaulding, 1997a, b) that form the basis of the model, are then solved in this transformed space. In addition, an algebraic transformation is used in the vertical to map the free surface and bottom onto coordinate surfaces. The resulting equations are solved using an efficient semi-implicit finite difference algorithm.

The hydrodynamic model (BFHYDRO) has been validated in numerous applications, including in Muin and Spaulding (1997a, b), Spaulding et al. (1999a), and

Sankaranarayanan and Spaulding (2003) where the governing equations are described. Applications that have been validated include: for San Francisco Bay (Sankaranarayanan and French McCay, 2003a); for the Narragansett Bay system (Swanson et al., 1998; Spaulding et al., 1999b; Kim and Swanson, 2001); for Bay of Fundy (Sankaranarayanan and French McCay, 2003b); the Savannah River (Mendelsohn et al., 1999), and Charleston Harbor, SC (Peene et al., 1997; Yassuda et al., 2000a,b; Mendelsohn et al., 2001).

Existing sources of current data were considered for the oil spill modeling of the Strait of Juan de Fuca, outer coast and Columbia River scenarios. However, we need to model spills for sample dates from at least a decade, with the tidal and other forces for those dates, and in high resolution in the area of the spill site. Thus, we applied BFHYDRO, and compared the predictions to existing current data, as well as National Oceanic and Atmospheric Administration tidal predictions, as part of the calibration and verification of the hydrodynamic model results. The ASA model also is compatible with the oil trajectory model SIMAP, requiring no data processing step to input the current data to SIMAP.

BFHYDRO was applied in the three-dimensional mode in the Strait of Juan de Fuca and outer coast application, and two-dimensional model in the Columbia River applications. Known physical conditions are input to the model grid at the edges, termed “open boundaries”. These inputs are described as “forcing factors”. The forcing factors are water height, available from tidal height data, and river flow. Salinity driven (i.e., density driven) flows, were not considered for the present analysis. Forcing factors due to wind stress on the water surface were included in the wind drift calculation in the oil fates model.

Tidal currents are driven by a mix of forces with semi-diurnal and diurnal periodicity, causing the elevations of successive high and low tides to be unequal. The major 6 constituents are M_2, S_2, N_2, K_1, O_1 and P_1, where the letter and number codes for the tidal constituents are standard terminology based on harmonic analysis of tidal height data (Defant, 1961), with the number indicating the approximate frequency of the sinusoidal cycle per day (1 is diurnal and 2 is semi-diurnal). The letter indicates the sinusoidal periodicities included in the component. M_2 and S_2 are pure lunar and solar components, respectively. All the others are mixtures of signals resulting from various periodic changes in the position of the sun and moon relative to the earth. For more information, see Defant (1961) or similar oceanographic text book.

Tidal forcing is accomplished by defining the water height over time at the model grid boundaries. The forcing is specified for each tidal constituent. The current vectors for each constituent are computed for each model grid cell and time step based on physical laws (conservation of mass and momentum). Current vectors for non-tidal flows (i.e., river) are computed in an analogous manner. In the oil spill model, the various tidal constituent and non-tidal current vectors are summed to determine the actual transport of oil components and plankton in the particular grid cell and time step of interest.

BFHYDRO current predictions were compared to existing current data, as well as National Oceanic and Atmospheric Administration tidal predictions, as part of the calibration and verification of the model results. The model grid and application are described in Section C of Volumes III, VI, IX, XII, XXI, and XXIV. These sections also contain current vector plots for the dominant tidal constituents at selected intervals relative to maximum flood and maximum ebb. The actual summed current vectors for all tidal and non-tidal constituents vary for each individual model run, as the 100 spill dates run vary randomly over a long-term period.

3.3.1.2 San Juan Islands and Inner Straits Scenarios

Currents were based on hydrodynamic model data from D.O. Hodgins (1998; Seaconsult Marine Research Ltd, 8805 Osler Street, Vancouver V6P 4G1, Canada), who simulated currents in the Strait of Georgia. The surface currents from Hodgins' three-dimensional model outputs were formatted for use in SIMAP. The tidal forcing functions applied were the 9 harmonic constituents (M_2, S_2, N_2, K_2, MF, Q_1, K_1, O_1 and P_1).

The model grid and application are described in Section C of Volumes XXV, and XXVIII. These sections also contain current vector plots for the dominant tidal constituents at selected intervals relative to maximum flood and maximum ebb. The actual summed current vectors for all tidal and non-tidal constituents vary for each individual model run, as the 100 spill dates run vary randomly over a long-term period.

3.3.2 Wind-driven Surface Currents

Local wind-driven surface currents are calculated within the SIMAP fates model, based on local wind speed and direction. Surface wind drift of oil has been observed in the field to be 1-6% (average 3-4%) of wind speed in a direction 0-30 degrees to the right (in the northern hemisphere) of the down-wind direction (ASCE, 1996). In restricted waters with little fetch, the angle tends to be near zero, while in open waters the angle develops to be 20°-30° to the right of down wind.

Wind drift speed and angle were studied in detail by Youssef and Spaulding (Youssef, 1993; Youssef and Spaulding, 1993, 1994). Wind drift speed is a percentage of wind speed over the water, highest at low wind speed and decreasing as wind speed increases. The range of drift speed for winds up to 20 kts (averaged over time) is 2-4% of wind speed. At 10 kts or less, the percent of wind speed is about 3.5-4% at the water surface, decreasing to 2% at 0.1m below the surface. The angle to the right of down wind is highest at low wind speed, on the water surface ranging from about 20°-30° at 10 kts or less. The drift speed decreases, and the drift angle increases, deeper into the water column.

Youssef and Spaulding (Youssef, 1993; Youssef and Spaulding, 1993, 1994) developed a set of equations to describe the percent of wind speed and angle as functions of wind speed and depth in the water. This algorithm has been incorporated into SIMAP. The

wind drift is applied to the upper 5 meters of the water column. The SIMAP algorithm was validated with observations of the drift of floating fuel and bitumen in surface water after an intentional (test) Orimulsion spill (French et al., 1997). This Youssef and Spaulding algorithm was used in model runs for surface wind drift.

3.4 Oil Properties, Toxicity, and Impact Thresholds

The oil types modeled were crude oil, Bunker C (heavy fuel oil), and diesel (light fuel oil). Physical and chemical data on the oils were taken from the NRDAM/CME database (French et al., 1996b) and the Environment Canada catalogue of crude oil and oil product properties (Whiticar et al., 1992; Jokuty et al, 1996, 1999). PAH concentrations were based on data in French McCay (2002) or Lee et al. (1992); MAH concentrations were from Jokuty et al. (1996, 1999) or Wang et al. (1995) ; and the volatile aliphatic concentrations were calculated from boiling curves (in Jokuty et al. 1996, 1999), subtracting the volatile aromatics. The volatile aliphatics are evaporated and volatilize from the surface water and so their mass is accounted for in the overall mass balance. However, as they do not dissolve in significant amounts, they have no influence on the biological effects on water column and benthic organisms. Minimum oil slick thickness was assumed 1mm, based on McAuliffe (1987). Properties assumed in the modeling are in Section D of Volumes III, VI, IX, XII, XV, XVIII, XXI, and XXIV.

There are two categories of components in oil that need to be considered as to their potential for impact to aquatic organisms.

1. Whole oil (floating and subsurface)
2. Low molecular weight aromatics (MAHs and PAHs)

Each of these components has a separate fate and is tracked separately in the model. For surface floating and shoreline oil, a threshold was identified above which there is some potential for impacts. Aquatic toxicity is caused by the sum of the contributions from each of the components in the water column.

3.4.1 Whole oil

French et al. (1996a) reviewed the literature regarding the necessary dose to affect birds and other wildlife. This was translated to a minimum thickness of floating oil, which is 10 g/m^2 (10 micron thick oil).

The threshold for effects on intertidal vegetation has been observed to be much higher than this level (by 2-3 orders of magnitude, French et al., 1996a). On the other hand, intertidal invertebrates have been observed to be more sensitive than vegetation. Thus, 100 g/m^2 was assumed as the threshold for potential effects on fauna due to smothering and/or toxic exposures of oil in intertidal habitats.

Whole oil droplets in the water column may affect fish and invertebrates by interfering with feeding or clogging gills. However, data quantifying a threshold level for effects

has not been identified. A conservative threshold of 10 ppb for fish and invertebrates was used in the modeling as a minimum for inclusion in model outputs. This level is based on literature reviewed by Markarian et al. (1993) and French et al. (1996a).

3.4.2 Low molecular weight aromatics

For crude oil, diesel and heavy fuel oil spills at the water surface, MAHs do not have a significant impact on aquatic organisms for the following reasons. MAH concentrations are typically $\leq$3% in fresh oils. MAHs are soluble, and so some becomes bioavailable (dissolved). MAH compounds are also very volatile, and will volatilize (from the water surface and water column) very quickly after a spill. The threshold for toxic effects for these compounds is about 500 ppb for sensitive species (French McCay, 2002). MAHs evaporate faster than they dissolve, such that toxic concentrations are not reached. The small concentrations of MAHs in the water will quickly be diluted to levels well below toxic thresholds immediately after a spill. Thus, the assumed values for MAH concentrations in the oil, as well as their fates, have little influence on model results. The percentage of PAHs has a significant influence on the model results. Thus, data for well-defined oils were used in the model runs, and the LC50s assumed were for total dissolved PAH concentrations in the water ($LC50_{mix}$).

To estimate $LC50_{mix}$ values for dissolved PAHs in the water, the additive model described in French McCay (2002) was used. French McCay (2002) estimated $LC50_{mix}$ = 50 ppb for typical fuels at infinite exposure time and for the average species. Ninety-five percent of species have LC50s between 6 and 400 μg/L (ppb). In the assessment of impacts, all species are assumed to be of average sensitivity to oil hydrocarbons.

The LC50s above are for the concentration of *dissolved* PAHs that would be lethal to 50% of exposed organisms for a long enough times of exposure for mortality to occur. For PAHs, this is for at least 2 weeks of exposure at warm temperature. For chemicals in general, toxicity is higher, and the LC50 lower, at longer time of exposure and higher temperature (French et al, 1996a; French McCay, 2002). The model corrects this LC50 to temperature and duration of exposure for each group of organisms exposed.

3.4.3 Toxicity Thresholds of Concern

The literature shows that, for most organic and inorganic chemicals, the threshold for sublethal effects is approximately 10 times lower than the 96-hour LC50 (Call et al 1985; Gobas, 1989; Giesy and Graney, 1989). The only chemicals where higher ratios occur are those that have very high $\log(K_{ow})$, and so bioaccumulate. PAHs have ratio of up to 10. Thus, the sublethal effect threshold for PAHs in oils would be about 1ppb. Dissolved PAH concentrations below 1 ppb would not be expected to have toxic effects on aquatic organisms. Note that exceedance of the chronic threshold would need to be for long time periods (>1 week) for effects to occur.

The model results show that the duration of water column exposures are on the order of hours. Thus, the exposures are acute rather than long-term, and the LC50 for infinite

exposure time is very conservative in considering potential for effects. Sublethal effects would also be expected to vary by duration of exposure. Table 3-3 lists acute toxicity values for soluble fuel components in oil, and for sensitive (5th percentile) and average (50th percentile) species, at different durations of exposure at $25^{o}C$ (based on equations in French McCay, 2002). The LC50s for short exposure times are higher at colder temperatures (Figure 2-2).

Table 3-3. LC50s for fuel components and varying exposure times.

	BTEX (μg/l)	**C3 Benzenes (μg/l)**	**MAHs (μg/l)**	**PAHs (μg/l)**
Sensitive Species (2.5^{th} percentile):				
LC50, 6 hours	1600	632	1190	99
LC50, 96 hours	506	136	374	9
LC50 (infinite exposure)	505	133	373	6
Average Species (50th percentile):				
LC50, 6 hours	13,400	5300	9920	789
LC50, 96 hours	4230	1140	3123	76
LC50 (infinite exposure)	4230	1115	3115	48

For PAHs, the LC50 for six hours of exposure for the 2.5^{th} percentile species is 100 μg PAH/L (Table 3-3). To account for variation among individuals of the sensitive species, 10% of this LC50 is assumed as the threshold for potential effects. Thus, to the nearest order of magnitude, peak exposure PAH concentrations below 10 ppb would have no significant impact on aquatic organisms for short exposure times.

The thresholds for effects were used in the stochastic model analysis to determine potential for impacts and the needed duration of model simulations. In the individual model runs and biological model analysis, the LC50 is corrected for temperature and time of exposure.

3.5 Shoreline Oil Retention

Retention of oil on a shoreline depends on the shoreline type, width and angle of the shoreline, viscosity of the oil, the tidal amplitude, and the wave energy. In the NRDAM/CME (French et al., 1996a,b,c), shore holding capacity was based on observations from the *Amoco Cadiz* spill in France and the *Exxon Valdez* spill in Alaska (based on Gundlach (1987) and later work summarized in French et al., 1996a). These

data are used here (Table 3-4). The shore width (intertidal zone width where oiling would occur) was assumed 1 m.

Table 3-4. Maximum surface oil thicknesses for various beach types as a function of oil viscosity (from French et al., 1996a, based on Gundlach, 1987).

	Oil Thickness (mm) by Oil Type		
Shore Type	Light (<30 cSt)	Medium (30-2000 cSt)	Heavy (>2000 cSt)
Rocky shore	1	5	10
Gravel beach	2	9	15
Sand beach	4	17	25
Mud flat	6	30	40
Wetland	6	30	40
Artificial	1	2	2

3.6 Scenarios

Table 1-1 lists the scenarios examined, including 13 main stochastic scenarios and 34 alternate response scenarios for the 5th, 50th and 95th percentile runs in the main stochastic scenario base case. Figures 1-1 and 1-2 show the hypothetical spill locations examined. For scenarios involving Alaskan North Slope crude oil and diesel, the spill volume is assumed 65,000 bbl. For the Bunker C fuel spills, the spill volume is 25,000 bbl. All spills were assumed to be at or near the water surface and over 4 hours. The model was run for 2 weeks, by which time most of the oil came ashore or dispersed. One hundred randomly selected dates and times were selected over the period of the wind file used for each location. The same set of dates and times were run for all stochastic scenarios at a single location.

Specifics of the spill response scenarios were developed by D. S. Etkin (Environmental Research Consulting) based on state and federal planning standards and assumptions provided by WDOE. In all scenarios, including no mechanical removal, protective booming was included. The mechanical removal capacities were assumed to be one of three options (when included in the scenario), in increasing order of capacity: (1) US Coast Guard federal response capability standards, (2) current Washington State standards, and (3) a theoretical higher response capability. In the scenarios where dispersant use is included, the assumptions of the US Coast Guard federal response capability standards were used with the amount of equipment available set by the Washington state standards. Dispersant use was assumed to occur >3 nm offshore and was assumed effective when the thickness of the oil exceeded 13 microns and the wind speed was between 3 knots and 27 knots. In situ burning was assumed to be used with a wind speed of less than 25 knots; wave height of less than 3 feet, and current speed of less than 1 knot. Burning was assumed to occur >3 nm offshore and conducted at a rate of three 500-bbl/day burns daily. The minimum oil thickness assumed for ignition was 2

mm, which lowered 1 mm once burning started. All response alternatives were assumed to only occur during daylight hours (8am to 6pm).

Maps of the areas where response activities were assumed to occur are in Section B.4 of Volumes III, VI, IX, XII, XV, XVIII, XXI, and XXIV. Section E of these volumes contains a list of model inputs for the SIMAP physical fates model.

3.7 Biological Abundance

Wildlife species include aquatic birds, marine mammals and other mammals common in freshwater environments (e.g., muskrat, mink, beaver, otters). The model uses average number per unit area (#/km^2) in appropriate habitats. Section 2.2 describes the assignment of each species to a set of habitats that it uses. The species is assumed uniformly distributed across its preferred habitats. Thus, the habitat grid defines the habitat map, and so the abundance of each species.

Fish and invertebrates are also input as average density by species (or group) per unit area in assigned habitats. Fish and invertebrates abundance varies by landward open water, seaward open water, and structured habitat (i.e., wetlands, reefs, and macroalgal beds, Table 3-1). In the NRDAM/CME (French et al., 1996c), the abundances are for fished stocks and the biomass includes those animals greater than the age of recruitment to fishing. In the biological effects model the age/size distribution is computed from fishery modeling parameters (natural and fishing instantaneous mortality rates, length as a function of age, and weight-length relationships), such that the mortality is calculated for all age classes from age 1 year up (and assuming the various age classes live in the same habitat in that age structure).

Young-of-the-year mortality is quantified separately. The biological database includes number of age 1-year (365 day old) individuals per km^2. The young-of-the-year abundances in the NRDAM/CME (French et al., 1996c) were calculated from the spawning stock and life history information as to where those animals would live for each month of their first year of life. The numbers are those needed to recruit to the stock at age one year in order to maintain a stable population size. Thus, young-of-the-year mortality is for only those that would have survived their first year if not for the spill.

The NRDAM/CME (French et al., 1996c) contains mean seasonal or monthly abundances for 77 biological provinces in US coastal and marine waters. The biological data for wildlife, fish, invertebrates and lower trophic levels in the province of the spill are used for the SIMAP simulations in the lower Columbia River (province 48 in the NRDAM/CME), outer coast (province 49 in the NRDAM/CME) and Straits/Puget Sound (province 51 in the NRDAM/CME) areas.

The bird densities for NRDAM/CME province 49 were updated for common murre abundance using data from Thompson (1999), which surveyed marbled murrelets and common murres on the outer coast of Washington from the summer of 1997 to the winter

of 1998-1999. The wading bird and shorebird densities for the Straits/Puget Sound were from NRDAM/CME province 51. However, the winter densities for diving bird species were updated from NRDAM/CME province 51 using Nysewander et al. (2001).

For the upper Columbia River, biological data compiled by French et al. (1993a,b) were used. These data were compilations of typical fish and wildlife densities (by season) in Pacific Northwest Rivers and wetlands. Invertebrate impacts were assessed by evaluating lost production of lower trophic levels, as described in French et al. (1996a).

Tables 3-5 to 3-8 list the wildlife densities and Tables 3-9 to 3-17 list the fish and invertebrate densities in the four biological databases used. Production rates of lower trophic levels are described in French et al. (1996b).

Table 3-5. Wildlife densities assumed for the Strait of Juan de Fuca (seaward) and Puget Sound (landward), as seasonal means in number per km^2.

Species group	Winter	Spring	Summer	Fall
Black brant	2.0	6.1	0.0	0.7
Bufflehead	60.0	6.0	0.3	5.2
Common loon	0.8	0.03	0.1	1.8
Goldeneyes	15.0	0.3	0.0	3.0
Harlequin duck	13.0	0.5	0.3	0.4
Horned grebe	2.0	0.7	0.5	3.1
Loons, general	1.8	0.03	0.1	1.8
Mergansers, gen.	13.0	1.0	0.3	3.5
Red-necked grebe	0.5	0.4	0.5	1.2
Scaups	8.0	3.7	0.4	4.9
Scoters	35.0	28.1	4.2	19.0
Western grebe	2.0	4.1	0.8	11.6
Cormorants, general	7.0	1.3	2.7	3.8
Double-crested cormorant	2.0	0.7	1.0	1.3
Gulls, general	75.0	3.5	26.2	14.3
Marbled murrelet	0.2	0.4	1.0	0.9
Pigeon guillemot	0.7	2.7	2.2	1.0
Great blue heron	4.0	12.7	12.7	4.0
Black oystercatcher	0.0	0.2	0.2	0.0
Shorebirds, gen.	961.0	378.0	0.0	766.0
Bald eagle	0.1	0.2	0.2	0.02
Killer whales	0.01	0.01	0.01	0.01
Harbor seal	0.3	0.3	0.3	0.3
Sea lions, general	0.1	0.1	0.0	0.0
Group Totals:				
Waterfowl	153.1	50.8	7.5	56.2
Seabirds	84.9	8.6	33.0	21.2
Wading birds	4.0	12.7	12.7	4.0
Shorebirds	961.0	378.2	0.2	766.0
Raptors	0.1	0.2	0.2	0.0
Kingfishers	0.0	0.0	0.0	0.0
Cetaceans	0.0	0.0	0.0	0.0
Pinnipeds (seals)	0.3	0.3	0.3	0.3
Other mammals	0.0	0.0	0.0	0.0
Total all species	1203.4	450.8	53.9	847.6

Table 3-6. Wildlife densities assumed for the outer coast of Washington, as seasonal means in number per km^2.

Species group	Winter	Spring	Summer	Fall
Arctic loon	0.02	0.1	0.1	0.1
Dabblers, general	138.1	138.1	0.0	0.0
Diving ducks, gen.	3.7	3.7	0.0	0.0
Geese, general	13.4	13.4	0.0	0.0
Scoters	1.0	1.0	0.0	0.0
Trumpeter swan	0.1	0.0	0.0	0.0
Western grebe	0.04	0.02	0.10	0.01
Whistling swan	1.2	0.0	0.0	0.0
Alcids, general	6.8	3.9	5.7	7.1
Blackfoot. Albatross	0.0	0.1	0.1	0.0
Black-leg. kittiwake	0.7	0.01	0.003	0.2
California gull	0.2	0.01	0.5	0.1
Caspian tern	0.0	1.0	1.0	0.0
Cassin's auklet	1.8	0.5	2.0	2.8
Common murre	6.2	29.9	31.8	6.2
Cormorants, general	0.1	0.1	0.1	0.4
Forktail. Stormpet.	0.04	0.1	0.6	0.01
Glaucous-winged gull	0.3	0.2	0.4	0.7
Gulls, general	0.1	0.3	1.0	1.1
Herring gull	0.3	0.04	0.2	0.3
Leach's storm-petrel	0.0	0.004	0.01	0.0
Marbled murrelet	0.03	0.1	0.1	0.03
Northern fulmar	0.1	0.1	2.9	0.1
Parakeet auklet	0.01	0.2	0.2	0.01
Pinkfoot. Shearwater	0.0	0.05	0.3	0.02
Sooty shearwater	0.01	3.6	18.9	0.1
Western gull	0.1	0.3	0.6	0.01
Great blue heron	4.0	12.7	12.7	4.0
Black oystercatcher	0.0	0.7	0.7	0.0
Sandpipers, general	961.0	378.0	0.0	766.0
Kingfishers, general	1.6	2.6	2.6	1.6
Dall's porpoise	0.0	0.01	0.02	0.02
Gray whale	0.2	0.03	0.02	0.01
Harbor porpoise	1.4	1.4	1.4	1.4
Humpback whale	0.0	0.004	0.004	0.004
Killer whales	0.001	0.001	0.001	0.001
Risso's dolphin	0.0003	0.01	0.0003	0.004
California sea lion	0.01	0.003	0.001	0.01
Harbor seal	0.3	0.3	0.3	0.3
Northern fur seal	0.02	0.02	0.003	0.003

Species group	Winter	Spring	Summer	Fall
Northern sea lion	0.01	0.02	0.02	0.03
Sea otter	0.01	0.01	0.01	0.01
Group Totals:				
Waterfowl	157.6	156.3	0.2	0.1
Seabirds	16.7	40.4	66.4	19.2
Wading birds	4.0	12.7	12.7	4.0
Shorebirds	961.0	378.7	0.7	766.0
Raptors	0.0	0.0	0.0	0.0
Kingfishers	1.6	2.6	2.6	1.6
Cetaceans	1.7	1.5	1.5	1.5
Pinnipeds (seals)	0.3	0.3	0.3	0.3
Other mammals	0.0	0.0	0.0	0.0
Reptiles	0.0	0.0	0.0	0.0
Amphibians	0.0	0.0	0.0	0.0
Total all species	1142.9	592.6	84.4	792.7

Table 3-7. Wildlife densities assumed for the lower Columbia River, as seasonal means in number per km^2.

Species group	Winter	Spring	Summer	Fall
Diving ducks, gen.	769.0	425.0	637.0	442.0
Grebes, general	12.7	6.3	0.0	3.8
Loons, general	0.3	0.0	0.0	0.3
Alcids, general	0.1	0.1	0.1	0.1
Caspian tern	93.0	93.0	93.0	93.0
Cormorants, general	1.3	1.0	0.9	1.3
Glaucous-winged gull	9.3	9.3	9.3	9.3
Mew gull	400.0	193.0	0.0	193.0
Heron family, gen.	3.8	3.8	0.4	7.6
Shorebirds, general	961.0	378.0	0.0	766.0
Kingfishers, general	0.2	0.2	0.2	0.2
California sea lion	0.2	0.3	0.0	0.03
Harbor seal	3.4	3.4	3.4	3.4
Northern sea lion	0.1	0.0	0.0	0.01
Group Totals:				
Waterfowl	782.0	431.3	637.0	446.0
Seabirds	503.7	296.4	103.3	296.7
Wading birds	3.8	3.8	0.4	7.6
Shorebirds	961.0	378.0	0.0	766.0
Raptors	0.0	0.0	0.0	0.0
Kingfishers	0.2	0.2	0.2	0.2
Cetaceans	0.0	0.0	0.0	0.0
Pinnipeds (seals)	3.7	3.7	3.4	3.5
Other mammals	0.0	0.0	0.0	0.0
Reptiles	0.0	0.0	0.0	0.0
Amphibians	0.0	0.0	0.0	0.0
Total all species	2254.3	1113.5	744.3	1520.0

Table 3-8. Wildlife densities assumed for the upper Columbia River, as seasonal means in number per km^2. [lwd = landward, i.e., tributaries and bays; swd = seaward, i.e., main river; wetl = wetland]

Species group	Winter	Spring	Summer	Fall
American coot, lwd	0.0	7.3	0.0	7.3
American coot, wetl	0.0	7.3	0.0	7.3
American widgeon	0.0	1.6	0.0	1.6
Blue-winged teal	0.0	6.5	0.0	6.5
Bufflehead, lwd	0.0	0.02	0.0	0.02
Bufflehead, wetl	0.0	0.02	0.0	0.02
Canvasback, lwd	0.0	0.03	0.0	0.03
Canvasback, wetl	0.0	0.03	0.0	0.03
Common goldeneye, lwd	0.0	0.4	0.0	0.4
Common goldeneye, wetl	0.0	0.4	0.0	0.4
Coots, lwd	1.7	0.0	0.0	0.0
Coots, wetl	1.7	0.0	0.0	0.0
Dabbling ducks, wetl	59.2	0.0	0.0	0.0
Diving ducks, lwd	14.5	0.0	0.0	0.0
Diving ducks, wetl	14.5	0.0	0.0	0.0
Gadwall	0.0	1.3	0.0	1.3
Geese, lwd	7.1	0.0	0.0	0.0
Geese, wetl	7.1	0.0	0.0	0.0
Green-winged teal	0.0	1.1	0.0	1.1
Mallard	0.0	14.3	0.0	14.3
Merganser, lwd	0.0	0.04	0.0	0.04
Merganser, wetl	0.0	0.04	0.0	0.04
Northern pintail	0.0	1.3	0.0	1.3
Northern shoveler	0.0	1.3	0.0	1.3
Redhead, lwd	0.0	2.6	0.0	2.6
Redhead, wetl	0.0	2.6	0.0	2.6
Ring-necked duck, lwd	0.0	0.5	0.0	0.5
Ring-necked duck, wetl	0.0	0.5	0.0	0.5
Ruddy duck, lwd	0.0	1.9	0.0	1.9
Ruddy duck, wetl	0.0	1.9	0.0	1.9
Scaup, lwd	0.0	1.5	0.0	1.5
Scaup, wetl	0.0	1.5	0.0	1.5
Swans, wetl	0.5	0.0	0.0	0.0
White wing. scoter lwd	0.0	0.01	0.0	0.0
White wing. scoter wetl	0.0	0.01	0.0	0.0
Wood duck	0.0	1.7	0.0	0.0
Glaucous-wing gull lwd	4.1	4.1	4.1	4.1
Glaucous-wing gull swd	4.1	4.1	4.1	4.1
Glaucous-wing gull wetl	4.1	4.1	4.1	4.1

Species group	Winter	Spring	Summer	Fall
Ringbill-CA gull lwd	0.03	3.4	3.4	3.4
Ringbill-CA gull swd	0.03	3.4	3.4	3.4
Ringbill-CA gull wetl	0.03	3.4	3.4	3.4
Heron family, gen.	3.8	3.8	0.4	7.6
Shorebirds, general	961.0	378.0	0.0	766.0
Bald eagle, lwd	0.0	0.04	0.04	0.04
Bald eagle, wetl	0.0	0.04	0.04	0.04
Beaver	0.6	0.6	0.6	0.6
Mink	0.1	0.1	0.1	0.1
Muskrat	50.0	50.0	50.0	50.0
River otter	0.01	0.01	0.01	0.01
Group Totals:				
Waterfowl	106.1	57.7	0.0	55.9
Seabirds	12.4	22.6	22.6	22.6
Wading birds	3.8	3.8	0.4	7.6
Shorebirds	961.0	378.0	0.0	766.0
Raptors	0.0	0.1	0.1	0.1
Kingfishers	0.0	0.0	0.0	0.0
Cetaceans	0.0	0.0	0.0	0.0
Pinnipeds (seals)	0.0	0.0	0.0	0.0
Other mammals	50.7	50.7	50.7	50.7
Reptiles	0.0	0.0	0.0	0.0
Amphibians	0.0	0.0	0.0	0.0
Total all species	1133.9	512.8	73.7	902.9

Table 3-9. Fish and invertebrate densities (kg/km^2) assumed for the Strait of Juan de Fuca (seaward) and Puget Sound (landward), as seasonal mean by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Pacific herring	Seaward Open Water	1608.0	1608.0	1608.0	1608.0
	Landward Open Water	1608.0	1608.0	1608.0	1608.0
	Wetland and Seagrass	1608.0	1608.0	1608.0	1608.0
Smelts, general	Seaward Open Water	3.3	3.3	3.3	3.3
	Landward Open Water	3.3	3.3	3.3	3.3
	Wetland and Seagrass	3.3	3.3	3.3	3.3
Chinook	Seaward Open Water	0.0	0.0	153.0	1.5
	Landward Open Water	0.0	0.0	153.0	1.5
	Wetland and Seagrass	0.0	0.0	153.0	1.5
Chum = keta salmon	Seaward Open Water	0.0	0.0	331.0	9.8
	Landward Open Water	0.0	0.0	331.0	9.8
	Wetland and Seagrass	0.0	0.0	331.0	9.8
Coho	Seaward Open Water	0.0	0.0	268.0	2.7
	Landward Open Water	0.0	0.0	268.0	2.7
	Wetland and Seagrass	0.0	0.0	268.0	2.7
Pink salmon	Seaward Open Water	0.0	0.0	487.0	14.4
	Landward Open Water	0.0	0.0	487.0	14.4
	Wetland and Seagrass	0.0	0.0	487.0	14.4
Sockeye	Seaward Open Water	0.0	0.0	914.0	27.1
	Landward Open Water	0.0	0.0	914.0	27.1
	Wetland and Seagrass	0.0	0.0	914.0	27.1
Dogfish, general	Seaward Open Water	1485.0	1485.0	1485.0	1485.0
	Landward Open Water	148.5	148.5	148.5	148.5
	Wetland and Seagrass	148.5	148.5	148.5	148.5
Lingcod	Seaward Open Water	122.6	122.6	122.6	122.6
	Landward Open Water	122.6	122.6	122.6	122.6
	Wetland and Seagrass	122.6	122.6	122.6	122.6
Pacific cod	Seaward Open Water	114.8	114.8	114.8	114.8
	Landward Open Water	114.8	114.8	114.8	114.8
	Wetland and Seagrass	114.8	114.8	114.8	114.8
Pacific halibut	Seaward Open Water	0.0	13.2	13.2	13.2
	Landward Open Water	0.0	13.2	13.2	13.2
	Wetland and Seagrass	0.0	13.2	13.2	13.2
Rockfish, scorpionfish	Seaward Open Water	161.2	161.2	161.2	161.2
	Landward Open Water	161.2	161.2	161.2	161.2
	Wetland and Seagrass	161.2	161.2	161.2	161.2
Walleye pollock	Seaward Open Water	147.0	147.0	147.0	147.0
	Landward Open Water	147.0	147.0	147.0	147.0
	Wetland and Seagrass	147.0	147.0	147.0	147.0
Flatfish	Seaward Open Water	537.6	537.6	537.6	537.6
	Landward Open Water	537.6	537.6	537.6	537.6
	Wetland and Seagrass	537.6	537.6	537.6	537.6
Midshipman	Seaward Open Water	0.7	0.7	0.7	0.7

Species group	Habitat	Winter	Spring	Summer	Fall
	Landward Open Water	0.7	0.7	0.7	0.7
	Wetland and Seagrass	0.7	0.7	0.7	0.7
Surfperches	Seaward Open Water	18.5	18.5	18.5	18.5
	Landward Open Water	18.5	18.5	18.5	18.5
	Wetland and Seagrass	18.5	18.5	18.5	18.5
Dungeness crab	Landward Open Water	450.0	450.0	450.0	450.0
Northern pink shrimp	Seaward Open Water	1.0	1.0	1.0	1.0
Geoduck	Seaward Open Water	164000.0	164000.0	164000.0	164000.0
	Landward Open Water	164000.0	164000.0	164000.0	164000.0
Hard clams, general	Landward Open Water	7400.0	7400.0	7400.0	7400.0
Pacific oyster	Seaward Reef	109000.0	109000.0	109000.0	109000.0
	Landward Reef	109000.0	109000.0	109000.0	109000.0
Softshell clams	Landward Open Water	1037.0	1037.0	1037.0	1037.0
Sea urchins	Seaward Open Water	117.0	117.0	117.0	117.0
	Landward Open Water	117.0	117.0	117.0	117.0
Total all species	Seaward Open Water	168316.7	168329.9	170482.9	168385.4
	Landward Open Water	175866.2	175879.4	178032.4	175934.9
	Wetland and Seagrass	2862.2	2875.4	5028.4	2930.9

Table 3-10. Fish and invertebrate densities (kg/km^2) assumed for the outer coast of Washington, as seasonal mean by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Longfin smelt	Landward Open Water	241.0	241.0	241.0	241.0
	Wetland and Seagrass	241.0	241.0	241.0	241.0
Pacific = N. anchovy	Seaward Open Water	3509.0	3509.0	3509.0	3509.0
Pacific herring	Landward Open Water	11381.0	0.0	0.0	0.0
	Wetland and Seagrass	11381.0	0.0	0.0	0.0
Chinook	Landward Open Water	0.0	0.0	0.0	24.8
	Wetland and Seagrass	0.0	0.0	0.0	24.8
Coho	Landward Open Water	0.0	0.0	0.0	45.3
	Wetland and Seagrass	0.0	0.0	0.0	45.3
Sockeye	Landward Open Water	0.0	0.0	0.0	3.2
	Wetland and Seagrass	0.0	0.0	0.0	3.2
Pacific tomcod	Landward Open Water	291.0	291.0	291.0	291.0
	Wetland and Seagrass	291.0	291.0	291.0	291.0
English sole	Landward Open Water	156.1	156.1	156.1	156.1
	Wetland and Seagrass	156.1	156.1	156.1	156.1
Surfperches	Landward Open Water	260.0	260.0	260.0	260.0
	Wetland and Seagrass	260.0	260.0	260.0	260.0
Dungeness crab	Landward Open Water	527.0	527.0	527.0	527.0
Market squid	Landward Open Water	13000.0	13000.0	13000.0	13000.0
Hard clams, general	Landward Open Water	7400.0	7400.0	7400.0	7400.0
Pacific razor clam	Landward Open Water	1893.0	1893.0	1893.0	1893.0
Softshell clams	Landward Open Water	1037.0	1037.0	1037.0	1037.0
Sea urchins	Landward Open Water	704.0	704.0	704.0	704.0
Total all species	Seaward Open Water	3509.0	3509.0	3509.0	3509.0
	Landward Open Water	36890.1	25509.1	25509.1	25582.4
	Wetland and Seagrass	12329.1	948.1	948.1	1021.4

Table 3-11. Fish and invertebrate densities (kg/km^2) assumed for the lower Columbia River, as seasonal mean by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Eulachon	Seaward Open Water	1793.0	1793.0	1793.0	1793.0
	Landward Open Water	1793.0	1793.0	1793.0	1793.0
	Wetland and Seagrass	1793.0	1793.0	1793.0	1793.0
Pacific herring	Seaward Open Water	11381.0	0.0	0.0	0.0
	Landward Open Water	11381.0	0.0	0.0	0.0
	Wetland and Seagrass	11381.0	0.0	0.0	0.0
Chinook	Seaward Open Water	0.0	0.0	0.0	34.4
	Landward Open Water	0.0	0.0	0.0	34.4
	Wetland and Seagrass	0.0	0.0	0.0	34.4
Coho	Seaward Open Water	0.0	0.0	0.0	20.3
	Landward Open Water	0.0	0.0	0.0	20.3
	Wetland and Seagrass	0.0	0.0	0.0	20.3
Rockfish, scorpion fish	Seaward Open Water	0.4	0.4	0.4	0.4
	Landward Open Water	0.4	0.4	0.4	0.4
	Wetland and Seagrass	0.4	0.4	0.4	0.4
Flatfish	Seaward Open Water	70.9	70.9	70.9	70.9
	Landward Open Water	70.9	70.9	70.9	70.9
	Wetland and Seagrass	70.9	70.9	70.9	70.9
Razor clam	Seaward Open Water	884.0	884.0	884.0	884.0
	Landward Open Water	884.0	884.0	884.0	884.0
	Wetland and Seagrass	884.0	884.0	884.0	884.0
Softshell clams	Seaward Open Water	1037.0	1037.0	1037.0	1037.0
	Landward Open Water	1037.0	1037.0	1037.0	1037.0
Total all species	Seaward Open Water	15166.3	3785.3	3785.3	3840.0
	Landward Open Water	15166.3	3785.3	3785.3	3840.0
	Wetland and Seagrass	14129.3	2748.3	2748.3	2803.0

Table 3-12. Fish and invertebrate densities (kg/km^2) assumed for the upper Columbia River, as seasonal mean by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
American shad	Seaward Open Water	1663.0	1663.0	1663.0	1663.0
Longfin smelt	Swd Wetland/Seagrass	994.0	994.0	994.0	994.0
Chinook	Seaward Open Water	2286.0	2286.0	2286.0	2286.0
	Landward Open Water	0.0	0.0	0.0	34.4
	Wetland and Seagrass	0.0	0.0	0.0	34.4
Chum = keta salmon	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Coho	Seaward Open Water	1030.0	1030.0	1030.0	1030.0
	Landward Open Water	0.0	0.0	0.0	20.3
	Wetland and Seagrass	0.0	0.0	0.0	20.3
Sockeye salmon	Seaward Open Water	255.0	255.0	255.0	255.0
Walleye	Seaward Open Water	424.0	424.0	424.0	424.0
	Wetland and Seagrass	847.0	847.0	847.0	847.0
Brown trout	Seaward Open Water	520.0	520.0	520.0	520.0
Cutthroat trout	Seaward Open Water	420.0	420.0	420.0	420.0
Dolly vardon	Seaward Open Water	2483.0	2483.0	2483.0	2483.0
Rainbow trout	Seaward Open Water	404.0	404.0	404.0	404.0
Black bullhead	Seaward Open Water	50.0	50.0	50.0	50.0
Black crappie	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Bluegill	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Bridgelip sucker	Seaward Open Water	9254.0	9254.0	9254.0	9254.0
Brown bullhead	Seaward Open Water	803.0	803.0	803.0	803.0
	Landward Open Water	803.0	803.0	803.0	803.0
	Wetland and Seagrass	1606.0	1606.0	1606.0	1606.0
Carp	Landward Open Water	268.0	268.0	268.0	268.0
	Wetland and Seagrass	535.0	535.0	535.0	535.0
Channel catfish	Seaward Open Water	3189.0	3189.0	3189.0	3189.0
	Landward Open Water	3189.0	3189.0	3189.0	3189.0
	Wetland and Seagrass	6378.0	6378.0	6378.0	6378.0
Green sunfish	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Largemouth bass	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Longnose sucker	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Mountain sucker	Seaward Open Water	9254.0	9254.0	9254.0	9254.0
	Landward Open Water	9254.0	9254.0	9254.0	9254.0
Mountain whitefish	Seaward Open Water	7752.0	7752.0	7752.0	7752.0

Species group	Habitat	Winter	Spring	Summer	Fall
	Wetland and Seagrass	89.0	89.0	89.0	89.0
Pumpkinseed	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Smallmouth bass	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Swd Wetland/Seagrass	18505.0	18505.0	18505.0	18505.0
White crappie	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
White sturgeon	Seaward Open Water	50.0	50.0	50.0	50.0
Yellow perch	Landward Open Water	2252.0	2252.0	2252.0	2252.0
	Wetland and Seagrass	4504.0	4504.0	4504.0	4504.0
Razor clam	Seaward Open Water	884.0	884.0	884.0	884.0
	Landward Open Water	884.0	884.0	884.0	884.0
	Wetland and Seagrass	884.0	884.0	884.0	884.0
Softshell clams	Seaward Open Water	1037.0	1037.0	1037.0	1037.0
	Landward Open Water	1037.0	1037.0	1037.0	1037.0
Total all species	Seaward Open Water	111184.0	111184.0	111184.0	111184.0
	Landward Open Water	17687.0	17687.0	17687.0	17741.7
	Wetland and Seagrass	182382.0	182382.0	182382.0	182436.7

Table 3-13. Fish and invertebrate taxonomic grouping used in modeling.

Code	Taxonomic group	Group - Injury Summary
1	small pelagic fish	small pelagic fish
2	lg pelagic fish	lg pelagic fish[1]
3	semi demersal	lg pelagic fish[1]
4	demersal fish	demersal fish
5	crustaceans	crustaceans
6	squid	lg pelagic fish[1]
7	mollusks = bivalves mostly	mollusks = bivalves mostly
8	other invertebrates	other invertebrates

[1]*Note that semi-demersal fish and squid have been combined with large pelagic fish.*

Table 3-14. Fish and invertebrate taxa codes for species in Strait of Juan de Fuca and Puget Sound.

Species	Taxa #
Chum = keta salmon	2
Dogfish, general	3
Dungeness crab	5
Flatfish	4
Geoduck	7
Hard clams, general	7
Pacific cod	3
Pacific halibut	3
Pacific herring	1
Pacific oyster	7
Pink salmon	2
Rockfish, scorpion fish	3
Sea urchins	8
Softshell clams	7
Walleye pollock	3

Table 3-15. Fish and invertebrate taxa codes for species for the outer coast of Washington.

Species	Taxa #
Chinook	2
Chum = keta salmon	2
Coho	2
Dogfish, general	3
Dungeness crab	5
English sole	4
Flatfish	4
Hard clams, general	7
Longfin smelt	1
Market squid	6
Pacific = N. anchovy	1
Pacific cod	3
Pacific halibut	3
Pacific herring	1
Pacific ocean perch	3
Pacific oyster	7
Pacific razor clam	7
Pacific tomcod	3
Pink salmon	2
Rockfish, scorpionfish	3
Sablefish	3
Sea urchins	8
Sockeye	2
Softshell clams	7
Surfperches	4
Walleye pollock	3

Table 3-16. Fish and invertebrate taxa codes for species for the lower Columbia River.

Species	Taxa #
Chinook	2
Coho	2
Eulachon	1
Flatfish	4
Pacific herring	1
Razor clam	7
Rockfish, scorpion fish	3
Softshell clams	7

Table 3-17. Fish and invertebrate taxa codes for species for the upper Columbia River.

Species	Taxa #
American shad	1
Black bullhead	4
Black crappie	4
Bluegill	4
Bridgelip sucker	4
Brown bullhead	4
Brown trout	3
Carp	4
Channel catfish	4
Chinook	2
Chum = keta salmon	2
Coho	2
Cutthroat trout	3
Dolly vardon	3
Green sunfish	4
Largemouth bass	4
Longfin smelt	1
Longnose sucker	4
Mountain sucker	4
Mountain whitefish	4
Pumpkinseed	4
Rainbow trout	3
Razor clam	7
Smallmouth bass	4
Sockeye salmon	2
Softshell clams	7
Walleye	2
White crappie	4
White sturgeon	4
Yellow perch	4

Table 3-18. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the Strait of Juan de Fuca (seaward) and Puget Sound (landward), as seasonal means by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Pacific herring	Seaward Open Water	9039.7	9039.8	9040.0	9040.0
	Landward Open Water	9039.7	9039.8	9040.0	9040.0
	Wetland and Seagrass	9039.7	9039.8	9040.0	9040.0
Chum = keta salmon	Seaward Open Water	620.6	706.8	1944.0	1944.0
	Landward Open Water	620.6	706.8	1944.0	1944.0
	Wetland and Seagrass	620.6	706.8	1944.0	1944.0
Pink salmon	Landward Open Water	2244.0	14303.7	0.0	0.0
Dogfish, general	Seaward Open Water	9291.0	9291.0	9291.0	9291.0
	Landward Open Water	9291.0	9291.0	9291.0	9291.0
	Wetland and Seagrass	9291.0	9291.0	9291.0	9291.0
Pacific cod	Seaward Open Water	170.3	170.3	170.3	170.3
	Landward Open Water	170.3	170.3	170.3	170.3
	Wetland and Seagrass	170.3	170.3	170.3	170.3
Pacific halibut	Seaward Open Water	1.0	1.0	1.0	1.0
	Landward Open Water	1.0	1.0	1.0	1.0
	Wetland and Seagrass	1.0	1.0	1.0	1.0
Rockfish, scorpion fish	Seaward Open Water	26.1	26.1	26.1	26.1
	Landward Open Water	26.1	26.1	26.1	26.1
	Wetland and Seagrass	26.1	26.1	26.1	26.1
Walleye pollock	Seaward Open Water	201.4	201.4	201.4	201.4
	Landward Open Water	201.4	201.4	201.4	201.4
	Wetland and Seagrass	201.4	201.4	201.4	201.4
Flatfish	Seaward Open Water	0.3	0.3	0.3	0.3
	Landward Open Water	0.3	0.3	0.3	0.3
	Wetland and Seagrass	0.3	0.3	0.3	0.3
Dungeness crab	Landward Open Water	580.5	580.4	580.4	580.4
Geoduck	Seaward Open Water	4239.1	4238.8	4238.5	4239.0
	Landward Open Water	4239.1	4238.8	4238.5	4239.0
	Wetland and Seagrass	4239.1	4238.8	4238.5	4239.0
Hard clams, general	Landward Open Water	192102.3	192086.7	192081.2	192100.0
Pacific oyster	Landward Open Water	0.0	14846.7	70320.0	8316.7
Softshell clams	Landward Open Water	18750.3	18749.7	18748.6	18750.0
Sea urchins	Seaward Open Water	140.5	140.6	140.5	140.5
	Landward Open Water	140.5	140.6	140.5	140.5
	Wetland and Seagrass	140.5	140.6	140.5	140.5
Total all species	Seaward Open Water	23730.0	23815.9	25053.1	25053.6
	Landward Open Water	237407.1	264383.0	306783.4	244800.7
	Wetland and Seagrass	23730.0	23815.9	25053.1	25053.6

Table 3-19. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the outer coast of Washington, as seasonal means by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Longfin smelt	Landward Open Water	1868.90	1868.90	1869.00	1869.00
Pacific = N. anchovy	Seaward Open Water	169700.00	169700.00	169700.00	169700.00
	Landward Open Water	169700.00	169700.00	169700.00	169700.00
	Wetland/Seagrass	169700.00	169700.00	169700.00	169700.00
Pacific herring	Landward Open Water	123686.66	123683.34	123700.00	123700.00
Chum = keta salmon	Seaward Open Water	620.60	0.00	749.16	1944.00
	Landward Open Water	0.00	35898.60	61796.67	0.00
Pink salmon	Landward Open Water	15453.33	98536.66	0.00	0.00
Dogfish, general	Seaward Open Water	830.10	830.10	830.10	830.10
Pacific cod	Seaward Open Water	231.80	231.80	231.80	231.80
Pacific halibut	Seaward Open Water	1.02	1.02	1.02	1.02
Pacific ocean perch	Seaward Open Water	65.26	65.26	65.26	65.26
	Landward Open Water	65.26	65.26	65.26	65.26
	Wetland/Seagrass	65.26	65.26	65.26	65.26
Rockfish, scorpionfish	Seaward Open Water	590.80	590.80	590.80	590.80
	Landward Open Water	590.80	590.80	590.80	590.80
	Wetland/Seagrass	590.80	590.80	590.80	590.80
Sablefish	Seaward Open Water	619.10	619.10	619.10	619.10
Walleye pollock	Seaward Open Water	184.90	184.90	184.90	184.90
Flatfish	Seaward Open Water	0.19	0.19	0.19	0.19
	Landward Open Water	0.19	0.19	0.19	0.19
	Wetland/Seagrass	0.19	0.19	0.19	0.19
Dungeness crab	Seaward Open Water	337.60	326.53	0.00	0.00
	Landward Open Water	17747.27	18319.33	35211.33	35210.00
	Wetland/Seagrass	337.60	326.53	0.00	0.00
Hard clams, general	Landward Open Water	192102.33	192086.67	192081.23	192100.00
Pacific oyster	Landward Open Water	0.00	27366.67	129600.00	15333.33
Softshell clams	Landward Open Water	18750.33	18749.67	18748.58	18750.00
Sea urchins	Seaward Open Water	891.87	891.90	891.89	891.90
	Landward Open Water	891.87	891.90	891.89	891.90
	Wetland/Seagrass	891.87	891.90	891.89	891.90
Total all species	Seaward Open Water	174073.22	173441.59	173864.19	175059.06
	Landward Open Water	540856.88	687758.00	734255.00	558210.44
	Wetland/Seagrass	171585.70	171574.69	171248.12	171248.14

Table 3-20. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the lower Columbia River, as seasonal means by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Pacific herring	Seaward Open Water	63980.00	63980.34	63980.00	63980.00
	Landward Open Water	63980.00	63980.34	63980.00	63980.00
	Wetland/Seagrass	63980.00	63980.34	63980.00	63980.00
Rockfish, scorpionfish	Seaward Open Water	0.06	0.06	0.06	0.06
	Landward Open Water	0.06	0.06	0.06	0.06
	Wetland/Seagrass	0.06	0.06	0.06	0.06
Flatfish	Seaward Open Water	0.04	0.04	0.04	0.04
	Landward Open Water	0.04	0.04	0.04	0.04
	Wetland/Seagrass	0.04	0.04	0.04	0.04
Softshell clams	Landward Open Water	18750.33	18749.67	18748.58	18750.00
Total all species	Seaward Open Water	63980.11	63980.44	63980.11	63980.11
	Landward Open Water	82730.43	82730.10	82728.69	82730.10
	Wetland/Seagrass	63980.11	63980.44	63980.11	63980.11

Table 3-21. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the upper Columbia River, as seasonal means by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
American shad	Seaward Open Water	469.00	469.17	468.83	469.00
Longfin smelt	Wetland/Seagrass	133263.33	133000.00	133000.00	133000.00
Chinook	Seaward Open Water	181.00	181.00	180.50	180.80
Chum = keta salmon	Seaward Open Water	298.35	298.80	299.00	298.83
Coho	Seaward Open Water	106.03	106.00	106.03	106.00
Sockeye salmon	Seaward Open Water	2.67	2.67	2.67	2.67
Walleye	Seaward Open Water	421.00	420.57	421.00	421.00
	Wetland/Seagrass	841.00	840.33	841.00	841.00
Brown trout	Seaward Open Water	1092.77	1091.00	1090.00	1092.67
Cutthroat trout	Seaward Open Water	2570.00	4825.67	2480.00	2480.00
Dolly vardon	Seaward Open Water	6441.90	6440.00	6439.67	6440.27
Rainbow trout	Seaward Open Water	805.97	806.00	805.87	806.00
Black bullhead	Seaward Open Water	9300.00	9300.00	9300.00	9300.00
Black crappie	Seaward Open Water	298.35	298.80	299.00	298.83
Bluegill	Seaward Open Water	298.35	298.80	299.00	298.83
Bridgelip sucker	Seaward Open Water	808000.00	12262277.00	813500.00	808000.00
Brown bullhead	Seaward Open Water	9300.00	9300.00	9300.00	9300.00
	Landward Open Water	9190.00	9190.00	9190.00	9190.00
	Wetland/Seagrass	18400.00	18400.00	18400.00	18400.00
Carp	Landward Open Water	32.29	32.29	32.30	32.30
	Wetland/Seagrass	64.41	64.46	64.40	64.40
Channel catfish	Seaward Open Water	9300.00	9300.00	9300.00	9300.00
	Landward Open Water	9190.00	9190.00	9190.00	9190.00
	Wetland/Seagrass	18400.00	18400.00	18400.00	18400.00
Green sunfish	Seaward Open Water	298.35	298.80	299.00	298.83
Largemouth bass	Seaward Open Water	298.35	298.80	299.00	298.83
Longnose sucker	Seaward Open Water	808000.00	12262277.00	813500.00	808000.00
	Wetland/Seagrass	570000.00	561250.00	570200.00	570000.00
Mountain sucker	Seaward Open Water	808000.00	12262277.00	813500.00	808000.00
	Landward Open Water	285000.00	284966.66	285033.31	285000.00
Mountain whitefish	Seaward Open Water	36800.00	36800.00	36800.00	36813.33
	Wetland/Seagrass	419.83	420.00	420.00	251.07
Pumpkinseed	Seaward Open Water	298.35	298.80	299.00	298.83
Smallmouth bass	Seaward Open Water	298.35	298.80	299.00	298.83
White crappie	Seaward Open Water	298.35	298.80	299.00	298.83
White sturgeon	Seaward Open Water	36800.00	36800.00	36800.00	36813.33
Yellow perch	Landward Open Water	11800.00	11800.00	11800.00	11800.00
	Landward Reef	23600.00	23586.67	23600.00	23600.00
Softshell clams	Landward Open Water	18750.33	18749.67	18748.58	18750.00
Total all species	Seaward Open Water	2539976.25	36905076.00	2556387.00	2539915.00
	Landward Open Water	333962.62	333928.59	333994.22	333962.31
	Wetland/Seagrass	764988.56	755961.44	764925.38	764556.38

Table 3-22. Intertidal invertebrate densities (kg/km^2) by location.

Location	NRDAM/CME Province	Species	kg/km^2
Outer Coast	49	Hard Clams	7400
		Soft Shell Clams	1,037
		Pacific Razor Clam	1,893
		Total Clams	10,330
Straits and Puget Sound	51	Geoduck	164,000
		Hard Clams	7,400
		Soft Shell Clams	1,037
		Total Clams	172,437
Lower Columbia R	48	Soft Shell Clams	1,037
		Pacific Razor Clam	884
		Total Clams	1,921
Upper Columbia R	Inland	Total Clams	-

4. OIL FATES MODEL RESULTS

4.1 Explanation of Model Outputs

4.1.1 Stochastic Output to Estimate Probabilities and Degrees of Exposure

The model evaluates the oil mass per unit area and concentration over time after the spill, recording the maximum exposure and time first exposed in each grid cell. The probability of exposure and area exposed over threshold thicknesses are calculated from these data. Exposure measures and thresholds used to evaluate the probabilities of oil reaching each grid cell in the model domain were:

- Surface slick or floating oil: $\geq$ 0.01 g/m^2 (average thickness $\geq$ 0.01 micron)
- Shoreline: average mass loading over the shore segment (length of one grid cell times typical width for the habitat type) $\geq$ 0.01 g/m^2
- Dissolved aromatics: average over the water cell $\geq$ 1 ppb (1 mg/m^3)
- Subsurface oil (entrained in water): average over the water cell $\geq$ 10 ppb (10 mg/m^3)
- Sediment total hydrocarbons: average over the cell $\geq$ 0.0001 g/ m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)
- Sediment dissolved aromatic concentrations: average over the cell $\geq$ 0.0001 g/ m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10 cm)

Section B of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV contains maps for each of the 13 main stochastic scenarios of the following statistics:

- Probability of exposure greater than the threshold listed above (probability that the threshold thickness or concentration will be exceeded at each location at any time following the spill). For surface oil, the model records if any oil of greater than that thickness (0.01 μm) passes through the grid cell, regardless of the area coverage of the oil. For concentrations, the average concentration in the grid cell is used to determine if the threshold is exceeded. *Note that the thresholds used for the water concentration and sediment plots are very conservative and much lower than thresholds for potential impacts. These figures indicate the fate of contamination.*
- Time (hours) to first exceedance of the threshold at each location
- Maximum exposure (thickness, volume or concentration) at any time after the spill, at a given location (peak exposure at each location delineated by the grid cells). The amounts are averaged over the area of the model grid cell.
    - Worst case maximum exposure for all releases evaluated (i.e., maximum peak exposure for all the model runs). This is calculated in two steps: (1) For each individual run (for each spill date run), the maximum amount over all time after the spill is saved for each location in the model grid. (2) The runs are evaluated to determine the highest amount at each location. Note that these worst case maximum amounts are not additive over all locations. These represent estimated maximum possible amounts of fuel that could ever reach each site (grid cell), considered individually. The probability of the worst

case amount is (n-1)/n, where n is the number of model runs performed. Thus, it is the most adverse of all the runs examined.

- Mean expected maximum exposure for all releases evaluated (i.e., mean peak exposure of all model runs). This is calculated in two steps: (1) For each individual run (for each spill date run), the maximum amount over all time after the spill is saved for each location in the model grid. (2) The runs are evaluated to determine the mean expected peak exposure (mean amount for all runs) at each location. Note that these mean expected maximum amounts are not additive over all locations. These represent the mean of many different runs, affecting different sites to maximum extent at different times after the spill.

Note that these maps are the maximum exposure at any time after the spill. The time of exposure may be as short as 1 hour. In addition, the plots are composites of results for multiple runs for varying spill dates and times. These results may be used to determine what the highest possible exposure is at any time after a spill. The "worst case" is the most adverse case of the runs that were made. As 100 runs were made, the most adverse is the 99th percentile case. The "worst case" would have a likelihood of 1% for spills of the simulated size, i.e., 1% of spills would have more adverse impacts and 99% of spills would have less impact.

Floating oil is mapped in g/m^2, where 1 g/m^2 ~ 1 micron thick oil. Table 4-1 gives approximate thickness ranges for surface oil of varying appearance. Dull brown sheens are about 1000 mg/m^2 thick. Rainbow sheen is about 200-800 mg/m^2 and silver sheens are 50-800 mg/m^2 thick (NRC, 1985). Crude and heavy (Bunker C) fuel oil > 1mm thick appears as black oil. Light fuels and diesel > 1mm thick are not black in appearance, but appear brown or reddish. Floating oil will not always have these appearances, however, as weathered oil would be in the form of scattered floating tar balls and tar mats where currents converge.

Table 4-1. Oil thickness (microns ~ g/m^2) and appearance on water (NRC, 1985).

Minimum	Maximum	Appearance
0.05	0.2	Colorless and silver sheen
0.2	0.8	Rainbow sheen
1	4	Dull brown sheen
10	100	Dark brown sheen
1000	10000	Black oil

The thresholds for potential biological effects were discussed in Section 3.4.3. For surface floating oil, the threshold is 10 g/m^2 (about 10 microns thick). For shoreline oil, the threshold is 100 g/m^2 (about 100 microns thick). Since the exposures for dissolved aromatics are primarily to PAHs for hours to days, the threshold of concern would be that for acute effects of short exposures (for the most sensitive species) of about 10 ppb. For

gasoline the threshold for potential effects would be 120 ppb. Exposures of < 1ppb would not be expected to have effects under any circumstances.

4.1.2 Summary of Exposure for the Sampled Range of Environmental Conditions

Tabular model output for a scenario were saved for the following matrix:

- For each model run (i.e., for each of the runs in a scenario)
- For each resource (habitat or shore) type
- For each exposure level over 6 order-of-magnitude intervals (i.e., if H = threshold used in the modeling: 1H-10H, 10H-100H, 100H-1000H, 1000H-10000H, 10000H-100000H, >100000H)

The following impact measures were calculated and saved for each combination of the above matrix for maximum extent (m^2) of contamination (where exposure level = peak exposure of each grid cell at any time after the spill):

- Water surface oiling (area) for each exposure level (mass/area or thickness)
- Shoreline oiling (area or length) for each exposure level (mass/area or thickness)
- Dissolved aromatic contamination in water: peak exposure (area) for each exposure level (concentration)
- Subsurface oil (total hydrocarbon) contamination in water: peak exposure (area) for each exposure level (concentration)
- Sediment total hydrocarbons: (area) for each exposure level (mass/area or concentration)
- Sediment dissolved aromatic: (area) for each exposure level (concentration)

Total dosage measures were also calculated for each model run for contamination that changes rapidly in time:

- Water surface oiling: Oil mass per unit area times time present (mass per area - time) for each run and by dosage level ($g\text{-}m^{-2}\text{-}hrs$)
- Dissolved aromatic contamination in water: Water area (entire water column) exposed at each dosage level (concentration-time, i.e., ppb-hrs)
- Total hydrocarbon contamination in water: Water area (entire water column) exposed at each dosage level (concentration-time, i.e., ppb-hrs)

The tabular results for each oil constituent (water surface, shoreline, etc.) and resource (habitat or shore) type are analyzed over all 100 runs of the main stochastic scenarios to determine the 5th, 50th and 95th percentile conditions (using the above impact measures) expected for that scenario. The runs producing the 5th, 50th and 95th percentile result for shoreline impact as indexed by shoreline cleanup cost were identified for further impact analysis. As noted above, the cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are used) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Therefore, total costs related to a spill are for the most part related to shoreline oiling.

Note that the same model run is not the 5th, 50th and 95th percentile case for water surface, shoreline, and water column impacts. In fact, when shoreline impacts are highest, water column impacts tend to be relatively low, and *visa versa*. The impact measures from the stochastic modeling provide a quantitative method for determining which runs are the 5th, 50th and 95th percentile cases for the resource of interest.

Birds and other wildlife are impacted in proportion to the water and shoreline surface area oiled above a threshold thickness for effects. Shoreline habitat impacts are proportional to surface area oiled above a threshold thickness for effects. Impacts to fish and invertebrates in the water and on the sediments are related to water column and sediment pore water concentrations of dissolved aromatics.

Contamination in the water column changes rapidly in space and time, such that a dosage measure as the product of concentration and time is a more appropriate index of impacts than simply peak concentration. As described above, toxicity to aquatic organisms increases with time of exposure, such that organisms may be unaffected by brief exposures to the same concentration that is lethal at long times of exposure. Toxicity data indicate that the 96-hour LC50 (which may serve as an acute lethal threshold) for dissolved aromatics (primarily PAHs) averages about 50 μg/l (ppb). Thus, this exposure dosage is 5,000 ppb-hours. The threshold for chronic and tainting effects is (for sensitive species) about 1% of the LC50, or 0.5 ppb (50 ppb-hours). Contamination in sediments remains longer than 100 hours, such that the use of 50 ppb for acute impacts, and 0.5 ppb for chronic effects, is appropriate as an index. The maps of fates model outputs in the accompanying volumes indicate the spatial distribution of where impacts could potentially occur. However, the biological exposure model, which considers duration of exposure, was used to evaluate the actual expected impacts of the spill scenarios examined.

Recreational, tourism, boating/shipping, and other socioeconomic impacts are functionally related to the length of shore and area of water oiled. Cleanup costs are related to volume spilled, portion remaining on the water surface, and area (or length) of shore oiled. Response costs and socioeconomic damages were evaluated in a companion study by D. S. Etkin (Environmental Research Consulting) using the model outputs.

The histograms in Section C of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV show the distribution of model results for all 100 runs within a stochastic scenario, indicating the range of possible impacts depending on the weather conditions and currents at the time of the spill. The following impact indices are plotted as rank order distributions:

- Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 (which is sheen) times duration of exposure (in m^2-hrs)
- Shoreline area (m^2) exposed to hydrocarbons of various threshold thicknesses (>0.01, 1, 10, 100, and 1000 g/m^2)
- Water volume exposed to > 1 ppb (>1 mg/m^3) of dissolved aromatic concentration at some time after the spill

- Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill
- Percent of spilled hydrocarbon mass eventually going ashore
- Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats)
- Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill, and
- Percent of spilled hydrocarbon mass removed mechanically an by in situ burning (ISB, if applicable).

In most cases, there is a smooth frequency distribution about the median case. However, occasionally extreme events occur, i.e., the weather conditions are just right to cause the most impact. These figures indicate the median and distribution of impact indices, including the degree of variability and likelihood of extreme events.

Section D of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV contains summary tables for the main stochastic scenarios of shoreline areas exposed above a range of threshold levels. The results are provided by shore type and for all shorelines. These data were used in the calculations of shoreline cleanup costs (by D. S. Etkin, Environmental Research Consulting).

4.1.3 Exposure Results for Individual Runs

Section E of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV contains summary graphics for individual model runs for each of the main stochastic scenarios: the 5th, 50th and 95th percentile run based on shoreline costs. Maps for the alternate response scenarios are in Section B of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, and XXVI. Maps are presented of the following measures of exposure:

- Water surface exposure to floating hydrocarbons (g/m^2)
- Shoreline exposure to hydrocarbons (g/m^2) (for 95th percentile run only)
- Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill

Note that the fate of the oil is very dynamic, moving rapidly in space over time. What is shown in the maps is the cumulative path of the contamination. Thus, this contamination is not present in all locations at one time.

4.2 Stochastic Model Results

Volume II, Section 2 contains summary tables of water surface, shoreline, water column and sediment areas oiled or contaminated for the 13 mains stochastic scenarios. The tables contain mean; standard deviation; mean plus or minus two standard deviations (the range for 95 percent of results, assuming a normal (Gaussian) distribution); results for the individual 5th, 50th, and 95th percentile runs based on shore costs; and results for the individual 5th, 50th, and 95th percentile runs based on the specific exposure index being tabulated. The tables in this section summarize these results for each exposure index examined.

The percent of oil removed by mechanical recovery averages 59-85% of the spilled oil in the simulations (Table 4-2). The application of dispersant reduces the amount removed mechanically only by a small amount because the mechanical response is so efficient. By the time the dispersant could be applied, the mechanical removal has removed most of the surface floating oil, or the oil has already come ashore, entrained naturally, or become too viscous to be dispersed. This indicates that the amount of equipment and the planned response times are sufficient to remove most of the oil *under ideal conditions where everything goes according to plan and where responders know where the oil is at all times*. In reality, people and equipment will not be able to meet the schedules exactly and there will not be perfect knowledge of the oil movements allowing the responders to arrive at all possible locations where oil would be transported. Thus, the percentage removed mechanically is the maximum possible given the equipment capacities, and dispersant use would likely account for more of the oil removal from the water surface in an actual spill event than is reflected by these results.

Table 4-2. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	-	-
OC-Crud-R-ST	65	10	45	85
OC-Crud-C-ST	59	9	42	77
S1-Bunk-R-ST	85	10	66	104
S1-Dies-R-ST	48	20	7	89
S2-Crud-R-ST	67	8	51	83
S2-Crud-C-ST	64	8	48	79
SI-Crud-R-ST	68	3	62	73
SI-Crud-C-ST	66	3	60	73
IS-Crud-R-ST	69	3	63	76
IS-Crud-C-ST	64	4	57	72
C1-Bunk-R-ST	76	11	54	98
C2-Bunk-R-ST	73	14	45	101

Tables 4-3 and 4-4 summarize the shoreline oiling, listing the percent of oil coming ashore and the length of shore where cleanup would occur. Areas and lengths of shoreline oiling for other thresholds are summarized in Section 2 of Volume II, as are the per area portion of the cleanup costs. Comparing the scenarios of the same spill location and oil, particularly the outer coast scenarios where three scenarios were run (no removal, state removal, and state removal plus dispersant), the difference between no response and mechanical removal is large, while adding dispersant to the state mechanical removal has little effect on total shoreline oiled *to some degree*. However, the shoreline length heavily oiled is reduced somewhat by addition of dispersant. In some locations, such as the San Juan Islands scenarios, the areas where dispersants could be applied are far removed from the spill sites, and so the mechanical removal takes care of the surface oil before the oil reaches the dispersant application zones, or the oil is too emulsified to be dispersed by the time it enters those zones. In the outer coast scenarios, not all the oil comes ashore, and so the dispersant effect on shoreline oil is not always indicative of reduced impact.

Table 4-3. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	5.9	5.2	-	16.3
OC-Crud-R-ST	1.1	1.5	-	4.2
OC-Crud-C-ST	1.0	1.4	-	3.9
S1-Bunk-R-ST	4.2	3.1	-	10.4
S1-Dies-R-ST	0.3	0.5	-	1.3
S2-Crud-R-ST	0.7	0.6	-	2.0
S2-Crud-C-ST	0.7	0.6	-	2.0
SI-Crud-R-ST	2.1	1.2	-	4.6
SI-Crud-C-ST	2.1	1.2	-	4.5
IS-Crud-R-ST	1.3	1.0	-	3.4
IS-Crud-C-ST	1.2	1.0	-	3.2
C1-Bunk-R-ST	9.1	8.1	-	25.3
C2-Bunk-R-ST	10.8	6.1	-	22.9

Table 4-4. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 0.01 g/m2 (where cleanup would occur).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	97	66	-	229
OC-Crud-R-ST	33	27	-	87
OC-Crud-C-ST	33	29	-	91
S1-Bunk-R-ST	15	11	-	37
S1-Dies-R-ST	20	14	-	49
S2-Crud-R-ST	23	16	-	54
S2-Crud-C-ST	23	17	-	57
SI-Crud-R-ST	54	30	-	114
SI-Crud-C-ST	53	30	-	113
IS-Crud-R-ST	41	33	-	107
IS-Crud-C-ST	39	31	-	101
C1-Bunk-R-ST	24	21	-	67
C2-Bunk-R-ST	22	12	-	45

The percentage of the spilled oil reaching the sediments is very small (Table 4-5) because the spills examined are in open deep water with low suspended sediment concentrations. The percent settling is much higher in the upper Columbia River scenario because of the shallower water and more extensive shoreline interaction.

Table 4-5. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	-	-
OC-Crud-R-ST	-	-	-	-
OC-Crud-C-ST	-	-	-	-
S1-Bunk-R-ST	0.1486	0.3081	-	0.7648
S1-Dies-R-ST	-	-	-	-
S2-Crud-R-ST	-	-	-	-
S2-Crud-C-ST	0.0001	0.0006	-	0.0013
SI-Crud-R-ST	0.0009	0.0078	-	0.0165
SI-Crud-C-ST	0.0010	0.0076	-	0.0162
IS-Crud-R-ST	0.0001	0.0004	-	0.0009
IS-Crud-C-ST	0.0001	0.0003	-	0.0007
C1-Bunk-R-ST	0.3864	0.9482	-	2.2828
C2-Bunk-R-ST	2.2715	2.4709	-	7.2133

The maximum percent of the oil mass entrained in the water column at any time after the spill (Table 4-6) gives an indication of the amount of oil dispersed, both naturally and chemically. The difference between paired runs is the amount chemically dispersed (1-7% for the scenarios examined).

Table 4-6. Summary of results for all stochastic scenarios of 100 runs each: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2.5	2.1	-	6.7
OC-Crud-R-ST	1.1	1.5	-	4.1
OC-Crud-C-ST	7.6	4.6	-	16.7
S1-Bunk-R-ST	0.7	0.7	-	2.0
S1-Dies-R-ST	18.9	20.1	-	59.0
S2-Crud-R-ST	1.0	1.5	-	4.0
S2-Crud-C-ST	4.7	4.4	-	13.5
SI-Crud-R-ST	1.1	1.0	-	3.0
SI-Crud-C-ST	2.3	2.5	-	7.4
IS-Crud-R-ST	0.9	1.0	-	2.9
IS-Crud-C-ST	6.5	4.5	-	15.5
C1-Bunk-R-ST	1.4	1.3	-	3.9
C2-Bunk-R-ST	2.3	1.9	-	6.1

The water surface areas swept by floating oil are listed in Tables 4-7 and 4-8. Sheen has a thickness of >0.01 g/m^2. The thresholds for mechanical removal (skimming), effective dispersant use, in situ burning, and biological effects (on wildlife) are all about 10 g/m^2 (10 microns thick). Comparison of no dispersant and dispersant runs shows some reduction in thick oil area. However, the difference between no removal and removal is much greater, reflecting the assumed high efficiency of the state standards for mechanical removal.

Table 4-7. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,553	2,099	-	6,751
OC-Crud-R-ST	1,283	1,884	-	5,051
OC-Crud-C-ST	1,139	1,774	-	4,686
S1-Bunk-R-ST	174	128	-	431
S1-Dies-R-ST	216	119	-	455
S2-Crud-R-ST	315	224	-	764
S2-Crud-C-ST	301	220	-	740
SI-Crud-R-ST	223	150	-	523
SI-Crud-C-ST	207	128	-	464
IS-Crud-R-ST	368	219	-	805
IS-Crud-C-ST	346	206	-	757
C1-Bunk-R-ST	156	106	-	368
C2-Bunk-R-ST	6	3	-	12

Table 4-8. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	1,707	1,497	-	4,701
OC-Crud-R-ST	429	687	-	1,803
OC-Crud-C-ST	391	661	-	1,713
S1-Bunk-R-ST	174	128	-	430
S1-Dies-R-ST	128	83	-	295
S2-Crud-R-ST	135	86	-	306
S2-Crud-C-ST	127	79	-	286
SI-Crud-R-ST	96	57	-	211
SI-Crud-C-ST	93	53	-	198
IS-Crud-R-ST	173	92	-	357
IS-Crud-C-ST	162	84	-	330
C1-Bunk-R-ST	156	106	-	368
C2-Bunk-R-ST	6	3	-	12

4.3 Results for Individual Scenarios

Results for alternate response scenarios for the 5th, 50th and 95th percentile runs based on shore costs (of the base case stochastic scenario) are tabulated in Volume II, Sections II.3 to III.10. The results show patterns in line with those of the main stochastic scenarios described in Section 4.2. The percent of oil removed by mechanical recovery was about 60-85% of the spilled oil. Generally, the amount of oil mechanically removed assuming the federal standards was lower, and the amount removed under the 3rd alternative higher.

With respect to shoreline oiling, the difference between no response and mechanical removal is large, while adding dispersant to the state mechanical removal has little effect on total shoreline oiled for the reasons discussed above. Generally, the shoreline area oiled assuming the federal standards was less, and that under the 3rd alternative more than the shoreline oiled assuming the state standards. However, slight differences in the path of the oil such that different shorelines were hit or possibly missed (such as an island or peninsula grazed in one run but missed in another) induced some random noise into the results.

The water surface areas swept by floating oil followed from the changes in percent mechanically removed. Generally, the area swept by oil assuming the federal standards was less, and that under the 3rd alternative more than the area swept by oil assuming the state standards. There was also some random noise in the results induced by specific details in the trajectories of the individual runs.

5. BIOLOGICAL EFFECTS MODEL RESULTS

As mentioned in the introduction to this volume, the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model. This results in variability in the movements of oil spillets in the simulation, which in turn can affect the amount of shoreline oiled, the water surface area swept, and the percentage of oil that becomes entrained in the water column. Since impacts of subtidal fish and invertebrates, intertidal invertebrates, and wildlife are proportional to the volume of oil above a threshold in the water column, the length of soft shoreline (wetlands, mud flats and sand beaches) oiled, and the water surface area swept, respectively, the random variability incorporated into the oil trajectory model can also influence biological impacts. This random variability explains why impacts to fish and wildlife from runs using the federal, state, and 3rd alternative responses occasionally may not be in the expected order.

5.1 Intertidal Habitats

Section D of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV summarizes the intertidal areas oiled by shore type, including wetlands, above different threshold levels. Complete mortality of the vegetation in saltmarsh wetlands occurs above about 14 mm of oil, based on the literature reviewed in French et al. (1996a). However, oiling by more than 1 mm would likely affect the vegetation to some degree.

Intertidal (shoreline) habitats oiled by more than 0.1mm (>100 g/m^2) of oil were assumed to impact intertidal invertebrates (Section 3.4.3). Impacts were evaluated for geoducks, soft-shell clams, razor clams, and hard clams in soft shoreline habitats (wetlands, mud flats and sand beaches). The main species affected in the straits scenarios (S1, S2, SI and IS) was the geoduck, an important fishery species. On the outer coast, the other clam species are more abundant. The area of soft shoreline (wetland, mud or sand) impacted was multiplied by clam density to estimate impacts to intertidal invertebrates. Clam abundance along upper Columbia River shorelines was assumed zero, so no intertidal impact to invertebrates was assessed for the upper Columbia River scenario.

Table 5-1 summarizes the results for the 13 main stochastic scenarios. Tables 5-2 to 5-8 list the results for the alternate response scenarios. In general, the 5th, 50th and 95th run showed increasing impact on intertidal invertebrates. However, the clams assessed are only in soft shorelines, while the 5th, 50th and 95th runs were selected based on cleanup costs for all shorelines. Thus, there was not always an increasing impact with increasing shoreline cleanup cost. The impacts to clams are proportional to the shoreline area heavily oiled. Thus, removal of oil from the water surface, which results in less shoreline oiled, reduced the impact to intertidal clams. Complete results for the all scenarios are listed in Volume II.

Table 5-1. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (clams).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	150	281	-	713
OC-Crud-R-ST	31	132	-	295
OC-Crud-C-ST	31	136	-	304
S1-Bunk-R-ST	257	429	-	1,115
S1-Dies-R-ST	282	445	-	1,171
S2-Crud-R-ST	198	355	-	907
S2-Crud-C-ST	185	347	-	880
SI-Crud-R-ST	1,134	716	-	2,566
SI-Crud-C-ST	1,087	648	-	2,383
IS-Crud-R-ST	506	554	-	1,615
IS-Crud-C-ST	490	578	-	1,647
C1-Bunk-R-ST	22	20	-	61
C2-Bunk-R-ST	-	-	-	-

Table 5-2. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to intertidal invertebrates (clams).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
OC-Crud-N	-	43	1,274
OC-Crud-R-ST-base	-	-	-
OC-Crud-R-Fed	-	-	-
OC-Crud-R-3	-	-	-
OC-Crud-R-ISB	-	-	-
OC-Crud-C-ST-base	-	-	-
OC-Crud-C-Fed	-	-	-
OC-Crud-C-3	-	-	-

Table 5-3. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (clams).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
S1-Bunk-N	388	324	518
S1-Bunk-R-ST	-	-	227
S1-Bunk-R-Fed	-	-	129
S1-Bunk-R-3	-	-	97
S1-Bunk-R-ISB	-	-	-

Table 5-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total impact (kg) to intertidal invertebrates (clams).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
S1-Dies-N	907	1,068	2,234
S1-Dies-R-ST	-	356	2,007
S1-Dies-R-Fed	-	227	1,813
S1-Dies-R-3	-	32	1,845

Table 5-5. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total impact (kg) to intertidal invertebrates (clams).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
S2-Crud-N	4,565	2,396	1,683
S2-Crud-R-ST	-	-	1,360
S2-Crud-R-Fed	-	-	1,424
S2-Crud-R-3	-	-	1,489
S2-Crud-R-ISB	-	-	1,392
S2-Crud-C-ST-base	-	-	1,392
S2-Crud-C-Fed	-	-	1,457
S2-Crud-C-3	-	-	1,424

Table 5-6. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to intertidal invertebrates (clams).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
SI-Crud-N	19,976	8,273	12,992
SI-Crud-R-ST	252	566	1,636
SI-Crud-R-Fed	472	1,132	3,397
SI-Crud-R-3	315	786	1,132
SI-Crud-C-ST-base	252	786	1,636
SI-Crud-C-Fed	503	944	3,209
SI-Crud-C-3	346	786	1,070

Table 5-7. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total impact (kg) to intertidal invertebrates (clams).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
IS-Crud-N	5,002	5,442	16,578
IS-Crud-R-ST	-	-	724
IS-Crud-R-Fed	31	31	1,007
IS-Crud-R-3	-	-	409
IS-Crud-C-ST-base	-	-	315
IS-Crud-C-Fed	-	-	849
IS-Crud-C-3	-	31	189

Table 5-8. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (clams).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
C1-Bunk-N	-	163	189
C1-Bunk-R-ST	-	15	56
C1-Bunk-R-Fed	-	19	60
C1-Bunk-R-3	-	19	40

5.2 Wildlife

Tables 5-9 and 5-10 summarize the model-estimated bird and mammal kills for the main stochastic scenario simulations. Section F of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV contains the impact estimates by species group for the main 13 scenarios. Section C of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, and XXVI contains impact estimates for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.10 for the alternate response scenarios.

The estimates are proportional to the habitat area oiled by > 10 g/m^2 and to the pre-spill abundance assumed. If the pre-spill abundance were, for example, a factor two different, the model kill estimate would change by that same factor. Abundance varies by season as well as many other factors, such as long term trends in abundance, patchiness in the prey base, variability in habitat characteristics and so on. Thus, there is considerable variability and uncertainty in the estimates. Thus, the results should be used in a comparative sense and to indicate general patterns relative to the response plans assumed. In a specific incident, the details of the biological distributions should be evaluated to develop a specific result for that spill.

Table 5-9. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	153,783	119,773	-	393,329
OC-Crud-R-ST	51,432	54,953	-	161,339
OC-Crud-C-ST	48,407	52,859	-	154,125
S1-Bunk-R-ST	6,916	3,042	833	12,999
S1-Dies-R-ST	10,688	5,089	510	20,865
S2-Crud-R-ST	9,598	3,619	2,361	16,835
S2-Crud-C-ST	9,264	3,357	2,549	15,978
SI-Crud-R-ST	4,904	2,911	-	10,725
SI-Crud-C-ST	4,705	2,671	-	10,046
IS-Crud-R-ST	10,363	4,098	2,166	18,559
IS-Crud-C-ST	9,844	3,746	2,351	17,336
C1-Bunk-R-ST	28,580	11,827	4,926	52,234
C2-Bunk-R-ST	306	272	-	851

Table 5-10. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	40.9	31.8	-	104.6
OC-Crud-R-ST	13.7	14.6	-	42.9
OC-Crud-C-ST	12.9	14.1	-	41.0
S1-Bunk-R-ST	0.6	0.3	0.0	1.1
S1-Dies-R-ST	0.8	0.4	0.1	1.6
S2-Crud-R-ST	0.7	0.2	0.3	1.1
S2-Crud-C-ST	0.7	0.2	0.3	1.1
SI-Crud-R-ST	0.4	0.2	0.0	0.7
SI-Crud-C-ST	0.4	0.2	0.0	0.7
IS-Crud-R-ST	0.8	0.4	0.0	1.6
IS-Crud-C-ST	0.8	0.4	0.1	1.5
C1-Bunk-R-ST	4.6	2.0	0.6	8.6
C2-Bunk-R-ST	3.4	1.1	1.1	5.7

The majority of the biological impacts are to birds, particularly to seabirds and waterfowl (diving ducks). The breakdowns by species groups are available in Volume II for the 13 main scenarios (Section II.2) and alternate scenarios (Sections II.3 to II.10). The total bird impacts (Table 5-9) are highest for the outer coast and lower Columbia River scenarios (which include spill sites up to 3 miles off the coast), because the oil remains at sea longer than for the straits and upper Columbia River scenarios, and there are higher abundances of birds on the outer coast than in the straits. In outer coast scenario, the mechanical recovery assumed would be projected to save 100,000 birds, and adding dispersant to the mechanical removal would save 3,000 more birds on average. This is certainly an idealized situation where the mechanical cleanup would need to proceed without a hitch and with perfect knowledge of where the oil is located at all (daylight) times. In reality, the mechanical recovery would not be so efficient and the dispersant could be more effective in reducing the number of birds oiled by a spill.

Table 5-10, which summarizes the results for the 13 main stochastic scenarios, shows that the mammal impacts are projected to be minor, with the exception of the outer coast and Columbia River scenarios. The mammals primarily impacted in the outer coast and Columbia River scenarios would be sea otters and fur seals, with lesser impacts to harbor seals and harbor porpoises. In the upper Columbia River, the mammals impacted would be mostly muskrat and mink.

5.3 Fish and Invertebrates

Table 5-11 summarizes estimated impacts to subtidal fish and invertebrates (those in the water exposed to water and submerged sediment concentrations) for the 13 main stochastic scenarios. Section G of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV contains the impact estimates by species group for the main 13 scenarios. Section D of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, and XXVI contains impact estimates for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.10 for the alternate response scenarios.

The outer coast scenarios have the least impacts because of the large dilution volumes involved. Addition of dispersant off the outer coast did not significantly increase the effects on fish and invertebrates. Diesel is much more readily dispersed (naturally) into the water column than crude oil, and so the impacts are projected to be much higher for diesel than for the same volume of crude oil. This is because Alaskan crude oil emulsifies rapidly, minimizing entrainment and dissolution into the water. In the scenarios examined, use of dispersants on crude oil spilled in the straits (S2, SI or IS) increased the impacts on fish and invertebrates.

The Bunker C spills were of lower volume, had low content of soluble and toxic components, and were not readily dispersed naturally into the water because of the high viscosity of the oil. For these reasons, the effects on fish and invertebrates for the Bunker C spills were very minimal in areas where there is rapid dilution, i.e., in the Straits or

lower Columbia River. Impacts to fish and invertebrates for Bunker C spills offshore would also be insignificant. In the upper Columbia River, the impacts were primarily on demersal fish such as suckers, catfish and sunfishes.

It should be noted that these fish and invertebrate impacts were calculated assuming all the species were of average sensitivity to dissolved aromatics. Some species will be much more sensitive, and impacts to those species would be higher. There would also likely be species less sensitive than average. As there are insufficient toxicity data available to quantify the degree of sensitivity to aromatics for all species in Washington waters, there is considerable uncertainty around the results based on average sensitivity. Experience with past modeling efforts indicate the uncertainty in the impact estimate related to species sensitivity is on the order of a factor ten higher or lower (95% confidence range). As there is a mix of species sensitivity present, the uncertainty in the total fish and invertebrate impact would be less than a factor ten.

Table 5-11. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	3	0	3	4
OC-Crud-R-ST	3	0	3	4
OC-Crud-C-ST	3	0	2	3
S1-Bunk-R-ST	10	6	-	21
S1-Dies-R-ST	114,144	38,077	37,990	190,298
S2-Crud-R-ST	8,669	9,481	-	27,631
S2-Crud-C-ST	21,771	16,381	-	54,532
SI-Crud-R-ST	6,752	6,090	-	18,932
SI-Crud-C-ST	10,799	8,283	-	27,366
IS-Crud-R-ST	8,736	13,767	-	36,269
IS-Crud-C-ST	41,996	25,320	-	92,636
C1-Bunk-R-ST	0	1	-	3
C2-Bunk-R-ST	3,630	4,123	-	11,877

Table 5-12 contains a summary of the total estimated impacts to fish and invertebrates in all subtidal and intertidal habitats. Again, Section G of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV contains the impact estimates by species group for the main 13 scenarios and Section D of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, and XXVI contains those for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.10 for the alternate response scenarios.

If subtidal fish and invertebrates were affected to a significant degree, the majority of the impacts were to subtidal biota. However, for the Bunker C and offshore scenarios, the

intertidal impacts were the largest fraction of the losses. Note that no intertidal losses were assessed for the upper Columbia River bunker C scenario.

Table 5-12. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal and intertidal fish and invertebrates.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	154	282	3	717
OC-Crud-R-ST	34	132	3	299
OC-Crud-C-ST	34	137	2	308
S1-Bunk-R-ST	266	435	-	1,136
S1-Dies-R-ST	114,426	38,522	37,990	191,469
S2-Crud-R-ST	8,867	9,835	-	28,538
S2-Crud-C-ST	21,956	16,728	-	55,412
SI-Crud-R-ST	7,886	6,806	-	21,498
SI-Crud-C-ST	11,887	8,931	-	29,749
IS-Crud-R-ST	9,242	14,321	-	37,884
IS-Crud-C-ST	42,487	25,898	-	94,283
C1-Bunk-R-ST	22	21	-	64
C2-Bunk-R-ST	3,630	4,123	-	11,877

6. POTENTIAL NATURAL RESOURCE DAMAGES

6.1 NRD Based on Restoration Costs

Historically, NRDA costs associated with impacts were based on economic valuation methods and that approach was used in the CERCLA regulations (including the type A model, the NRDAM/CME). However, under the 1990 Oil Pollution Act NRDA regulations published in January of 1996 by NOAA, the federal approach to NRDA has been focused on use of compensatory restoration costs rather than the economic valuation. Present practice by NRDA trustees is to use and cost restoration of resources similar in value to the injured resources when primary restoration of the injured resources is not feasible (i.e., the recovery rate of the injured resources cannot be accelerated over natural recovery). Thus, this refocusing of the NRDA cost functions is used in the current analysis and restoration costs are used for both primary and compensatory restoration of injured resources.

The scaling of the compensatory restoration uses methods currently practiced by NOAA and other trustees, i.e., Habitat Equivalency Analysis (HEA). Scaling methods used here were initially developed for use in the *North Cape* case, as described in French et al (2001), French McCay and Rowe (2003) and French McCay et al (2003a). These methods have also been used in several other cases, as well as in successful claims for 23 cases submitted by the Florida Department of Environmental Protection to the US Coast Guard, National Pollution Fund Center (French McCay et al., 2003c).

Restoration should provide equivalent quality fish and invertebrate biomass to compensate for the lost fish and invertebrate production. The restoration should also replace the wildlife lost. Equivalent quality implies same or similar species with equivalent ecological role and value for human uses. The equivalent production or replacement should be discounted to present-day values to account for the interim loss between the time of the injury and the time restoration provides equivalent ecological and human services.

Habitat creation or preservation projects have been used to compensate for injuries of wildlife, fish and invertebrates. The concept is that the restored habitat leads to a net gain in wildlife, fish and invertebrate production over and above that produced by the location before the restoration. The size of the habitat (acreage) is scaled to just compensate for the injury (interim loss).

In the model used here, the habitat may be seagrass bed, saltmarsh, oyster reef, freshwater or brackish wetland, or other structural habitats that provide such ecological services as food, shelter, and nursery habitat and are more productive than open bottom habitats. The injuries are scaled to the new primary (plant) or secondary (e.g., benthic) production produced by the created habitat, as the entire food web benefits from this production. A preservation project that would avoid the loss of habitat could also be scaled to the production preserved. The latter method would only be of net gain if the

habitat is otherwise destined to be destroyed. In this analysis we assume only habitat creation projects would be undertaken.

The approach to scaling the size of the needed project is to use primary production to measure the benefits of the restoration. The total injuries in kg are translated into equivalent plant (angiosperm) production as follows. Plant biomass passes primarily through the detrital food web via detritivores consuming the plant material and attached microbial communities. When macrophytes are consumed by detritivores, the ecological efficiency is low because of the high percentage of structural material produced by the plant, which must be broken down by microorganisms before it can be used by the detritivore. Each species group is assigned a trophic level relative to that of the detritivores. If the species group is at the same trophic level, it is assumed 100% equivalent, as the resource injured would presumably have the same ecological value in the food web as the detritivores. If the injured resource preys on detritivores or that trophic level occupied by the detritivores, the ecological efficiency is that for trophic transfer from the prey to the predator. Values for production of predator per unit production of prey (i.e., ecological efficiency) are taken from the ecological literature, as reviewed by French McCay and Rowe (2003). The ecological efficiencies assumed are in Table 6-1.

Table 6-1. Assumed ecological efficiencies for one trophic step.

Consumer	Prey/food	% Efficiency
Invertebrate detritivore	Angiosperm	6.6
Invertebrate	Microalgae	10
Invertebrate	Microorganisms	20
Invertebrate or fish bottom feeder	Detritivores, microalgae	10
Invertebrate or fish	Invertebrate	20
Invertebrate or fish filter feeder	Plankton	20
Invertebrate or fish piscivore	Finfish	20
Sea turtles	Macrophytes, invertebrates	4
Birds, mammals	Invertebrate	2
Birds, mammals, piscivores	Finfish	2

Equivalent compensatory angiosperm (plant) of the restored resource is calculated as kg of injury divided by ecological efficiency. The ecological efficiency is the product of the efficiency of transfer from angiosperm to invertebrate detritivore and efficiency from detritivore to the injured resource, accounting for each step up the food chain from detritivore to the trophic level of concern. Table 6-2 lists the composite ecological efficiency relative to benthic invertebrate production for each trophic group evaluated in the modeling.

Table 6-2 Composite ecological efficiency relative to benthic invertebrate production by trophic group.

Species Category	Trophic Level	Ecological Efficiency Relative to Benthic Detritivores (%)
Fish and Invertebrates:		
Small pelagic fish	planktivorous	20
Large pelagic fish	Piscivores/predators	0.8
Demersal fish	bottom feeders	10
Mollusks	filter/bottom feeder	20
Benthic invertebrates (non-molluscan)	filter/bottom feeder	20
Demersal macroinvertebrate predators	predate bottom feeders	4
Birds:		
Waterfowl	bottom feeders	2
Seabirds	piscivores	0.4
Waders	piscivores	0.4
Shorebirds	bottom feeders	2
Raptors	piscivores	0.4
Other wildlife:		
Sea turtles	secondary consumers	4
Sea otters	secondary consumers	2
Pinnipeds	piscivores	0.4
Cetaceans	piscivores	0.4

The productivity gained by the created habitat is corrected for less than full functionality during recovery using a sigmoid recovery curve. Discounting at 3% per year is included for delays in production because of development of the habitat, and delays between the time of the injury and when the production is realized in the restored habitat. The equations and assumptions may be found in French McCay and Rowe (2003).

The needed data for the scaling calculations are:

- number of years for development of full function;
- annual primary production rate per unit area (P) of restored habitat at full function (which may be less than that of natural habitats);
- delay before restoration project begins; and
- project lifetime (years the restored habitat will provide services).

In Washington, it is most likely that saltmarsh restoration would be undertaken as restoration for wildlife, fish and invertebrate injuries. Seagrass (eelgrass) bed restoration is also an option. However, this requires good water quality and appropriate environmental conditions to be successful. The calculatations for both habitats are included here for comparative purposes. However, the best estimate for NRDA costs is that based on (saltmarsh) wetland restoration, as this is most likely to be pursued.

6.1.1 Saltmarsh Restoration

HEA calculations for saltmarsh are performed following the methods in French McCay and Rowe (2003). It is assumed that the saltmarsh requires 15 years to reach 99% of full

function (based on PERL, 1990; Zedler, 1992; Seneca and Broome, 1992; French et al., 1996a), ultimately reaching 80% of natural habitat productivity, the restoration begins 3 years after the spill, and the project lifetime is 50 years.

Above-ground primary production rate of saltmarsh cord grasses on the Oregon coast was estimated from data in Continental Shelf Associates (1991) as 2636 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 93 g dry weight m^{-2} (Phillips, 1984). Thus, estimated total primary production rate in saltmarshes is 2729 g dry weight m^{-2} yr^{-1}. It is assumed that created marshes reach 80% of the production rate in natural marshes, i.e., 2184 g dry weight m^{-2} yr^{-1}.

For the injured resources, all weights are as wet weight and dry weight is assumed 22% of wet weight. For the wildlife, the body mass per animal (from French et al 1996b) is used to estimate injury in kg (multiplying by number killed and summing each species category). Saltmarsh creation cost ($46.30/$m^2$) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year.

The amounts of saltmarsh required in compensation for the quantified wildlife, fish and invertebrate injuries and the cost of the restoration are summarized for the 13 main stochastic scenarios in Tables 6-3 and 6-4. Section H of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV contains the restoration scale (area required for compensation) and cost estimates by species group for the main 13 scenarios and Section E of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, and XXVI contains those for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.10 for the alternate response scenarios. The executive summary also contains summary tables of the NRDA cost estimates for all species groups, as these costs are carried forward into the cost-benefit analysis performed by the Department of Ecology.

According to HEA-scaled calculations, the offshore crude oil scenario would be the most expensive to provide compensatory restoration because of the relatively large impact on birds. Use of dispersant in the offshore scenario reduced damages, while dispersant use increased damages (due to increase fish and invertebrate impacts) in the straits scenarios.

The changes in natural resource damages with different response alternatives are summarized in Tables E-9 to E-16 of the executive summary. In these tables, individual runs are examined, holding spill conditions constant so comparisons can be made. In all scenarios, the difference between no mechanical removal and any of the mechanical removal capacity assumptions (state, federal or 3rd alternative) is substantial, again because the capacities were high relative to the oil spill volume and the efficiency of the response was assumed high (as planned). The state mechanical response capacities were higher than the federal, and the 3rd alternative capacities were higher than the state's, so that the damages typically were higher for the federal and lower for the 3rd alternative than for the state standards. ISB or dispersant use added to the state mechanical capacities did not incrementally reduce damages in most scenarios because the mechanical removal rates were very high, removing 59-85% of the spilled oil.

(Variability in some of the results involving mechanical response was insignificant and due to the randomization routine employed to simulate natural dispersion.)

Table 6-3. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	4,712	3,658	0	12,028
OC-Crud-R-ST	1,590	1,676	0	4,942
OC-Crud-C-ST	428	472	0	1,371
S1-Bunk-R-ST	39	27	4	92
S1-Dies-R-ST	514	243	41	1,000
S2-Crud-R-ST	101	77	11	256
S2-Crud-C-ST	166	111	11	387
SI-Crud-R-ST	46	37	0	120
SI-Crud-C-ST	62	45	0	152
IS-Crud-R-ST	112	106	11	325
IS-Crud-C-ST	223	144	12	511
C1-Bunk-R-ST	186	82	24	351
C2-Bunk-R-ST	3	3	0	8

Table 6-4. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	883	685	0	2,254
OC-Crud-R-ST	298	314	0	926
OC-Crud-C-ST	80	88	0	257
S1-Bunk-R-ST	7	5	1	17
S1-Dies-R-ST	96	45	8	187
S2-Crud-R-ST	19	15	2	48
S2-Crud-C-ST	31	21	2	72
SI-Crud-R-ST	9	7	0	22
SI-Crud-C-ST	12	8	0	28
IS-Crud-R-ST	21	20	2	61
IS-Crud-C-ST	42	27	2	96
C1-Bunk-R-ST	35	15	4	66
C2-Bunk-R-ST	1	1	0	2

6.1.2 Seagrass Bed Restoration

HEA calculations for seagrass are performed following the methods in French McCay and Rowe (2003). It is assumed that the habitat requires 3 years to reach 99% of full function (French et al., 1996a; Fonseca et al., 1998), ultimately reaching 80% of natural habitat productivity, the restoration begins 3 years after the spill, and the project lifetime is 50 years.

The estimated primary production rate for eelgrass in Puget Sound (Phillips 1984) is 1079 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 93 g dry weight m^{-2} (Phillips, 1984). Thus, estimated total primary production rate in seagrass beds is 1172 g dry weight m^{-2} yr^{-1}. It is assumed that created seagrass bed reach 80% of the production rate in natural beds, i.e., 938 g dry weight m^{-2} yr^{-1}.

For the injured resources, all weights are as wet weight and dry weight is assumed 22% of wet weight. For the wildlife, the body mass per animal (from French et al 1996b) is used to estimate injury in kg (multiplying by number killed and summing each species category). Seagrass bed creation cost ($29.50/$m^2$) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

The amounts of seagrass bed required in compensation for the quantified wildlife, fish and invertebrate injuries and the cost of the restoration are summarized for the 13 main stochastic scenarios in Tables 6-5 and 6-6. Section H of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV contains the restoration scale and cost estimates by species group for the main 13 scenarios and Section E of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, and XXVI contains those for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.10 for the alternate response scenarios.

The results based on seagrass restoration show the same patterns as for saltmarsh restoration (discussed above in Section 6.1.1), as the values are proportional to the injuries. The area of saltmarsh required for compensation is 1.6 times the area of seagrass bed, and the total costs for saltmarsh compensation are 2.5 times those for seagrass bed. However, it is likely that saltmarsh would be the restoration option selected by NRD trustees because it is more likely to be successfully implemented. Thus, the saltmarsh costs, and not the seagrass costs, are the best and most conservative estimates to carry forward to the cost-benefit analysis.

Table 6-5. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming seagrass bed creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,944	2,286	0	7,516
OC-Crud-R-ST	993	1,047	0	3,088
OC-Crud-C-ST	267	295	0	857
S1-Bunk-R-ST	24	17	2	58
S1-Dies-R-ST	321	152	25	625
S2-Crud-R-ST	63	48	7	160
S2-Crud-C-ST	104	69	7	242
SI-Crud-R-ST	29	23	0	75
SI-Crud-C-ST	39	28	0	95
IS-Crud-R-ST	70	67	7	203
IS-Crud-C-ST	140	90	7	319
C1-Bunk-R-ST	116	51	15	219
C2-Bunk-R-ST	2	2	0	5

Table 6-6. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is seagrass bed creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	352	273	0	897
OC-Crud-R-ST	119	125	0	369
OC-Crud-C-ST	32	35	0	102
S1-Bunk-R-ST	3	2	0	7
S1-Dies-R-ST	38	18	3	75
S2-Crud-R-ST	8	6	1	19
S2-Crud-C-ST	12	8	1	29
SI-Crud-R-ST	3	3	0	9
SI-Crud-C-ST	5	3	0	11
IS-Crud-R-ST	8	8	1	24
IS-Crud-C-ST	17	11	1	38
C1-Bunk-R-ST	14	6	2	26
C2-Bunk-R-ST	0	0	0	1

6.2 Washington State Compensation Schedule

The Washington Compensation Schedule, as described in the State of Washington's Chapter 173-183 WAC, Preassessment Screening and Oil Spill Compensations Schedule Regulations, was applied to the model results for hypothetical spills simulated in estuarine and marine waters. The Compensation Schedule is designed to be a simplified procedure for small spills. Thus, for spills the size of those considered here, the OPA procedures using restoration costs (Section 6.1) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

The resource damage assessment using Compensation Schedule includes:

- Relative ranking for each class of oil based on factors that affect severity and persistence of spill on environment.
- Relative vulnerability ranking of the environment, which involves:
    - location of spill;
    - habitat and public resource sensitivity to oil;
    - seasonal distribution of the public resource;
    - areas of recreational use and aesthetic importance;
    - proximity of the spill to important habitats for birds, mammals, fish, and endangered species; and
    - other areas of special ecological or recreational importance.
- A quantitative method for determining public resource damages based on oil effects and vulnerability rankings designed to compensate people of the state; i.e., the damages range from $1 to $50 per gallon spilled, scaled by the vulnerability score based on the above considerations.
- A method to adjust damages calculated under comp. schedule to account for actions taken by responsible party; i.e., the amount of oil recovered in the first 24 hours is subtracted from the amount spilled in performing the calculations.

The Compensation Schedule procedures for marine and estuarine waters, excluding the estuarine waters of the Columbia River, were applied using the spill volume less the amount of oil mechanically recovered in the first 24 hours. The results, including $/gal, percent removed in the first 24 hours, and total damages (in millions of dollars) are listed in tables in Volumes II through XXVI. Table 6-7 summarizes the results for the 13 main stochastic scenarios and Tables 6-8 to 6-14 give those comparing the alternate response scenarios. The Compensation Schedule was not applied to the upper Columbia River spills.

Table 6-7. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of $), using the WA Compensation Schedule.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	64.3	0.7460	62.8	65.8
OC-Crud-R-ST	59.8	1.2695	57.3	62.3
OC-Crud-C-ST	59.8	1.2696	57.3	62.4
S1-Bunk-R-ST	27.1	0.0082	27.1	27.2
S1-Dies-R-ST	16.9	0.0167	16.8	16.9
S2-Crud-R-ST	51.5	0.0054	51.4	51.5
S2-Crud-C-ST	51.0	5.3068	40.3	61.6
SI-Crud-R-ST	51.2	0.0175	51.2	51.3
SI-Crud-C-ST	59.3	0.0143	59.3	59.4
IS-Crud-R-ST	49.5	0.0419	49.5	49.6
IS-Crud-C-ST	51.8	0.0574	51.7	51.9
C1-Bunk-R-ST	26.7	6.0944	14.5	38.9

Table 6-8. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (in millions of $), using the WA Compensation Schedule.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
OC-Crud-N	61.9	64.5	64.5
OC-Crud-R-ST-base	61.9	64.5	58.6
OC-Crud-R-Fed	61.9	61.9	64.5
OC-Crud-R-3	58.0	61.0	55.5
OC-Crud-R-ISB	59.2	60.5	57.9
OC-Crud-C-ST-base	61.9	64.5	58.5
OC-Crud-C-Fed	61.9	61.9	64.5
OC-Crud-C-3	58.0	61.0	55.1

Table 6-9. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of $), using the WA Compensation Schedule.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
S1-Bunk-N	29.6	29.6	29.6
S1-Bunk-R-ST	27.6	26.5	27.4
S1-Bunk-R-Fed	26.3	25.8	26.9
S1-Bunk-R-3	25.2	22.3	25.8
S1-Bunk-R-ISB	25.4	24.9	24.9

Table 6-10. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of $), using the WA Compensation Schedule.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
S1-Dies-N	18.9	18.9	18.9
S1-Dies-R-ST	15.6	18.2	18.4
S1-Dies-R-Fed	17.7	18.9	18.7
S1-Dies-R-3	13.2	15.6	16.9

Table 6-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total NRDA costs (in millions of $), using the WA Compensation Schedule.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
S2-Crud-N	61.9	61.9	61.9
S2-Crud-R-ST	52.8	46.6	52.3
S2-Crud-R-Fed	61.4	58.0	59.7
S2-Crud-R-3	48.6	52.5	51.4
S2-Crud-R-ISB	52.2	45.8	52.3
S2-Crud-C-ST-base	52.8	46.6	52.3
S2-Crud-C-Fed	61.4	56.0	59.8
S2-Crud-C-3	44.5	44.0	47.4

Table 6-12. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of $), using the WA Compensation Schedule.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
SI-Crud-N	59.3	59.4	59.4
SI-Crud-R-ST	53.9	48.4	57.5
SI-Crud-R-Fed	57.4	55.5	59.3
SI-Crud-R-3	52.0	44.7	51.1
SI-Crud-C-ST-base	53.9	48.4	57.5
SI-Crud-C-Fed	67.5	65.3	69.7
SI-Crud-C-3	61.1	52.6	60.1

Table 6-13. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total NRDA costs (in millions of $), using the WA Compensation Schedule.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
IS-Crud-N	59.3	59.4	59.4
IS-Crud-R-ST	48.9	47.6	49.2
IS-Crud-R-Fed	54.0	53.6	54.7
IS-Crud-R-3	50.5	48.6	48.7
IS-Crud-C-ST-base	51.1	49.8	51.7
IS-Crud-C-Fed	54.0	53.6	54.7
IS-Crud-C-3	50.5	48.6	48.8

Table 6-14. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of $), using the WA Compensation Schedule.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs
C1-Bunk-N	28.1	28.0	27.7
C1-Bunk-R-ST	30.9	27.6	27.9
C1-Bunk-R-Fed	28.1	28.4	28.5
C1-Bunk-R-3	28.4	24.9	26.8

7. CONCLUSIONS

The model results and analysis of biological impacts indicate that the mechanical removal capacities examined are sufficient for cleaning up the spill volumes evaluated and can greatly reduce impacts to biota and shorelines. However, the simulations assume that everything goes according to plan and responders know where the oil is at all times. In reality, people and equipment will not be able to meet the schedules exactly and there will not be perfect knowledge of the oil movements allowing the responders to mechanically clean up as much oil as the results suggest. Thus, the percentage removed mechanically is the maximum possible given the equipment capacities, and dispersant use would likely account for more of the oil removal from the water surface in an actual spill event than is reflected by these results.

The model results show that dispersant use on spills up to 65,000 bbl in the offshore would not cause significant impacts to fish and invertebrates. Because a highly efficient mechanical response at the capacity standards examined would be difficult to accomplish, use of dispersants instead of mechanical removal would be unlikely to adversely affect the environment and may be more realistically achieved. However, dispersant use would likely increase impacts to fish and invertebrates in the inner straits, Puget Sound and Rosario Strait. Similar results would be likely in other confined waters, such as inside the Columbia River estuary. Thus, based on the modeling analysis, dispersant use in confined waters in the state of Washington is not suggested unless protection of sensitive shorelines and wildlife cannot be accomplished by other means.

The natural resource damages were based on estimated costs to restore equivalent resources and/or ecological services, as this is the preferred method used by natural resource trustees based on guidance in the OPA regulations. The Washington Compensation Schedule is designed for small spills, much less than the volumes considered here. Habitat Equivalency Analysis (HEA) was used to estimate the required amount of habitat restoration for NRD compensation of injuries to wildlife, fish and invertebrate species. Production by the restored habitat ultimately benefits wildlife, fish and invertebrates, and equivalency is assumed if equal production of similar species (i.e., the same general taxonomic group and trophic level) results.

The estimated costs of saltmarsh restoration required in compensation for the quantified wildlife, fish and invertebrate injuries are summarized for the 13 main stochastic and the alternate response scenarios in Tables E-8 to E-16 of the executive summary. The total costs for saltmarsh compensation are 2.5 times those estimated assuming seagrass beds would be restored in compensation. However, it is likely that saltmarsh would be the restoration option selected by NRD trustees because it is more likely to be successfully implemented. Thus, the saltmarsh costs, and not the seagrass costs, are the best and most conservative estimates to carry forward to the cost-benefit analysis.

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Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume II: Summary of Results for All Scenarios

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II.1. INTRODUCTION

Table II-1.1 lists the oil spill modeling scenarios, defined by spill location, oil type and response assumed. The number scheme indicates the 13 main stochastic scenarios, where 100 randomly selected dates were run for each (listed first in the group, as noted by the s). The main stochastic cases were either involving no removal (main scenario #1) or the Washington state standard removal (Washington State Caps). In some cases, the main stochastic case involved Washington state standard removal and dispersant application.

For each main stochastic case, alternate scenarios were also run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). In the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup (see next section for explanation).

The results of the modeling are summarized in the tables in Section II-2 to II-9, organized by location. Each of the base cases run for the location are presented first, followed by comparisons of the alternative response scenarios. The discussion of these results may be found in Volume I. Details of the model inputs and results are in Volumes III to XXVI.

It should be noted that the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model. This results in variability in the movements of oil spillets in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This results in variation in the specific water areas and shoreline locations oiled and in some cases the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported. If this uncertainty were not included in the model simulations, the oil would all move along a single trajectory path to one shoreline location down wind and down current, clearly an unrealistic event to analyze.

Consequently, the timing of oil removal and arrival on shore changes in some cases, as may be seen in the figures showing oil amounts in various environmental compartments (i.e., mass balance) as a function of time in Section B of Volumes V, VIII, XI, XIV, XVII, XX, XXIII, and XXVI. The figures in Section B of these volumes are those Washington Department of Ecology will find most useful in evaluating the various planning standards.

Changes in the specific locations where spillets hit shore may result in differences in the amount of shoreline oiled by more than or less than selected thresholds. For example, in one simulation two spillets might hit a single location and be additive in the amount of oil on shore in that segment, while in another simulation the two spillets might hit adjacent shorelines and be additive in area of shore oiled, but not in thickness of oiling. This

results in different thicknesses of oil on each shore segment from one simulation to the next. Thus, it should be noted that impact to the shoreline at any threshold level is not necessarily proportional to the shore length or area oiled. This explains some variability seen in the results.

Table II.1-1 Oil spill modeling scenarios: Scenario/response and number scheme.

#[1]	Scenario Name	Site	Location	Oil	Bbls	Re-sponse	SIMAP SCENARIOS[2]
1 (s)	1-NOREM	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	65,000	No Removal	PROT BOOM
2 (s)	2-MECHST	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	65,000	Mech WA	MECH WA – OC PROT BOOM
2	2-MECHFED	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	65,000	Mech Fed	MECH FED – OFF PROT BOOM – FED
2	2-MECH3RD	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	65,000	Mech 3rd	MECH 3RD – OC PROT BOOM – 3RD
2	2- ISB	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	65,000	ISB	ISB MECH WA – OC PROT BOOM
3 (s)	3- DISP MECHST	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	65,000	Disp + Mech WA	DISP MECH WA – OC PROT BOOM
3	3- DISP MECHFED	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	65,000	Disp + Mech Fed	DISP MECH FED – OFF PROT BOOM – FED
3	3- DISP MECH3RD	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	65,000	Disp + Mech 3rd	DISP MECH 3RD – OC PROT BOOM – 3RD
4 (s)	4-MECHST	Str Juan de Fuca	Neah Bay to Port Angeles	Bunker C	25,000	Mech WA	MECH WA – STR25 PROT BOOM
4	4-NOREM	Str Juan de Fuca	Neah Bay to Port Angeles	Bunker C	25,000	No Removal	PROT BOOM
4	4-MECHFED	Str Juan de Fuca	Neah Bay to Port Angeles	Bunker C	25,000	Mech Fed	MECH FED – NR25 PROT BOOM – FED
4	4-MECH3RD	Str Juan de Fuca	Neah Bay to Port Angeles	Bunker C	25,000	Mech 3rd	MECH 3RD – STR25 PROT BOOM – 3RD
4	4-ISB	Str Juan de Fuca	Neah Bay to Port Angeles	Bunker C	25,000	ISB	ISB MECH WA – STR25 PROT BOOM

Table II.1-1 Oil spill modeling scenarios: Scenario/response and number scheme (continued).

#[1]	Response	Site	Location	Oil	Bbls	Re-sponse	SIMAP SCENARIOS[2]
5 (s)	5-MECHST	Str Juan de Fuca	Neah Bay to Port Angeles	Diesel	65,000	Mech WA	MECH WA – STR65 PROT BOOM
5	5-NOREM	Str Juan de Fuca	Neah Bay to Port Angeles	Diesel	65,000	No Removal	PROT BOOM
5	5-MECHFED	Str Juan de Fuca	Neah Bay to Port Angeles	Diesel	65,000	Mech Fed	MECH FED – NR65 PROT BOOM – FED
5	5-MECH3RD	Str Juan de Fuca	Neah Bay/Port Angeles	Diesel	65,000	Mech 3rd	MECH 3RD – STR65 PROT BOOM – 3RD
6 (s)	6-MECHST	Str Juan de Fuca	Neah Bay to Port Angeles	ANS Crude	65,000	Mech WA	MECH WA – STR65 PROT BOOM
6	6-NOREM	Str Juan de Fuca	Neah Bay to Port Angeles	ANS Crude	65,000	No Removal	PROT BOOM
6	6-MECHFED	Str Juan de Fuca	Neah Bay to Port Angeles	ANS Crude	65,000	Mech Fed	MECH FED – NR65 PROT BOOM – FED
6	6-MECH3RD	Str Juan de Fuca	Neah Bay to Port Angeles	ANS Crude	65,000	Mech 3rd	MECH 3RD – STR65 PROT BOOM – 3RD
6	6-ISB	Str Juan de Fuca	Neah Bay to Port Angeles	ANS Crude	65,000	ISB	ISB MECH WA – STR65 PROT BOOM
7 (s)	7-DISP MECHST	Str Juan de Fuca	Neah Bay to Port Angeles	ANS Crude	65,000	Disp + Mech WA	DISP MECH WA – STR65 PROT BOOM
7	7-DISP MECHFED	Str Juan de Fuca	Neah Bay to Port Angeles	ANS Crude	65,000	Disp + Mech Federal	DISP MECH FED – NR65 PROT BOOM – FED
7	7-DISP MECH3RD	Str Juan de Fuca	Neah Bay to Port Angeles	ANS Crude	65,000	Disp + Mech 3rd	DISP MECH 3RD – STR65 PROT BOOM – 3RD

Table II.1-1 Oil spill modeling scenarios: Scenario/response and number scheme (continued).

#[1]	Response	Site	Location	Oil	Bbls	Re-sponse	SIMAP SCENARIOS[2]
8 (s)	8-MECHST	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS Crude	65,000	Mech WA	MECH WA – STR65 PROT BOOM
8	8-NOREM	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS Crude	65,000	No Removal	PROT BOOM
8	8-MECHFED	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS Crude	65,000	Mech Fed	MECH FED – NR65 PROT BOOM – FED
8	8-MECH3RD	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS Crude	65,000	Mech 3rd	MECH 3RD – STR65 PROT BOOM – 3RD
9 (s)	9-DISP MECHST	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS Crude	65,000	Disp + Mech WA	DISP MECH WA – STR65 PROT BOOM
9	9-DISP MECHFED	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS Crude	65,000	Disp + Mech Federal	DISP MECH FED – NR65 PROT BOOM – FED
9	9-DISP MECH3RD	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS Crude	65,000	Disp + Mech 3rd	DISP MECH 3RD – STR65 PROT BOOM – 3RD
10 (s)	10-MECHST	Inner Str/Puget Sound	Port Angeles to south end Lopez Island	ANS Crude	65,000	Mech WA	MECH WA – STR65 PROT BOOM
10	10-NOREM	Inner Str/Puget Sound	Port Angeles to south end Lopez Island	ANS Crude	65,000	No Removal	PROT BOOM
10	10-MECHFED	Inner Str/Puget Sound	Port Angeles to south end Lopez Island	ANS Crude	65,000	Mech Fed	MECH FED – NR65 PROT BOOM – FED
10	10-MECH3RD	Inner Str/Puget Sound	Port Angeles to south end Lopez Island	ANS Crude	65,000	Mech 3rd	MECH 3RD – STR65 PROT BOOM – 3RD

Table II.1-1 Oil spill modeling scenarios: Scenario/response and number scheme (continued).

#[1]	Response	Site	Location	Oil	Bbls	Re-sponse	SIMAP SCENARIOS[2]
11 (s)	11-DISP MECHST	Inner Str/Puget Sound	Port Angeles to south end Lopez Island	ANS Crude	65,000	Disp + Mech WA	DISP MECH WA – STR65 PROT BOOM
11	11-DISP MECHFED	Inner Str/Puget Sound	Port Angeles to south end Lopez Island	ANS Crude	65,000	Disp + Mech Federal	DISP MECH FED – NR65 PROT BOOM – FED
11	11-DISP MECH3RD	Inner Str/Puget Sound	Port Angeles to south end Lopez Island	ANS Crude	65,000	Disp + Mech 3rd	DISP MECH 3RD – STR65 PROT BOOM – 3RD
12 (s)	12-MECHST	Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	Mech WA	MECH WA – CR PROT BOOM
12	12-NOREM	Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	No Removal	PROT BOOM
12	12-MECHFED	Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	Mech Fed	MECH FED – RIV PROT BOOM – FED
12	12-MECH3RD	Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	Mech 3rd	MECH 3RD – CR PROT BOOM – 3RD
13 (s)	13-MECHST	Columbia River	Portland to Longview	Bunker C	25,000	Mech WA	MECH WA – CR PROT BOOM
13	13-NOREM	Columbia River	Portland to Longview	Bunker C	25,000	No Removal	PROT BOOM
13	13-MECHFED	Columbia River	Portland to Longview	Bunker C	25,000	Mech Fed	MECH FED – RIV PROT BOOM – FED
13	13-MECH3RD	Columbia River	Portland to Longview	Bunker C	25,000	Mech 3rd	MECH 3RD – CR PROT BOOM – 3RD

[1] Scenarios run in stochastic mode are indicated by an (s) listed underneath their run number.

[2] SIMAP RESPONSE SCENARIOS: PROT BOOM = protective booming; MECH WA = mechanical recovery under Washington State caps; MECH FED = mechanical recovery under Federal caps; MECH 3rd = mechanical recovery under 3rd Alternative caps; DISP = dispersant application; ISB = in situ burning. OC = outer coast; STR = Strait of Juan de Fuca; San Juan Islands; inner straits; CR = Columbia River.

NOTE: For all responses, Canada and the state of Oregon are both assumed to respond based on the equivalent of the US Federal CAPS standard.

Table II.1-2 Oil spill modeling scenarios: Scenario abbreviations.

Location	Response	Mechanical Removal	Dispersant Included	ISB	Abbreviation
Outer Coast	1-NOREM				OC-Crud-N
Outer Coast	2-MECHST	*			OC-Crud-R-ST
Outer Coast	2-MECHFED	*			OC-Crud-R-Fed
Outer Coast	2-MECH3RD	*			OC-Crud-R-3
Outer Coast	2- ISB	*		*	OC-Crud-R-ISB
Outer Coast	3- DISP MECHST	*	*		OC-Crud-C-ST
Outer Coast	3- DISP MECHFED	*	*		OC-Crud-C-Fed
Outer Coast	3- DISP MECH3RD	*	*		OC-Crud-C-3
Strait of Juan de Fuca	4-NOREM				S1-Bunk-N
Strait of Juan de Fuca	4-MECHST	*			S1-Bunk-R-ST
Strait of Juan de Fuca	4-MECHFED	*			S1-Bunk -R-Fed
Strait of Juan de Fuca	4-MECH3RD	*			S1-Bunk -R-3
Strait of Juan de Fuca	4-ISB	*		*	S1-Bunk-R-ISB
Strait of Juan de Fuca	5-NOREM				S1-Dies-N
Strait of Juan de Fuca	5-MECHST	*			S1-Dies-R-ST
Strait of Juan de Fuca	5-MECHFED	*			S1-Dies-R-Fed
Strait of Juan de Fuca	5-MECH3RD	*			S1-Dies-R-3
Strait of Juan de Fuca	6-NOREM				S2-Crud-N
Strait of Juan de Fuca	6-MECHST	*			S2-Crud-R-ST
Strait of Juan de Fuca	6-MECHFED	*			S2-Crud-R-Fed
Strait of Juan de Fuca	6-MECH3RD	*			S2-Crud-R-3
Strait of Juan de Fuca	6-ISB	*		*	S2-Crud-R-ISB
Strait of Juan de Fuca	7-DISP MECHST	*	*		S2-Crud-C-ST
Strait of Juan de Fuca	7-DISP MECHFED	*	*		S2-Crud-C-Fed
Strait of Juan de Fuca	7-DISP MECH3RD	*	*		S2-Crud-C-3
San Juan Islands	8-NOREM				SI-Crud-N
San Juan Islands	8-MECHST	*			SI-Crud-R-ST
San Juan Islands	8-MECHFED	*			SI-Crud-R-Fed
San Juan Islands	8-MECH3RD	*			SI-Crud-R-3
San Juan Islands	9-DISP MECHST	*			SI-Crud-C-ST
San Juan Islands	9-DISP MECHFED	*			SI-Crud-C-Fed
San Juan Islands	9-DISP MECH3RD	*			SI-Crud-C-3
Inner Str/Puget Sound	10-NOREM				IS-Crud-N
Inner Str/Puget Sound	10-MECHST	*			IS-Crud-R-ST
Inner Str/Puget Sound	10-MECHFED	*			IS-Crud-R-Fed
Inner Str/Puget Sound	10-MECH3RD	*			IS-Crud-R-3
Inner Str/Puget Sound	11-DISP MECHST	*	*		IS-Crud-C-ST
Inner Str/Puget Sound	11-DISP MECHFED	*	*		IS-Crud-C-Fed
Inner Str/Puget Sound	11-DISP MECH3RD	*	*		IS-Crud-C-3
Lower Columbia River	12-NOREM				C1-Bunk-N
Lower Columbia River	12-MECHST	*			C1-Bunk-R-ST
Lower Columbia River	12-MECHFED	*			C1-Bunk-R-Fed
Lower Columbia River	12-MECH3RD	*			C1-Bunk-R-3
Upper Columbia River	13-NOREM				C2-Bunk-N
Upper Columbia River	13-MECHST	*			C2-Bunk-R-ST
Upper Columbia River	13-MECHFED	*			C2-Bunk-R-Fed
Upper Columbia River	13-MECH3RD	*			C2-Bunk-R-3

II.2. SUMMARY OF THE 13 MAIN STOCHASTIC SCENARIOS

The tables in this section summarize the model results for the 13 main stochastic scenarios, where 100 randomly selected dates were run for each scenario. The 100 runs of each scenario were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shore costs are presented. Because other impact indices are not necessarily correlated with shore cost, the results for other indices may not be in increasing order from 5th to 95th percentile run by shore cost. The actual 5th, 50th and 95th percentile results for the 100 values of the index were calculated by sorting only the index being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. In Sections II.3 to II.10, the individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made. A base case scenario was selected for the purpose of identifying which runs were 5th, 50th and 95th percentile ordered by shoreline cleanup cost. For the Outer Coast, no response was the base case. For all the scenarios in the Straits and the Columbia River, Washington state mechanical response was the base case used to sort the runs. For scenarios other than the base case, the 5th, 50th or 95th percentile runs for shoreline costs listed in the tables in this section (i.e., in Section II.2) are those sorted within the particular response scenario, and they are not the same runs as the base case at that location. This explains why in some cases the patterns do not appear to follow the response assumed. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for that index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact indices of a given scenario. Thus, to evaluate the various impact results within a single scenario, the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table II.2-1. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	4.4	22.5	-	4.9	16.0	5.9	5.2	-	16.3
OC-Crud-R-ST	-	0.5	3.6	-	0.7	3.7	1.1	1.5	-	4.2
OC-Crud-C-ST	-	0.5	2.7	-	0.7	3.4	1.0	1.4	-	3.9
S1-Bunk-R-ST	-	3.3	8.4	-	3.6	10.1	4.2	3.1	-	10.4
S1-Dies-R-ST	-	0.1	0.9	0.0	0.1	1.3	0.3	0.5	-	1.3
S2-Crud-R-ST	0.0	0.5	2.5	0.0	0.6	1.9	0.7	0.6	-	2.0
S2-Crud-C-ST	0.0	0.6	2.5	-	0.6	1.9	0.7	0.6	-	2.0
SI-Crud-R-ST	0.8	1.6	4.1	0.6	2.0	4.4	2.1	1.2	-	4.6
SI-Crud-C-ST	1.0	2.7	3.9	0.6	2.0	4.2	2.1	1.2	-	4.5
IS-Crud-R-ST	0.0	1.1	2.9	0.0	1.1	2.8	1.3	1.0	-	3.4
IS-Crud-C-ST	0.0	1.1	2.2	0.0	1.0	2.7	1.2	1.0	-	3.2
C1-Bunk-R-ST	-	7.1	26.6	-	7.2	25.1	9.1	8.1	-	25.3
C2-Bunk-R-ST	2.6	10.4	21.1	2.9	9.7	22.3	10.8	6.1	-	22.9

Table II.2-2. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	-	-	-	-	-	-	-	-
OC-Crud-R-ST	-	-	-	-	-	-	-	-	-	-
OC-Crud-C-ST	-	-	-	-	-	-	-	-	-	-
S1-Bunk-R-ST	0.0001	0.0371	0.4376	-	0.0307	0.6789	0.1486	0.3081	-	0.7648
S1-Dies-R-ST	-	-	-	-	-	-	-	-	-	-
S2-Crud-R-ST	-	-	-	-	-	-	-	-	-	-
S2-Crud-C-ST	0.0002	-	-	-	-	0.0004	0.0001	0.0006	-	0.0013
SI-Crud-R-ST	-	-	-	-	-	0.0006	0.0009	0.0078	-	0.0165
SI-Crud-C-ST	-	-	-	-	-	0.0005	0.0010	0.0076	-	0.0162
IS-Crud-R-ST	-	-	-	-	-	0.0000	0.0001	0.0004	-	0.0009
IS-Crud-C-ST	0.0003	-	-	-	-	0.0006	0.0001	0.0003	-	0.0007
C1-Bunk-R-ST	0.0001	0.0003	2.4265	-	0.0369	2.4424	0.3864	0.9482	-	2.2828
C2-Bunk-R-ST	0.3927	1.2408	7.3153	0.1495	1.3521	7.5492	2.2715	2.4709	-	7.2133

Table II.2-3. Summary of results for all stochastic scenarios of 100 runs each: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	9.9	1.4	5.5	0.3	1.6	6.3	2.5	2.1	-	6.7
OC-Crud-R-ST	0.2	0.1	4.0	0.1	0.5	4.1	1.1	1.5	-	4.1
OC-Crud-C-ST	13.4	9.2	1.4	1.4	7.2	15.4	7.6	4.6	-	16.7
S1-Bunk-R-ST	0.0	0.2	2.0	0.0	0.5	1.7	0.7	0.7	-	2.0
S1-Dies-R-ST	0.1	0.2	53.7	0.3	9.4	60.9	18.9	20.1	-	59.0
S2-Crud-R-ST	0.0	0.2	3.4	0.0	0.4	3.6	1.0	1.5	-	4.0
S2-Crud-C-ST	10.8	1.6	3.4	0.2	3.3	13.8	4.7	4.4	-	13.5
SI-Crud-R-ST	0.1	2.2	0.9	0.2	0.8	3.4	1.1	1.0	-	3.0
SI-Crud-C-ST	3.7	1.0	1.0	0.3	1.3	7.6	2.3	2.5	-	7.4
IS-Crud-R-ST	0.0	2.4	0.6	0.0	0.4	3.3	0.9	1.0	-	2.9
IS-Crud-C-ST	13.9	6.5	0.4	0.7	5.3	15.3	6.5	4.5	-	15.5
C1-Bunk-R-ST	0.0	0.1	0.7	0.0	1.1	4.0	1.4	1.3	-	3.9
C2-Bunk-R-ST	0.7	3.5	0.4	0.2	2.2	5.7	2.3	1.9	-	6.1

Table II.2-4. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass mechanically removed and/or burned (%).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	-	-	-	-	-	-	-	-
OC-Crud-R-ST	70	69	61	45	67	73	65	10	45	85
OC-Crud-C-ST	57	63	60	45	61	66	59	9	42	77
S1-Bunk-R-ST	91	88	80	79	87	91	85	10	66	104
S1-Dies-R-ST	74	71	11	9	54	72	48	20	7	89
S2-Crud-R-ST	73	68	62	61	68	74	67	8	51	83
S2-Crud-C-ST	64	68	61	56	65	71	64	8	48	79
SI-Crud-R-ST	72	67	65	63	68	72	68	3	62	73
SI-Crud-C-ST	67	68	65	61	67	71	66	3	60	73
IS-Crud-R-ST	74	72	67	64	70	74	69	3	63	76
IS-Crud-C-ST	62	68	63	58	64	70	64	4	57	72
C1-Bunk-R-ST	89	82	61	54	80	88	76	11	54	98
C2-Bunk-R-ST	85	78	67	46	77	85	73	14	45	101

Table II.2-5. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	1,759	3,825	853	428	1,770	6,548	2,553	2,099	-	6,751
OC-Crud-R-ST	656	3,432	702	255	496	5,735	1,283	1,884	-	5,051
OC-Crud-C-ST	598	297	5,371	232	446	5,555	1,139	1,774	-	4,686
S1-Bunk-R-ST	87	115	90	50	129	428	174	128	-	431
S1-Dies-R-ST	326	531	141	78	188	474	216	119	-	455
S2-Crud-R-ST	227	519	209	82	269	744	315	224	-	764
S2-Crud-C-ST	106	145	215	78	240	850	301	220	-	740
SI-Crud-R-ST	317	227	143	57	181	507	223	150	-	523
SI-Crud-C-ST	220	323	147	59	171	433	207	128	-	464
IS-Crud-R-ST	505	548	704	153	300	762	368	219	-	805
IS-Crud-C-ST	256	375	250	142	279	783	346	206	-	757
C1-Bunk-R-ST	86	209	197	17	148	344	156	106	-	368
C2-Bunk-R-ST	10	5	3	1	5	13	6	3	-	12

Table II.2-6. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	5,005	694	1,958	240	1,171	5,005	1,707	1,497	-	4,701
OC-Crud-R-ST	136	261	484	126	252	2,602	429	687	-	1,803
OC-Crud-C-ST	121	341	349	121	221	2,330	391	661	-	1,713
S1-Bunk-R-ST	319	95	485	50	129	464	174	128	-	430
S1-Dies-R-ST	220	169	170	42	106	318	128	83	-	295
S2-Crud-R-ST	118	65	120	37	117	318	135	86	-	306
S2-Crud-C-ST	64	52	115	36	112	304	127	79	-	286
SI-Crud-R-ST	55	58	124	24	83	208	96	57	-	211
SI-Crud-C-ST	81	66	121	24	84	190	93	53	-	198
IS-Crud-R-ST	139	176	162	77	147	362	173	92	-	357
IS-Crud-C-ST	114	110	94	75	135	343	162	84	-	330
C1-Bunk-R-ST	246	65	155	17	155	347	156	106	-	368
C2-Bunk-R-ST	2	6	13	1	5	13	6	3	-	12

Table II.2-7. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	86	237	-	86	213	97	66	-	229
OC-Crud-R-ST	1	31	78	1	30	83	33	27	-	87
OC-Crud-C-ST	1	41	48	1	28	77	33	29	-	91
S1-Bunk-R-ST	-	16	28	-	13	35	15	11	-	37
S1-Dies-R-ST	3	16	54	3	18	40	20	14	-	49
S2-Crud-R-ST	2	37	42	1	23	53	23	16	-	54
S2-Crud-C-ST	1	34	46	1	23	50	23	17	-	57
SI-Crud-R-ST	22	68	122	19	52	113	54	30	-	114
SI-Crud-C-ST	23	55	120	19	50	118	53	30	-	113
IS-Crud-R-ST	3	30	102	2	34	102	41	33	-	107
IS-Crud-C-ST	1	36	105	1	31	100	39	31	-	101
C1-Bunk-R-ST	-	13	69	-	18	69	24	21	-	67
C2-Bunk-R-ST	6	21	47	6	19	46	22	12	-	45

Table II.2-8. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 100 g/m^2.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	81	223	-	79	181	88	61	-	211
OC-Crud-R-ST	-	13	54	-	16	52	20	20	-	59
OC-Crud-C-ST	-	10	43	-	15	48	19	20	-	60
S1-Bunk-R-ST	-	16	28	-	13	35	15	11	-	37
S1-Dies-R-ST	-	7	36	-	9	28	11	10	-	32
S2-Crud-R-ST	0	20	33	-	14	33	14	11	-	36
S2-Crud-C-ST	-	15	34	-	13	32	14	11	-	36
SI-Crud-R-ST	11	35	77	9	34	73	35	21	-	77
SI-Crud-C-ST	13	35	76	10	34	72	35	20	-	76
IS-Crud-R-ST	-	17	57	-	22	60	25	20	-	65
IS-Crud-C-ST	-	20	59	-	20	59	23	19	-	61
C1-Bunk-R-ST	-	13	69	-	18	69	24	21	-	67
C2-Bunk-R-ST	6	21	47	6	19	45	22	12	-	45

Table II.2-9. Summary of results for all stochastic scenarios of 100 runs each: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	11,688	58,819	-	18,475	60,328	23,090	18,726	-	60,542
OC-Crud-R-ST	754	19,229	37,328	377	14,328	59,197	18,174	16,590	-	51,354
OC-Crud-C-ST	754	31,672	11,311	754	14,705	56,180	18,637	17,625	-	53,887
S1-Bunk-R-ST	-	-	376	-	-	1,314	267	557	-	1,381
S1-Dies-R-ST	3,380	11,453	44,496	3,192	15,583	37,362	16,390	11,632	-	39,654
S2-Crud-R-ST	1,690	26,848	16,146	1,127	11,265	33,044	12,731	10,197	-	33,125
S2-Crud-C-ST	1,127	26,285	20,277	751	10,514	35,860	13,154	11,052	-	35,258
SI-Crud-R-ST	11,493	46,519	62,208	6,750	21,709	59,654	26,374	17,459	-	61,292
SI-Crud-C-ST	14,229	24,445	62,573	7,297	21,344	62,573	26,054	17,740	-	61,534
IS-Crud-R-ST	2,919	17,148	56,370	1,277	16,054	70,600	22,747	21,860	-	66,467
IS-Crud-C-ST	1,095	15,689	68,046	1,277	15,506	68,046	21,537	20,572	-	62,681
C1-Bunk-R-ST	-	-	502	-	167	1,506	296	404	-	1,105
C2-Bunk-R-ST	-	669	502	-	167	1,339	300	378	-	1,055

Table II.2-10. Summary of results for all stochastic scenarios of 100 runs each: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	74,655	177,970	-	62,967	177,970	74,026	52,710	-	179,446
OC-Crud-R-ST	-	11,689	40,721	-	12,066	39,213	14,701	14,792	-	44,285
OC-Crud-C-ST	-	9,803	36,574	-	10,934	38,459	14,215	15,120	-	44,455
S1-Bunk-R-ST	-	15,771	27,787	-	12,579	37,550	14,526	10,842	-	36,210
S1-Dies-R-ST	-	4,694	9,012	-	2,253	12,391	3,565	4,424	-	12,413
S2-Crud-R-ST	-	10,138	25,909	-	9,951	24,783	10,634	9,027	-	28,687
S2-Crud-C-ST	-	7,322	25,909	-	10,138	25,346	10,264	9,135	-	28,534
SI-Crud-R-ST	10,763	21,709	59,471	7,844	26,999	59,289	27,979	17,139	-	62,257
SI-Crud-C-ST	8,392	30,648	57,647	7,480	26,087	57,647	27,432	16,581	-	60,594
IS-Crud-R-ST	-	12,952	45,789	-	17,513	45,789	18,728	14,624	-	47,976
IS-Crud-C-ST	-	19,885	37,398	-	16,601	41,411	17,415	13,975	-	45,365
C1-Bunk-R-ST	-	13,054	68,786	-	17,573	70,125	23,889	21,227	-	66,343
C2-Bunk-R-ST	5,858	20,084	46,360	5,858	19,582	46,360	21,389	11,715	-	44,819

Table II.2-11. Summary of results for all stochastic scenarios of 100 runs each: Cost (2003$) for shoreline cleanup (per area costs only).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	3,122,300	8,262,200	-	3,122,300	8,262,200	3,544,100	2,522,600	-	8,589,300
OC-Crud-R-ST	5,279	647,390	1,977,200	5,279	647,390	1,977,200	777,970	710,010	-	2,197,990
OC-Crud-C-ST	5,279	631,930	1,954,200	5,279	631,930	1,954,200	764,370	741,530	-	2,247,430
S1-Bunk-R-ST	-	1,241,800	3,443,300	-	1,241,800	3,443,300	1,508,000	1,127,800	-	3,763,600
S1-Dies-R-ST	13,706	99,319	232,620	13,706	88,805	232,620	98,654	71,931	-	242,516
S2-Crud-R-ST	14,269	596,100	1,571,600	14,269	596,100	1,571,600	637,350	473,910	-	1,585,170
S2-Crud-C-ST	8,449	582,020	1,628,000	8,449	582,020	1,628,000	618,540	492,650	-	1,603,840
SI-Crud-R-ST	580,300	1,668,900	3,667,900	580,300	1,668,900	3,667,900	1,735,700	949,250	-	3,634,200
SI-Crud-C-ST	534,330	1,690,400	3,560,600	534,330	1,690,400	3,560,600	1,692,800	929,500	-	3,551,800
IS-Crud-R-ST	21,527	1,079,600	2,696,100	21,527	1,079,600	2,696,100	1,136,600	803,960	-	2,744,520
IS-Crud-C-ST	19,702	1,012,100	2,488,300	19,702	1,012,100	2,488,300	1,060,000	764,750	-	2,589,500
C1-Bunk-R-ST	-	1,757,600	7,282,300	-	1,757,600	7,282,300	2,361,600	2,206,200	-	6,774,000
C2-Bunk-R-ST	582,760	1,708,500	4,521,500	582,760	1,708,500	4,521,500	1,951,900	1,139,000	-	4,229,900

Table II.2-12. Summary of results for all stochastic scenarios of 100 runs each: Total number of waterfowl oiled.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	275,245	49,834	115,927	26,080	74,134	271,291	102,764	78,294	-	259,352
OC-Crud-R-ST	20,638	27,180	38,802	20,112	26,686	85,669	35,961	35,910	-	107,782
OC-Crud-C-ST	19,850	31,358	31,768	19,847	24,888	71,952	33,984	34,541	-	103,066
S1-Bunk-R-ST	7,907	4,550	10,401	3,870	5,050	9,550	5,734	1,925	1,884	9,584
S1-Dies-R-ST	13,291	10,877	10,915	4,898	7,885	16,825	8,933	3,930	1,073	16,794
S2-Crud-R-ST	7,191	5,617	7,260	4,799	7,141	12,055	7,686	2,539	2,608	12,763
S2-Crud-C-ST	5,598	5,237	7,099	4,755	6,965	11,993	7,459	2,346	2,767	12,150
SI-Crud-R-ST	2,515	2,649	5,724	1,048	3,796	9,075	4,430	2,660	-	9,749
SI-Crud-C-ST	3,700	3,005	5,559	1,090	3,833	8,315	4,248	2,438	-	9,124
IS-Crud-R-ST	7,022	7,637	7,404	5,975	7,156	10,570	7,596	1,542	4,512	10,679
IS-Crud-C-ST	6,593	6,524	6,267	5,947	6,942	10,342	7,400	1,412	4,576	10,224
C1-Bunk-R-ST	34,160	15,451	24,739	10,510	24,004	44,209	24,888	10,877	3,134	46,642
C2-Bunk-R-ST	72	178	378	49	159	379	170	92	-	354

Table II.2-13. Summary of results for all stochastic scenarios of 100 runs each: Total number of seabirds oiled.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	142,309	22,807	57,846	10,214	35,690	140,212	50,868	41,508	-	133,883
OC-Crud-R-ST	7,329	10,797	16,959	7,050	10,535	41,805	15,452	19,038	-	53,528
OC-Crud-C-ST	6,911	13,012	13,230	6,910	9,582	34,533	14,404	18,312	-	51,028
S1-Bunk-R-ST	2,442	493	3,890	98	784	3,396	1,182	1,116	-	3,415
S1-Dies-R-ST	3,014	2,300	2,312	535	1,417	4,057	1,727	1,161	-	4,048
S2-Crud-R-ST	1,557	902	1,586	562	1,536	3,582	1,763	1,057	-	3,877
S2-Crud-C-ST	894	744	1,519	543	1,463	3,556	1,669	976	-	3,621
SI-Crud-R-ST	203	214	474	79	311	758	365	225	-	815
SI-Crud-C-ST	303	244	461	82	314	694	350	206	-	762
IS-Crud-R-ST	1,777	2,809	2,418	19	2,000	7,733	2,764	2,557	-	7,879
IS-Crud-C-ST	1,055	940	509	-	1,642	7,350	2,441	2,335	-	7,111
C1-Bunk-R-ST	2,693	1,205	1,944	812	1,885	3,493	1,956	865	225	3,686
C2-Bunk-R-ST	4	5	7	3	5	7	5	1	2	7

Table II.2-14. Summary of results for all stochastic scenarios of 100 runs each: Total number of wading birds and shorebirds oiled.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	64	405	-	63	922	151	290	-	731
OC-Crud-R-ST	-	11	43	-	13	41	19	42	-	103
OC-Crud-C-ST	-	8	34	-	12	38	19	42	-	102
S1-Bunk-R-ST	-	-	-	-	-	-	-	-	-	-
S1-Dies-R-ST	35	32	18	-	30	35	28	9	10	45
S2-Crud-R-ST	-	189	367	-	109	394	149	194	-	536
S2-Crud-C-ST	-	124	380	-	101	370	136	172	-	480
SI-Crud-R-ST	34	108	238	29	104	225	109	64	-	237
SI-Crud-C-ST	40	107	233	31	106	222	107	63	-	233
IS-Crud-R-ST	1	1	2	1	1	3	2	4	-	9
IS-Crud-C-ST	1	1	2	1	1	2	2	4	-	10
C1-Bunk-R-ST	1,122	1,793	2,110	1,122	1,219	3,333	1,736	1,576	-	4,888
C2-Bunk-R-ST	95	35	114	16	61	414	131	202	-	534

Table II.2-15. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	417,553	72,706	174,178	36,338	109,874	411,681	153,783	119,773	-	393,329
OC-Crud-R-ST	27,967	37,988	55,803	27,174	37,231	127,518	51,432	54,953	-	161,339
OC-Crud-C-ST	26,761	44,378	45,032	26,757	34,492	106,511	48,407	52,859	-	154,125
S1-Bunk-R-ST	10,348	5,044	14,290	3,968	5,834	12,946	6,916	3,042	833	12,999
S1-Dies-R-ST	16,340	13,209	13,244	5,466	9,333	20,917	10,688	5,089	510	20,865
S2-Crud-R-ST	8,748	6,709	9,213	5,486	8,799	16,787	9,598	3,619	2,361	16,835
S2-Crud-C-ST	6,492	6,105	8,998	5,463	8,494	15,551	9,264	3,357	2,549	15,978
SI-Crud-R-ST	2,752	2,971	6,437	1,208	4,206	10,041	4,904	2,911	-	10,725
SI-Crud-C-ST	4,044	3,357	6,253	1,220	4,219	9,220	4,705	2,671	-	10,046
IS-Crud-R-ST	8,800	10,447	9,825	5,995	9,157	18,305	10,363	4,098	2,166	18,559
IS-Crud-C-ST	7,649	7,465	6,779	5,950	8,586	17,693	9,844	3,746	2,351	17,336
C1-Bunk-R-ST	37,975	18,448	28,793	12,586	27,348	48,917	28,580	11,827	4,926	52,234
C2-Bunk-R-ST	171	218	500	71	231	790	306	272	-	851

Table II.2-16. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	111.1	19.4	46.3	9.7	29.3	109.5	40.9	31.8	-	104.6
OC-Crud-R-ST	7.5	10.2	14.9	7.3	10.0	34.0	13.7	14.6	-	42.9
OC-Crud-C-ST	7.2	11.9	12.0	7.2	9.2	28.4	12.9	14.1	-	41.0
S1-Bunk-R-ST	0.8	0.4	1.2	0.3	0.5	1.1	0.6	0.3	0.0	1.1
S1-Dies-R-ST	1.2	1.0	1.0	0.4	0.7	1.6	0.8	0.4	0.1	1.6
S2-Crud-R-ST	0.7	0.5	0.7	0.5	0.7	1.1	0.7	0.2	0.3	1.1
S2-Crud-C-ST	0.5	0.5	0.7	0.5	0.7	1.1	0.7	0.2	0.3	1.1
SI-Crud-R-ST	0.2	0.3	0.5	0.1	0.3	0.7	0.4	0.2	0.0	0.7
SI-Crud-C-ST	0.3	0.3	0.5	0.1	0.3	0.6	0.4	0.2	0.0	0.7
IS-Crud-R-ST	0.7	0.8	0.8	0.4	0.7	1.6	0.8	0.4	0.0	1.6
IS-Crud-C-ST	0.6	0.6	0.5	0.4	0.7	1.5	0.8	0.4	0.1	1.5
C1-Bunk-R-ST	6.3	2.9	4.6	2.0	4.4	8.2	4.6	2.0	0.6	8.6
C2-Bunk-R-ST	2.2	3.5	6.0	1.9	3.3	6.0	3.4	1.1	1.1	5.7

Table II.2-17. Summary of results for all stochastic scenarios of 100 runs each: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	702	47	114	2	117	410	152	139	-	429
OC-Crud-R-ST	32	1	357	1	103	357	135	122	-	379
OC-Crud-C-ST	308	559	285	181	338	578	356	126	104	609
S1-Bunk-R-ST	-	-	-	-	-	-	-	-	-	-
S1-Dies-R-ST	6	30	338	30	176	504	220	176	-	571
S2-Crud-R-ST	0	23	103	0	70	245	80	76	-	232
S2-Crud-C-ST	186	96	138	27	157	447	183	123	-	430
SI-Crud-R-ST	3	269	5	0	72	357	112	115	-	342
SI-Crud-C-ST	165	48	35	5	165	481	188	156	-	501
IS-Crud-R-ST	23	291	75	1	96	456	143	145	-	432
IS-Crud-C-ST	470	508	217	145	438	909	458	216	26	890
C1-Bunk-R-ST	-	0	-	-	-	-	0	0	-	0
C2-Bunk-R-ST	-	-	-	-	-	0	0	0	-	0

Table II.2-18. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2	3	3	3	3	4	3	0	3	4
OC-Crud-R-ST	3	4	3	3	3	4	3	0	3	4
OC-Crud-C-ST	3	2	3	2	3	3	3	0	2	3
S1-Bunk-R-ST	10	10	10	10	10	10	10	6	-	21
S1-Dies-R-ST	67,739	72,878	139,688	72,874	104,520	169,375	114,144	38,077	37,990	190,298
S2-Crud-R-ST	904	1,028	10,944	905	6,433	26,630	8,669	9,481	-	27,631
S2-Crud-C-ST	22,025	9,919	15,563	1,049	17,737	56,307	21,771	16,381	-	54,532
SI-Crud-R-ST	1,085	15,085	1,132	945	4,602	18,154	6,752	6,090	-	18,932
SI-Crud-C-ST	9,560	3,354	2,684	1,170	9,191	26,040	10,799	8,283	-	27,366
IS-Crud-R-ST	-	21,734	-	-	-	36,818	8,736	13,767	-	36,269
IS-Crud-C-ST	43,155	47,752	12,875	4,183	39,362	95,298	41,996	25,320	-	92,636
C1-Bunk-R-ST	-	1	-	-	-	-	0	1	-	3
C2-Bunk-R-ST	3,630	3,630	3,630	3,630	3,630	3,630	3,630	4,123	-	11,877

Table II.2-19. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	43	1,274	-	47	813	150	281	-	713
OC-Crud-R-ST	-	-	8	-	-	59	31	132	-	295
OC-Crud-C-ST	-	-	19	-	-	59	31	136	-	304
S1-Bunk-R-ST	-	-	227	-	-	1,038	257	429	-	1,115
S1-Dies-R-ST	-	356	2,007	-	97	1,267	282	445	-	1,171
S2-Crud-R-ST	-	-	1,360	-	-	1,004	198	355	-	907
S2-Crud-C-ST	-	1,101	1,392	-	-	947	185	347	-	880
SI-Crud-R-ST	252	566	1,636	94	1,101	2,395	1,134	716	-	2,566
SI-Crud-C-ST	1,541	1,478	1,636	94	991	2,235	1,087	648	-	2,383
IS-Crud-R-ST	-	-	724	-	283	1,386	506	554	-	1,615
IS-Crud-C-ST	-	189	1,007	-	299	1,513	490	578	-	1,647
C1-Bunk-R-ST	-	15	56	-	17	59	22	20	-	61
C2-Bunk-R-ST	-	-	-	-	-	-	-	-	-	-

Table II.2-20. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2	46	1,277	3	50	817	154	282	3	717
OC-Crud-R-ST	3	4	10	3	3	63	34	132	3	299
OC-Crud-C-ST	3	2	22	2	3	62	34	137	2	308
S1-Bunk-R-ST	10	10	236	10	10	1,047	266	435	-	1,136
S1-Dies-R-ST	67,739	73,235	141,695	72,874	104,617	170,643	114,426	38,522	37,990	191,469
S2-Crud-R-ST	904	1,028	12,304	905	6,433	27,634	8,867	9,835	-	28,538
S2-Crud-C-ST	22,025	11,020	16,955	1,049	17,737	57,254	21,956	16,728	-	55,412
SI-Crud-R-ST	1,337	15,651	2,768	1,039	5,703	20,549	7,886	6,806	-	21,498
SI-Crud-C-ST	11,102	4,833	4,319	1,264	10,182	28,275	11,887	8,931	-	29,749
IS-Crud-R-ST	-	21,734	724	-	283	38,203	9,242	14,321	-	37,884
IS-Crud-C-ST	43,155	47,940	13,882	4,183	39,661	96,811	42,487	25,898	-	94,283
C1-Bunk-R-ST	-	16	56	-	17	59	22	21	-	64
C2-Bunk-R-ST	3,630	3,630	3,630	3,630	3,630	3,630	3,630	4,123	-	11,877

Table II.2-21. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	12,770	2,239	5,326	1,129	3,374	12,585	4,712	3,658	0	12,028
OC-Crud-R-ST	875	1,180	1,722	850	1,157	3,910	1,590	1,676	0	4,942
OC-Crud-C-ST	235	392	397	235	303	946	428	472	0	1,371
S1-Bunk-R-ST	69	23	103	13	30	92	39	27	4	92
S1-Dies-R-ST	303	447	671	253	452	887	514	243	41	1,000
S2-Crud-R-ST	56	39	108	29	84	243	101	77	11	256
S2-Crud-C-ST	146	80	130	29	139	394	166	111	11	387
SI-Crud-R-ST	13	72	28	6	34	114	46	37	0	120
SI-Crud-C-ST	54	26	34	8	53	143	62	45	0	152
IS-Crud-R-ST	60	159	75	21	65	324	112	106	11	325
IS-Crud-C-ST	196	210	76	32	196	525	223	144	12	511
C1-Bunk-R-ST	255	116	185	79	179	331	186	82	24	351
C2-Bunk-R-ST	3	3	3	3	3	4	3	3	0	8

Table II.2-22. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,393	420	998	212	632	2,358	883	685	0	2,254
OC-Crud-R-ST	164	221	323	159	217	733	298	314	0	926
OC-Crud-C-ST	44	73	74	44	57	177	80	88	0	257
S1-Bunk-R-ST	13	4	19	3	6	17	7	5	1	17
S1-Dies-R-ST	57	84	126	47	85	166	96	45	8	187
S2-Crud-R-ST	11	7	20	5	16	46	19	15	2	48
S2-Crud-C-ST	27	15	24	5	26	74	31	21	2	72
SI-Crud-R-ST	3	14	5	1	6	21	9	7	0	22
SI-Crud-C-ST	10	5	6	1	10	27	12	8	0	28
IS-Crud-R-ST	11	30	14	4	12	61	21	20	2	61
IS-Crud-C-ST	37	39	14	6	37	98	42	27	2	96
C1-Bunk-R-ST	48	22	35	15	34	62	35	15	4	66
C2-Bunk-R-ST	0	1	1	0	1	1	1	1	0	2

Table II.2-23. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	7,980	1,399	3,328	706	2,109	7,865	2,944	2,286	0	7,516
OC-Crud-R-ST	547	737	1,076	531	723	2,443	993	1,047	0	3,088
OC-Crud-C-ST	147	245	248	147	190	591	267	295	0	857
S1-Bunk-R-ST	43	14	65	8	19	57	24	17	2	58
S1-Dies-R-ST	189	279	420	158	283	554	321	152	25	625
S2-Crud-R-ST	35	24	68	18	52	152	63	48	7	160
S2-Crud-C-ST	91	50	81	18	87	246	104	69	7	242
SI-Crud-R-ST	8	45	18	4	21	71	29	23	0	75
SI-Crud-C-ST	34	16	21	5	33	89	39	28	0	95
IS-Crud-R-ST	37	99	47	13	41	202	70	67	7	203
IS-Crud-C-ST	123	131	47	20	122	328	140	90	7	319
C1-Bunk-R-ST	159	72	116	49	112	207	116	51	15	219
C2-Bunk-R-ST	2	2	2	2	2	2	2	2	0	5

Table II.2-24. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	953	167	397	84	252	939	352	273	0	897
OC-Crud-R-ST	65	88	128	63	86	292	119	125	0	369
OC-Crud-C-ST	18	29	30	18	23	71	32	35	0	102
S1-Bunk-R-ST	5	2	8	1	2	7	3	2	0	7
S1-Dies-R-ST	23	33	50	19	34	66	38	18	3	75
S2-Crud-R-ST	4	3	8	2	6	18	8	6	1	19
S2-Crud-C-ST	11	6	10	2	10	29	12	8	1	29
SI-Crud-R-ST	1	5	2	0	3	8	3	3	0	9
SI-Crud-C-ST	4	2	3	1	4	11	5	3	0	11
IS-Crud-R-ST	4	12	6	2	5	24	8	8	1	24
IS-Crud-C-ST	15	16	6	2	15	39	17	11	1	38
C1-Bunk-R-ST	19	9	14	6	13	25	14	6	2	26
C2-Bunk-R-ST	0	0	0	0	0	0	0	0	0	1

Table II.2-25. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of $), using WA Compensation Schedule.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	61.9	64.5	64.5	61.9	64.5	64.5	64.3	0.75	62.8	65.8
OC-Crud-R-ST	64.5	57.5	63.0	61.9	61.1	51.7	59.8	1.27	57.3	62.3
OC-Crud-C-ST	64.5	64.5	64.4	61.9	61.1	51.8	59.8	1.27	57.3	62.4
S1-Bunk-R-ST	21.3	20.5	21.2	21.7	21.1	21.4	21.1	0.71	19.7	22.5
S1-Dies-R-ST	18.1	21.0	23.2	21.5	20.0	17.4	19.6	0.42	18.8	20.5
S2-Crud-R-ST	52.8	46.6	52.3	55.8	52.5	48.0	52.0	1.67	48.7	55.4
S2-Crud-C-ST	44.5	47.6	52.3	55.7	52.5	48.0	51.5	5.62	40.3	62.8
SI-Crud-R-ST	58.6	56.9	60.0	57.2	55.6	53.6	55.9	4.10	47.7	64.1
SI-Crud-C-ST	47.0	60.6	60.0	57.2	55.6	53.6	64.8	4.38	56.1	73.6
IS-Crud-R-ST	48.9	45.4	56.0	55.0	54.8	49.6	52.7	3.39	45.9	59.5
IS-Crud-C-ST	50.2	57.1	59.6	55.0	54.8	49.7	52.7	3.19	46.3	59.1
C1-Bunk-R-ST	30.9	27.6	27.9	14.1	28.0	29.5	26.7	6.09	14.5	38.9
C2-Bunk-R-ST[1]	–	–	–	–	–	–	–	–	–	–

[1] Note that the Washington Compensation Schedule is not applicable to spills in this location. Thus, NRDA costs using that method are not presented.

II.3. COMPARISON OF ALTERNATIVE RESPONSES: OUTER COAST AT DUNTZ ROCK OFF CAPE FLATTERY – ALASKAN NORTH SLOPE CRUDE

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). The tables in this section summarize the model results for the alternate response scenarios for Outer Coast spills at Duntz Rock off Cape Flattery of Alaskan North Slope Crude. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup.

The main stochastic scenario assuming no response was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs. The 100 main stochastic scenario runs of this base case were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shore costs are presented. Because each impact index is not necessarily correlated with shore cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th or 95th percentile runs for shoreline costs *using the base case* were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. In Section II.2, the individual runs identified as the 5th, 50th or 95th percentile runs for shoreline costs (and their dates and times) varied by stochastic scenario, and for the alternate scenarios other than the base case, they are not the same runs as those reported in this section. Thus, in this section, the alternate response scenarios are labeled with “-base”.

This indicates the base case 5th, 50th or 95th percentile runs for shoreline costs were rerun with the same start date and time but with the alternate response. (For scenarios other than the base case, the 5th, 50th or 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this section.)

Table II.3-1. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	4.4	22.5	5.9	5.2	-	16.3
OC-Crud-R-ST-base	-	0.4	1.8	1.1	1.5	-	4
OC-Crud-R-Fed	-	0.5	1.9	0.8	1.0	-	3
OC-Crud-R-3	-	0.4	1.4	0.6	0.7	-	2
OC-Crud-R-ISB	-	0.4	1.6	0.7	0.9	-	2
OC-Crud-C-ST-base	-	0.4	1.7	1.0	1.4	-	4
OC-Crud-C-Fed	-	0.5	1.8	0.8	0.9	-	3
OC-Crud-C-3	-	0.4	1.3	0.6	0.7	-	2

Table II.3-2. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	-	-	-	-	-
OC-Crud-R-ST-base	-	-	-	-	-	-	-
OC-Crud-R-Fed	-	-	-	-	-	-	-
OC-Crud-R-3	-	-	-	-	-	-	-
OC-Crud-R-ISB	-	-	-	-	-	-	-
OC-Crud-C-ST-base	-	-	-	-	-	-	-
OC-Crud-C-Fed	-	-	-	-	-	-	-
OC-Crud-C-3	-	-	-	-	-	-	-

Table II.3-3. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	9.9	1.4	5.5	2.5	2.1	-	6.7
OC-Crud-R-ST-base	9.0	0.2	0.5	1.1	1.5	-	4.1
OC-Crud-R-Fed	11.3	0.2	0.5	4.0	6.3	-	16.6
OC-Crud-R-3	8.5	0.2	0.5	3.1	4.7	-	12.5
OC-Crud-R-ISB	8.0	0.2	0.5	2.9	4.4	-	11.7
OC-Crud-C-ST-base	12.0	9.0	2.1	7.6	4.6	-	16.7
OC-Crud-C-Fed	13.7	9.0	1.7	8.1	5.2	-	18.5
OC-Crud-C-3	11.0	9.0	1.6	7.2	4.9	-	17.0

Table II.3-4. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed and/or burned (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	-	-	-	-	-
OC-Crud-R-ST-base	-	65	64	65	10	45	85
OC-Crud-R-Fed	10	64	63	46	31	-	107
OC-Crud-R-3	22	67	66	52	26	0	103
OC-Crud-R-ISB	21	66	65	50	26	-	102
OC-Crud-C-ST-base	-	59	63	59	9	42	77
OC-Crud-C-Fed	10	57	62	43	13	17	69
OC-Crud-C-3	21	59	66	48	24	-	97

Table II.3-5. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	1,759	3,825	853	2,553	2,099	-	6,751
OC-Crud-R-ST-base	5,754	447	664	1,283	3,004	-	7,290
OC-Crud-R-Fed	6,250	499	646	2,465	3,279	-	9,023
OC-Crud-R-3	6,114	464	631	2,403	3,215	-	8,833
OC-Crud-R-ISB	7,422	513	615	2,850	3,960	-	10,769
OC-Crud-C-ST-base	5,771	575	671	1,139	2,972	-	7,083
OC-Crud-C-Fed	4,350	506	706	1,854	2,164	-	6,181
OC-Crud-C-3	5,937	228	235	2,133	3,294	-	8,722

Table II.3-6. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	5,005	694	1,958	1,707	1,497	-	4,701
OC-Crud-R-ST-base	4,740	284	378	429	687	-	1,803
OC-Crud-R-Fed	5,256	293	389	1,979	2,838	-	7,656
OC-Crud-R-3	4,980	254	355	1,863	53	1,756	1,970
OC-Crud-R-ISB	5,893	285	370	2,183	3,213	-	8,609
OC-Crud-C-ST-base	4,806	283	373	391	661	-	1,713
OC-Crud-C-Fed	4,870	274	384	1,843	2,622	-	7,087
OC-Crud-C-3	5,010	248	358	1,872	2,718	-	7,308

Table II.3-7. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	86	237	97	66	-	229
OC-Crud-R-ST-base	-	37	35	24	21	-	65
OC-Crud-R-Fed	-	48	39	29	26	-	80
OC-Crud-R-3	-	48	37	28	25	-	78
OC-Crud-R-ISB	-	48	33	27	25	-	76
OC-Crud-C-ST-base	-	57	38	32	29	-	89
OC-Crud-C-Fed	-	53	34	29	27	-	83
OC-Crud-C-3	-	45	36	27	24	-	74

Table II.3-8. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Shoreline length (km) oiled by > 100 g/m^2. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	81	223	88	61	-	211
OC-Crud-R-ST-base	-	10	27	12	14	-	40
OC-Crud-R-Fed	-	11	27	13	13	-	39
OC-Crud-R-3	-	8	23	10	11	-	33
OC-Crud-R-ISB	-	9	24	11	12	-	35
OC-Crud-C-ST-base	-	10	25	12	13	-	37
OC-Crud-C-Fed	-	10	27	12	14	-	39
OC-Crud-C-3	-	9	25	11	12	-	36

Table II.3-9. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	11,688	58,819	23,090	18,726	-	60,542
OC-Crud-R-ST-base	-	27,525	15,459	18,174	16,590	-	51,354
OC-Crud-R-Fed	-	36,951	17,344	18,098	18,487	-	55,072
OC-Crud-R-3	-	39,590	18,852	19,481	14,644	-	48,769
OC-Crud-R-ISB	-	39,590	13,197	17,596	20,158	-	57,912
OC-Crud-C-ST-base	-	47,885	19,229	18,637	17,625	-	53,887
OC-Crud-C-Fed	-	43,738	12,443	18,727	22,536	-	63,799
OC-Crud-C-3	-	36,951	18,475	18,475	18,476	-	55,426

Table II.3-10. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	74,655	177,970	74,026	52,710	-	179,446
OC-Crud-R-ST-base	-	9,049	19,607	14,701	14,792	-	44,285
OC-Crud-R-Fed	-	10,934	21,869	10,934	10,935	-	32,803
OC-Crud-R-3	-	7,918	18,475	8,798	9,269	-	27,336
OC-Crud-R-ISB	-	8,672	19,607	9,426	9,825	-	29,077
OC-Crud-C-ST-base	-	9,049	18,475	14,215	15,120	-	44,455
OC-Crud-C-Fed	-	9,426	21,869	10,432	10,969	-	32,370
OC-Crud-C-3	-	7,918	17,344	8,421	8,683	-	25,787

Table II.3-11. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	3.1	8.3	3.5	2.5	-	8.6
OC-Crud-R-ST-base	-	0.6	0.9	0.8	0.7	-	2.2
OC-Crud-R-Fed	-	0.7	1.0	0.6	0.5	-	1.6
OC-Crud-R-3	-	0.6	0.9	0.5	0.4	-	1.2
OC-Crud-R-ISB	-	0.6	0.9	0.5	0.4	-	1.4
OC-Crud-C-ST-base	-	0.7	0.9	0.8	0.7	-	2.2
OC-Crud-C-Fed	-	0.7	0.9	0.5	0.5	-	1.5
OC-Crud-C-3	-	0.6	0.8	0.5	0.4	-	1.3

Table II.3-12. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of waterfowl oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	275,245	49,834	115,927	102,764	78,294	-	259,352
OC-Crud-R-ST-base	261,356	28,354	33,284	107,665	133,123	-	373,912
OC-Crud-R-Fed	288,354	28,823	33,864	117,014	148,406	-	413,827
OC-Crud-R-3	273,901	26,808	32,102	110,937	141,156	-	393,248
OC-Crud-R-ISB	321,652	28,443	32,890	127,662	168,015	-	463,693
OC-Crud-C-ST-base	264,839	28,302	33,017	108,719	135,224	-	379,168
OC-Crud-C-Fed	268,144	27,826	33,619	109,863	137,106	-	384,075
OC-Crud-C-3	275,491	26,503	32,251	111,415	142,123	-	395,660

Table II.3-13. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of seabirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	142,309	22,807	57,846	50,868	41,508	-	133,883
OC-Crud-R-ST-base	134,946	11,420	14,033	53,466	70,575	-	194,617
OC-Crud-R-Fed	149,258	11,668	14,341	58,422	78,678	-	215,778
OC-Crud-R-3	141,596	10,600	13,407	55,201	74,834	-	204,868
OC-Crud-R-ISB	166,912	11,467	13,824	64,068	89,073	-	242,214
OC-Crud-C-ST-base	136,792	11,392	13,891	54,025	71,689	-	197,403
OC-Crud-C-Fed	138,544	11,140	14,211	54,631	72,687	-	200,005
OC-Crud-C-3	142,439	10,438	13,485	55,454	75,346	-	206,147

Table II.3-14. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of wading birds and shorebirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	64	405	151	290	-	731
OC-Crud-R-ST-base	-	8	22	10	11	-	32
OC-Crud-R-Fed	-	9	21	10	11	-	32
OC-Crud-R-3	-	6	18	8	9	-	26
OC-Crud-R-ISB	-	8	19	9	10	-	28
OC-Crud-C-ST-base	-	8	20	9	10	-	30
OC-Crud-C-Fed	-	8	21	10	11	-	31
OC-Crud-C-3	-	7	20	9	10	-	29

Table II.3-15. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of birds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	417,553	72,706	174,178	153,783	119,773	-	393,329
OC-Crud-R-ST-base	396,302	39,782	47,339	161,141	203,690	-	568,522
OC-Crud-R-Fed	437,612	40,500	48,226	175,446	227,075	-	629,597
OC-Crud-R-3	415,497	37,415	45,527	166,146	215,982	-	598,111
OC-Crud-R-ISB	488,564	39,918	46,733	191,738	257,081	-	705,901
OC-Crud-C-ST-base	401,631	39,702	46,928	162,754	206,905	-	576,564
OC-Crud-C-Fed	406,688	38,974	47,851	164,504	209,784	-	584,072
OC-Crud-C-3	417,929	36,949	45,755	166,878	217,462	-	601,801

Table II.3-16. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of mammals oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	111.1	19.4	46.3	40.9	31.8	-	104.6
OC-Crud-R-ST-base	105.4	10.6	12.6	42.9	54.2	-	151.2
OC-Crud-R-Fed	116.4	10.8	12.9	46.7	60.4	-	167.4
OC-Crud-R-3	110.5	10.0	12.2	44.2	57.4	-	159.1
OC-Crud-R-ISB	129.9	10.7	12.5	51.0	68.3	-	187.7
OC-Crud-C-ST-base	106.8	10.6	12.5	43.3	55.0	-	153.3
OC-Crud-C-Fed	108.2	10.4	12.8	43.8	55.8	-	155.3
OC-Crud-C-3	111.2	9.9	12.2	44.4	57.8	-	160.0

Table II.3-17. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	702	47	114	152	139	-	429
OC-Crud-R-ST-base	622	45	99	135	122	-	379
OC-Crud-R-Fed	607	48	102	253	308	-	870
OC-Crud-R-3	603	46	91	247	179	-	604
OC-Crud-R-ISB	548	47	112	236	272	-	780
OC-Crud-C-ST-base	676	457	245	356	126	104	609
OC-Crud-C-Fed	599	478	259	445	172	100	790
OC-Crud-C-3	604	364	172	380	216	-	813

Table II.3-18. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2	3	3	3	0	3	4
OC-Crud-R-ST-base	2	3	3	3	1	2	4
OC-Crud-R-Fed	2	3	3	3	1	2	4
OC-Crud-R-3	2	3	3	3	1	2	4
OC-Crud-R-ISB	2	3	3	3	1	2	4
OC-Crud-C-ST-base	2	2	3	2	0	2	3
OC-Crud-C-Fed	2	2	3	2	0	2	3
OC-Crud-C-3	2	3	3	3	0	2	4

Table II.3-19. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	43	1,274	150	281	-	713
OC-Crud-R-ST-base	-	-	-	-	-	-	-
OC-Crud-R-Fed	-	-	-	-	-	-	-
OC-Crud-R-3	-	-	-	-	-	-	-
OC-Crud-R-ISB	-	-	-	-	-	-	-
OC-Crud-C-ST-base	-	-	-	-	-	-	-
OC-Crud-C-Fed	-	-	-	-	-	-	-
OC-Crud-C-3	-	-	-	-	-	-	-

Table II.3-20. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2	46	1,277	154	282	3	717
OC-Crud-R-ST-base	2	3	3	3	1	2	4
OC-Crud-R-Fed	2	3	3	3	1	2	4
OC-Crud-R-3	2	3	3	3	1	2	4
OC-Crud-R-ISB	2	3	3	3	1	2	4
OC-Crud-C-ST-base	2	2	3	2	0	2	3
OC-Crud-C-Fed	2	2	3	2	0	2	3
OC-Crud-C-3	2	3	3	3	0	2	4

Table II.3-21. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	12,770	2,239	5,326	4,712	3,658	0	12,028
OC-Crud-R-ST-base	3,532	408	1,466	1,802	1,978	0	5,758
OC-Crud-R-Fed	3,900	416	1,493	1,936	2,158	0	6,252
OC-Crud-R-3	3,703	383	1,411	1,832	2,051	0	5,934
OC-Crud-R-ISB	4,355	410	1,448	2,071	2,367	0	6,804
OC-Crud-C-ST-base	3,579	407	1,453	1,813	1,997	0	5,807
OC-Crud-C-Fed	3,624	400	1,482	1,835	2,030	0	5,894
OC-Crud-C-3	3,725	378	1,418	1,840	2,065	0	5,971

Table II.3-22. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,393	420	998	883	685	0.0021	2,254
OC-Crud-R-ST-base	662	76	275	338	371	0.0002	1,079
OC-Crud-R-Fed	731	78	280	363	404	0.0003	1,171
OC-Crud-R-3	694	72	264	343	384	0.0003	1,112
OC-Crud-R-ISB	816	77	271	388	444	0.0007	1,275
OC-Crud-C-ST-base	671	76	272	340	374	0.0002	1,088
OC-Crud-C-Fed	679	75	278	344	380	0.0006	1,104
OC-Crud-C-3	698	71	266	345	387	0.0005	1,119

Table II.3-23. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	7,980	1,399	3,328	2,944	2,286	0	7,516
OC-Crud-R-ST-base	2,207	255	916	1,126	1,236	0	3,598
OC-Crud-R-Fed	2,437	260	933	1,210	1,348	0	3,907
OC-Crud-R-3	2,314	239	882	1,145	1,282	0	3,708
OC-Crud-R-ISB	2,721	256	905	1,294	1,479	0	4,252
OC-Crud-C-ST-base	2,237	254	908	1,133	1,248	0	3,629
OC-Crud-C-Fed	2,265	250	926	1,147	1,268	0	3,683
OC-Crud-C-3	2,328	236	886	1,150	1,291	0	3,731

Table II.3-24. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	953	167	397	352	273	0.0009	897
OC-Crud-R-ST-base	263	30	109	134	148	0.0001	430
OC-Crud-R-Fed	291	31	111	144	161	0.0001	466
OC-Crud-R-3	276	29	105	137	153	0.0001	443
OC-Crud-R-ISB	325	31	108	154	177	0.0003	508
OC-Crud-C-ST-base	267	30	108	135	149	0.0001	433
OC-Crud-C-Fed	270	30	111	137	151	0.0003	440
OC-Crud-C-3	278	28	106	137	154	0.0002	445

Table II.3-25. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	61.9	64.5	64.5	64.3	0.75	62.8	65.8
OC-Crud-R-ST-base	61.9	64.5	58.6	59.8	1.27	57.3	62.3
OC-Crud-R-Fed	61.9	61.9	64.5	62.8	1.50	59.8	65.8
OC-Crud-R-3	58.0	61.0	55.5	58.2	1.40	55.4	61.0
OC-Crud-R-ISB	59.2	60.5	57.9	59.2	1.44	56.4	62.1
OC-Crud-C-ST-base	61.9	64.5	58.5	59.8	1.27	57.3	62.4
OC-Crud-C-Fed	61.9	61.9	64.5	62.8	1.50	59.8	65.8
OC-Crud-C-3	58.0	61.0	55.1	58.1	1.40	55.3	60.9

II.4. COMPARISON OF ALTERNATIVE RESPONSES: STRAIT OF JUAN DE FUCA – BUNKER C

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). The tables in this section summarize the model results for the alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs. The 100 main stochastic scenario runs of the Washington state mechanical removal base case were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shore cleanup costs are presented. Because each impact index is not necessarily correlated with shore cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th or 95th percentile runs for shoreline costs *using the base case* were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. In Section II.2, the individual runs identified as the 5th, 50th or 95th percentile runs for shoreline costs (and their dates and times) varied by stochastic scenario, and for the alternate scenarios other than the base case, they are not the same runs as those reported in this section. Thus, in this section, the alternate response scenarios are labeled with “-base”. This indicates the base case 5th, 50th or 95th percentile runs for shoreline costs were rerun with the same start date and time but with the

alternate response. (For scenarios other than the base case, the 5th, 50th or 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this section.)

Table II.4-1. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Percent of spilled hydrocarbon mass coming ashore (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	14.6	13.5	13.1	13.7	0.8	12.2	15.2
S1-Bunk-R-ST	-	3.3	8.4	4.2	3.1	-	10.4
S1-Bunk-R-Fed	-	3.6	8.2	3.9	4.1	-	12.2
S1-Bunk-R-3	-	1.8	7.2	3.0	3.7	-	10.5
S1-Bunk-R-ISB	-	3.0	-	1.0	1.8	-	4.5

Table II.4-2. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	0.0001	0.0261	0.1232	0.050	0.065	-	0.180
S1-Bunk-R-ST	0.0001	0.0371	0.4376	0.149	0.308	-	0.765
S1-Bunk-R-Fed	0.0001	0.0183	0.6311	0.217	0.359	-	0.935
S1-Bunk-R-3	0.0001	0.1015	1.5940	0.565	0.892	-	2.350
S1-Bunk-R-ISB	0.0001	0.0753	0.0001	0.025	0.043	-	0.112

Table II.4-3. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	2.5	1.5	2.5	2.1	0.6	1.0	3.3
S1-Bunk-R-ST	0.0	0.2	2.0	0.7	0.7	-	2.0
S1-Bunk-R-Fed	0.0	0.3	1.7	0.7	0.9	-	2.6
S1-Bunk-R-3	0.0	0.0	0.5	0.2	0.3	-	0.7
S1-Bunk-R-ISB	0.0	0.8	0.0	0.3	0.5	-	1.2

Table II.4-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Percent of spilled hydrocarbon mass mechanically removed and/or burned (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	-	-	-	-	-	-	-
S1-Bunk-R-ST	91	88	80	85	10	66	104
S1-Bunk-R-Fed	92	87	82	87	5	77	97
S1-Bunk-R-3	95	93	84	91	6	79	102
S1-Bunk-R-ISB	92	88	94	91	3	86	97

Table II.4-5. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	663	226	510	466	222	22	911
S1-Bunk-R-ST	87	115	90	174	128	-	431
S1-Bunk-R-Fed	292	94	374	253	144	-	540
S1-Bunk-R-3	123	85	266	158	96	-	349
S1-Bunk-R-ISB	294	168	60	174	118	-	409

Table II.4-6. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	654	953	597	734	191	352	1,117
S1-Bunk-R-ST	319	95	485	174	128	-	430
S1-Bunk-R-Fed	292	94	374	253	144	-	540
S1-Bunk-R-3	123	85	266	158	98	-	354
S1-Bunk-R-ISB	294	166	59	173	56	62	284

Table II.4-7. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	44	63	42	50	12	26	73
S1-Bunk-R-ST	-	16	28	15	11	-	37
S1-Bunk-R-Fed	-	16	27	14	14	-	42
S1-Bunk-R-3	-	8	23	11	12	-	34
S1-Bunk-R-ISB	-	11	-	4	6	-	16

Table II.4-8. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Shoreline length (km) oiled by > 100 g/m^2. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	44	63	42	50	12	26	73
S1-Bunk-R-ST	-	16	28	15	11	-	37
S1-Bunk-R-Fed	-	16	27	14	14	-	42
S1-Bunk-R-3	-	8	23	11	12	-	34
S1-Bunk-R-ISB	-	11	-	4	6	-	16

Table II.4-9. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	1,502	4,131	939	2,190	1,704	-	5,598
S1-Bunk-R-ST	-	-	376	267	557	-	1,381
S1-Bunk-R-Fed	-	-	-	-	-	-	-
S1-Bunk-R-3	-	-	188	63	108	-	279
S1-Bunk-R-ISB	-	-	-	-	-	-	-

Table II.4-10. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	42,243	58,953	41,117	47,438	9,988	27,461	67,415
S1-Bunk-R-ST	-	15,771	27,787	14,526	10,842	-	36,210
S1-Bunk-R-Fed	-	16,146	27,036	14,394	13,603	-	41,600
S1-Bunk-R-3	-	8,261	23,093	10,451	11,701	-	33,854
S1-Bunk-R-ISB	-	10,514	-	3,505	6,070	-	15,645

Table II.4-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	5.9	5.2	5.9	5.7	0.4	4.9	6.4
S1-Bunk-R-ST	-	1.2	3.4	1.5	1.1	-	3.8
S1-Bunk-R-Fed	-	1.3	3.4	1.6	1.7	-	5.0
S1-Bunk-R-3	-	0.6	2.9	1.2	1.5	-	4.2
S1-Bunk-R-ISB	-	1.5	-	0.5	0.8	-	2.2

Table II.4-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of waterfowl oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	12,939	17,432	12,088	14,153	2,871	8,411	19,895
S1-Bunk-R-ST	7,907	4,550	10,401	5,734	1,925	1,884	9,584
S1-Bunk-R-Fed	7,500	4,539	8,734	6,924	2,156	2,612	11,236
S1-Bunk-R-3	4,970	4,394	7,116	5,493	1,434	2,625	8,362
S1-Bunk-R-ISB	7,542	5,621	4,004	5,722	1,771	2,179	9,265

Table II.4-13. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of seabirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	5,363	7,972	4,870	6,068	1,667	2,735	9,402
S1-Bunk-R-ST	2,442	493	3,890	1,182	1,116	-	3,415
S1-Bunk-R-Fed	2,206	487	2,922	1,871	1,252	-	4,375
S1-Bunk-R-3	737	403	1,983	1,041	833	-	2,706
S1-Bunk-R-ISB	2,230	1,115	176	1,174	1,028	-	3,230

Table II.4-14. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of wading birds and shorebirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	-	-	-	-	-	-	-
S1-Bunk-R-ST	-	-	-	-	-	-	-
S1-Bunk-R-Fed	-	-	-	-	-	-	-
S1-Bunk-R-3	-	-	-	-	-	-	-
S1-Bunk-R-ISB	-	-	-	-	-	-	-

Table II.4-15. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of birds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	18,305	25,403	16,959	20,222	4,537	11,148	29,296
S1-Bunk-R-ST	10,348	5,044	14,290	6,916	3,042	833	12,999
S1-Bunk-R-Fed	9,705	5,025	11,656	8,795	3,408	1,980	15,611
S1-Bunk-R-3	5,708	4,797	9,099	6,534	2,267	2,000	11,069
S1-Bunk-R-ISB	9,772	6,736	4,180	6,896	2,800	1,297	12,495

Table II.4-16. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of mammals oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	1.5	2.1	1.4	1.7	0.4	0.9	2.5
S1-Bunk-R-ST	0.8	0.4	1.2	0.6	0.3	0.0	1.1
S1-Bunk-R-Fed	0.8	0.4	1.0	0.7	0.3	0.1	1.3
S1-Bunk-R-3	0.4	0.4	0.7	0.5	0.2	0.1	0.9
S1-Bunk-R-ISB	0.8	0.5	0.3	0.6	0.2	0.1	1.0

Table II.4-17. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	-	-	-	-	-	-	-
S1-Bunk-R-ST	-	-	-	-	-	-	-
S1-Bunk-R-Fed	-	-	-	-	-	-	-
S1-Bunk-R-3	-	-	-	-	-	-	-
S1-Bunk-R-ISB	-	-	-	-	-	-	-

Table II.4-18. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	10	10	10	10	6	-	21
S1-Bunk-R-ST	10	10	10	10	6	-	21
S1-Bunk-R-Fed	10	10	10	10	6	-	21
S1-Bunk-R-3	10	10	10	10	6	-	21
S1-Bunk-R-ISB	10	10	10	10	6	-	21

Table II.4-19. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	388	324	518	410	99	212	608
S1-Bunk-R-ST	-	-	227	257	429	-	1,115
S1-Bunk-R-Fed	-	-	129	43	75	-	193
S1-Bunk-R-3	-	-	97	32	56	-	145
S1-Bunk-R-ISB	-	-	-	-	-	-	-

Table II.4-20. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	398	333	528	420	104	212	628
S1-Bunk-R-ST	10	10	236	266	435	-	1,136
S1-Bunk-R-Fed	10	10	139	53	80	-	213
S1-Bunk-R-3	10	10	107	42	62	-	165
S1-Bunk-R-ISB	10	10	10	10	6	-	21

Table II.4-21. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	147	212	134	164	42	81	248
S1-Bunk-R-ST	69	23	103	39	27	4	92
S1-Bunk-R-Fed	68	25	86	59	31	7	122
S1-Bunk-R-3	31	23	62	39	21	8	80
S1-Bunk-R-ISB	68	40	17	42	26	5	93

Table II.4-22. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	27	40	25	31	8	15	46
S1-Bunk-R-ST	13	4	19	7	5	1	17
S1-Bunk-R-Fed	13	5	16	11	6	1	23
S1-Bunk-R-3	6	4	12	7	4	1	15
S1-Bunk-R-ISB	13	8	3	8	5	1	17

Table II.4-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	92	132	84	103	26	51	155
S1-Bunk-R-ST	43	14	65	24	17	2	58
S1-Bunk-R-Fed	42	15	53	37	20	5	76
S1-Bunk-R-3	19	14	39	24	13	5	50
S1-Bunk-R-ISB	43	25	11	26	16	3	58

Table II.4-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	11	16	10	12	3	6	18
S1-Bunk-R-ST	5	2	8	3	2	0.3	7
S1-Bunk-R-Fed	5	2	6	4	2	1	9
S1-Bunk-R-3	2	2	5	3	2	1	6
S1-Bunk-R-ISB	5	3	1	3	2	0.41	7

Table II.4-25. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (millions of $), using WA Compensation Schedule. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Bunk-N	22.8	21.8	22.8	22.5	0.58	21.3	23.7
S1-Bunk-R-ST	21.3	20.5	21.2	21.1	0.71	19.7	22.5
S1-Bunk-R-Fed	21.3	19.9	20.8	20.7	0.00	20.7	20.7
S1-Bunk-R-3	20.4	17.2	19.9	19.1	0.00	19.1	19.1
S1-Bunk-R-ISB	20.5	20.1	20.1	20.2	0.00	20.2	20.2

II.5. COMPARISON OF ALTERNATIVE RESPONSES: STRAIT OF JUAN DE FUCA – DIESEL

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). The tables in this section summarize the model results for the alternate response scenarios for Strait of Juan de Fuca spills of diesel. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs. The 100 main stochastic scenario runs of the Washington state mechanical removal base case were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shore cleanup costs are presented. Because each impact index is not necessarily correlated with shore cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs using the base case were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. In Section II.2, the individual runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs (and their dates and times) varied by stochastic scenario, and for the alternate scenarios other than the base case, they are not the same runs as those reported in this section. Thus, in this section, the alternate response scenarios are labeled with “-base”. This indicates the base case 5th, 50th, and 95th percentile runs for shoreline costs were rerun with the same start date and time but with

the alternate response. (For scenarios other than the base case, the 5th, 50th, and 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this section.)

Table II.5-1. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Percent of spilled hydrocarbon mass coming ashore (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	1.963	0.661	1.6	1.4	0.7	0.1	2.8
S1-Dies-R-ST	-	0.121	0.9	0.3	0.5	-	1.3
S1-Dies-R-Fed	0.001	0.144	1.0	0.4	0.5	-	1.4
S1-Dies-R-3	-	0.002	0.7	0.2	0.4	-	1.1

Table II.5-2. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	-	0.009	-	0.003	0.005	-	0.013
S1-Dies-R-ST	-	-	-	0.002	0.015	-	0.032
S1-Dies-R-Fed	-	-	-	1.343	3.003	-	7.350
S1-Dies-R-3	-	0.00010	-	0.00003	0.00006	-	0.00015

Table II.5-3. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	50.58	34.46	61.24	48.8	13.5	21.8	75.7
S1-Dies-R-ST	0.08	0.19	53.72	18.9	20.1	-	59.0
S1-Dies-R-Fed	0.08	1.31	54.82	18.7	31.3	-	81.2
S1-Dies-R-3	0.01	0.05	48.39	16.2	27.9	-	72.0

Table II.5-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Percent of spilled hydrocarbon mass mechanically removed and/or burned (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	-	-	-	-	-	-	-
S1-Dies-R-ST	74	71	11	48	20	7	89
S1-Dies-R-Fed	69	62	9	47	33	-	113
S1-Dies-R-3	80	76	19	58	34	-	126

Table II.5-5. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	513	469	247	410	143	124	695
S1-Dies-R-ST	326	531	141	216	119	-	455
S1-Dies-R-Fed	83	181	253	172	85	2	343
S1-Dies-R-3	52	-	284	112	151	-	414

Table II.5-6. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Water surface area (km2) oiled by > 10.0 g/m^2 at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	463	439	172	358	162	34	682
S1-Dies-R-ST	220	169	170	128	83	-	295
S1-Dies-R-Fed	58	154	172	128	61	6	251
S1-Dies-R-3	32	74	171	101	86	-	273

Table II.5-7. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	31	56	60	49	16	17	81
S1-Dies-R-ST	3	16	54	20	14	-	49
S1-Dies-R-Fed	5	13	63	27	31	-	89
S1-Dies-R-3	4	9	57	23	29	-	82

Table II.5-8. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline length (km) oiled by > 100 g/m^2. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	19.3	38.7	46.2	35	14	7	62
S1-Dies-R-ST	-	6.9	36.4	11	10	-	32
S1-Dies-R-Fed	0.2	8.3	40.6	16	21	-	59
S1-Dies-R-3	-	0.6	38.1	13	22	-	57

Table II.5-9. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	16,897	28,162	51,443	32,167	17,618	-	67,403
S1-Dies-R-ST	3,380	11,453	44,496	16,390	11,632	-	39,654
S1-Dies-R-Fed	5,445	6,947	53,508	21,966	27,326	-	76,619
S1-Dies-R-3	3,943	8,824	48,627	20,465	24,511	-	69,487

Table II.5-10. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	13,706	9,387	9,012	10,702	2,608	5,485	15,919
S1-Dies-R-ST	-	4,694	9,012	3,565	4,424	-	12,413
S1-Dies-R-Fed	-	5,820	9,200	5,007	4,653	-	14,314
S1-Dies-R-3	-	-	8,449	2,816	4,878	-	12,572

Table II.5-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	1.72	2.4	1.7	1.9	0.4	1.1	2.7
S1-Dies-R-ST	0.01	0.1	0.2	0.1	0.1	-	0.2
S1-Dies-R-Fed	0.02	0.5	0.3	0.3	0.2	-	0.7
S1-Dies-R-3	0.01	0.1	0.3	0.1	0.1	-	0.4

Table II.5-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of waterfowl oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	26,773	25,451	10,545	20,923	9,012	2,899	38,947
S1-Dies-R-ST	13,291	10,877	10,915	8,933	3,930	1,073	16,794
S1-Dies-R-Fed	4,239	9,544	10,598	8,127	3,408	1,310	14,943
S1-Dies-R-3	2,755	5,108	10,456	6,106	3,947	-	14,000

Table II.5-13. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of seabirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	5,732	5,474	2,574	4,593	1,753	1,087	8,100
S1-Dies-R-ST	3,014	2,300	2,312	1,727	1,161	-	4,048
S1-Dies-R-Fed	1,347	2,380	2,584	2,104	663	778	3,430
S1-Dies-R-3	1,059	1,516	2,557	1,711	768	175	3,246

Table II.5-14. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of wading birds and shorebirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	1,332	262	313	636	603	-	1,843
S1-Dies-R-ST	35	32	18	28	9	10	45
S1-Dies-R-Fed	-	55	275	110	146	-	401
S1-Dies-R-3	-	2	258	87	149	-	384

Table II.5-15. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of birds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	33,837	31,198	13,432	26,156	11,098	3,961	48,351
S1-Dies-R-ST	16,340	13,209	13,244	10,688	5,089	510	20,865
S1-Dies-R-Fed	5,586	11,979	13,457	10,341	4,184	1,973	18,708
S1-Dies-R-3	3,813	6,627	13,272	7,904	4,857	-	17,617

Table II.5-16. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of mammals oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	2.5	2.3	1.0	1.9	0.8	0.3	3.5
S1-Dies-R-ST	1.2	1.0	1.0	0.8	0.4	0.1	1.6
S1-Dies-R-Fed	0.4	0.9	1.0	0.8	0.3	0.2	1.4
S1-Dies-R-3	0.3	0.5	1.1	0.7	0.4	-	1.5

Table II.5-17. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	584	194	304	361	201	-	762
S1-Dies-R-ST	6	30	338	220	176	-	571
S1-Dies-R-Fed	5	93	322	140	164	-	468
S1-Dies-R-3	-	19	302	107	169	-	446

Table II.5-18. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	123,187	64,807	81,257	89,750	30,103	29,545	149,956
S1-Dies-R-ST	67,739	72,878	139,688	114,144	38,077	37,990	190,298
S1-Dies-R-Fed	36,367	49,670	84,007	56,681	24,582	7,518	105,845
S1-Dies-R-3	35,680	38,518	80,993	51,730	25,382	967	102,494

Table II.5-19. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	907	1,068	2,234	1,403	724	-	2,851
S1-Dies-R-ST	-	356	2,007	282	445	-	1,171
S1-Dies-R-Fed	-	227	1,813	680	988	-	2,656
S1-Dies-R-3	-	32	1,845	626	1,056	-	2,738

Table II.5-20. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	124,094	65,875	83,491	91,153	30,827	29,545	152,807
S1-Dies-R-ST	67,739	73,235	141,695	114,426	38,522	37,990	191,469
S1-Dies-R-Fed	36,367	49,897	85,820	57,361	25,570	7,518	108,500
S1-Dies-R-3	35,680	38,551	82,839	52,356	26,438	967	105,233

Table II.5-21. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	742	464	424	543	215	115	972
S1-Dies-R-ST	303	447	671	514	243	41	1,000
S1-Dies-R-Fed	162	269	438	290	145	22	579
S1-Dies-R-3	148	182	424	251	152	6	555

Table II.5-22. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	139	87	79	102	40	22	182
S1-Dies-R-ST	57	84	126	96	45	8	187
S1-Dies-R-Fed	30	50	82	54	27	4	109
S1-Dies-R-3	28	34	79	47	28	1	104

Table II.5-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	463	290	265	339	134	72	608
S1-Dies-R-ST	189	279	420	321	152	25	625
S1-Dies-R-Fed	101	168	274	181	90	14	362
S1-Dies-R-3	93	113	265	157	95	4	347

Table II.5-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	55	35	32	41	16	9	73
S1-Dies-R-ST	23	33	50	38	18	3	75
S1-Dies-R-Fed	12	20	33	22	11	2	43
S1-Dies-R-3	11	14	32	19	11	0.5	41

Table II.5-25. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (millions of $), using WA Compensation Schedule. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S1-Dies-N	21.8	22.9	23.8	22.8	1.00	20.8	24.8
S1-Dies-R-ST	18.1	21.0	23.2	19.6	0.42	18.8	20.5
S1-Dies-R-Fed	20.5	21.8	23.6	22.0	1.12	19.8	24.2
S1-Dies-R-3	15.3	18.1	21.3	18.2	1.04	16.1	20.2

II.6. COMPARISON OF ALTERNATIVE RESPONSES: STRAIT OF JUAN DE FUCA – ALASKAN NORTH SLOPE CRUDE

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). The tables in this section summarize the model results for the alternate response scenarios for Strait of Juan de Fuca spills of Alaskan North Slope Crude. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs. The 100 main stochastic scenario runs of the Washington state mechanical removal base case were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shore cleanup costs are presented. Because each impact index is not necessarily correlated with shore cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs using the base case were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. In Section II.2, the individual runs identified as the 5th, 50th, and 95th percentile runs for

shoreline costs (and their dates and times) varied by stochastic scenario, and for the alternate scenarios other than the base case, they are not the same runs as those reported in this section. Thus, in this section, the alternate response scenarios are labeled with "-base". This indicates the base case 5th, 50th, and 95th percentile runs for shoreline costs were rerun with the same start date and time but with the alternate response. (For scenarios other than the base case, the 5th, 50th, and 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this section.)

Table II.6-1. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	6.8808	5.3	3.7	5.3	1.6	2.1	8.5
S2-Crud-R-ST	0.0007	0.5	2.5	0.7	0.6	-	2.0
S2-Crud-R-Fed	0.9946	0.9	2.7	1.0	1.0	-	3.0
S2-Crud-R-3	-	0.8	2.5	0.7	1.0	-	2.8
S2-Crud-R-ISB	-	0.4	2.5	1.0	1.4	-	3.7
S2-Crud-C-ST-base	-	0.4	2.5	0.7	0.6	-	2.0
S2-Crud-C-Fed	0.6053	0.5	2.5	1.2	1.1	-	3.4
S2-Crud-C-3	-	0.3	2.4	0.9	1.3	-	3.6

Table II.6-2. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	-	-	-	-	-	-	-
S2-Crud-R-ST	-	-	-	-	0.0005	-	0.0010
S2-Crud-R-Fed	-	-	-	-	-	-	-
S2-Crud-R-3	-	-	-	-	-	-	-
S2-Crud-R-ISB	-	-	-	-	-	-	-
S2-Crud-C-ST-base	0.0004	-	-	0.0001	0.0006	-	0.0013
S2-Crud-C-Fed	0.0001	-	-	-	0.0001	-	0.0002
S2-Crud-C-3	0.0003	-	-	0.0001	0.0002	-	0.0005

Table II.6-3. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	1.23	1.32	3.61	2.1	1.3	-	4.7
S2-Crud-R-ST	0.05	0.16	3.43	1.0	1.5	-	4.0
S2-Crud-R-Fed	0.19	0.21	3.43	0.8	1.5	-	3.7
S2-Crud-R-3	0.01	0.19	3.43	0.8	1.5	-	3.7
S2-Crud-R-ISB	0.05	0.15	3.43	1.2	1.9	-	5.1
S2-Crud-C-ST-base	15.67	2.95	3.43	4.7	4.4	-	13.5
S2-Crud-C-Fed	16.67	2.84	3.43	7.6	7.8	-	23.3
S2-Crud-C-3	12.00	3.06	3.43	6.2	5.1	-	16.3

Table II.6-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed and/or burned (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	-	-	-	-	-	-	-
S2-Crud-R-ST	73	68	62	67	8	51	83
S2-Crud-R-Fed	64	65	60	65	3	58	72
S2-Crud-R-3	78	67	65	72	5	61	83
S2-Crud-R-ISB	74	69	62	68	6	56	80
S2-Crud-C-ST-base	59	66	61	64	8	48	79
S2-Crud-C-Fed	50	64	60	58	7	44	72
S2-Crud-C-3	67	67	64	66	1.7	63	69

Table II.6-5. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	1,706	560	480	915	686	-	2,287
S2-Crud-R-ST	227	519	209	315	224	-	764
S2-Crud-R-Fed	441	239	176	231	138	-	507
S2-Crud-R-3	109	40	2	45	54	-	153
S2-Crud-R-ISB	262	174	177	204	50	104	305
S2-Crud-C-ST-base	108	151	209	301	51	199	402
S2-Crud-C-Fed	309	179	189	226	72	82	370
S2-Crud-C-3	95	129	174	133	40	54	212

Table II.6-6. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	968	308	449	575	347	-	1,270
S2-Crud-R-ST	118	65	120	135	86	-	306
S2-Crud-R-Fed	214	110	121	126	72	-	270
S2-Crud-R-3	67	95	115	86	50	-	185
S2-Crud-R-ISB	99	50	115	88	34	20	156
S2-Crud-C-ST-base	67	56	115	127	79	-	286
S2-Crud-C-Fed	195	59	118	124	68	-	260
S2-Crud-C-3	57	39	113	70	39	-	147

Table II.6-7. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	107.8	78	67	84	21	43	126
S2-Crud-R-ST	1.7	37	42	23	16	-	54
S2-Crud-R-Fed	29.5	36	41	35	6	24	47
S2-Crud-R-3	0.2	35	43	26	23	-	72
S2-Crud-R-ISB	0.2	29	42	24	21	-	66
S2-Crud-C-ST-base	-	29	46	25	23	-	72
S2-Crud-C-Fed	19.7	27	43	30	12	6	54
S2-Crud-C-3	-	21	41	21	20	-	61

Table II.6-8. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Shoreline length (km) oiled by > 100 g/m^2. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	100.6	75	62	79	20	40	119
S2-Crud-R-ST	0.2	20	33	14	11	-	36
S2-Crud-R-Fed	19.9	24	35	26	8	10	42
S2-Crud-R-3	-	22	33	18	17	-	52
S2-Crud-R-ISB	-	15	32	15	16	-	47
S2-Crud-C-ST-base	-	13	34	16	17	-	50
S2-Crud-C-Fed	15.8	17	34	22	10	2	42
S2-Crud-C-3	-	11	32	14	16	-	46

Table II.6-9. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	21,403	14,269	13,330	16,334	4,415	7,504	25,164
S2-Crud-R-ST	1,690	26,848	16,146	12,731	10,197	-	33,125
S2-Crud-R-Fed	12,016	18,024	14,457	14,569	3,479	7,612	21,526
S2-Crud-R-3	188	18,963	17,461	9,876	8,193	-	26,262
S2-Crud-R-ISB	188	21,591	15,583	12,454	11,039	-	34,532
S2-Crud-C-ST-base	-	21,591	20,277	13,154	11,052	-	35,258
S2-Crud-C-Fed	9,387	15,020	18,587	14,331	4,638	5,054	23,608
S2-Crud-C-3	-	14,832	15,771	10,201	8,847	-	27,895

Table II.6-10. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	86,364	64,022	54,072	68,153	16,538	35,077	101,229
S2-Crud-R-ST	-	10,138	25,909	10,634	9,027	-	28,687
S2-Crud-R-Fed	17,461	17,648	26,473	13,180	10,808	-	34,796
S2-Crud-R-3	-	16,334	25,722	9,012	11,526	-	32,064
S2-Crud-R-ISB	-	7,322	26,097	11,140	13,461	-	38,062
S2-Crud-C-ST-base	-	7,510	25,909	10,264	9,135	-	28,534
S2-Crud-C-Fed	10,326	11,640	24,783	15,583	7,994	-	31,571
S2-Crud-C-3	-	6,196	24,783	10,326	12,897	-	36,120

Table II.6-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	5.112	3.0	2.7	3.6	1.3	1.0	6.2
S2-Crud-R-ST	0.014	0.6	1.6	0.6	0.5	-	1.6
S2-Crud-R-Fed	0.903	0.8	1.6	0.8	0.6	-	1.9
S2-Crud-R-3	0.001	0.8	1.6	0.5	0.7	-	1.9
S2-Crud-R-ISB	0.001	0.5	1.6	0.7	0.8	-	2.3
S2-Crud-C-ST-base	-	0.5	1.6	0.6	0.5	-	1.6
S2-Crud-C-Fed	0.574	0.6	1.6	0.9	0.6	-	2.1
S2-Crud-C-3	-	0.4	1.5	0.6	0.8	-	2.2

Table II.6-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total number of waterfowl oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	32,342	12,820	16,984	20,715	10,282	151	41,280
S2-Crud-R-ST	7,191	5,617	7,260	7,686	2,539	2,608	12,763
S2-Crud-R-Fed	10,021	6,949	7,279	8,083	1,687	4,709	11,456
S2-Crud-R-3	5,686	6,510	7,097	6,431	709	5,013	7,849
S2-Crud-R-ISB	6,613	5,161	7,097	6,290	1,007	4,276	8,305
S2-Crud-C-ST-base	5,680	5,356	7,099	6,045	927	4,191	7,899
S2-Crud-C-Fed	9,455	5,427	7,190	7,358	2,019	3,319	11,396
S2-Crud-C-3	5,392	4,850	7,051	5,765	1,147	3,471	8,058

Table II.6-13. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total number of seabirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	12,027	3,900	5,634	7,187	4,280	-	15,747
S2-Crud-R-ST	1,557	902	1,586	1,763	1,057	-	3,877
S2-Crud-R-Fed	2,735	1,456	1,594	1,928	702	524	3,333
S2-Crud-R-3	931	1,274	1,518	1,241	295	651	1,831
S2-Crud-R-ISB	1,317	712	1,518	1,182	419	344	2,021
S2-Crud-C-ST-base	928	793	1,519	1,080	386	309	1,852
S2-Crud-C-Fed	2,500	823	1,557	1,627	841	-	3,308
S2-Crud-C-3	808	583	1,499	963	477	9	1,918

Table II.6-14. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total number of wading birds and shorebirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	11,163	924	754	4,280	5,961	-	16,202
S2-Crud-R-ST	-	189	367	149	194	-	536
S2-Crud-R-Fed	192	242	395	276	106	65	488
S2-Crud-R-3	-	222	367	196	185	-	566
S2-Crud-R-ISB	-	122	347	156	176	-	509
S2-Crud-C-ST-base	-	104	380	161	196	-	554
S2-Crud-C-Fed	137	154	375	222	133	-	488
S2-Crud-C-3	-	71	347	140	183	-	506

Table II.6-15. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total number of birds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	55,532	17,645	23,371	32,183	20,423	-	73,028
S2-Crud-R-ST	8,748	6,709	9,213	9,598	3,619	2,361	16,835
S2-Crud-R-Fed	12,948	8,647	9,267	10,288	2,325	5,638	14,937
S2-Crud-R-3	6,616	8,006	8,982	7,868	1,189	5,490	10,247
S2-Crud-R-ISB	7,930	5,995	8,962	7,629	1,506	4,616	10,642
S2-Crud-C-ST-base	6,609	6,254	8,998	7,287	1,493	4,302	10,272
S2-Crud-C-Fed	12,092	6,404	9,122	9,206	2,845	3,517	14,895
S2-Crud-C-3	6,201	5,504	8,897	6,868	1,792	3,283	10,452

Table II.6-16. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total number of mammals oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	2.7	1.1	1.5	1.8	0.8	0.1	3.4
S2-Crud-R-ST	0.7	0.5	0.7	0.7	0.2	0.3	1.1
S2-Crud-R-Fed	0.9	0.7	0.7	0.7	0.1	0.5	1.0
S2-Crud-R-3	0.6	0.6	0.7	0.6	0.1	0.5	0.7
S2-Crud-R-ISB	0.6	0.5	0.7	0.6	0.1	0.4	0.8
S2-Crud-C-ST-base	0.6	0.5	0.7	0.6	0.1	0.4	0.7
S2-Crud-C-Fed	0.9	0.5	0.7	0.7	0.2	0.4	1.0
S2-Crud-C-3	0.5	0.5	0.7	0.6	0.1	0.4	0.7

Table II.6-17. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	14.6	26	134	58	66	-	190
S2-Crud-R-ST	0.4	23	103	80	76	-	232
S2-Crud-R-Fed	6.3	39	146	51	55	-	160
S2-Crud-R-3	4.7	41	106	41	38	-	118
S2-Crud-R-ISB	0.9	18	109	43	58	-	159
S2-Crud-C-ST-base	441.2	122	138	183	123	-	430
S2-Crud-C-Fed	455.6	128	136	240	187	-	614
S2-Crud-C-3	331.9	126	142	200	115	-	429

Table II.6-18. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	980	1,046	15,119	5,715	8,144	-	22,004
S2-Crud-R-ST	904	1,028	10,944	8,669	9,481	-	27,631
S2-Crud-R-Fed	936	2,365	16,703	6,668	8,720	-	24,108
S2-Crud-R-3	927	2,639	11,247	4,938	5,531	-	16,000
S2-Crud-R-ISB	907	1,001	11,753	4,554	6,235	-	17,024
S2-Crud-C-ST-base	56,265	13,446	15,563	28,425	24,134	-	76,692
S2-Crud-C-Fed	58,195	14,245	15,318	29,253	25,071	-	79,394
S2-Crud-C-3	41,615	13,985	16,136	23,912	15,369	-	54,649

Table II.6-19. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	4,565	2,396	1,683	2,881	1,501	-	5,883
S2-Crud-R-ST	-	-	1,360	198	355	-	907
S2-Crud-R-Fed	-	-	1,424	475	822	-	2,120
S2-Crud-R-3	-	-	1,489	496	860	-	2,216
S2-Crud-R-ISB	-	-	1,392	464	804	-	2,072
S2-Crud-C-ST-base	-	-	1,392	464	804	-	2,072
S2-Crud-C-Fed	-	-	1,457	486	841	-	2,168
S2-Crud-C-3	-	-	1,424	475	822	-	2,120

Table II.6-20. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	5,545	3,442	16,803	8,597	9,645	-	27,887
S2-Crud-R-ST	904	1,028	12,304	8,867	9,835	-	28,538
S2-Crud-R-Fed	936	2,365	18,128	7,143	9,543	-	26,228
S2-Crud-R-3	927	2,639	12,737	5,434	6,391	-	18,216
S2-Crud-R-ISB	907	1,001	13,145	5,018	7,039	-	19,095
S2-Crud-C-ST-base	56,265	13,446	16,955	28,889	24,937	-	78,764
S2-Crud-C-Fed	58,195	14,245	16,775	29,738	25,912	-	81,562
S2-Crud-C-3	41,615	13,985	17,560	24,387	16,191	-	56,769

Table II.6-21. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	304	121	240	222	138	31	497
S2-Crud-R-ST	56	39	108	101	77	11	256
S2-Crud-R-Fed	79	59	138	92	61	31	214
S2-Crud-R-3	37	56	108	67	43	16	154
S2-Crud-R-ISB	46	32	111	63	46	17	154
S2-Crud-C-ST-base	319	98	130	182	138	13	459
S2-Crud-C-Fed	366	102	130	200	149	17	497
S2-Crud-C-3	241	94	133	156	95	8	346

Table II.6-22. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	57	23	45	42	26	6	93
S2-Crud-R-ST	11	7	20	19	15	2	48
S2-Crud-R-Fed	15	11	26	17	11	6	40
S2-Crud-R-3	7	10	20	13	8	3	29
S2-Crud-R-ISB	9	6	21	12	9	3	29
S2-Crud-C-ST-base	60	18	24	34	26	2	86
S2-Crud-C-Fed	69	19	24	37	28	3	93
S2-Crud-C-3	45	18	25	29	18	2	65

Table II.6-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	190	76	150	139	86	19	311
S2-Crud-R-ST	35	24	68	63	48	7	160
S2-Crud-R-Fed	50	37	86	58	38	19	134
S2-Crud-R-3	23	35	68	42	27	10	96
S2-Crud-R-ISB	29	20	69	39	29	11	96
S2-Crud-C-ST-base	199	61	81	114	86	8	287
S2-Crud-C-Fed	229	64	81	125	93	10	310
S2-Crud-C-3	151	59	83	98	59	5	216

Table II.6-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	23	9	18	17	10	2	37
S2-Crud-R-ST	4	3	8	8	6	1	19
S2-Crud-R-Fed	6	4	10	7	5	2	16
S2-Crud-R-3	3	4	8	5	3	1	11
S2-Crud-R-ISB	3	2	8	5	3	1	11
S2-Crud-C-ST-base	24	7	10	14	10	1	34
S2-Crud-C-Fed	27	8	10	15	11	1	37
S2-Crud-C-3	18	7	10	12	7	1	26

Table II.6-25. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
S2-Crud-N	61.9	61.9	61.9	61.9	0.0002	61.9	61.9
S2-Crud-R-ST	52.8	46.6	52.3	51.5	0.0054	51.4	51.5
S2-Crud-R-Fed	61.4	58.0	59.7	59.7	0.0001	59.7	59.7
S2-Crud-R-3	48.6	52.5	51.4	50.8	0.0001	50.8	50.8
S2-Crud-R-ISB	52.2	45.8	52.3	50.1	0.0001	50.1	50.1
S2-Crud-C-ST-base	52.8	46.6	52.3	51.0	5.31	40.3	61.6
S2-Crud-C-Fed	61.4	56.0	59.8	59.1	0.0001	59.1	59.1
S2-Crud-C-3	44.5	44.0	47.4	45.3	0.0002	45.3	45.3

II.7. COMPARISON OF ALTERNATIVE RESPONSES: SAN JUAN ISLANDS – ALASKAN NORTH SLOPE CRUDE

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). The tables in this section summarize the model results for the alternate response scenarios for Strait of Georgia spills near the San Juan Islands of Alaskan North Slope Crude. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs. The 100 main stochastic scenario runs of the Washington state mechanical removal base case were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shore cleanup costs are presented. Because each impact index is not necessarily correlated with shore cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs using the base case were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. In Section II.2, the individual runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs (and their dates and times) varied by stochastic scenario, and for the alternate scenarios other than the base case, they

are not the same runs as those reported in this section. Thus, in this section, the alternate response scenarios are labeled with "-base". This indicates the base case 5th, 50th, and 95th percentile runs for shoreline costs were rerun with the same start date and time but with the alternate response. (For scenarios other than the base case, the 5th, 50th, and 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this section.)

Table II.7-1. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	24.5	12.5	20.4	19.1	6.1	6.9	31.4
SI-Crud-R-ST	0.8	1.6	4.1	2.1	1.2	-	4.6
SI-Crud-R-Fed	1.7	2.0	7.0	3.3	2.1	-	7.6
SI-Crud-R-3	0.8	1.5	3.1	2.0	0.9	0.3	3.7
SI-Crud-C-ST-base	0.8	1.6	3.9	2.1	1.2	-	4.5
SI-Crud-C-Fed	1.4	1.9	7.5	3.6	3.4	-	10.4
SI-Crud-C-3	0.8	1.6	3.0	1.8	1.1	-	4.0

Table II.7-2. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	-	-	-	-	-	-	-
SI-Crud-R-ST	-	-	-	-	-	-	-
SI-Crud-R-Fed	-	-	-	-	-	-	-
SI-Crud-R-3	-	-	-	-	-	-	-
SI-Crud-C-ST-base	-	-	-	-	-	-	-
SI-Crud-C-Fed	-	-	-	-	-	-	-
SI-Crud-C-3	-	-	-	-	-	-	-

Table II.7-3. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	7.3	2.6	4.5	4.8	2.4	0.0	9.5
SI-Crud-R-ST	0.1	2.2	0.9	1.1	1.0	-	3.0
SI-Crud-R-Fed	0.3	2.2	1.8	1.3	0.9	-	3.1
SI-Crud-R-3	0.1	2.2	0.6	1.0	0.9	-	2.9
SI-Crud-C-ST-base	1.5	2.4	1.0	2.3	2.5	-	7.4
SI-Crud-C-Fed	4.0	2.1	2.0	2.7	1.1	0.4	5.0
SI-Crud-C-3	0.1	2.2	0.6	1.0	1.1	-	3.2

Table II.7-4. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed and/or burned (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	-	-	-	-	-	-	-
SI-Crud-R-ST	72	67	65	68	3	62	73
SI-Crud-R-Fed	66	65	54	62	5	53	71
SI-Crud-R-3	74	70	71	70	3	65	75
SI-Crud-C-ST-base	71	67	65	66	3	60	73
SI-Crud-C-Fed	63	65	54	60	6	48	73
SI-Crud-C-3	74	70	71	71	2	67	76

Table II.7-5. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	1,412	716	593	907	442	24	1,790
SI-Crud-R-ST	317	227	143	223	150	-	523
SI-Crud-R-Fed	150	231	334	233	92	48	418
SI-Crud-R-3	58	194	282	203	113	-	430
SI-Crud-C-ST-base	75	198	334	207	129	-	466
SI-Crud-C-Fed	143	221	347	237	103	31	442
SI-Crud-C-3	54	205	281	180	115	-	411

Table II.7-6. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	1,076	447	367	630	389	-	1,407
SI-Crud-R-ST	55	58	124	96	57	-	211
SI-Crud-R-Fed	90	67	145	110	47	16	205
SI-Crud-R-3	39	57	102	83	41	0	166
SI-Crud-C-ST-base	45	65	121	93	53	-	198
SI-Crud-C-Fed	82	63	161	102	52	-	205
SI-Crud-C-3	37	58	103	66	33	-	133

Table II.7-7. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	493	256	301	350	126	98	602
SI-Crud-R-ST	22	68	122	54	30	-	114
SI-Crud-R-Fed	47	80	140	89	47	-	184
SI-Crud-R-3	18	64	98	60	40	-	141
SI-Crud-C-ST-base	20	70	120	70	50	-	170
SI-Crud-C-Fed	41	74	142	86	52	-	189
SI-Crud-C-3	15	70	96	60	42	-	143

Table II.7-8. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline length (km) oiled by > 100 g/m^2. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	464	212	273	316	132	53	580
SI-Crud-R-ST	11	35	77	35	21	-	77
SI-Crud-R-Fed	29	46	109	61	42	-	145
SI-Crud-R-3	11	33	62	35	25	-	86
SI-Crud-C-ST-base	11	36	76	41	33	-	106
SI-Crud-C-Fed	25	39	108	58	44	-	146
SI-Crud-C-3	9	36	61	35	26	-	87

Table II.7-9. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	105,440	89,208	59,837	84,829	23,116	38,597	131,061
SI-Crud-R-ST	11,493	46,519	62,208	26,374	17,459	-	61,292
SI-Crud-R-Fed	21,709	51,627	49,256	29,298	19,750	-	68,798
SI-Crud-R-3	6,203	44,877	50,533	28,130	18,838	-	65,806
SI-Crud-C-ST-base	9,669	48,343	62,573	26,054	17,740	-	61,534
SI-Crud-C-Fed	20,979	48,891	46,702	38,857	15,521	7,815	69,899
SI-Crud-C-3	5,108	49,438	51,262	35,269	26,137	-	87,543

Table II.7-10. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	388,020	166,920	241,350	265,430	112,500	40,430	490,430
SI-Crud-R-ST	10,763	21,709	59,471	27,979	17,139	-	62,257
SI-Crud-R-Fed	25,722	28,276	91,214	38,711	29,814	-	98,339
SI-Crud-R-3	11,311	19,520	47,431	23,132	14,678	-	52,488
SI-Crud-C-ST-base	10,763	21,344	57,647	27,432	16,581	-	60,594
SI-Crud-C-Fed	20,067	24,810	95,410	46,762	42,197	-	131,156
SI-Crud-C-3	9,486	20,067	45,060	24,871	18,267	-	61,405

Table II.7-11. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	20.7	9.8	14.2	14.9	5.5	4.0	25.9
SI-Crud-R-ST	0.6	1.7	3.7	1.7	0.9	-	3.6
SI-Crud-R-Fed	1.4	2.0	5.2	2.3	1.6	-	5.6
SI-Crud-R-3	0.6	1.5	2.8	1.5	0.8	-	3.1
SI-Crud-C-ST-base	0.6	1.7	3.6	1.7	0.9	-	3.6
SI-Crud-C-Fed	1.1	1.8	5.4	2.8	2.3	-	7.4
SI-Crud-C-3	0.5	1.6	2.8	1.6	1.1	-	3.9

Table II.7-12. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of waterfowl oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	49,889	20,702	16,972	29,188	18,024	-	65,236
SI-Crud-R-ST	2,515	2,649	5,724	365	225	-	815
SI-Crud-R-Fed	4,148	3,055	6,660	4,621	1,848	925	8,317
SI-Crud-R-3	1,768	2,595	4,667	3,010	1,493	23	5,996
SI-Crud-C-ST-base	2,058	2,979	5,559	3,532	1,815	-	7,162
SI-Crud-C-Fed	3,741	2,888	7,408	4,679	2,402	-	9,482
SI-Crud-C-3	1,683	2,666	4,722	3,024	1,551	-	6,126

Table II.7-13. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of seabirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	4,212	1,742	1,426	2,460	1,525	-	5,511
SI-Crud-R-ST	203	214	474	365	225	-	815
SI-Crud-R-Fed	341	249	554	381	156	68	694
SI-Crud-R-3	140	210	385	245	126	-	497
SI-Crud-C-ST-base	164	242	461	289	154	-	596
SI-Crud-C-Fed	307	234	617	386	203	-	792
SI-Crud-C-3	132	216	390	246	131	-	508

Table II.7-14. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of wading birds and shorebirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	1,431	652	842	975	406	163	1,787
SI-Crud-R-ST	34	108	238	109	64	-	237
SI-Crud-R-Fed	89	142	335	188	129	-	447
SI-Crud-R-3	35	102	191	109	78	-	265
SI-Crud-C-ST-base	33	111	233	126	101	-	328
SI-Crud-C-Fed	78	121	333	177	137	-	450
SI-Crud-C-3	29	110	189	109	80	-	269

Table II.7-15. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of birds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	55,532	23,097	19,243	32,624	19,932	-	72,489
SI-Crud-R-ST	2,752	2,971	6,437	4,904	2,911	-	10,725
SI-Crud-R-Fed	4,578	3,445	7,548	5,190	2,119	953	9,428
SI-Crud-R-3	1,942	2,907	5,242	3,364	1,697	-	6,757
SI-Crud-C-ST-base	2,255	3,332	6,253	3,947	2,069	-	8,084
SI-Crud-C-Fed	4,125	3,244	8,358	5,242	2,734	-	10,710
SI-Crud-C-3	1,845	2,991	5,301	3,379	1,760	-	6,900

Table II.7-16. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of mammals oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	3.5	1.5	1.3	2.1	1.3	-	4.6
SI-Crud-R-ST	0.2	0.3	0.5	0.4	0.2	0.0	0.7
SI-Crud-R-Fed	0.4	0.3	0.5	0.4	0.1	0.1	0.6
SI-Crud-R-3	0.2	0.2	0.4	0.3	0.1	0.1	0.5
SI-Crud-C-ST-base	0.2	0.3	0.5	0.3	0.1	0.1	0.6
SI-Crud-C-Fed	0.3	0.3	0.6	0.4	0.2	0.1	0.7
SI-Crud-C-3	0.2	0.3	0.4	0.3	0.1	0.1	0.5

Table II.7-17. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	33	266	10	103	142	-	387
SI-Crud-R-ST	3	269	5	112	115	-	342
SI-Crud-R-Fed	7	269	4	144	130	-	405
SI-Crud-R-3	5	244	2	122	112	-	347
SI-Crud-C-ST-base	68	282	35	188	156	-	501
SI-Crud-C-Fed	203	238	5	149	126	-	400
SI-Crud-C-3	9	296	2	102	168	-	438

Table II.7-18. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	2,543	14,919	1,363	6,275	7,509	-	21,293
SI-Crud-R-ST	1,085	15,085	1,132	6,752	6,090	-	18,932
SI-Crud-R-Fed	1,233	15,099	1,129	5,821	8,035	-	21,891
SI-Crud-R-3	1,148	13,751	1,019	5,306	7,314	-	19,933
SI-Crud-C-ST-base	4,431	15,749	2,684	7,621	7,093	-	21,806
SI-Crud-C-Fed	11,553	13,437	1,160	8,717	6,612	-	21,940
SI-Crud-C-3	1,343	16,504	1,035	6,294	8,844	-	23,981

Table II.7-19. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	19,976	8,273	12,992	13,747	5,888	1,972	25,523
SI-Crud-R-ST	252	566	1,636	1,134	716	-	2,566
SI-Crud-R-Fed	472	1,132	3,397	1,667	1,534	-	4,736
SI-Crud-R-3	315	786	1,132	744	411	-	1,566
SI-Crud-C-ST-base	252	786	1,636	891	698	-	2,287
SI-Crud-C-Fed	503	944	3,209	1,552	1,452	-	4,455
SI-Crud-C-3	346	786	1,070	734	365	5	1,463

Table II.7-20. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	22,518	23,192	14,355	20,022	13,397	1,972	46,816
SI-Crud-R-ST	1,337	15,651	2,768	7,886	6,806	-	21,498
SI-Crud-R-Fed	1,705	16,231	4,527	7,488	9,570	-	26,627
SI-Crud-R-3	1,462	14,537	2,152	6,050	7,724	-	21,499
SI-Crud-C-ST-base	4,683	16,535	4,319	8,512	7,791	-	24,094
SI-Crud-C-Fed	12,057	14,380	4,369	10,269	8,063	-	26,395
SI-Crud-C-3	1,689	17,291	2,104	7,028	9,208	5	25,445

Table II.7-21. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	233	158	82	158	116	3	389
SI-Crud-R-ST	13	72	28	46	37	0	120
SI-Crud-R-Fed	21	75	33	43	42	6	128
SI-Crud-R-3	10	67	23	34	38	2	109
SI-Crud-C-ST-base	26	77	34	46	38	2	122
SI-Crud-C-Fed	62	67	36	55	39	3	133
SI-Crud-C-3	11	79	23	38	44	1	126

Table II.7-22. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	43.7	29.6	15.4	29.6	21.7	0.52	72.9
SI-Crud-R-ST	2.5	13.5	5.3	8.6	6.9	0.02	22.5
SI-Crud-R-Fed	4.0	14.1	6.2	8.1	7.9	1.17	23.9
SI-Crud-R-3	2.0	12.6	4.3	6.3	7.1	0.33	20.5
SI-Crud-C-ST-base	4.8	14.5	6.4	8.6	7.2	0.30	22.9
SI-Crud-C-Fed	11.7	12.6	6.8	10.4	7.3	0.64	24.9
SI-Crud-C-3	2.1	14.8	4.3	7.1	8.3	0.26	23.7

Table II.7-23. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	146	99	51	99	72	1.7	243
SI-Crud-R-ST	8	45	18	29	23	0.1	75
SI-Crud-R-Fed	13	47	21	27	26	3.9	80
SI-Crud-R-3	7	42	14	21	24	1.1	68
SI-Crud-C-ST-base	16	48	21	29	24	1.0	76
SI-Crud-C-Fed	39	42	23	35	24	2.2	83
SI-Crud-C-3	7	49	14	24	28	0.9	79

Table II.7-24. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	17.4	11.8	6.1	11.8	8.6	0.21	29.0
SI-Crud-R-ST	1.0	5.4	2.1	3.4	2.8	0.01	8.9
SI-Crud-R-Fed	1.6	5.6	2.4	3.2	3.2	0.47	9.5
SI-Crud-R-3	0.8	5.0	1.7	2.5	2.8	0.13	8.1
SI-Crud-C-ST-base	1.9	5.8	2.5	3.4	2.9	0.12	9.1
SI-Crud-C-Fed	4.7	5.0	2.7	4.1	2.9	0.26	9.9
SI-Crud-C-3	0.8	5.9	1.7	2.8	3.3	0.10	9.4

Table II.7-25. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
SI-Crud-N	61.9	61.9	61.9	61.9	0.0002	61.9	61.9
SI-Crud-R-ST	52.8	46.6	52.3	52.0	1.67	48.7	55.4
SI-Crud-R-Fed	56.3	53.1	54.7	54.7	0.0001	54.7	54.7
SI-Crud-R-3	44.5	48.1	47.1	46.6	0.0001	46.6	46.6
SI-Crud-C-ST-base	52.2	45.8	52.3	50.1	0.0001	50.1	50.1
SI-Crud-C-Fed	52.8	46.6	52.3	51.5	5.62	40.3	62.8
SI-Crud-C-3	56.3	51.3	54.8	54.1	0.00	54.1	54.1

II.8. COMPARISON OF ALTERNATIVE RESPONSES: INNER STRAITS/PUGET SOUND – ALASKAN NORTH SLOPE CRUDE

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). The tables in this section summarize the model results for the alternate response scenarios for Inner Straits/Puget Sound spills of Alaskan North Slope Crude. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs. The 100 main stochastic scenario runs of the Washington state mechanical removal base case were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shore cleanup costs are presented. Because each impact index is not necessarily correlated with shore cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs using the base case were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. In Section II.2, the individual runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs (and their dates and times) varied by stochastic scenario, and for the alternate scenarios other than the base case, they

are not the same runs as those reported in this section. Thus, in this section, the alternate response scenarios are labeled with "-base". This indicates the base case 5th, 50th, and 95th percentile runs for shoreline costs were rerun with the same start date and time but with the alternate response. (For scenarios other than the base case, the 5th, 50th, and 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this section.)

Table II.8-1. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	8.9037	10.297	22.3	13.8	7.3	-	28.5
IS-Crud-R-ST	0.0002	1.146	2.9	1.3	1.0	-	3.4
IS-Crud-R-Fed	0.0391	1.296	4.5	2.3	2.1	-	6.5
IS-Crud-R-3	-	0.425	2.0	1.1	1.0	-	3.1
IS-Crud-C-ST-base	0.0001	0.504	2.3	1.2	1.0	-	3.2
IS-Crud-C-Fed	0.0005	0.940	3.4	1.5	1.8	-	5.0
IS-Crud-C-3	-	0.003	1.5	0.5	0.8	-	2.2

Table II.8-2. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	-	-	0.0172	0.0057	0.0099	-	0.0255
IS-Crud-R-ST	-	-	-	-	-	-	-
IS-Crud-R-Fed	-	-	-	-	-	-	-
IS-Crud-R-3	-	-	-	-	-	-	-
IS-Crud-C-ST-base	0.0002	0.0001	-	0.0001	0.0003	-	0.0007
IS-Crud-C-Fed	0.0003	0.0001	-	0.0001	0.0002	-	0.0005
IS-Crud-C-3	0.0001	0.0002	-	0.0001	0.0001	-	0.0003

Table II.8-3. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	6.56	6.3	5.0	6.0	0.8	4.3	7.6
IS-Crud-R-ST	0.03	2.4	0.6	0.9	1.0	-	2.9
IS-Crud-R-Fed	0.05	2.4	1.0	1.4	1.1	-	3.7
IS-Crud-R-3	0.05	2.4	0.4	1.1	1.2	-	3.6
IS-Crud-C-ST-base	10.78	8.4	10.8	6.5	4.5	-	15.5
IS-Crud-C-Fed	12.01	8.9	14.4	11.8	2.8	6	17
IS-Crud-C-3	7.94	7.6	9.0	8.2	0.7	6.7	9.7

Table II.8-4. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed and/or burned (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	-	-	-	-	-	-	-
IS-Crud-R-ST	74	72	67	69	3	63	76
IS-Crud-R-Fed	70	67	59	64	5	53	74
IS-Crud-R-3	76	76	71	72	4	65	79
IS-Crud-C-ST-base	64	66	59	64	4	57	72
IS-Crud-C-Fed	60	61	49	56	7	43	69
IS-Crud-C-3	68	70	65	68	3	62	73

Table II.8-5. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	1,078	611	2,396	1,362	926	-	3,214
IS-Crud-R-ST	505	548	704	368	219	-	805
IS-Crud-R-Fed	561	295	542	418	149	121	715
IS-Crud-R-3	246	369	357	335	68	199	471
IS-Crud-C-ST-base	281	271	414	346	80	186	505
IS-Crud-C-Fed	463	265	501	410	127	156	663
IS-Crud-C-3	162	234	360	252	100	52	453

Table II.8-6. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	779	522	2,011	1,104	796	-	2,696
IS-Crud-R-ST	139	176	162	173	92	-	357
IS-Crud-R-Fed	230	188	246	221	66	89	352
IS-Crud-R-3	110	154	120	155	67	21	288
IS-Crud-C-ST-base	124	154	149	162	84	-	330
IS-Crud-C-Fed	186	177	220	194	23	149	240
IS-Crud-C-3	107	153	109	123	26	72	174

Table II.8-7. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	217.6	202	453	291	141	10	573
IS-Crud-R-ST	2.9	30	102	41	33	-	107
IS-Crud-R-Fed	31.9	22	116	57	52	-	160
IS-Crud-R-3	0.7	45	68	38	34	-	106
IS-Crud-C-ST-base	2.9	25	82	37	41	-	118
IS-Crud-C-Fed	9.1	22	96	42	47	-	136
IS-Crud-C-3	0.2	12	61	24	32	-	89

Table II.8-8. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Shoreline length (km) oiled by > 100 g/m^2. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	202	190	428	273	134	5	542
IS-Crud-R-ST	-	17	57	25	20	-	65
IS-Crud-R-Fed	5	18	82	35	41	-	117
IS-Crud-R-3	-	16	38	18	19	-	56
IS-Crud-C-ST-base	-	10	48	19	25	-	70
IS-Crud-C-Fed	-	11	66	26	35	-	96
IS-Crud-C-3	-	1	32	11	18	-	47

Table II.8-9. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	56,005	50,533	118,210	74,916	37,594	-	150,104
IS-Crud-R-ST	2,919	17,148	56,370	22,747	21,860	-	66,467
IS-Crud-R-Fed	31,378	7,297	47,067	24,233	14,809	-	53,851
IS-Crud-R-3	730	37,215	35,209	21,526	13,879	-	49,284
IS-Crud-C-ST-base	2,919	18,243	42,506	21,537	20,572	-	62,681
IS-Crud-C-Fed	9,121	11,493	39,952	20,189	17,156	-	54,501
IS-Crud-C-3	182	12,405	35,391	15,993	17,876	-	51,745

Table II.8-10. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	161,630	151,780	335,120	216,180	103,130	9,920	422,440
IS-Crud-R-ST	-	12,952	45,789	18,728	14,624	-	47,976
IS-Crud-R-Fed	547	14,959	68,958	29,797	29,510	-	88,817
IS-Crud-R-3	-	7,844	32,472	14,959	14,011	-	42,981
IS-Crud-C-ST-base	-	6,567	39,587	17,415	13,975	-	45,365
IS-Crud-C-Fed	-	10,581	55,641	22,074	29,547	-	81,168
IS-Crud-C-3		-	25,357	8,453	14,640	-	37,733

Table II.8-11. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	7.35	8.6	18.9	11.6	6.3	-	24.3
IS-Crud-R-ST	0.02	1.1	2.7	1.1	0.8	-	2.7
IS-Crud-R-Fed	0.27	1.1	3.9	1.8	1.5	-	4.8
IS-Crud-R-3	0.01	0.9	1.9	1.0	0.7	-	2.4
IS-Crud-C-ST-base	0.04	0.6	2.3	1.1	0.8	-	2.6
IS-Crud-C-Fed	0.07	0.9	3.0	1.3	1.5	-	4.4
IS-Crud-C-3	0.00	0.1	1.5	0.5	0.8	-	2.2

Table II.8-12. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total number of waterfowl oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	17,753	13,443	38,410	23,202	13,346	-	49,894
IS-Crud-R-ST	7,022	7,637	7,404	7,596	1,542	4,512	10,679
IS-Crud-R-Fed	8,535	7,831	8,817	8,395	508	7,378	9,411
IS-Crud-R-3	6,536	7,266	6,696	6,833	384	6,065	7,601
IS-Crud-C-ST-base	6,766	7,268	7,187	7,073	270	6,534	7,613
IS-Crud-C-Fed	7,800	7,657	8,377	7,945	381	7,182	8,707
IS-Crud-C-3	6,482	7,245	6,521	6,749	430	5,890	7,609

Table II.8-13. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total number of seabirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	19,795	12,557	54,478	28,943	22,408	-	73,760
IS-Crud-R-ST	1,777	2,809	2,418	2,764	2,557	-	7,879
IS-Crud-R-Fed	4,317	3,134	4,791	4,081	853	2,374	5,788
IS-Crud-R-3	960	2,187	1,229	1,458	645	169	2,748
IS-Crud-C-ST-base	1,346	2,189	2,053	1,862	453	957	2,768
IS-Crud-C-Fed	3,082	2,842	4,051	3,325	640	2,045	4,605
IS-Crud-C-3	869	2,151	935	1,318	722	-	2,761

Table II.8-14. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total number of wading birds and shorebirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	34.5	4.3	26.0	21.6	15.6	-	52.8
IS-Crud-R-ST	1.1	1.4	2.1	2.2	3.6	-	9.3
IS-Crud-R-Fed	1.2	1.4	2.5	1.7	0.7	0.3	3.1
IS-Crud-R-3	1.1	1.4	1.7	1.4	0.3	0.8	2.0
IS-Crud-C-ST-base	1.1	1.3	1.9	1.4	0.4	0.6	2.3
IS-Crud-C-Fed	1.1	1.3	2.2	1.5	0.6	0.4	2.7
IS-Crud-C-3	1.1	1.1	1.6	1.3	0.3	0.7	1.9

Table II.8-15. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total number of birds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	37,584	26,007	92,927	52,173	35,766	-	123,704
IS-Crud-R-ST	8,800	10,447	9,825	10,363	4,098	2,166	18,559
IS-Crud-R-Fed	12,854	10,966	13,611	12,477	1,362	9,752	15,201
IS-Crud-R-3	7,497	9,454	7,927	8,293	1,029	6,235	10,350
IS-Crud-C-ST-base	8,113	9,458	9,241	8,937	722	7,493	10,382
IS-Crud-C-Fed	10,884	10,500	12,430	11,271	1,022	9,228	13,315
IS-Crud-C-3	7,352	9,397	7,457	8,069	1,151	5,766	10,371

Table II.8-16. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total number of mammals oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	3.4	2.3	8.7	4.8	3.4	-	11.6
IS-Crud-R-ST	0.7	0.8	0.8	0.8	0.4	0.0	1.6
IS-Crud-R-Fed	1.1	0.9	1.1	1.0	0.1	0.8	1.3
IS-Crud-R-3	0.6	0.7	0.6	0.6	0.1	0.4	0.8
IS-Crud-C-ST-base	0.6	0.8	0.7	0.7	0.1	0.6	0.8
IS-Crud-C-Fed	0.9	0.8	1.0	0.9	0.1	0.7	1.1
IS-Crud-C-3	0.5	0.7	0.6	0.6	0.1	0.4	0.8

Table II.8-17. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	121	282	99	167	100	-	367
IS-Crud-R-ST	23	291	75	143	145	-	432
IS-Crud-R-Fed	42	235	74	163	144	-	451
IS-Crud-R-3	42	248	71	149	130	-	410
IS-Crud-C-ST-base	444	485	556	458	216	26	890
IS-Crud-C-Fed	682	621	506	603	89	425	781
IS-Crud-C-3	344	440	555	446	106	235	658

Table II.8-18. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	1,350	20,699	-	7,350	11,580	-	30,510
IS-Crud-R-ST	-	21,734	-	8,736	13,767	-	36,269
IS-Crud-R-Fed	-	15,062	-	5,021	8,696	-	22,413
IS-Crud-R-3	-	16,628	-	5,543	9,600	-	24,742
IS-Crud-C-ST-base	40,024	45,003	53,501	46,176	6,815	32,546	59,806
IS-Crud-C-Fed	68,563	61,233	47,541	59,112	10,670	37,772	80,453
IS-Crud-C-3	28,060	39,565	53,377	40,334	12,676	14,983	65,685

Table II.8-19. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	5,002	5,442	16,578	9,007	6,560	-	22,128
IS-Crud-R-ST	-	-	724	506	554	-	1,615
IS-Crud-R-Fed	31	31	1,007	357	563	-	1,483
IS-Crud-R-3	-	-	409	136	236	-	609
IS-Crud-C-ST-base	-	-	315	105	182	-	468
IS-Crud-C-Fed	-	-	849	283	490	-	1,264
IS-Crud-C-3	-	31	189	73	101	-	276

Table II.8-20. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	6,352	26,141	16,578	16,357	18,141	-	52,638
IS-Crud-R-ST	-	21,734	724	9,242	14,321	-	37,884
IS-Crud-R-Fed	31	15,093	1,007	5,377	9,259	-	23,895
IS-Crud-R-3	-	16,628	409	5,679	9,836	-	25,351
IS-Crud-C-ST-base	40,024	45,003	53,816	46,281	6,996	32,546	60,274
IS-Crud-C-Fed	68,563	61,233	48,390	59,395	11,161	37,772	81,717
IS-Crud-C-3	28,060	39,597	53,565	40,407	12,777	14,983	65,961

Table II.8-21. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	508	294	1,248	683	573	-	1,830
IS-Crud-R-ST	60	159	75	112	106	11	325
IS-Crud-R-Fed	122	123	128	124	69	29	262
IS-Crud-R-3	39	113	48	67	43	27	153
IS-Crud-C-ST-base	190	215	256	220	39	143	297
IS-Crud-C-Fed	129	114	109	118	25	69	167
IS-Crud-C-3	135	195	230	187	57	72	302

Table II.8-22. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	95	55	234	128	107	-	343
IS-Crud-R-ST	11	30	14	21	20	2	61
IS-Crud-R-Fed	23	23	24	23	13	5	49
IS-Crud-R-3	7	21	9	13	8	5	29
IS-Crud-C-ST-base	36	40	48	41	7	27	56
IS-Crud-C-Fed	24	21	21	22	5	13	31
IS-Crud-C-3	25	37	43	35	11	14	57

Table II.8-23. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	317	184	780	427	358	-	1,144
IS-Crud-R-ST	37	99	47	70	67	7	203
IS-Crud-R-Fed	76	77	80	78	43	18	164
IS-Crud-R-3	25	71	30	42	27	17	96
IS-Crud-C-ST-base	119	134	160	138	24	90	186
IS-Crud-C-Fed	81	71	68	74	15	43	104
IS-Crud-C-3	85	122	144	117	36	45	188

Table II.8-24. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	38	22	93	51	43	-	137
IS-Crud-R-ST	4	12	6	8	8	1	24
IS-Crud-R-Fed	9	9	10	9	5	2	20
IS-Crud-R-3	3	8	4	5	3	2	11
IS-Crud-C-ST-base	14	16	19	16	3	11	22
IS-Crud-C-Fed	10	9	8	9	2	5	12
IS-Crud-C-3	10	15	17	14	4	5	23

Table II.8-25. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
IS-Crud-N	61.9	62.0	56.8	60.2	2.98	54.3	66.2
IS-Crud-R-ST	48.9	45.4	56.0	52.7	3.39	45.9	59.5
IS-Crud-R-Fed	59.0	51.1	62.2	57.4	5.34	46.7	68.1
IS-Crud-R-3	46.3	50.7	50.8	49.3	4.42	40.4	58.1
IS-Crud-C-ST-base	48.9	54.1	56.2	52.7	3.19	46.3	59.1
IS-Crud-C-Fed	54.0	51.2	62.2	55.8	5.33	45.1	66.4
IS-Crud-C-3	46.3	44.5	50.9	47.2	4.42	38.4	56.1

II.9. COMPARISON OF ALTERNATIVE RESPONSES: LOWER COLUMBIA RIVER – BUNKER C

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). The tables in this section summarize the model results for the alternate response scenarios for Lower Columbia River spills of Bunker C fuel. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs. The 100 main stochastic scenario runs of the Washington state mechanical removal base case were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shore cleanup costs are presented. Because each impact index is not necessarily correlated with shore cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs using the base case were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. In Section II.2, the individual runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs (and their dates and times) varied by stochastic scenario, and for the alternate scenarios other than the base case, they are not the same runs as those reported in this section. Thus, in this section, the alternate response scenarios are labeled with “-base”. This indicates the base case 5th, 50th, and 95th percentile runs for shoreline costs were rerun with the same start date and time but with

the alternate response. (For scenarios other than the base case, the 5th, 50th, and 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this section.)

Table II.9-1. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass coming ashore (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	57.3	59.1	38.8	33.6	-	106.1
C1-Bunk-R-ST	-	7.1	26.6	9.1	8.1	-	25.3
C1-Bunk-R-Fed	-	9.8	28.1	12.6	14.3	-	41.2
C1-Bunk-R-3	-	8.4	21.2	9.9	10.7	-	31.2

Table II.9-2. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	0.0001	0.1297	0.3001	0.14	0.15	-	0.44
C1-Bunk-R-ST	0.0001	0.0003	2.4265	0.39	0.95	-	2.28
C1-Bunk-R-Fed	0.0001	0.0678	0.9982	0.36	0.56	-	1.47
C1-Bunk-R-3	0.0001	0.1240	0.8261	0.32	0.45	-	1.21

Table II.9-3. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	0.0	4.5	6.3	3.6	3.2	-	10.0
C1-Bunk-R-ST	0.0	0.1	0.7	1.4	1.3	-	3.9
C1-Bunk-R-Fed	0.0	1.8	2.1	1.3	1.2	-	4
C1-Bunk-R-3	0.0	1.7	1.7	1.1	1.0	-	3

Table II.9-4. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass mechanically removed and/or burned (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	-	-	-	-	-	-
C1-Bunk-R-ST	89	82	61	76	11	54	98
C1-Bunk-R-Fed	89	78	59	75	15	45	105
C1-Bunk-R-3	89	82	69	80	10	60	100

Table II.9-5. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	512	250	299	353	35	284	423
C1-Bunk-R-ST	86	209	197	156	106	-	368
C1-Bunk-R-Fed	233	91	158	161	71	19	303
C1-Bunk-R-3	240	83	141	155	79	-	313

Table II.9-6. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	509	249	294	351	139	73	628
C1-Bunk-R-ST	246	65	155	156	106	-	368
C1-Bunk-R-Fed	233	91	158	161	71	19	303
C1-Bunk-R-3	239	83	141	155	79	-	312

Table II.9-7. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	0	136	163	100	87	0	274
C1-Bunk-R-ST	-	13	69	24	21	-	67
C1-Bunk-R-Fed	0	27	74	34	38	0	109
C1-Bunk-R-3	0	24	59	28	29	0	86

Table II.9-8. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 100 g/m^2. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	135	163	99	87	-	274
C1-Bunk-R-ST	-	13	69	24	21	-	67
C1-Bunk-R-Fed	-	27	74	34	38	-	109
C1-Bunk-R-3	-	24	59	28	29	-	86

Table II.9-9. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	9,205	8,033	5,746	5,011	-	15,767
C1-Bunk-R-ST	-	-	502	296	404	-	1,105
C1-Bunk-R-Fed	-	167	-	56	97	-	249
C1-Bunk-R-3	-	-	167	56	97	-	249

Table II.9-10. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	126,530	154,810	93,780	82,438	-	258,655
C1-Bunk-R-ST	-	13,054	68,786	23,889	21,227	-	66,343
C1-Bunk-R-Fed	-	26,611	74,141	33,584	37,559	-	108,702
C1-Bunk-R-3	-	24,268	58,409	27,559	29,343	-	86,245

Table II.9-11. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	14.7	17.5	10.7	9.4	-	29.5
C1-Bunk-R-ST	-	1.8	7.3	2.4	2.2	-	6.8
C1-Bunk-R-Fed	-	2.5	7.8	3.4	4.0	-	11.4
C1-Bunk-R-3	-	2.3	5.9	2.7	3.0	-	8.7

Table II.9-12. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of waterfowl oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	61,189	34,479	39,078	44,915	14,280	16,355	73,475
C1-Bunk-R-ST	34,160	15,451	24,739	24,888	10,877	3,134	46,642
C1-Bunk-R-Fed	32,816	18,202	25,118	25,379	7,310	10,758	40,000
C1-Bunk-R-3	33,439	17,398	23,352	24,730	8,109	8,512	40,947

Table II.9-13. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of seabirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	4,844	2,719	3,085	3,549	1,136	1,277	5,821
C1-Bunk-R-ST	2,693	1,205	1,944	1,956	865	225	3,686
C1-Bunk-R-Fed	2,586	1,424	1,974	1,995	582	832	3,158
C1-Bunk-R-3	2,636	1,360	1,834	1,943	645	653	3,233

Table II.9-14. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of wading birds and shorebirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	1,122	12,536	6,748	6,802	5,707	-	18,216
C1-Bunk-R-ST	1,122	1,793	2,110	1,736	1,576	-	4,888
C1-Bunk-R-Fed	1,122	1,381	2,026	1,510	466	597	2,441
C1-Bunk-R-3	1,122	1,221	1,773	1,372	351	685	2,073

Table II.9-15. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of birds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	67,155	49,733	48,910	55,266	10,304	34,658	75,874
C1-Bunk-R-ST	37,975	18,448	28,793	28,580	11,827	4,926	52,234
C1-Bunk-R-Fed	36,525	21,007	29,118	28,883	7,761	13,361	44,406
C1-Bunk-R-3	37,197	19,979	26,958	28,045	8,660	10,724	45,365

Table II.9-16. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of mammals oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	11.3	6.4	7.2	8.3	2.6	3.0	13.5
C1-Bunk-R-ST	6.3	2.9	4.6	4.6	2.0	0.6	8.6
C1-Bunk-R-Fed	6.1	3.4	4.6	4.7	1.3	2.0	7.4
C1-Bunk-R-3	6.2	3.2	4.3	4.6	1.5	1.6	7.6

Table II.9-17. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	0.20	-	0.07	0.11	-	0.29
C1-Bunk-R-ST	-	0.06	-	0.01	0.06	-	0.13
C1-Bunk-R-Fed	-	-	-	-	-	-	-
C1-Bunk-R-3	-	-	-	-	-	-	-

Table II.9-18. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	4.6	-	1.5	2.7	-	7
C1-Bunk-R-ST	-	1.3	-	0.2	1.4	-	3
C1-Bunk-R-Fed	-	-	-	-	-	-	-
C1-Bunk-R-3	-	-	-	-	-	-	-

Table II.9-19. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	163	189	117	102	-	322
C1-Bunk-R-ST	-	15	56	22	20	-	61
C1-Bunk-R-Fed	-	19	60	26	31	-	87
C1-Bunk-R-3	-	19	40	20	20	-	60

Table II.9-20. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	-	167	189	119	105	-	329
C1-Bunk-R-ST	-	16	56	22	21	-	64
C1-Bunk-R-Fed	-	19	60	26	31	-	87
C1-Bunk-R-3	-	19	40	20	20	-	60

Table II.9-21. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	393	267	296	319	89	146	496
C1-Bunk-R-ST	255	116	185	186	82	24	351
C1-Bunk-R-Fed	211	136	188	178	47	86	271
C1-Bunk-R-3	215	130	175	173	50	74	273

Table II.9-22. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	74	50	55	60	17	27	93
C1-Bunk-R-ST	48	22	35	35	15	4	66
C1-Bunk-R-Fed	40	26	35	33	9	16	51
C1-Bunk-R-3	40	24	33	32	9	14	51

Table II.9-23. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	246	167	185	199	55	91	310
C1-Bunk-R-ST	159	72	116	116	51	15	219
C1-Bunk-R-Fed	132	85	118	112	29	54	170
C1-Bunk-R-3	134	81	109	108	31	46	170

Table II.9-24. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	29	20	22	24	7	11	37
C1-Bunk-R-ST	19	9	14	14	6	2	26
C1-Bunk-R-Fed	16	10	14	13	3	6	20
C1-Bunk-R-3	16	10	13	13	4	6	20

Table II.9-25. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (millions of $), using WA Compensation Schedule. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C1-Bunk-N	28.1	28.0	27.7	28.0	0.19	27.6	28.3
C1-Bunk-R-ST	30.9	27.6	27.9	26.7	6.09	14.5	38.9
C1-Bunk-R-Fed	28.1	28.4	28.5	28.4	0.20	28.0	28.8
C1-Bunk-R-3	28.4	24.9	26.8	26.7	0.17	26.4	27.1

II.10. COMPARISON OF ALTERNATIVE RESPONSES: UPPER COLUMBIA RIVER – BUNKER C

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). The tables in this section summarize the model results for the alternate response scenarios for Upper Columbia River (or similar river) spills of Bunker C fuel. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs. The 100 main stochastic scenario runs of the Washington state mechanical removal base case were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shore cleanup costs are presented. Because each impact index is not necessarily correlated with shore cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs using the base case were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. In Section II.2, the individual runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs (and their dates and times) varied by stochastic scenario, and for the alternate scenarios other than the base case, they are not the same runs as those reported in this section. Thus, in this section, the alternate response scenarios are labeled with “-base”.

This indicates the base case 5th, 50th, and 95th percentile runs for shoreline costs were rerun with the same start date and time but with the alternate response. (For scenarios other than the base case, the 5th, 50th, and 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this section.)

Table II.10-1. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass coming ashore (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	33.1	25.4	32.6	30.3	4.3	21.8	38.9
C2-Bunk-R-ST	2.6	10.4	21.1	10.8	6.1	-	22.9
C2-Bunk -R-Fed	18.3	10.1	12.1	9.5	5.9	-	21.2
C2-Bunk -R-3	17.4	9.1	15.0	10.1	6.1	-	22.3

Table II.10-2. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	2.3	0.8	0.6	1.2	0.9	-	3.0
C2-Bunk-R-ST	0.4	1.2	7.3	2.3	2.5	-	7.2
C2-Bunk -R-Fed	3.1	4.4	3.8	2.7	1.9	-	6.6
C2-Bunk -R-3	2.5	1.1	0.4	1.1	1.0	-	3.2

Table II.10-3. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	12.6	7.8	10.8	10.4	2.4	5.5	15.3
C2-Bunk-R-ST	0.7	3.5	0.4	2.3	1.9	-	6.1
C2-Bunk -R-Fed	5.7	0.5	0.5	1.3	2.2	-	5.6
C2-Bunk -R-3	6.3	3.4	4.7	3.3	2.2	-	7.7

Table II.10-4. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass mechanically removed and/or burned (%). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	-	-	-	-	-	-	-
C2-Bunk-R-ST	85	78	67	73	14	45	101
C2-Bunk -R-Fed	67	78	76	79	7	64	93
C2-Bunk -R-3	64	80	73	78	9	59	96

Table II.10-5. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	18	10	16	15	4	6	23
C2-Bunk-R-ST	2	6	13	6	3	-	12
C2-Bunk -R-Fed	13	6	9	6	5	-	15
C2-Bunk -R-3	13	5	12	7	5	-	17

Table II.10-6. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	18	10	16	15	4	6	23
C2-Bunk-R-ST	10	5	3	6	3	-	12
C2-Bunk -R-Fed	13	6	10	6	4	-	13
C2-Bunk -R-3	13	5	12	7	4	-	15

Table II.10-7. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	75	50	69	65	13	38	91
C2-Bunk-R-ST	6	21	47	22	12	-	45
C2-Bunk -R-Fed	38	21	28	29	8	12	46
C2-Bunk -R-3	43	19	34	32	12	8	56

Table II.10-8. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 100 g/m^2. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	75	50	69	65	13	38	91
C2-Bunk-R-ST	6	21	47	22	12	-	45
C2-Bunk -R-Fed	38	21	28	29	8	12	46
C2-Bunk -R-3	43	19	34	32	12	8	56

Table II.10-9. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	3,013	167	1,339	1,506	1,430	-	4,366
C2-Bunk-R-ST	-	669	502	300	378	-	1,055
C2-Bunk -R-Fed	167	-	1,172	307	442	-	1,190
C2-Bunk -R-3	2,678	335	2,008	976	1,102	-	3,181

Table II.10-10. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	72,301	49,707	67,783	63,264	11,956	39,352	87,176
C2-Bunk-R-ST	5,858	20,084	46,360	21,389	11,715	-	44,819
C2-Bunk -R-Fed	37,490	20,921	26,444	19,526	12,064	-	43,654
C2-Bunk -R-3	39,833	18,577	31,799	21,841	13,559	-	48,959

Table II.10-11. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	6.8	4.7	6.5	6.0	1.1	3.7	8.3
C2-Bunk-R-ST	0.6	1.7	4.5	2.0	1.1	-	4.2
C2-Bunk -R-Fed	3.3	1.8	2.5	1.8	1.1	-	3.9
C2-Bunk -R-3	3.8	1.6	3.0	2.0	1.3	-	4.6

Table II.10-12. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of waterfowl oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	524	299	471	431	118	196	667
C2-Bunk-R-ST	72	178	378	170	92	-	354
C2-Bunk -R-Fed	376	174	282	278	101	75	480
C2-Bunk -R-3	386	166	346	299	117	65	534

Table II.10-13. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of seabirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	9.2	6.4	8.6	8.1	1.5	5.1	11.1
C2-Bunk-R-ST	3.5	4.8	7.4	4.7	1.2	2.4	7.1
C2-Bunk -R-Fed	7.4	4.8	6.2	6.1	1.3	3.5	8.7
C2-Bunk -R-3	7.5	4.7	7.0	6.4	1.5	3.4	9.4

Table II.10-14. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of wading birds and shorebirds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	855	201	641	566	334	-	1,233
C2-Bunk-R-ST	95	35	114	131	202	-	534
C2-Bunk -R-Fed	265	35	45	115	130	-	375
C2-Bunk -R-3	355	32	54	147	180	-	507

Table II.10-15. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of birds oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	1,389	506	1,121	1,005	452	100	1,910
C2-Bunk-R-ST	171	218	500	306	272	-	851
C2-Bunk -R-Fed	649	214	333	399	225	-	848
C2-Bunk -R-3	748	203	407	453	276	-	1,004

Table II.10-16. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of mammals oiled. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	7.8	5.0	7.2	6.7	1.5	3.8	9.6
C2-Bunk-R-ST	2.2	3.5	6.0	3.4	1.1	1.1	5.7
C2-Bunk -R-Fed	6.0	3.5	4.8	4.8	1.3	2.3	7.3
C2-Bunk -R-3	6.1	3.4	5.6	5.0	1.5	2.1	8.0

Table II.10-17. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	0.03	0.14	0.03	0.07	0.06	-	0.19
C2-Bunk-R-ST	-	-	-	0.02	0.06	-	0.15
C2-Bunk -R-Fed	-	-	-	-	-	-	-
C2-Bunk -R-3	-	-	-	-	-	-	-

Table II.10-18. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	3,630	3,630	3,630	3,630	-	3,630	3,630
C2-Bunk-R-ST	3,630	3,630	3,630	3,630	-	3,630	3,630
C2-Bunk -R-Fed	3,630	3,630	3,630	3,630	-	3,630	3,630
C2-Bunk -R-3	3,630	3,630	3,630	3,630	4,123	-	11,877

Table II.10-19. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	-	-	-	-	-	-	-
C2-Bunk-R-ST	-	-	-	-	-	-	-
C2-Bunk -R-Fed	-	-	-	-	-	-	-
C2-Bunk -R-3	-	-	-	-	-	-	-

Table II.10-20. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone). Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	3,630	3,630	3,630	3,630	-	3,630	3,630
C2-Bunk-R-ST	3,630	3,630	3,630	3,630	-	3,630	3,630
C2-Bunk -R-Fed	3,630	3,630	3,630	3,630	-	3,630	3,630
C2-Bunk -R-3	3,630	3,630	3,630	3,630	4,123	-	11,877

Table II.10-21. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	4.0	3.3	3.8	3.7	2.9	0.8	9.4
C2-Bunk-R-ST	2.6	2.9	3.5	2.9	2.8	0.2	8.4
C2-Bunk -R-Fed	3.5	2.9	3.2	3.2	2.8	0.4	8.8
C2-Bunk -R-3	3.5	2.9	3.4	3.3	2.8	0.4	8.9

Table II.10-22. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	0.8	0.6	0.7	0.7	0.5	0.1	1.8
C2-Bunk-R-ST	0.5	0.5	0.7	0.5	0.5	0.0	1.6
C2-Bunk -R-Fed	0.7	0.5	0.6	0.6	0.5	0.1	1.6
C2-Bunk -R-3	0.7	0.5	0.6	0.6	0.5	0.1	1.7

Table II.10-23. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	2.5	2.0	2.4	2.3	1.8	0.5	5.9
C2-Bunk-R-ST	1.6	1.8	2.2	1.8	1.7	0.1	5.3
C2-Bunk -R-Fed	2.2	1.8	2.0	2.0	1.7	0.2	5.5
C2-Bunk -R-3	2.2	1.8	2.1	2.0	1.8	0.2	5.6

Table II.10-24. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs.

Scenario	5th Run Based on Shore Costs	50th Run Based on Shore Costs	95th Run Based on Shore Costs	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
C2-Bunk-N	0.3	0.2	0.3	0.3	0.2	0.1	0.7
C2-Bunk-R-ST	0.2	0.2	0.3	0.2	0.2	0.0	0.6
C2-Bunk -R-Fed	0.3	0.2	0.2	0.2	0.2	0.0	0.7
C2-Bunk -R-3	0.3	0.2	0.3	0.2	0.2	0.0	0.7

Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XII: Model Inputs for Strait of Juan de Fuca – Alaskan North Slope Crude

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XII.A. INTRODUCTION

This appendix contains model input data (in maps, figures and tables) for the modeled locations and the sources for that information. The approach and sources applicable to all modeled locations are described in Volume I, Section 3 of this technical report. Specifics to this model location are below. Thus, the reader should refer to Volume I, Section 3 for background and the context within which these data are used.

XII.B. GEOGRAPHICAL DATA

Geographic data for the modeled location are presented in this section. The sources for these data are described in Volume I, Section 3. Maps are also presented below showing areas where mechanical removal, dispersant application (as applicable), and in situ burning (ISB, as applicable) were assumed to occur in the model simulations. The assumptions for the response scenarios are in Volume I, Section 3.

XII.B.1. Maps of the Vicinity of the Modeled Spill Locations

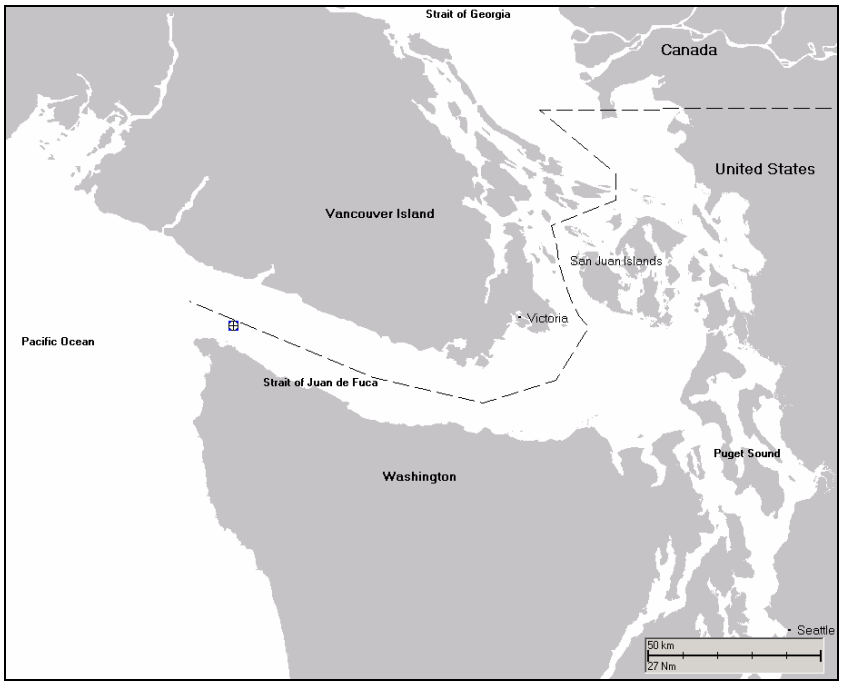

Figure XII.B.1-1 Map of the vicinity of the potential spill locations.

XII.B.2. Gridded Habitat Mapping

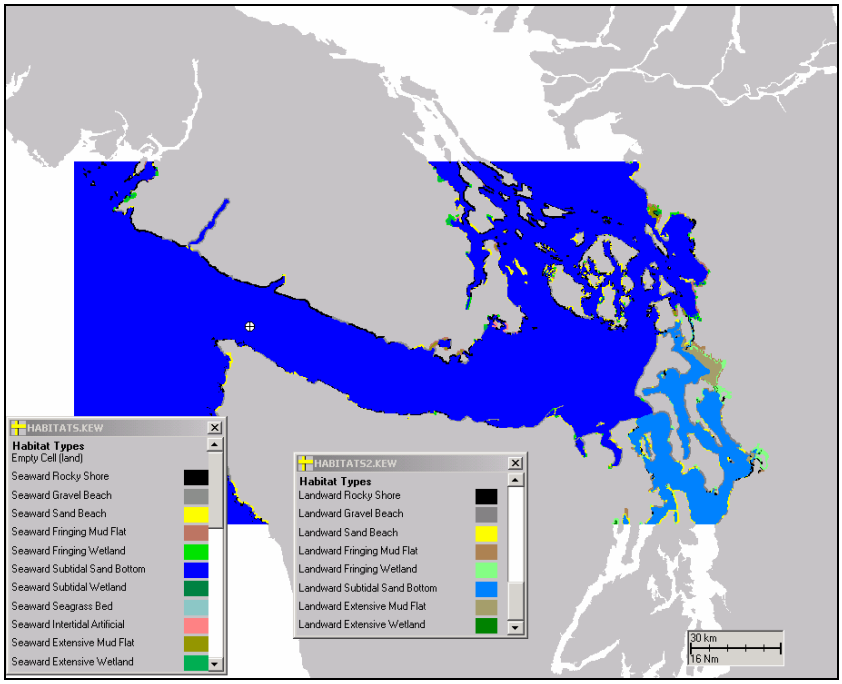

Figure XII.B.2-1 Habitat grid used for modeling the potential spills.

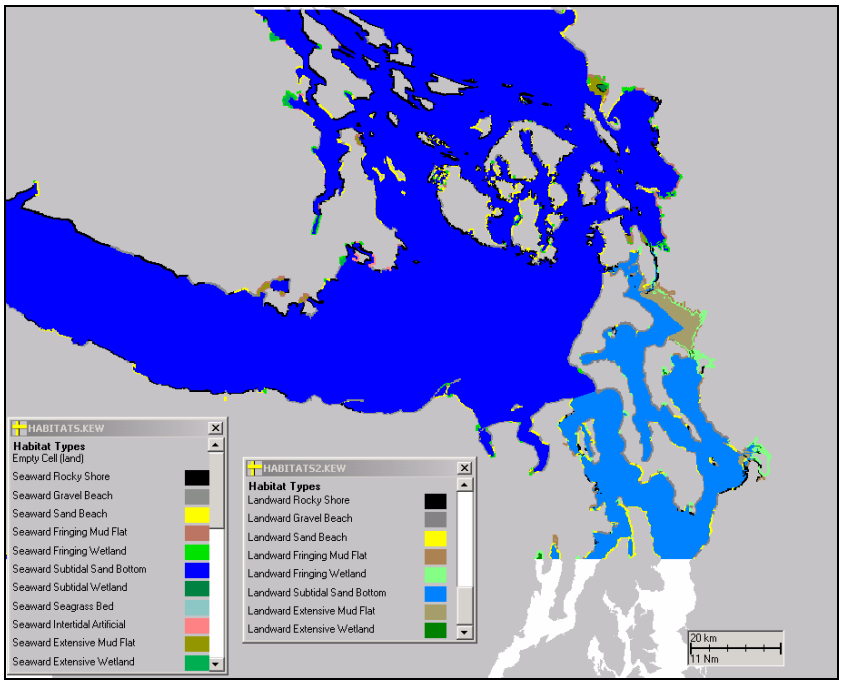

Figure XII.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XII.B-3. Gridded Depth Data

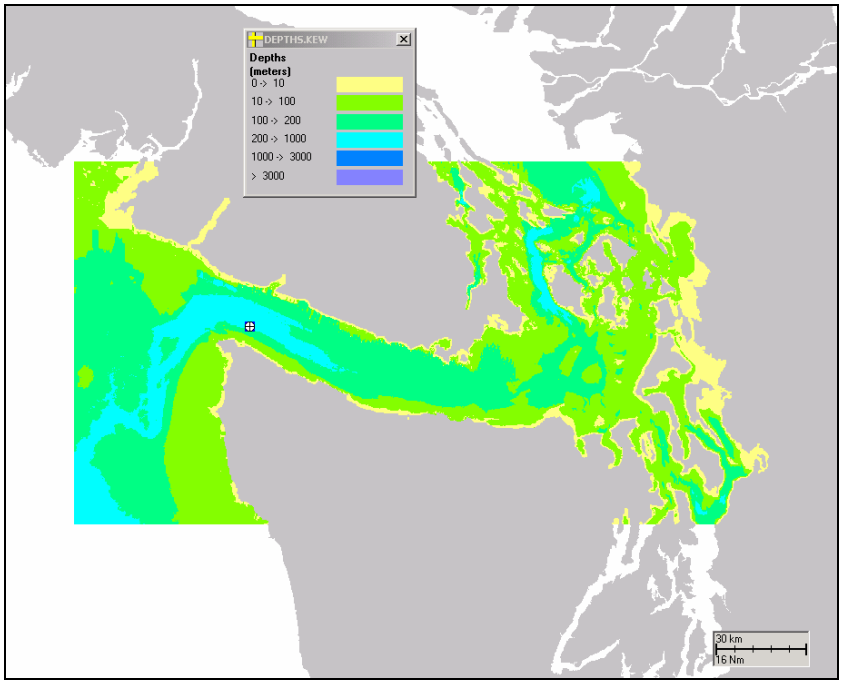

Figure XII.B.3-1 Depth grid used for modeling the potential spills.

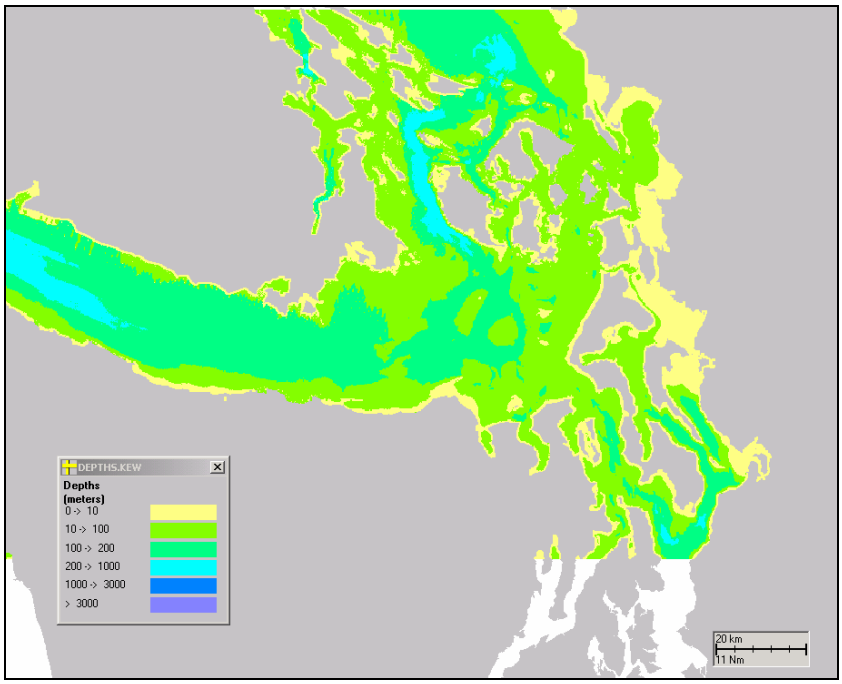

Figure XII.B.3-2 Depth grid used for modeling the potential spills (closer view).

XII.B-4. Areas Where Response Actions Assumed

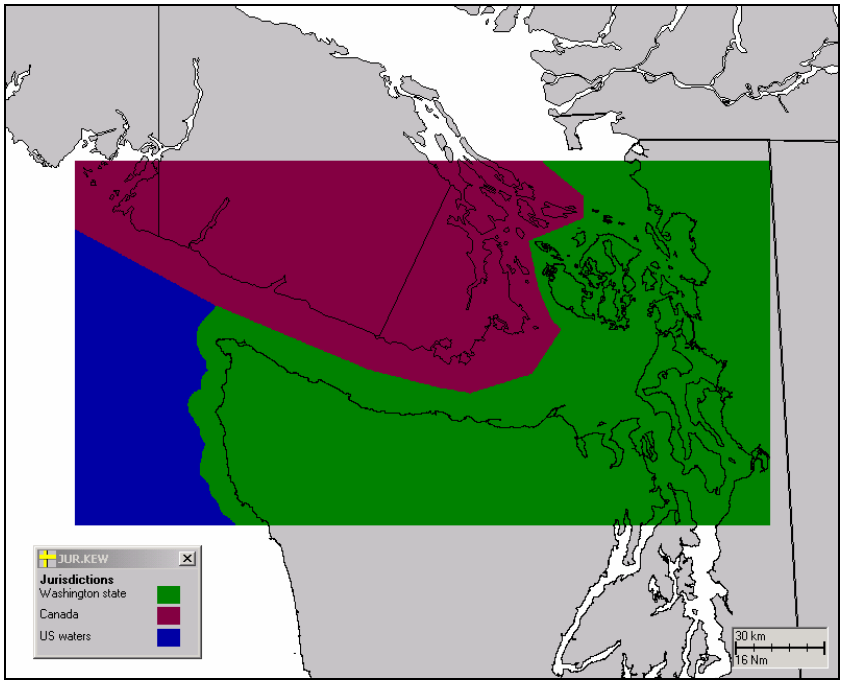

Figure XII.B.4-1 Jurisdictions in the area of the potential spills.

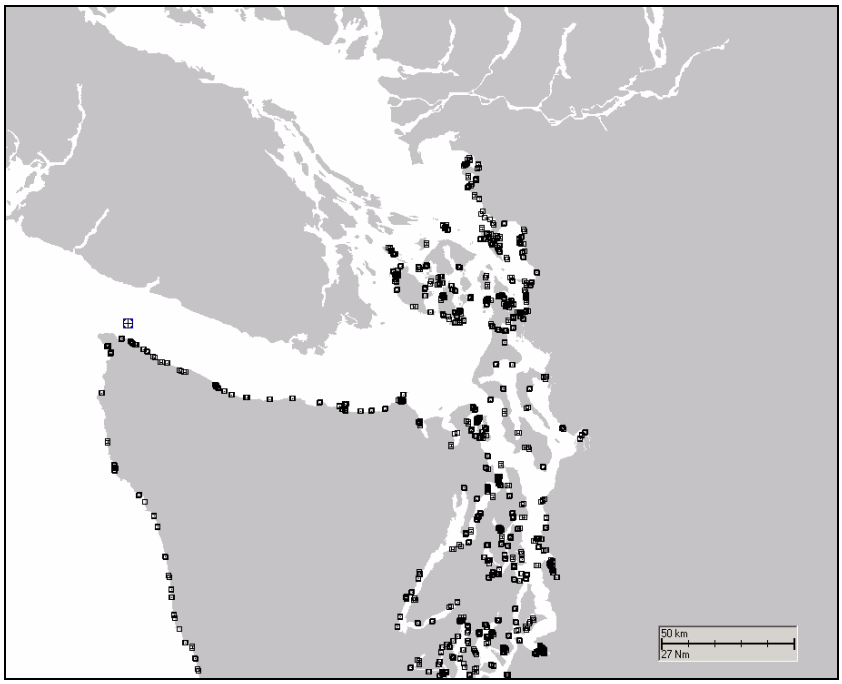

Figure XII.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

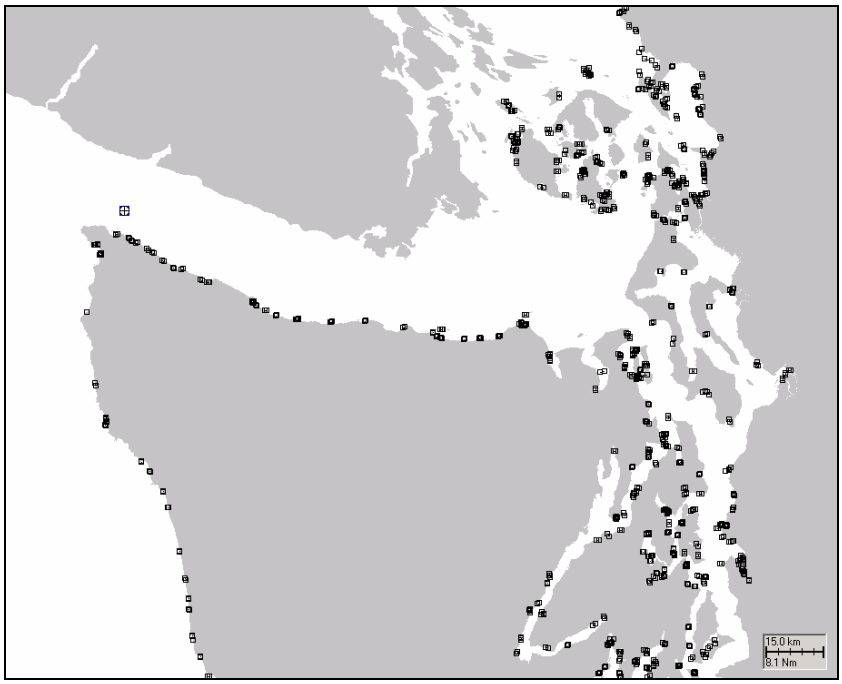

Figure XII.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

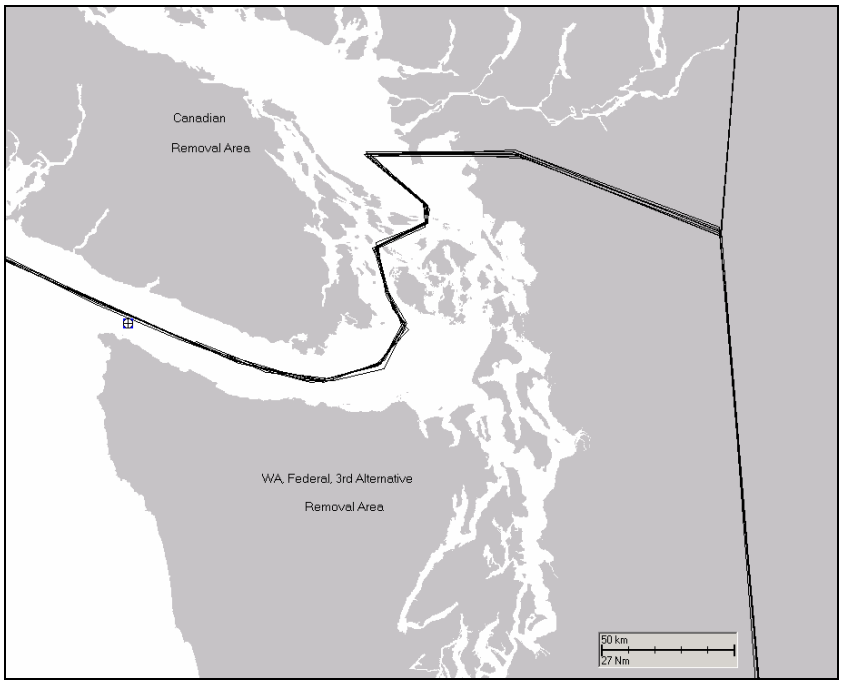

Figure XII.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

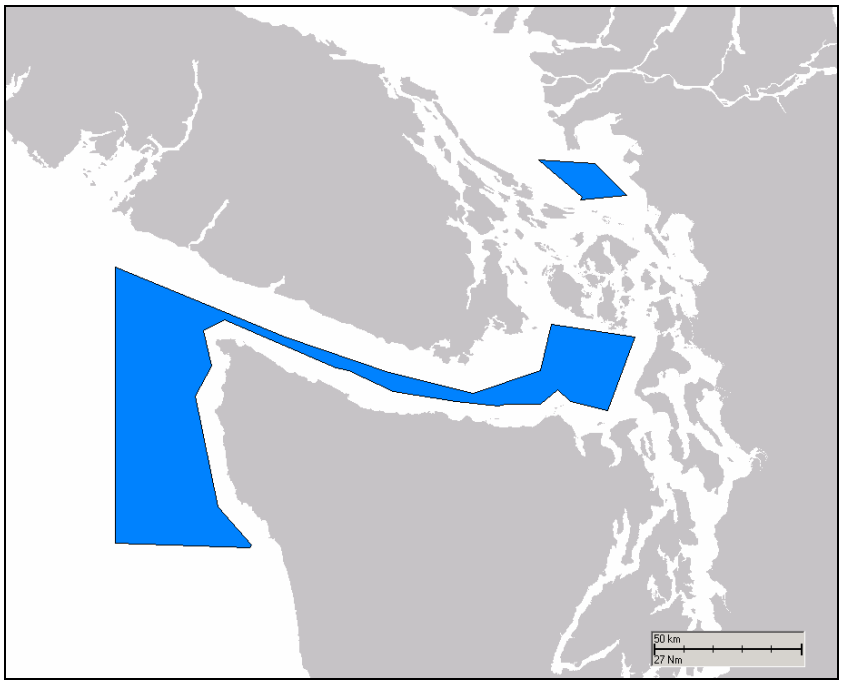

Figure XII.B.4-5 Areas where dispersant application was assumed to occur in modeling the potential spills.

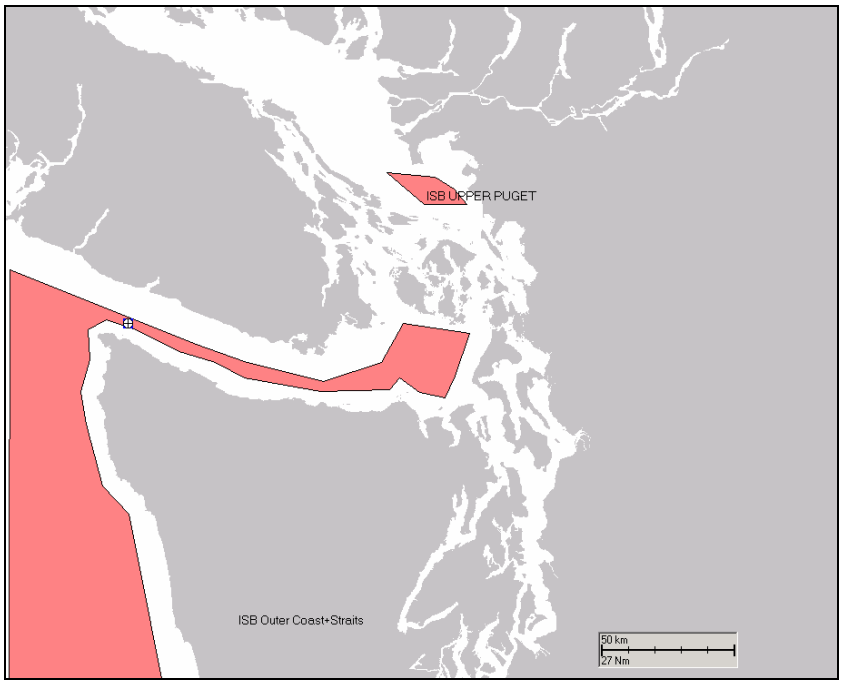

Figure XII.B.4-6 Areas where in situ burning (ISB) was assumed to occur in modeling the potential spills.

XII.C. CURRENT DATA

XII.C.1. Basis of Current Data

ASA's boundary fitted coordinate hydrodynamic model (BFHYDRO, see Volume I, Section 3) was used to generate an applicable current data set for the area surrounding the potential spill locations. The grid used in this study consists of 250 x 350 square water segments (1 km x 1 km) with 29200 water cells and 11 sigma layers in the vertical. The model forcing functions consist of surface elevations along the open boundaries and fresh water flow from the Fraser River. The mean flow in the Fraser River during summer is 800 m^3/s and the mean flow during winter is 8000 m^3/s (Morrison et al. 2002). The tidal forcing for the 6 major harmonic constituents (M_2, S_2, N_2, K_1, O_1 and P_1), derived from the Global Ocean Tidal Model (TPOX5.1) developed at the Oregon State University (Egbert et. al. 1994) was applied along the offshore open boundary, while the tidal forcing for the six major harmonic constituents at Lund, obtained from the Canadian Hydrographic Survey was applied along the open boundary in the Georgia Straits. The model predicted surface elevations and currents were calibrated using the observed harmonic constants for surface elevation and currents given in Parker (1977).

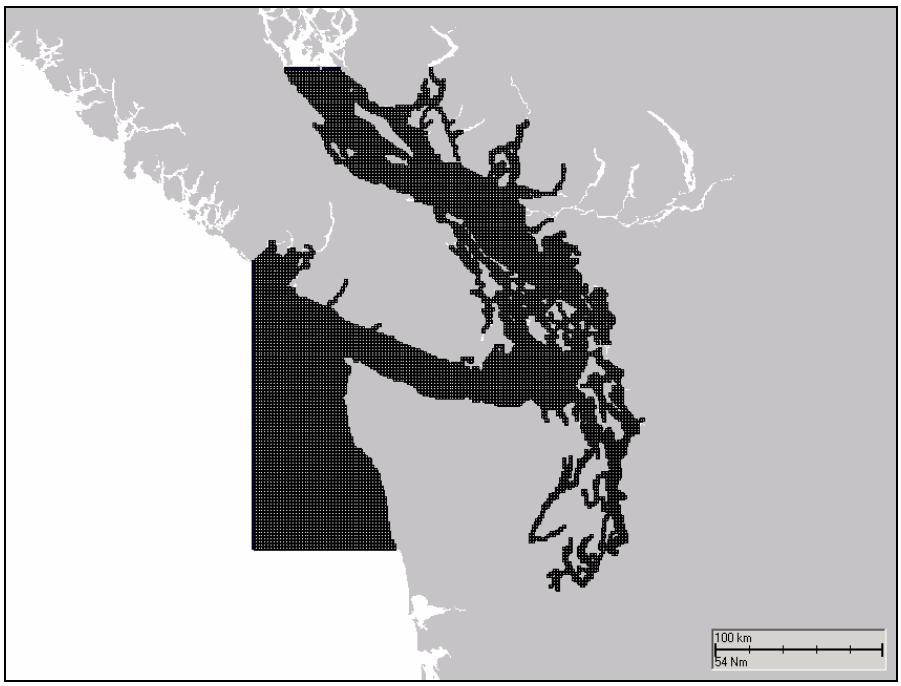

Figure XII.C.1-1 Grid used for the hydrodynamic model-generated current data.

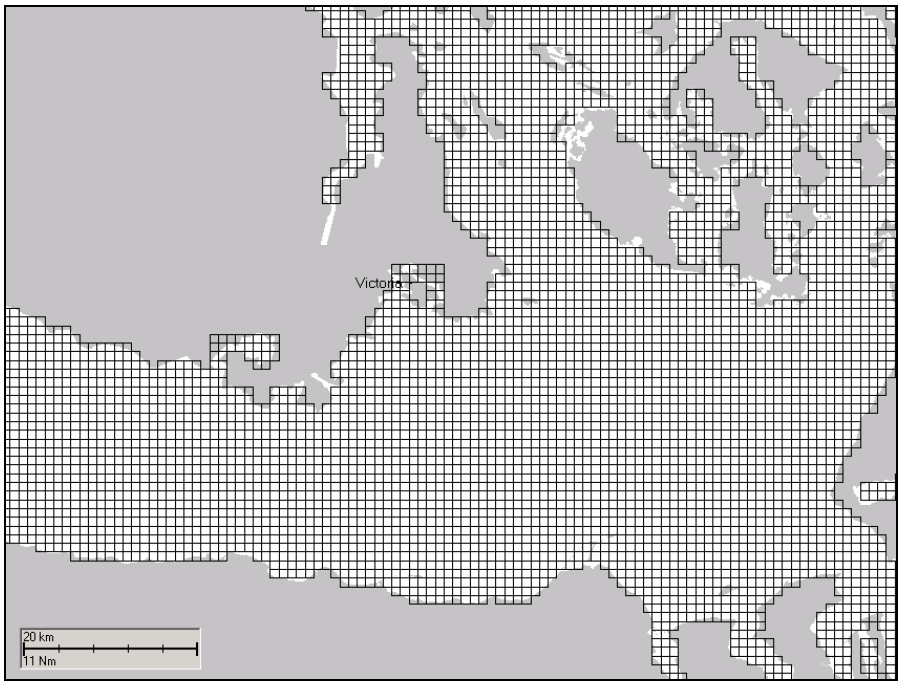

Figure XII.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC).

XII.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations

The figures below show the maximum flood and ebb of the M_2 and K_1 component. Note that 0.5 m/sec = 1 knot.

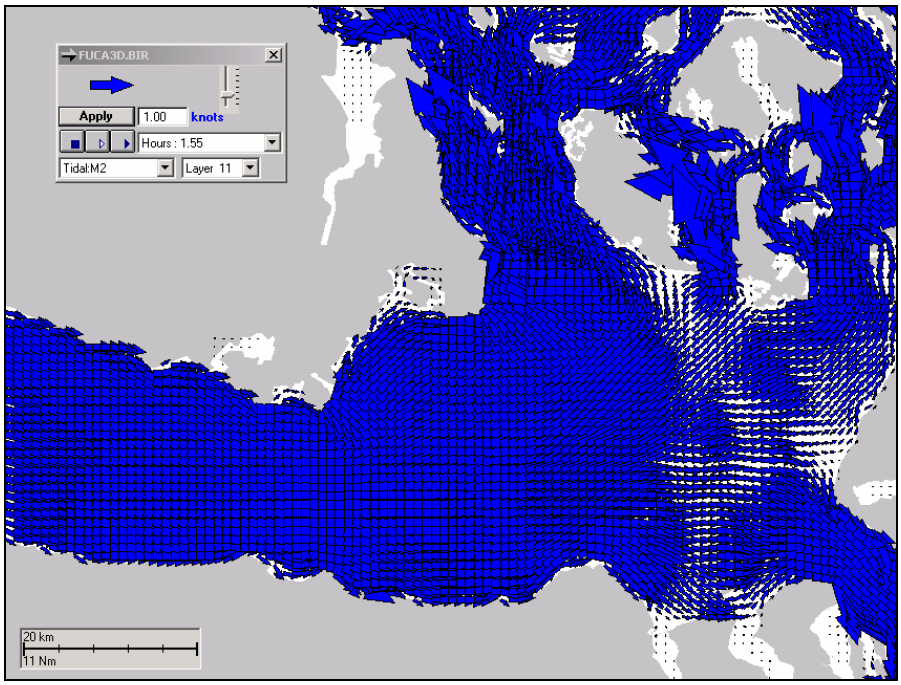

Figure XII.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Victoria, BC.

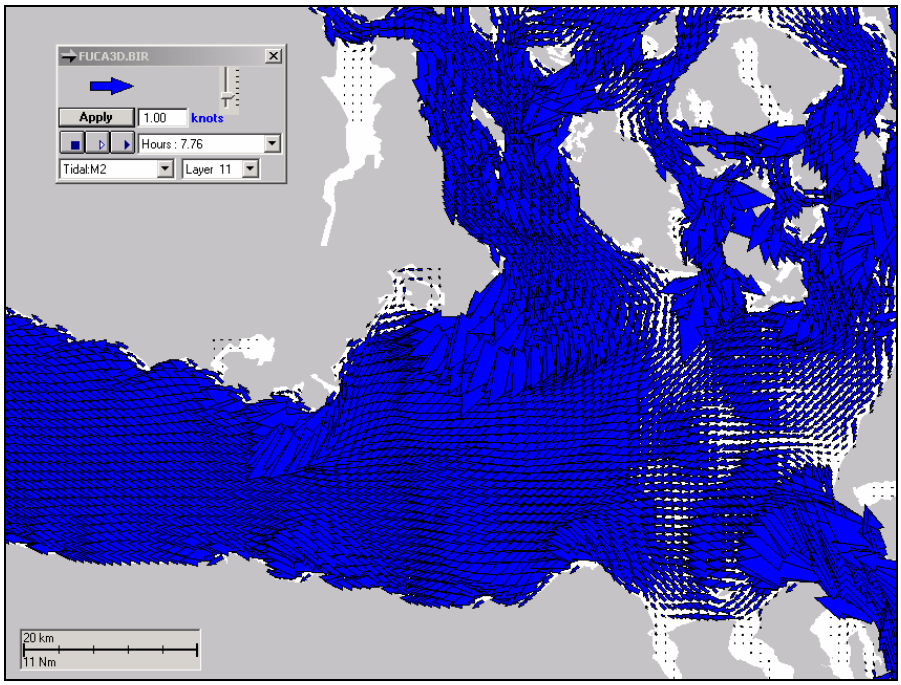

Figure XII.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Victoria, BC.

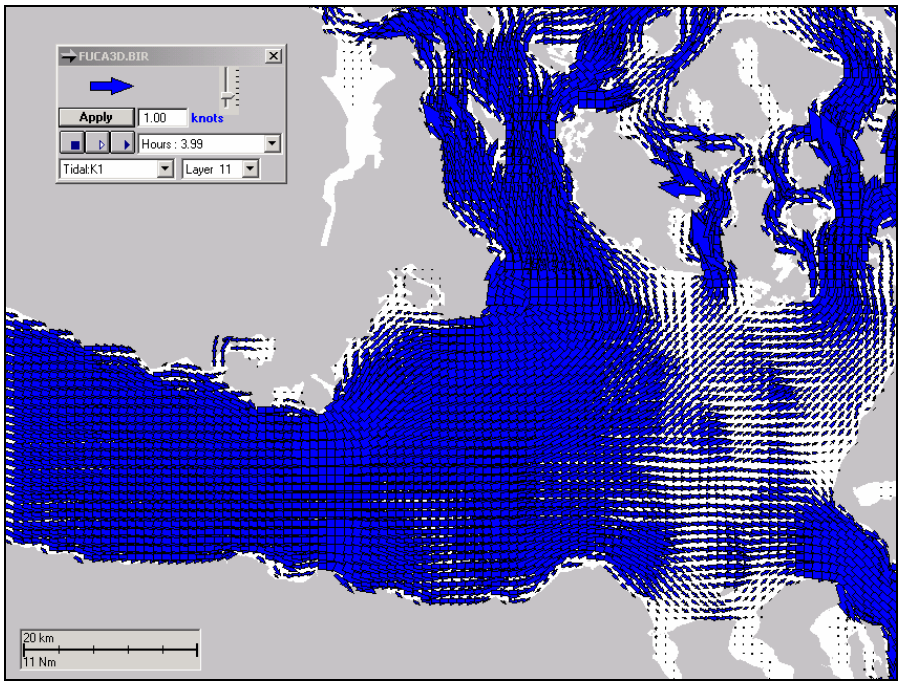

Figure XII.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Victoria, BC.

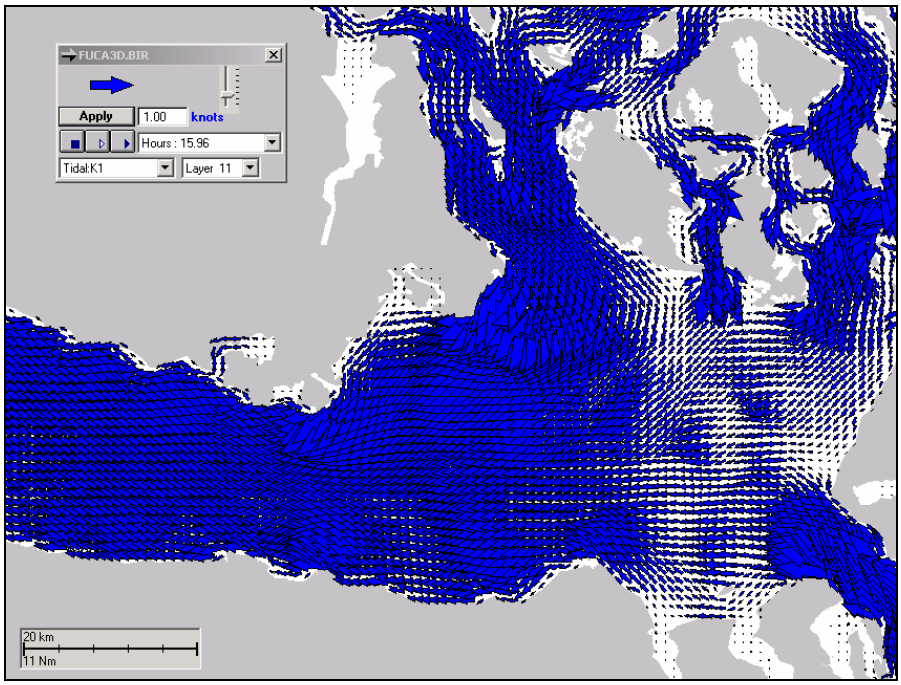

Figure XII.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Victoria, BC.

XII.D: OIL PROPERTIES

Table XII.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.8761	Wang et al. (1999)
Viscosity @ 25 deg. C (cp)	16	Wang et al. (1999)
Surface Tension (dyne/cm)	27	Wang et al. (1999)
Pour Point (deg. C)	-54	Wang et al. (1999)
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.030662	Wang et al. (1999)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.010372	A.D. Little (1996)
Fraction 2-ring aromatics (included in PAHs above)	0.00375	A.D. Little (1996)
Fraction 3-ring aromatics (included in PAHs above)	0.006622	A.D. Little (1996)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.189338	Wang et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.13325	Wang et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.200378	Wang et al. (1999)[1]
Minimum Oil Thickness (m)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	70	Wang et al. (1999)[2]; NOAA (2000)[2]
Mousse Water Content as Spilled (%)	0	-
Water content of fuel (not in mousse, %)	0	-
Degradation Rate (/day), Surface & Shore	0.01	National Research Council (1985)
Degradation Rate (/day), Hydrocarbons in Water	0.01	National Research Council (1985)
Degradation Rate (/day), Oil in Sediment	0.001	Haines and Atlas (1982)
Degradation Rate (/day), Aromatics in Water	0.01	French et al. (1996b)
Degradation Rate (/day), Aromatics in Sediment	0.001	French et al. (1996b)

[1] – Wang et al. (1999) provided total hydrocarbon data. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.
[2] – Mid-value used.

Table XII.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil.

Aromatic	Log(K_{ow})*	Concentration (mg/kg)
benzene	2.13	0.0
Toluene	2.69	0.0
Ethylbenzene	3.13	0.0
o-Xylene	3.15	0.0
p-Xylene	3.18	0.0
m-Xylene	3.2	0.0
Xylenes	3.18	0.0
styrene	3.05	0.0
methylstyrenes	3.35	0.0
1,2,3-Trimethylbenzene	3.55	0.0
1,2,4-Trimethylbenzene	3.6	0.0
1,3,4-Trimethylbenzene	3.6	0.0
1,3,5-Trimethylbenzene	3.58	0.0
Trimethylbenzenes	3.58	0.0
n-propylbenzene	3.69	0.0
iso-propylbenzene	3.63	0.0
ethyl-methylbenzenes	3.63	0.0
iso-propyl-4-methylbenzene	4.10	0.0
butylbenzenes	4.12	0.0
tetramethylbenzenes	4.01	0.0
tetralin	3.83	0.0
diphenylmethane	4.14	0.0
naphthalene	3.37	650
C1-naphthalenes	3.87	1,300
C2-naphthalenes	4.37	1,800
C3-naphthalenes	5.00	1,400
C4-naphthalenes	5.55	850
biphenyls	3.9	180
acenaphthylene	4.07	0.0
acenaphthene	3.92	0.0
dibenzofuran	4.31	0.0
Fluorene	4.18	82
C1-fluorenes	4.97	220
C2-fluorenes	5.20	260
C3-fluorenes	5.50	280

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

Table XII.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	200
C1-dibenzothiophene	4.86	360
C2-dibenzothiophene	5.50	540
C3-dibenzothiophene	5.73	460
phenanthrene	4.57	230
anthracene	4.54	0.0
C1-phenanthrenes/anthracenes	5.14	430
C2-phenanthrenes/anthracenes	5.25	490
C3-phenanthrenes/anthracenes	6.00	380
C4-phenanthrenes/anthracenes	6.51	260
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total log(K_{ow})$\leq$5.6	-	9,272

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

XII.E: INPUTS TO THE SIMAP PHYSICAL FATES MODEL

This section summarizes the model input data for the scenarios run and the sources for that information. The approach and sources applicable to all modeled locations are described in Volume I, Section 3 of this technical report. Specifics to this model location are below. Thus, the reader should refer to Volume I, Section 3 for background and the context within which these data are used.

The model grid and cell size were set to provide the maximum resolution (minimum cell size) possible within the memory constraints of the model, while also providing sufficient geographic coverage to encompass the maximum extent of oiling possible for the scenario. Test runs (randomizing weather conditions) were made to estimate the maximum extent of surface oiling and the grid size was set to cover that area.

Table XII.E-1. Inputs to the Fates Model for Stochastic Scenarios

Name	Description	Units	Source(s) of Information	Value(s)
Spill Site	Location of the spill site	-	Washington DOE	Neah Bay to Port Angeles
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure XII.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure XII.E-1)
Depth of release	Depth below the water surface of the release or 0 for surface release	m	Washington DOE	0 m
Start time and date	Randomized over selected months of the year	Date, hr,min	(randomized)	Jan-Dec
Spill duration	Hours over which the release occurs	Hours	(assumed)	4 hours
Total spill amount	Total volume (or weight) released (maximum if range)	bbl	Washington DOE	65,000 bbl
Model time step	Time step used for model calculations	Hours	-	0.25
Model duration	Length of each model simulation	Days	-	14 days

Table XII.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	320
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table XII.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Salinity	Surface water salinity	ppt	French et al. (1996b) province 51	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XII.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XII.E-4)
Air Temperature	Air water temperature at water surface	Degrees C	(assume = water temperature)	(= water temperature)
Fetch	Fetch = distance to land to N, S, E, W (if landfall not in model domain)	km	Chart	(calculated from model grid)
Wind drift speed	Speed oil moves down wind relative to wind	% of wind speed	Youssef (1993); Youssef and Spaulding (1993)	(model calculated)
Wind drift angle	Angle to right of wind (in northern hemisphere) that oil drifts	Deg. to right of down wind	Youssef (1993); Youssef and Spaulding (1993, 1994)	(model calculated)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y	m^2/sec	French et al. (1996, 1999a) based on Okubo (1971)	1 m^2/sec (estuaries and low energy coastal areas)
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z	m^2/sec	French et al. (1996, 1999) based on Okubo (1971)	0.0001 m^2/sec
Suspended sediment concentration	Average suspended sediment concentration during spill period	mg/l	French et al. (1996b)	10 mg/l
Suspended sediment settling rate	Net settling rate for suspended sediments	m/day	French et al. (1996b)	1 m/day

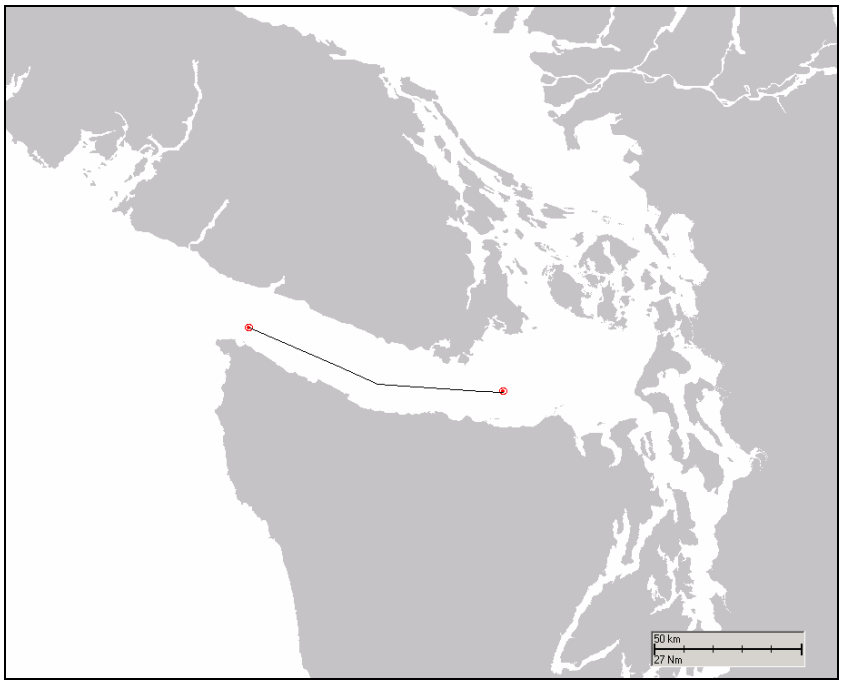

Figure XII.E-1 Varied range of spill site, shipping lane from Neah Bay to Port Angeles.

Table XII.E-2. Time, date and location inputs for each of the 100 stochastic runs.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	2002	10	25	3	48.22675	123.4791
2	1998	3	12	4	48.24016	123.7588
3	2000	7	30	2	48.38607	124.433
4	1993	6	10	15	48.23339	123.6192
5	2001	8	24	21	48.41598	124.5358
6	1994	1	17	6	48.26873	124.033
7	1992	11	21	18	48.36736	124.3687
8	2002	5	25	11	48.29595	124.1241
9	1999	12	1	6	48.37592	124.398
10	1992	1	12	5	48.25341	123.9817
11	2002	5	27	21	48.28667	124.0931
12	1998	3	13	16	48.35659	124.3316
13	1998	12	13	4	48.42313	124.5603
14	1993	1	27	23	48.28949	124.1025
15	1995	9	4	7	48.39771	124.4729
16	1993	3	14	17	48.22678	123.482
17	1992	6	11	23	48.24458	123.8498
18	1993	1	23	21	48.33187	124.2466
19	1999	7	21	1	48.25953	124.0022
20	1992	7	7	19	48.23313	123.6139
21	2001	5	19	16	48.31683	124.195
22	2001	11	20	11	48.24057	123.7673
23	2001	6	26	21	48.33824	124.2686
24	1992	5	22	12	48.40784	124.5078
25	1995	11	30	20	48.40442	124.496
26	2000	11	12	8	48.22769	123.5019
27	2001	10	8	9	48.22649	123.4588
28	2002	3	11	14	48.36306	124.3539
29	2003	3	24	16	48.23275	123.6062
30	1996	3	29	21	48.41785	124.5422
31	1998	6	3	21	48.30782	124.164
32	1996	5	17	6	48.42508	124.567
33	2002	2	17	17	48.30662	124.1599
34	1993	9	11	19	48.23872	123.729
35	1995	3	2	3	48.2364	123.6814
36	1998	1	7	2	48.30679	124.1605
37	1993	8	10	20	48.38878	124.4423
38	1998	11	24	1	48.26833	124.0317
39	2002	5	31	1	48.3918	124.4526
40	2002	5	14	22	48.24556	123.87
41	1996	3	13	10	48.22563	123.3916
42	2003	4	24	23	48.29722	124.1284
43	1997	5	10	21	48.37502	124.3949
44	2003	6	15	22	48.23846	123.7239
45	1996	2	9	15	48.24311	123.8196
46	2000	10	31	7	48.22755	123.4989
47	2000	3	11	5	48.27732	124.0617
48	1995	4	13	1	48.40302	124.4912
49	2002	2	12	3	48.25898	124.0003
50	2003	5	14	4	48.23626	123.6785

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
51	1999	10	1	8	48.23933	123.7417
52	1994	7	14	11	48.30342	124.1492
53	1997	2	22	2	48.22571	123.398
54	1995	7	22	4	48.30444	124.1526
55	2000	7	12	2	48.35349	124.321
56	2003	8	2	9	48.23631	123.6794
57	2003	6	4	2	48.31524	124.1895
58	1994	5	9	16	48.22585	123.4085
59	2002	7	12	7	48.31285	124.1813
60	1992	10	17	15	48.23282	123.6075
61	2001	6	19	18	48.2461	123.8811
62	2000	12	28	6	48.31212	124.1788
63	1994	7	13	4	48.27587	124.0569
64	2001	9	19	13	48.32818	124.234
65	2001	5	14	9	48.40291	124.4908
66	1992	10	12	17	48.22641	123.4526
67	1997	3	26	6	48.24678	123.8952
68	2000	3	14	12	48.42311	124.5603
69	1999	11	14	5	48.22632	123.446
70	2003	6	1	16	48.22619	123.4355
71	1996	2	25	17	48.24295	123.8163
72	2002	12	12	21	48.2308	123.566
73	1993	12	10	2	48.23368	123.6252
74	2000	8	21	5	48.38988	124.4461
75	1995	10	6	17	48.33747	124.2659
76	1999	2	19	2	48.22788	123.5057
77	2001	8	16	23	48.24784	123.9169
78	1995	1	19	14	48.22746	123.4971
79	1997	3	25	23	48.35339	124.3206
80	1995	1	2	7	48.38132	124.4166
81	1997	5	21	6	48.22599	123.4203
82	1995	12	9	10	48.24007	123.7569
83	1996	2	12	19	48.33024	124.2411
84	1992	5	9	21	48.3934	124.4581
85	1994	6	12	16	48.22598	123.4189
86	1992	11	20	19	48.23587	123.6703
87	2001	4	23	14	48.30344	124.1492
88	2003	3	21	6	48.22577	123.402
89	1994	12	10	15	48.23475	123.6472
90	2003	7	23	19	48.31435	124.1864
91	1993	4	13	13	48.28667	124.0931
92	1997	2	17	17	48.29125	124.1084
93	1999	4	14	11	48.22659	123.4668
94	1994	9	24	12	48.3381	124.2681
95	2003	2	16	4	48.31399	124.1852
96	1998	7	29	17	48.3829	124.4221
97	1999	8	29	17	48.23931	123.7412
98	1997	1	7	11	48.35633	124.3307
99	1998	12	28	11	48.24231	123.8029
100	1998	7	5	14	48.31825	124.1998

Table XII.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	S1_S2-COARSE.HAB
Grid W edge	125° 23.40180'W
Grid S edge	47° 48.72180' N
Cell size (^{o}longitude)	0.12^o W
Cell size (^{o}latitude)	0.12^o N
Cell size (m) west-east	153.86
Cell size (m) south-north	229.10
# cells west-east	1574
# cells south-north	545
Water cell area (m^2)	35,249.52
Shore cell length (m)	187.75
Shore cell width – Rocky shore (m)	1.0
Shore cell width – Artificial shore (m)	1.0
Shore cell width – Gravel beach (m)	1.0
Shore cell width – Sand beach (m)	1.0
Shore cell width – Mud flat (m)	1.0
Shore cell width – Wetlands (fringing,m)	1.0

Table XII.E-4. Water temperature by month of the year (from French et al., 1996b).

Month	**Surface Water Temperature (^{o}C)**	**Bottom Water Temperature (^{o}C)**	**Pycnocline Depth (m)**
January	10	8	20
February	10	8	20
March	10	8	20
April	11	8	20
May	12	8	20
June	14	8	20
July	14	7	10
August	14	7	10
September	14	7	10
October	13	7	20
November	12	7	20
December	10	7	20

Table XII.E-5. Wind data sources and records used.

File Name	Location	Latitude Longitude	Dates	Data Source
SISW1_1992_2003_ LST.WNE	Station SISW1 - Smith Island, WA	48.32 ºN 122.84 ºW	1991-2003	National Data Buoy Center

The SISW1_1992_2003_LST.WNE wind data were downloaded from one buoy Station SISW1 - Smith Island, WA. Figure XII.E-2 displays where the buoy is located along with surrounding buoys. SISW1_1992_2003_LST.WNE data start on 31 December 1991 and end on 31 December 2003.

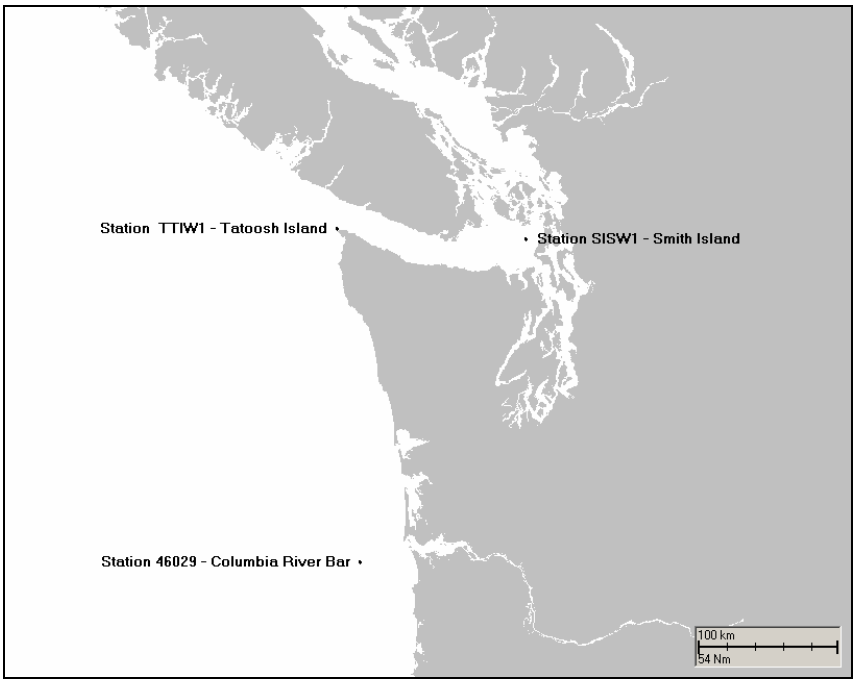

Figure XII.E-2 Wind Station Locations.

Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XIII: Stochastic Model Results for Strait of Juan de Fuca – Alaskan North Slope Crude

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XIII.A. INTRODUCTION

The results of the main stochastic scenarios for the Strait of Juan de Fuca – Alaskan North Slope Crude are contained in this volume. There were two main stochastic scenarios:

1. Mechanical removal under Washington state Caps standards
2. Mechanical removal under Washington state Caps standards plus dispersant application

XIII.B. MAPS OF EXPOSURE PROBABILITY, TIME FIRST EXPOSED, AND MAXIMUM POSSIBLE CONTAMINATION

The results of multiple model runs are evaluated to develop the following statistics, for each cell in the model grid ("location") and for each exposure index. Maps of the results summarizing all 100 runs of a scenario are contained in this section.

- Probability of exposure greater than the minimum threshold (probability that the minimum threshold thickness or concentration will be exceeded at each location at any time following the spill). For surface oil, the model records if any oil of greater than that thickness passes through the grid cell, regardless of the aerial coverage of the oil. For concentrations, the average concentration in the grid cell is used to determine if the threshold is exceeded.
- Time (hours) to first exceedance of the minimum threshold at each location (i.e., in teach cell).
- Worst-case maximum exposure (thickness, volume or concentration) at any time after the spill, at a given location (peak exposure at each location delineated by the grid cells). The amounts are averaged over the area of the model grid cell. The worst-case maximum amount is for all possible releases (i.e., maximum peak exposure for all the model runs). This is calculated in two steps: (1) For each individual run (for each spill date run), the maximum amount over all time after the spill is saved for each location (cell) in the model grid. (2) The runs are evaluated to determine the highest amount possible at each location. Note that these *worst-case maximum* amounts are not additive over all locations. These represent maximum possible amounts of oil that could ever reach each site (grid cell), considered individually, and based on the model runs performed. Thus, "worst-case" represents the highest exposure of the most adverse of the runs performed.

Exposure indices and minimum thresholds (i.e., those less than values that might have an impact on any resource) used in the modeling were:

- Surface slick or floating oil: $\geq$ 0.01 g/m^2 (average thickness $\geq$ 0.01 micron)
- Shoreline: average mass loading over the shore segment (length of one grid cell, calculated as the cell diagonal length, times the typical width for the habitat type) $\geq$ 0.01 g/m^2

- Dissolved aromatics: average over the water cell $\geq$ 1 ppb (1 mg/m^3)
- Subsurface oil (entrained in water): average over the water cell $\geq$ 10 ppb (10 mg/m^3)
- Sediment total hydrocarbons: average over the cell $\geq$ 0.0001 g/ m^2
- Sediment dissolved aromatic concentrations: average over the cell $\geq$ 0.0001 g/ m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10 cm, the assumed bioturbation zone)

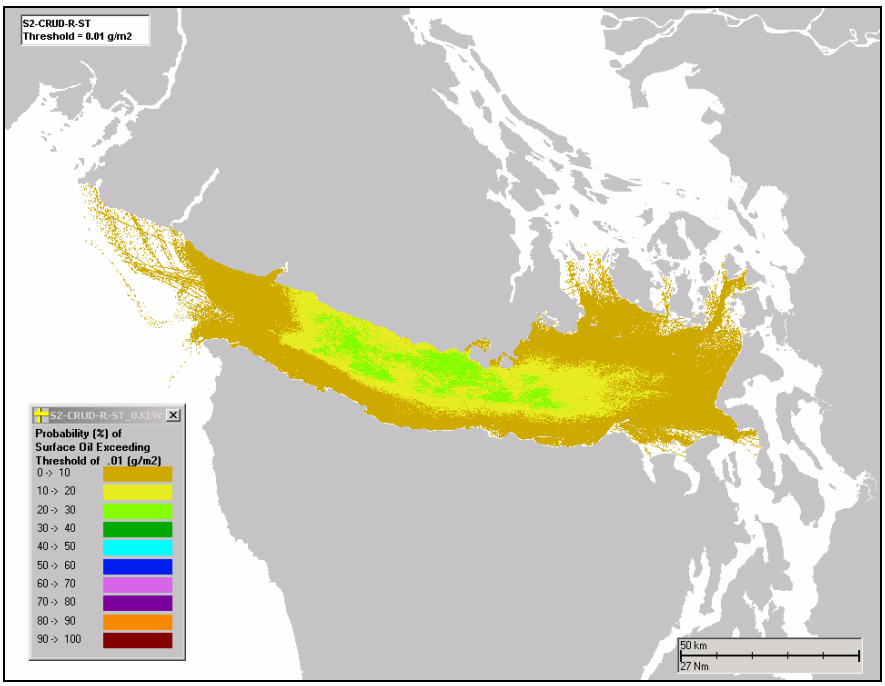

Figure XIII.B-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

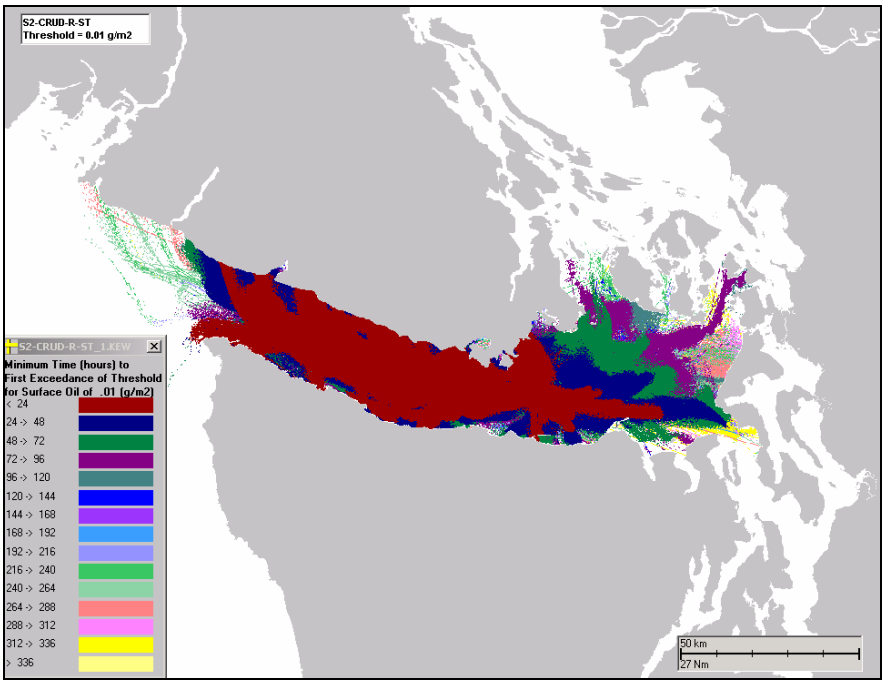

Figure XIII.B-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

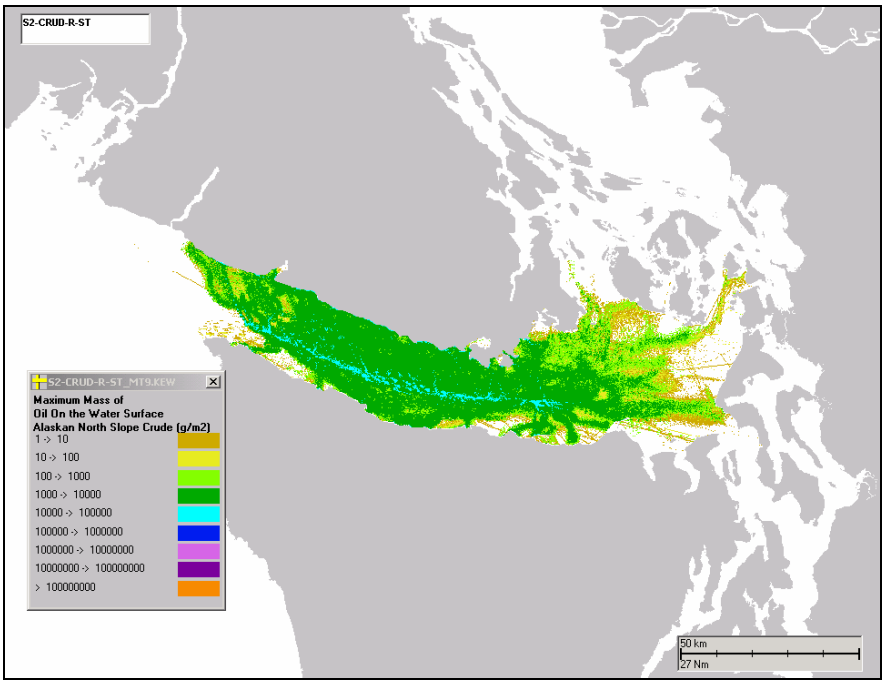

Figure XIII.B-3. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

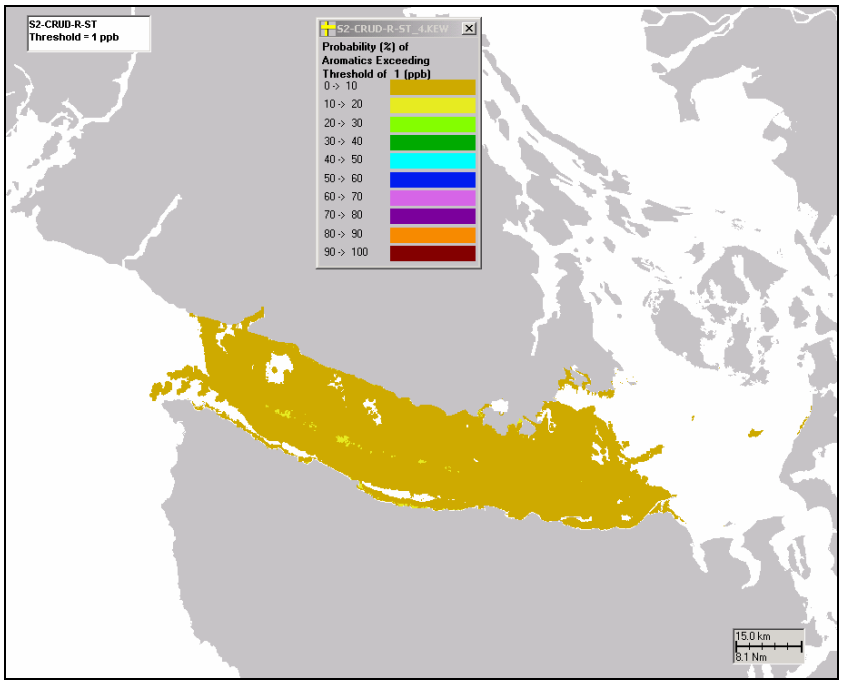

Figure XIII.B-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

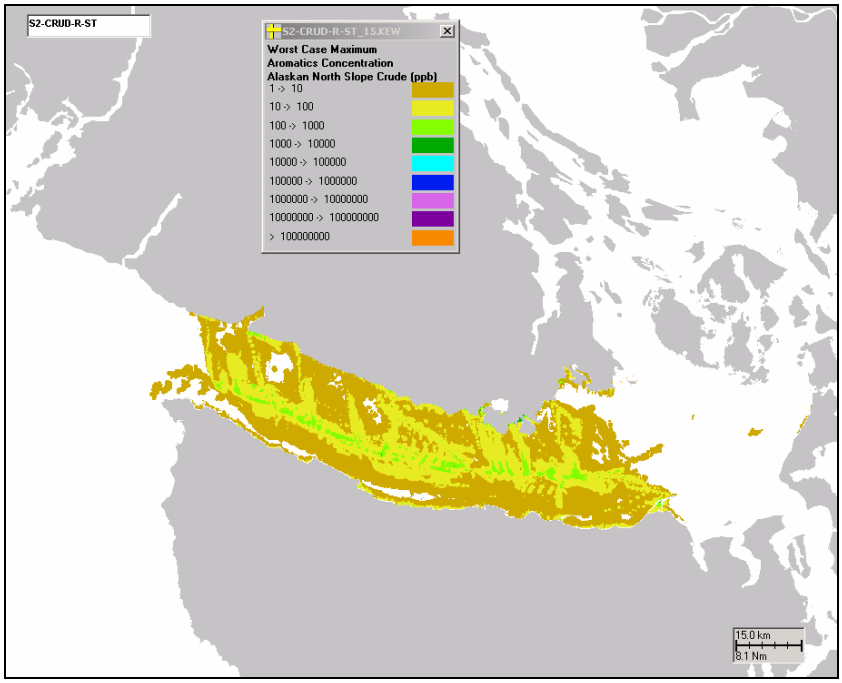

Figure XIII.B-5. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

Sediment exposure to total hydrocarbons does not exceed 0.01 g/m^2

Figure XIII.B-6. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Sediment exposure to total hydrocarbons (g/m^2) under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

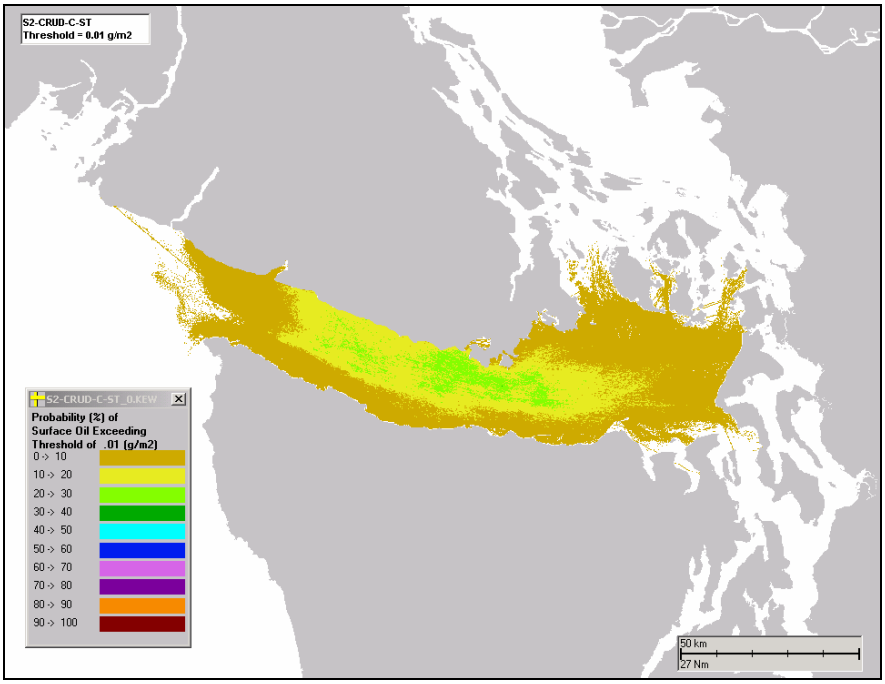

Figure XIII.B-7. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

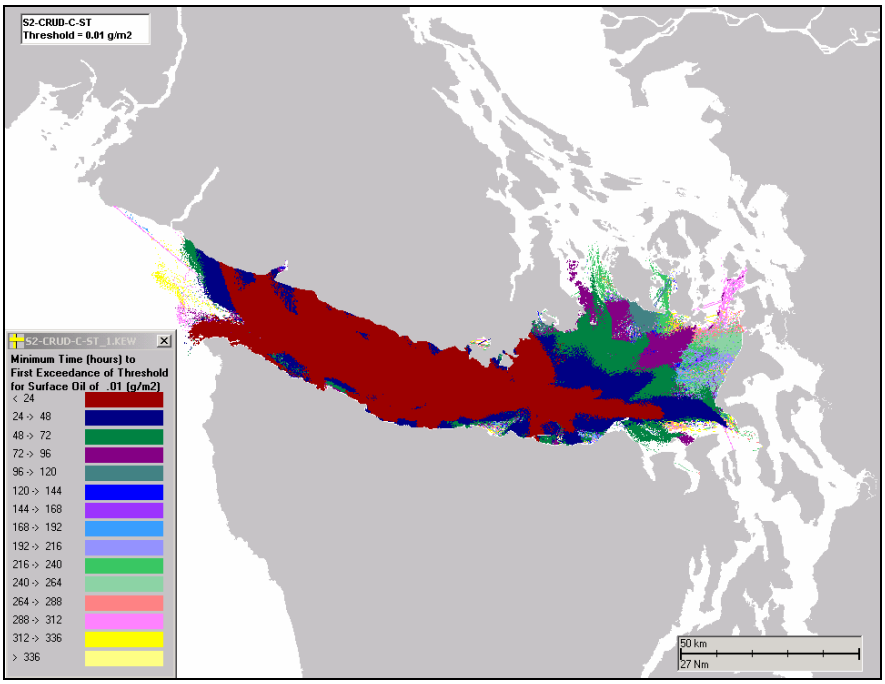

Figure XIII.B-8. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

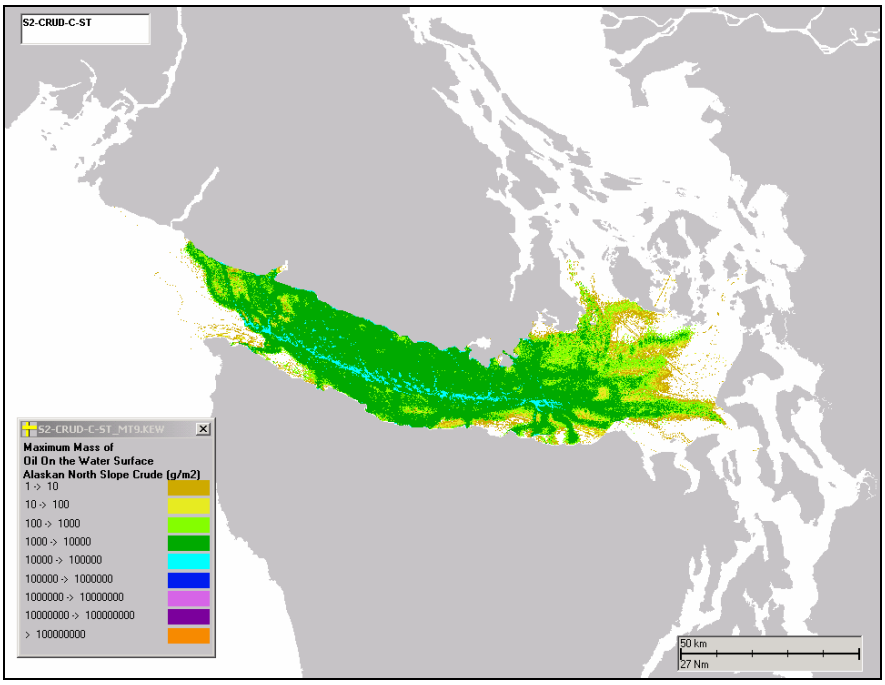

Figure XIII.B-9. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

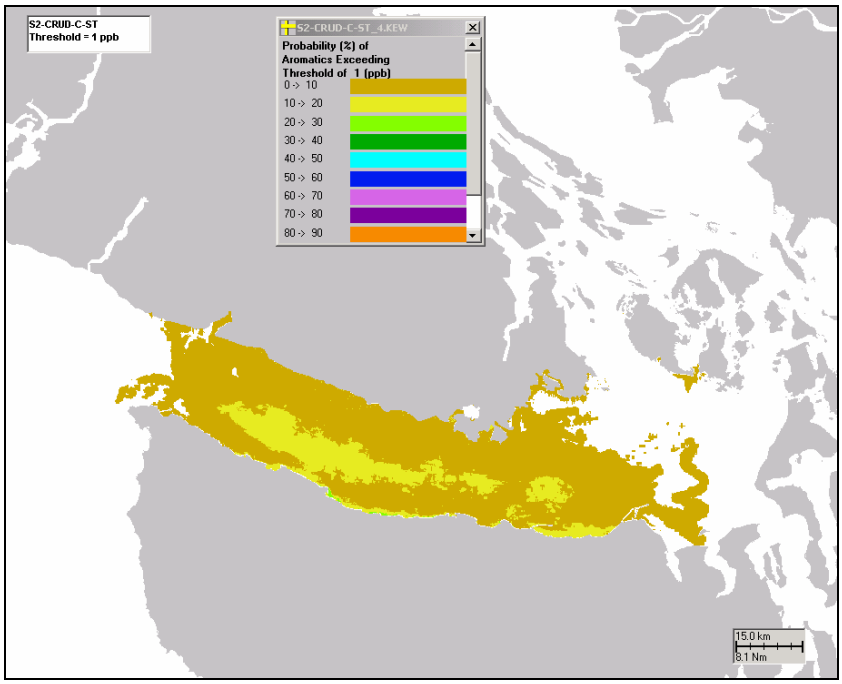

Figure XIII.B-10. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

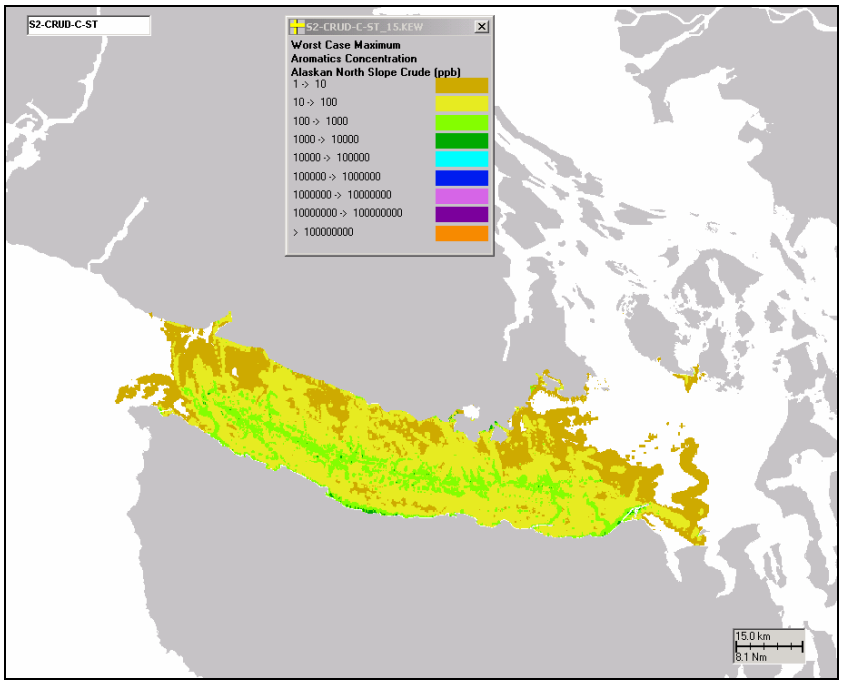

Figure XIII.B-11. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

Sediment exposure to total hydrocarbons does not exceed 0.01 g/m^2

Figure XIII.B-12. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Sediment exposure to total hydrocarbons (g/m^2) under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

XIII.C. RANK ORDER DISTRIBUTIONS FOR ALL MODEL RUNS

In this section, the following impact indices are plotted as rank order distributions:

- Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 (which is sheen) times duration of exposure (in m^2-hrs)
- Shoreline area (m^2) exposed to hydrocarbons of various threshold thicknesses (>0.01, 1, 10, 100, and 1000 g/m^2)
- Water volume exposed to > 1 ppb (>1 mg/m^3) of dissolved aromatic concentration at some time after the spill
- Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill
- Percent of spilled hydrocarbon mass eventually going ashore
- Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats)
- Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill, and
- Percent of spilled hydrocarbon mass removed mechanically an by in situ burning (ISB, if applicable).

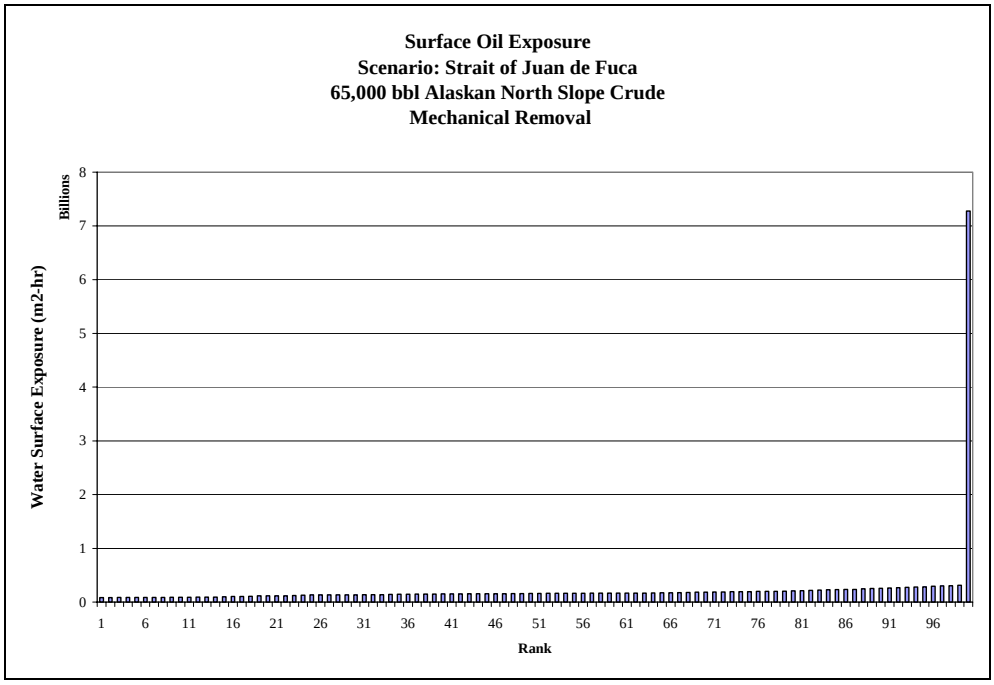

Figure XIII.C-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

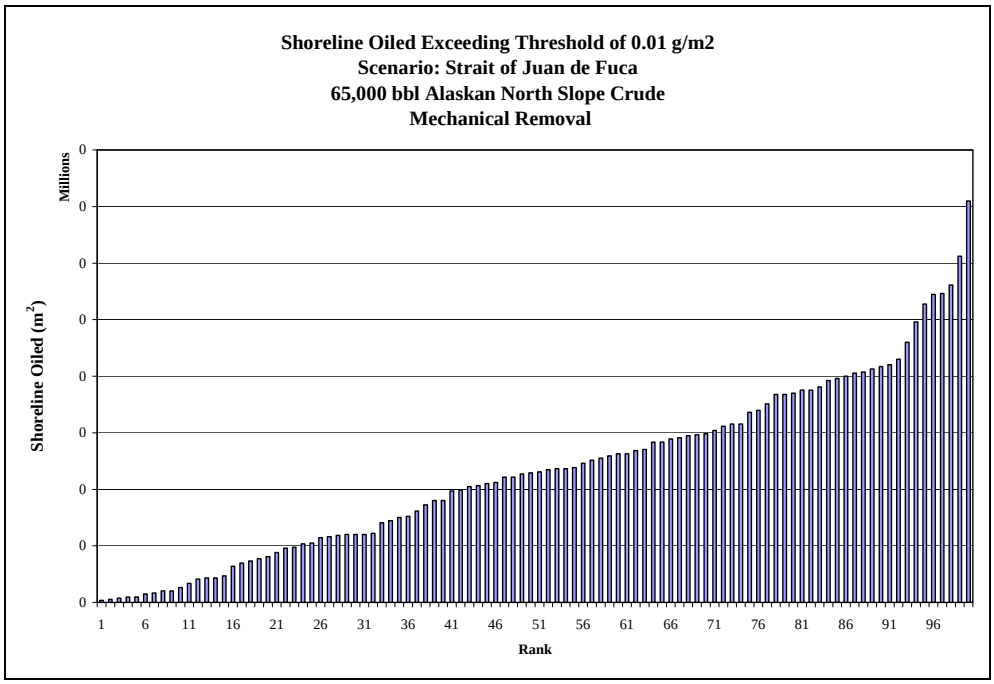

Figure XIII.C-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

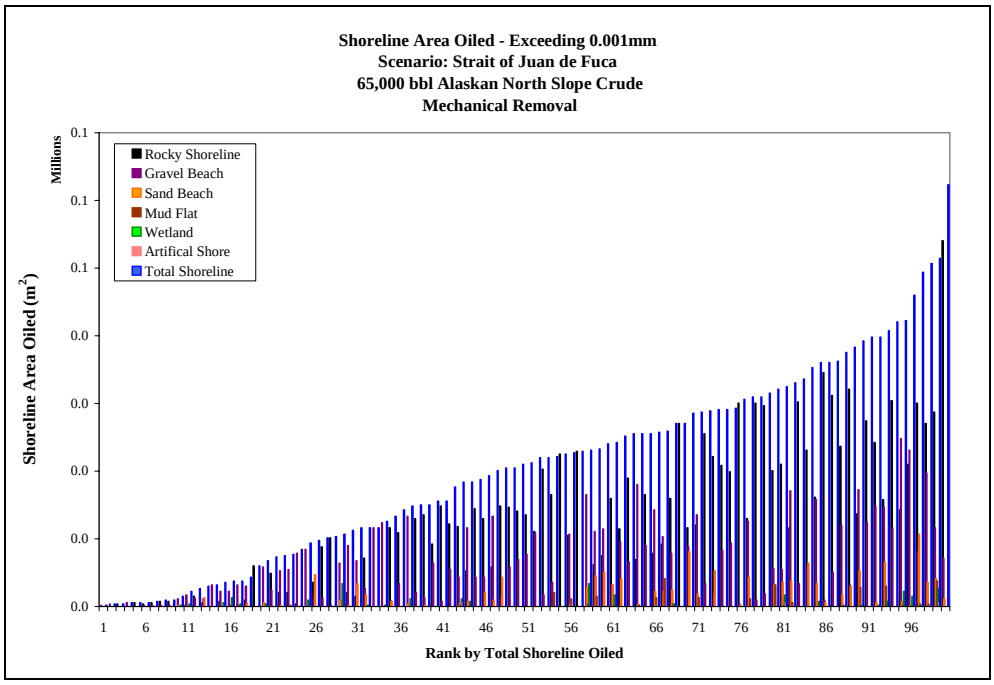

Figure XIII.C-3. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

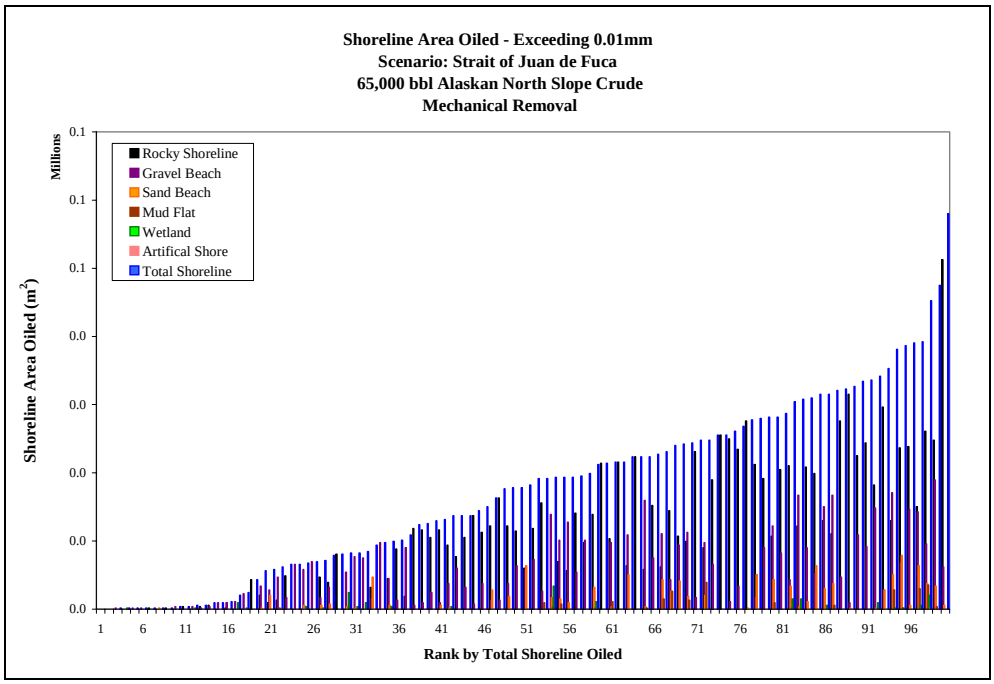

Figure XIII.C-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

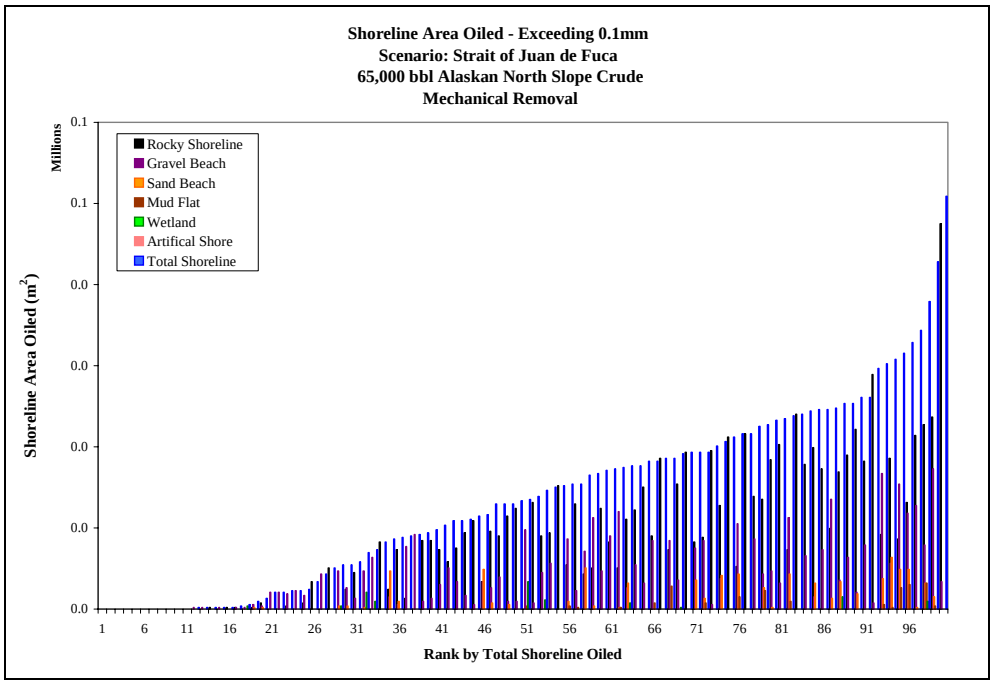

Figure XIII.C-5. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

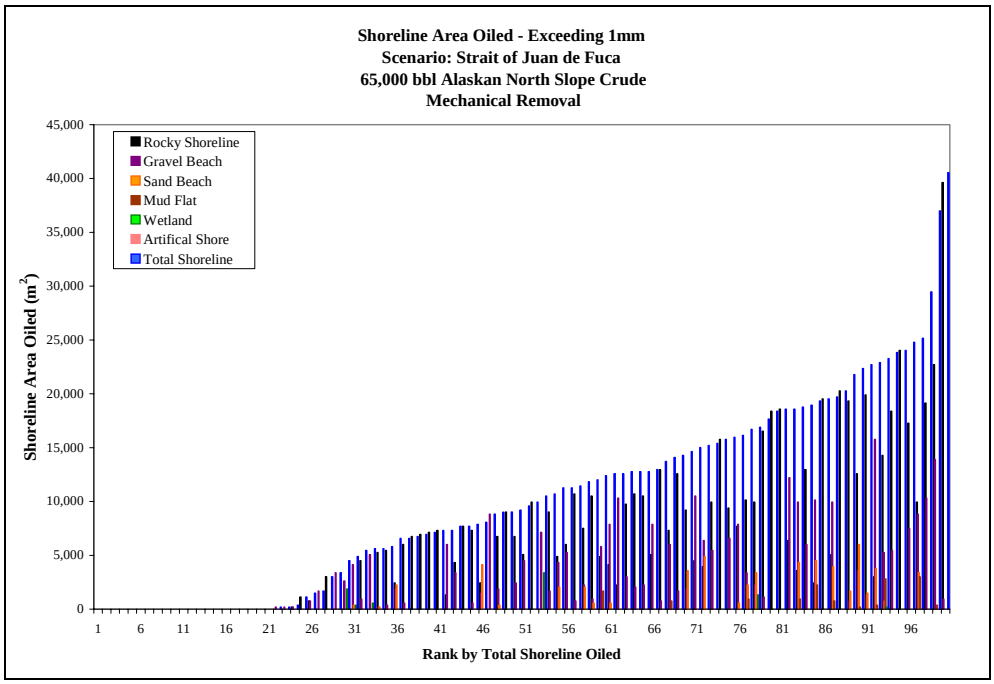

Figure XIII.C-6. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

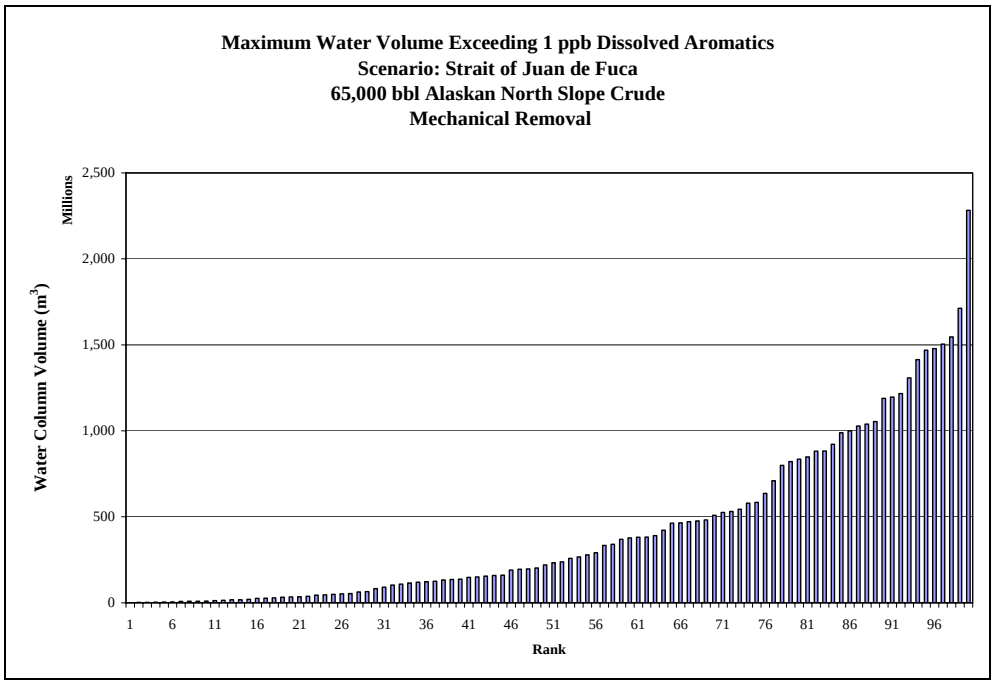

Figure XIII.C-7. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

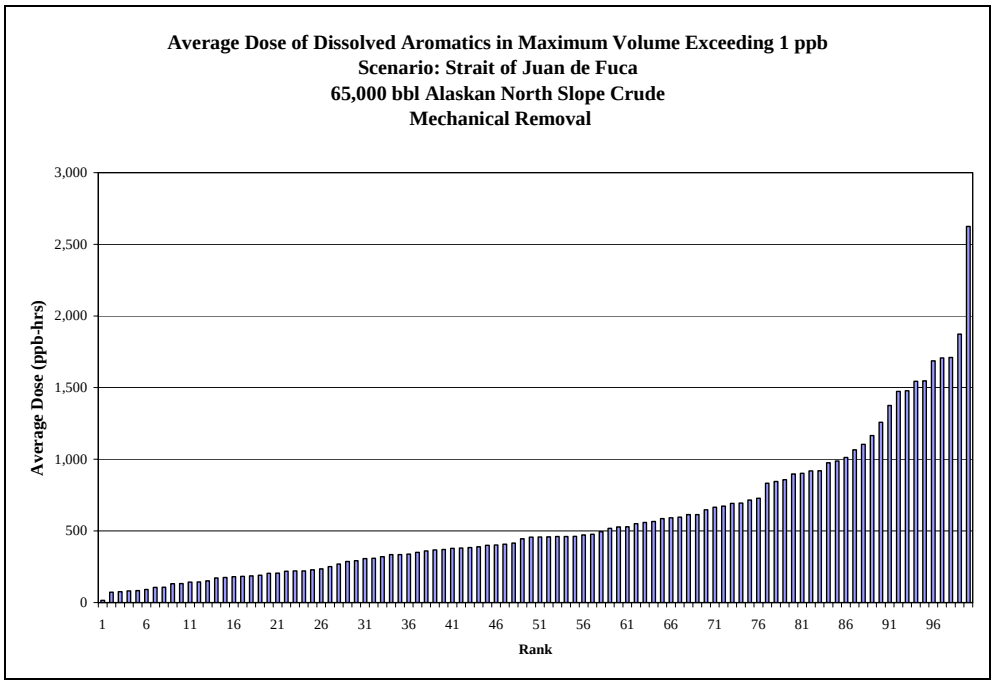

Figure XIII.C-8. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

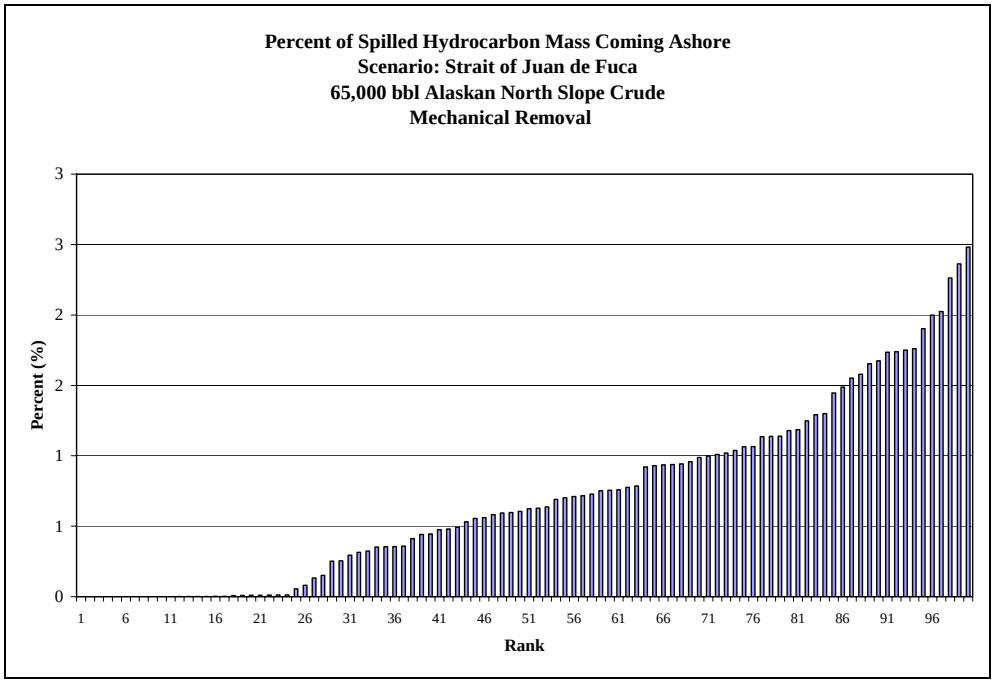

Figure XIII.C-9. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

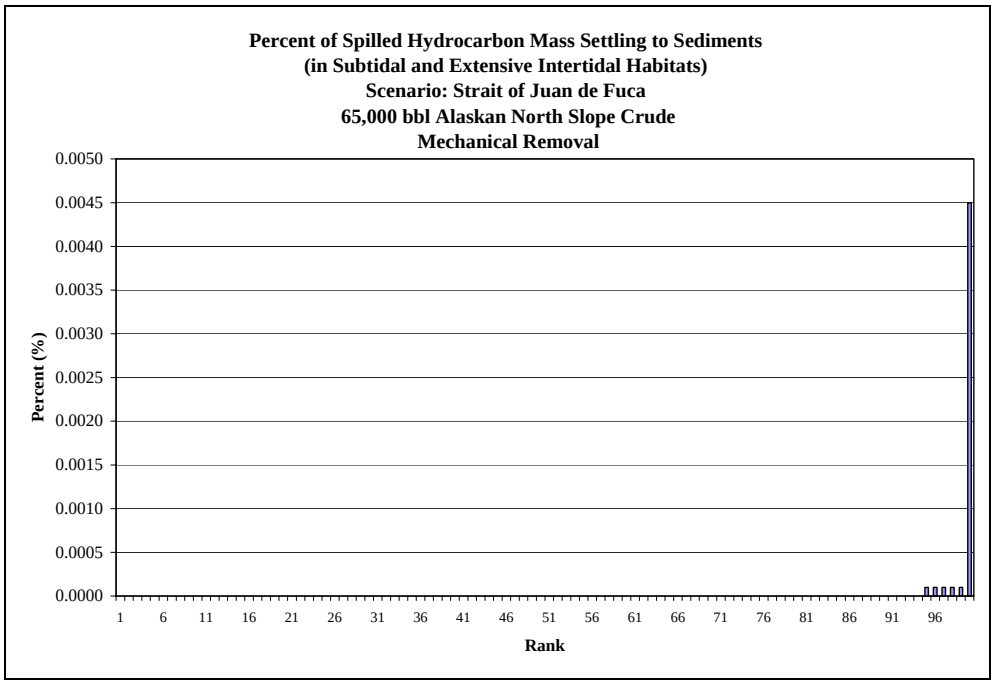

Figure XIII.C-10. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

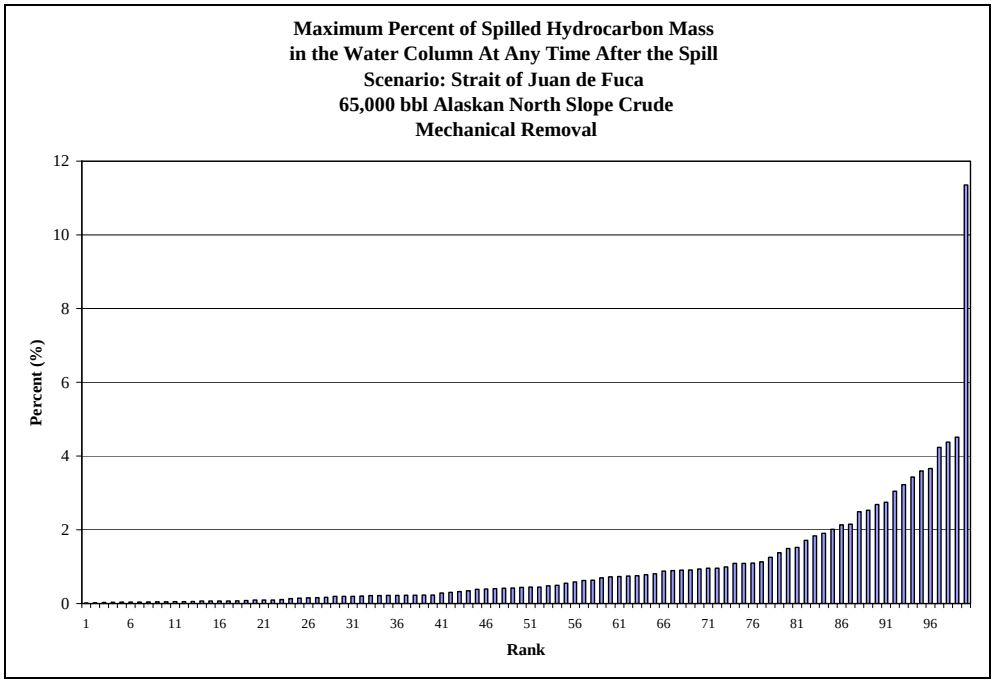

Figure XIII.C-11. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

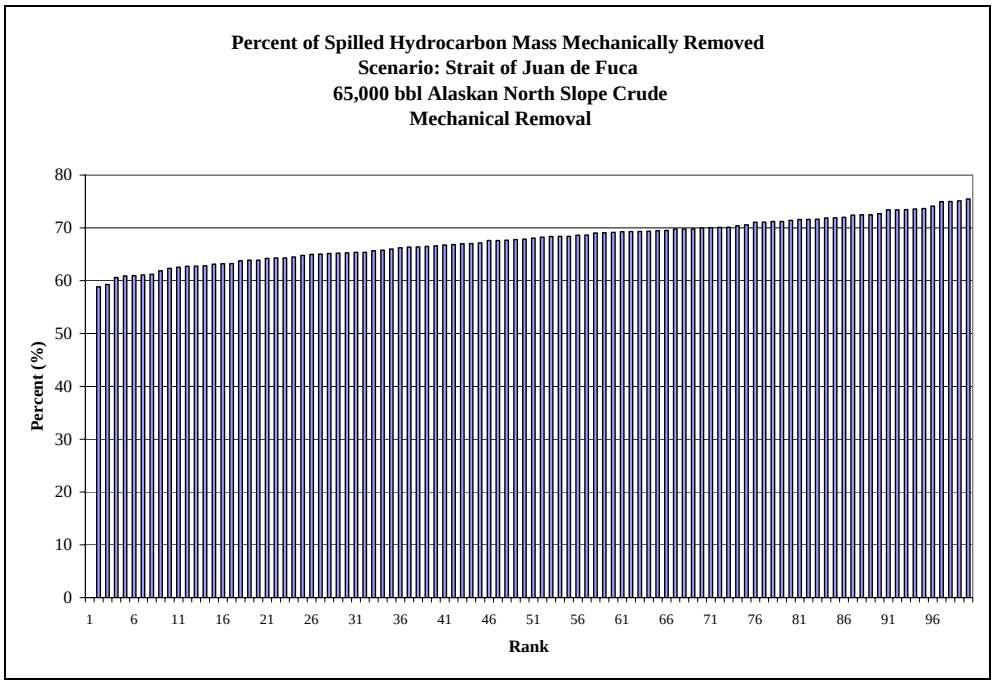

Figure XIII.C-12. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass mechanically removed.

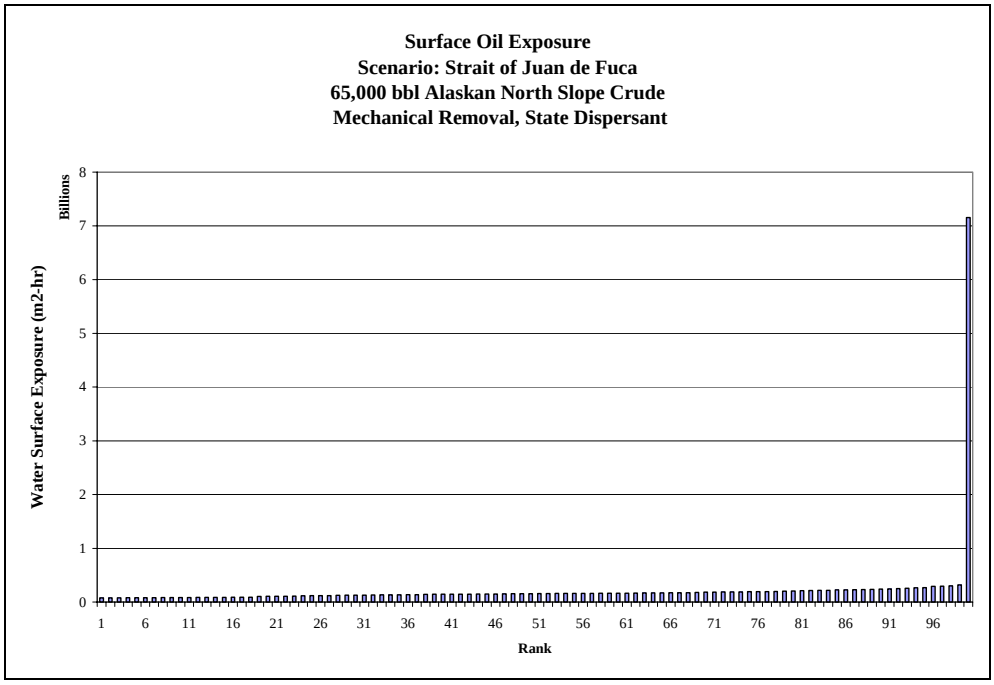

Figure XIII.C-13. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

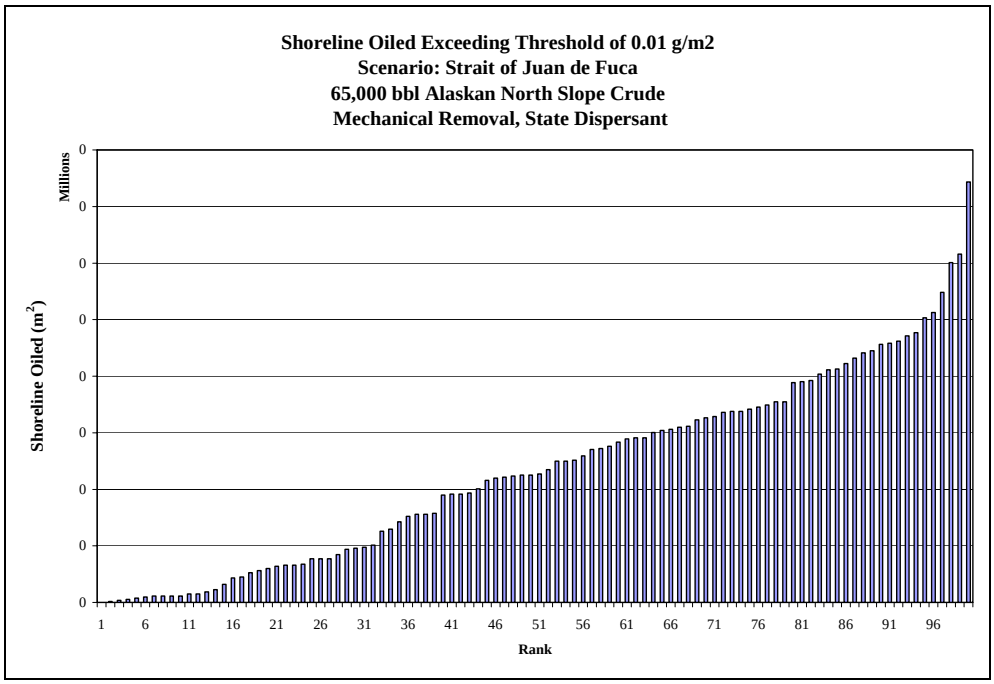

Figure XIII.C-14. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

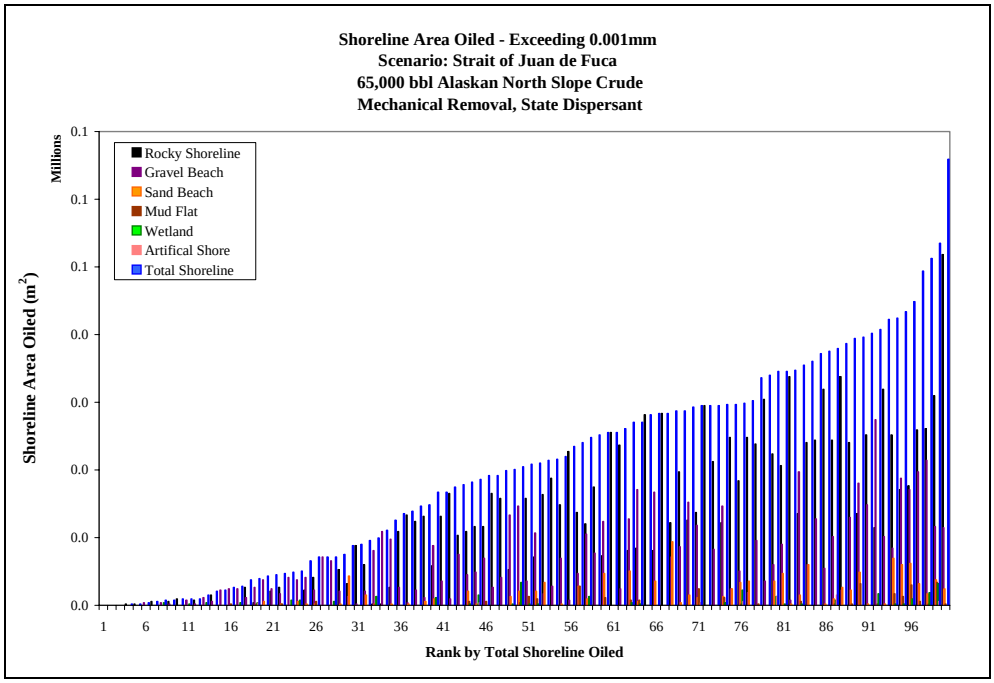

Figure XIII.C-15. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

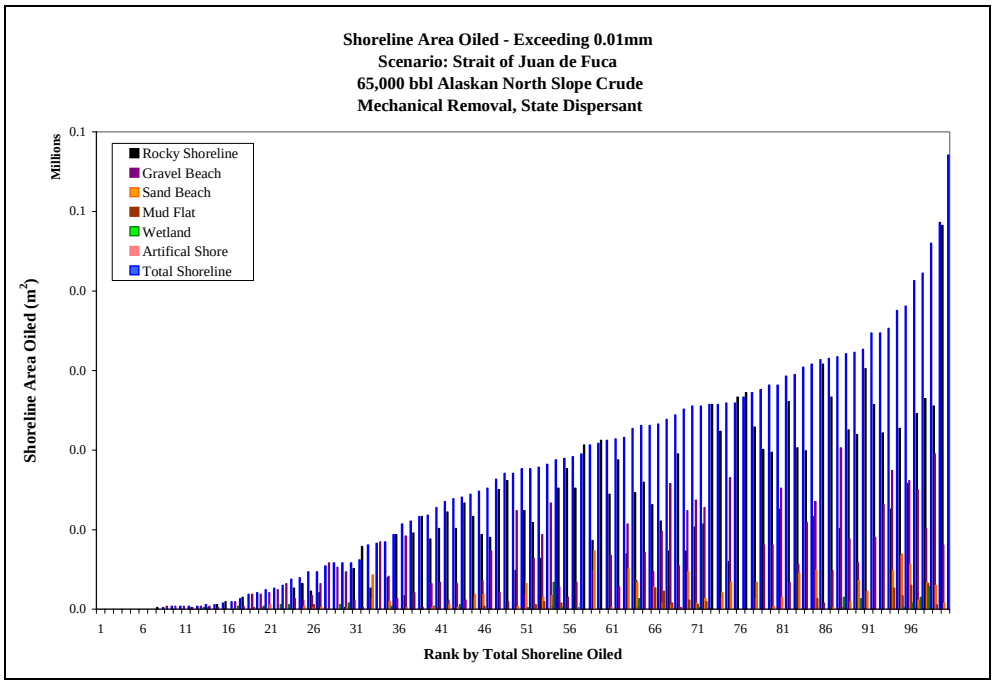

Figure XIII.C-16. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

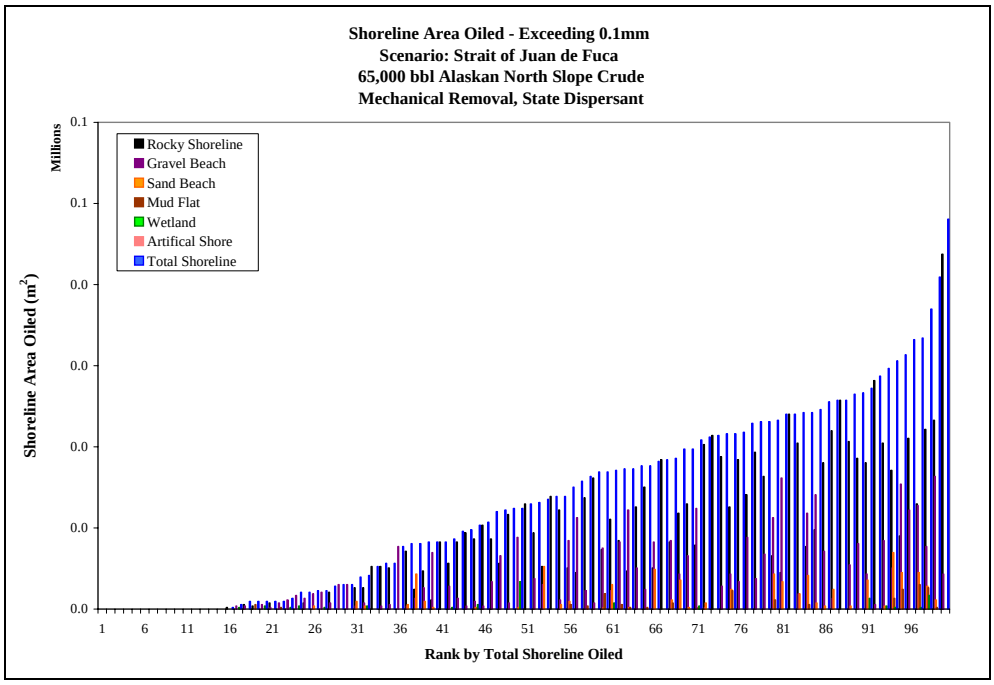

Figure XIII.C-17. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

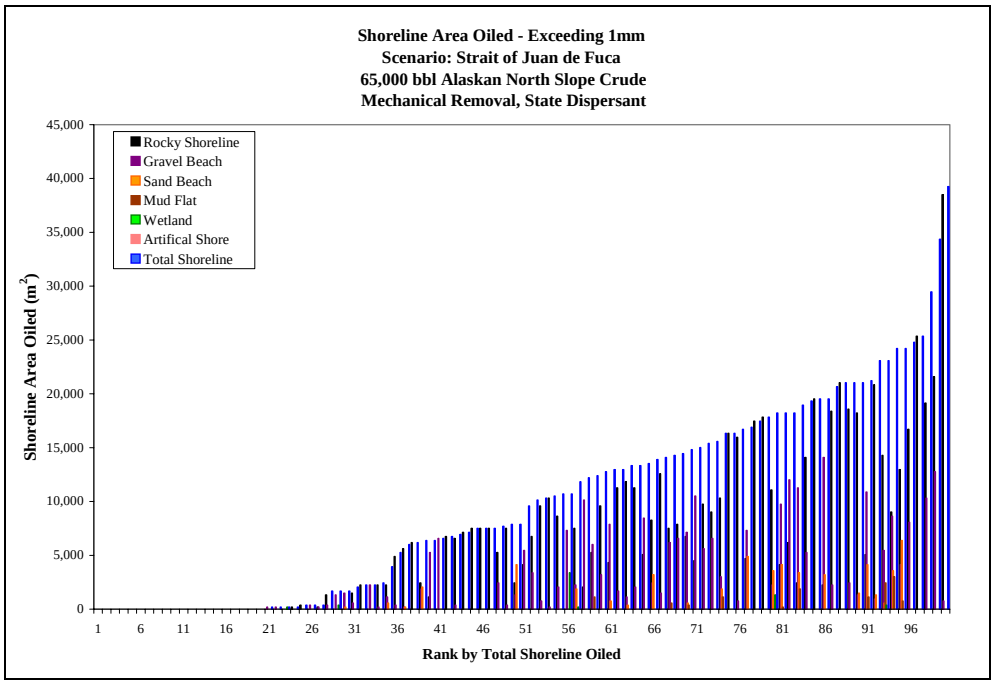

Figure XIII.C-18. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

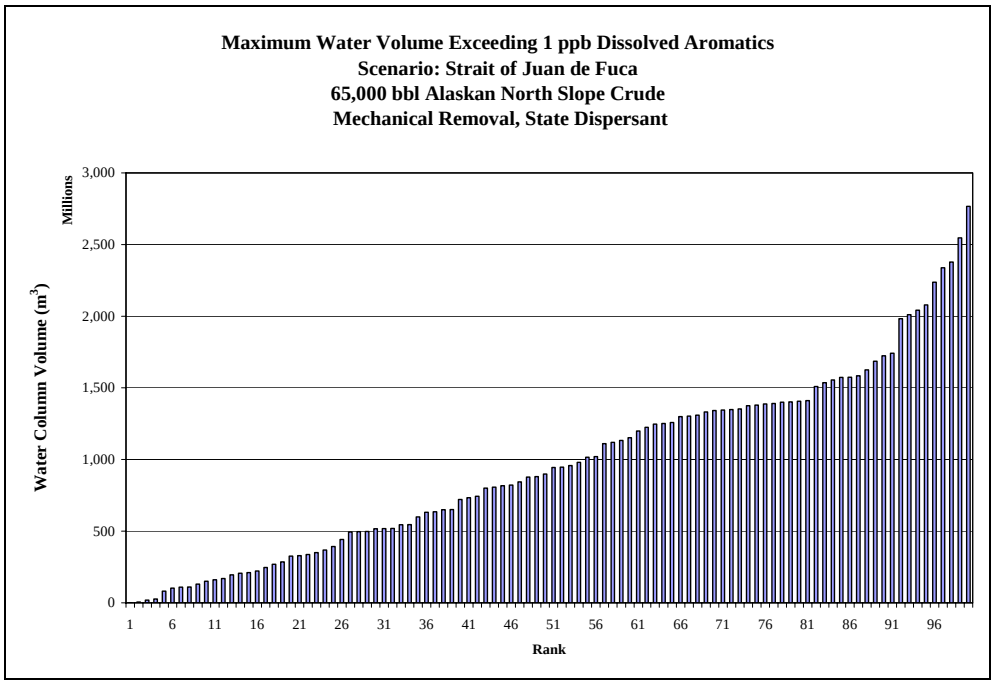

Figure XIII.C-19. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

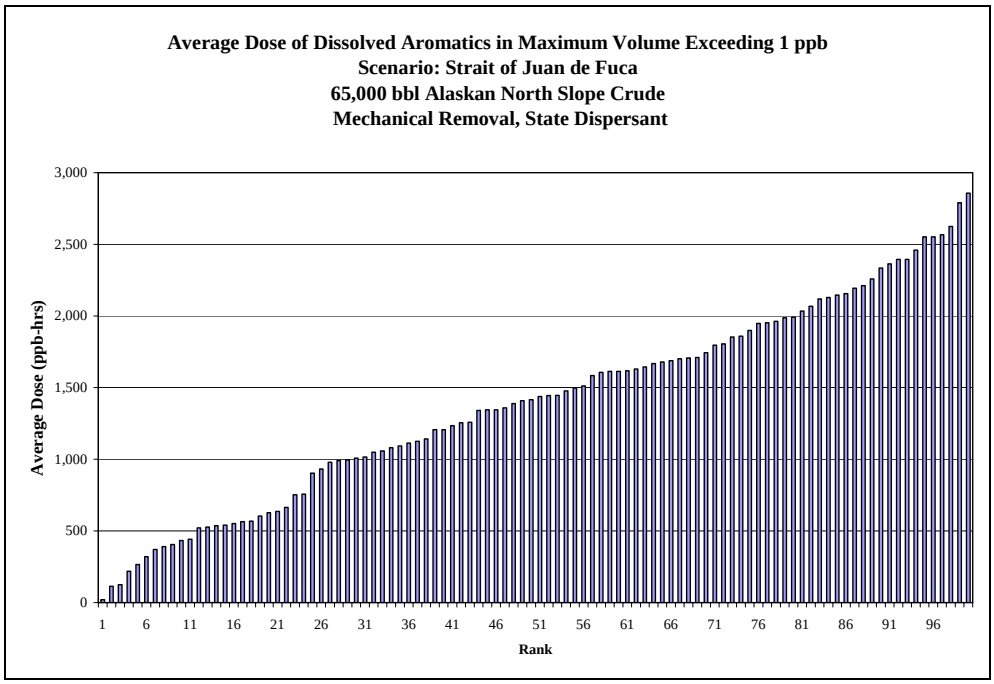

Figure XIII.C-20. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

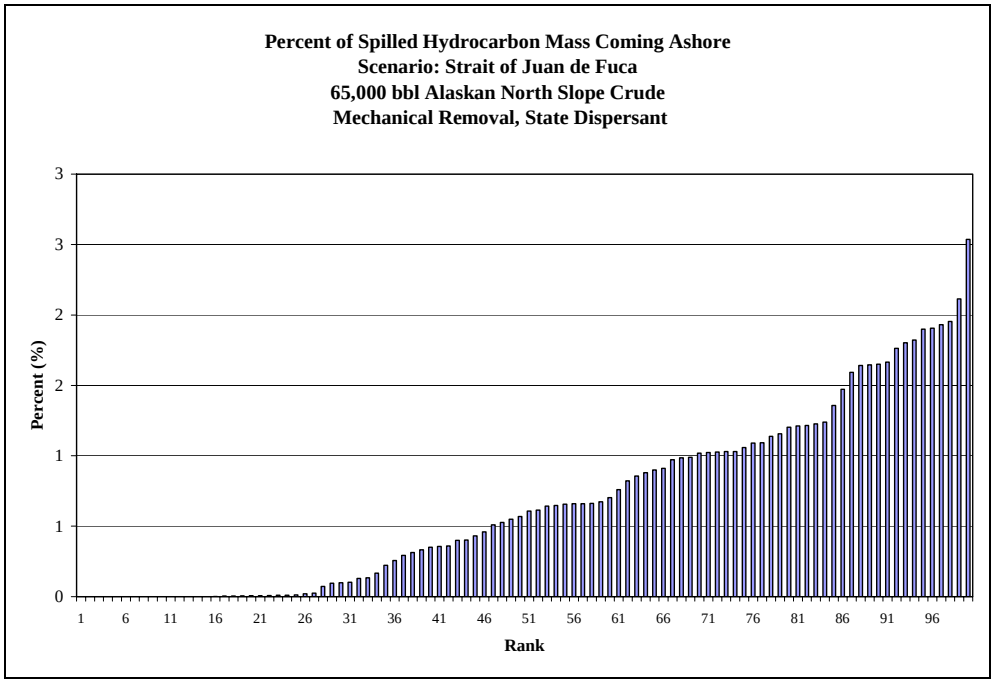

Figure XIII.C-21. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

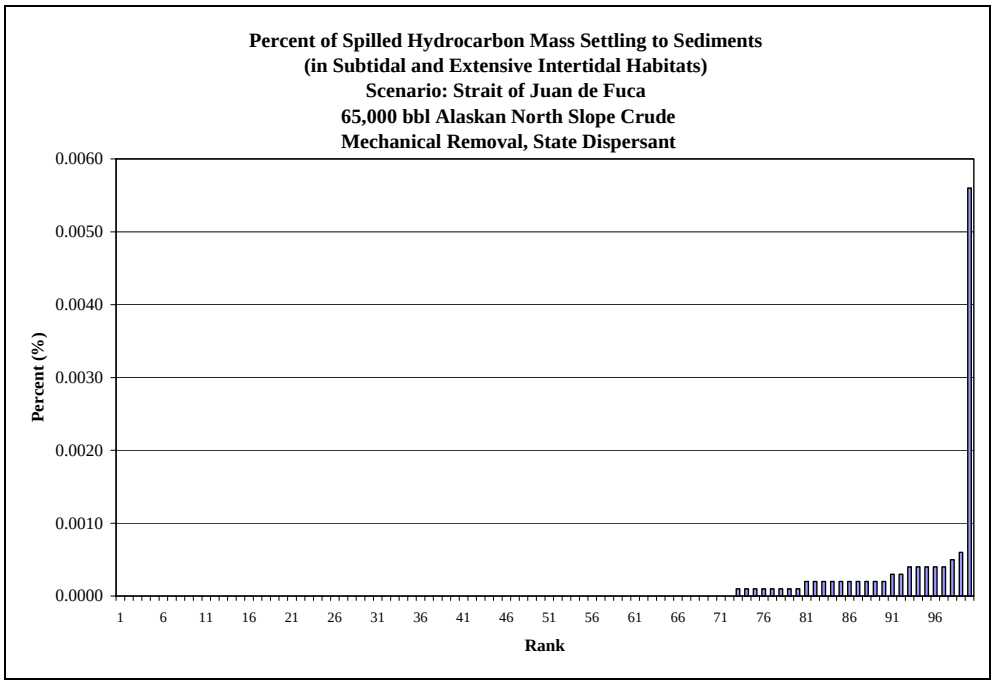

Figure XIII.C-22. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

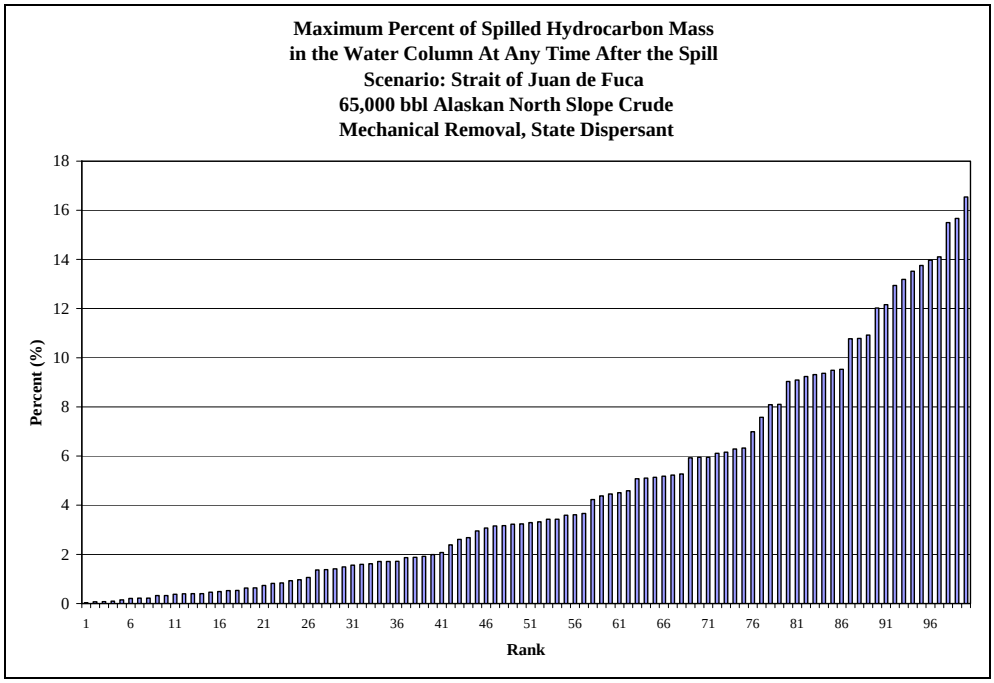

Figure XIII.C-23. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

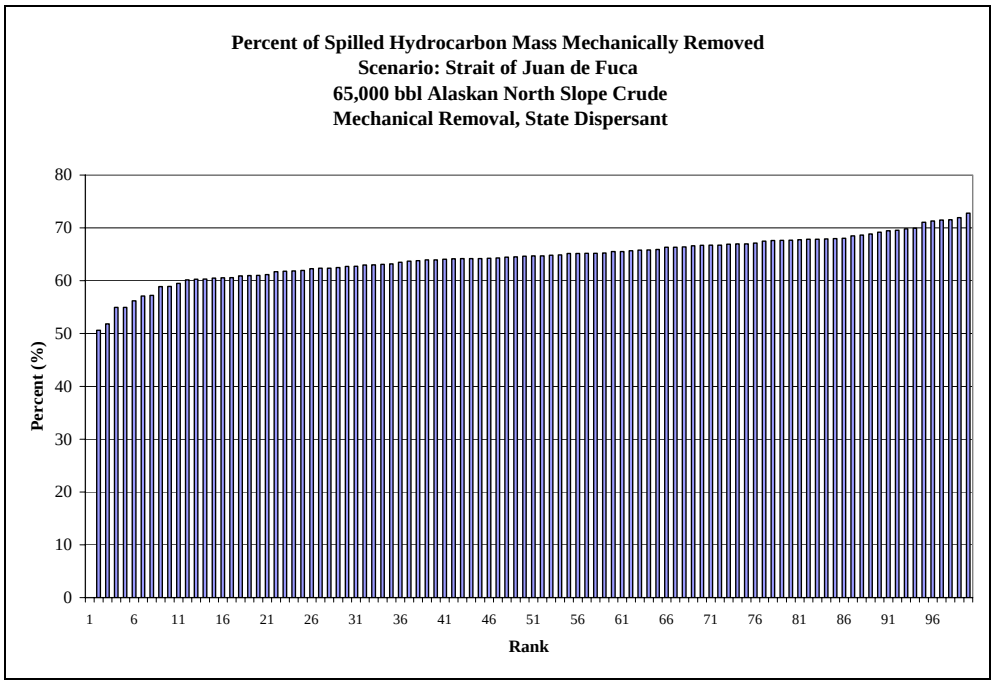

Figure XIII.C-24. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass mechanically removed.

XIII.D. SHORELINE AREAS EXPOSED BY SHORE TYPE

The tables in this section list the areas of shoreline oiled by shore type for the main stochastic scenarios. The 50th and 95th percentile results are sorted by total shoreline oiled at the indicated threshold. Thus, these are not the same runs as those sorted by shoreline cleanup cost (which are reported in Volume II).

Table XIII.D-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	21,216	13,518	7,698	0	0	0	0
95th	45,999	21,028	23,093	188	188	1,502	0
Maximum	62,332	54,072	24,783	10,702	4,130	3,379	563
Mean	20,740	12,412	6,464	1,288	293	265	19
Std. Dev.	14,003	10,960	5,753	2,084	801	664	98
Mean + 2 Std. Dev.	48,746	34,332	17,970	5,456	1,895	1,593	215

Table XIII.D-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	18,211	6,008	5,820	6,383	0	0	0
95th	39,051	23,844	14,644	563	0	0	0
Maximum	58014	51255	18963	7885	3943	3379	188
Mean	17633	10827	5285	1085	248	186	2
Std. Dev.	12830	9926	5052	1851	741	532	19
Mean + 2 Std. Dev.	43,293	30,679	15,389	4,787	1,730	1,250	40

Table XIII.D-3. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	13,517	0	9,763	0	375	3,379	0
95th	32,855	13,142	11,828	4,881	3,004	0	0
Maximum	50,879	47,500	17,273	6,383	3,192	3,379	0
Mean	13,820	8,790	3,933	779	201	116	0
Std. Dev.	11,007	8,619	4,270	1,563	637	455	0
Mean + 2 Std. Dev.	35,834	26,028	12,473	3,905	1,475	1,026	0

Table XIII.D-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	9,575	5,069	4,506	0	0	0	0
95th	45,999	17,273	7,510	0	188	0	0
Maximum	40,554	39,615	15,771	6,008	3,004	3,379	0
Mean	10,382	6,708	2,886	571	141	77	0
Std. Dev.	8,879	7,238	3,724	1,326	514	409	0
Mean + 2 Std. Dev.	28,140	21,184	10,334	3,223	1,169	895	0

Table XIII.D-5. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	20,840	15,771	3,567	0	1,314	188	0
95th	44,872	17,648	17,085	6,196	3,004	939	0
Maximum	65,901	51,819	27,411	9,387	3,379	3,379	1,502
Mean	20,678	12,617	6,259	1,192	291	268	51
Std. Dev.	15,046	11,082	6,088	1,922	704	625	220
Mean + 2 Std. Dev.	50,770	34,781	18,435	5,036	1,699	1,518	491

Table XIII.D-6. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	17,648	12,391	1,877	3,192	0	188	0
95th	41,304	15,771	16,146	5,632	3,004	751	0
Maximum	57075	48251	20277	7322	3192	3379	751
Mean	17312	10921	4968	980	252	182	9
Std. Dev.	13293	9976	5284	1709	653	524	77
Mean + 2 Std. Dev.	43,898	30,873	15,536	4,398	1,558	1,230	163

Table XIII.D-7. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	12,955	12,955	0	0	0	0	0
95th	33,232	21,028	12,204	0	0	0	0
Maximum	48,063	43,745	16,334	6,947	3,004	3,379	0
Mean	13,375	8,691	3,661	727	190	107	0
Std. Dev.	11,206	8,624	4,393	1,487	569	410	0
Mean + 2 Std. Dev.	35,787	25,939	12,447	3,701	1,328	927	0

Table XIII.D-8. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	9,575	4,130	5,445	0	0	0	0
95th	44,872	16,710	8,073	0	3,004	0	0
Maximum	39,239	38,488	14,081	6,383	3,004	3,379	0
Mean	10,046	6,646	2,692	524	126	58	0
Std. Dev.	9,004	7,311	3,679	1,281	469	365	0
Mean + 2 Std. Dev.	28,054	21,268	10,050	3,086	1,064	788	0

XIII.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

In this section, the results for the 5th, 50th, and 95th percentile runs based on shoreline oiling costs (using the base case scenario for sorting) are shown, as plots of the following measures of exposure:

- Water surface exposure to floating hydrocarbons (g/m^2)
- Shoreline exposure to hydrocarbons (g/m^2) (for 95th percentile run only)
- Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill

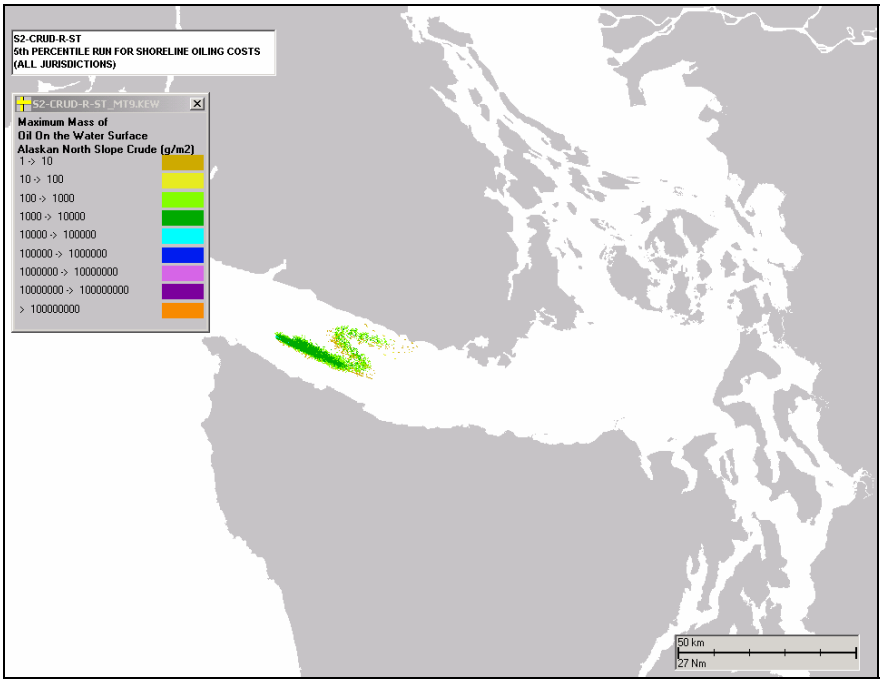

Figure XIII.E-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

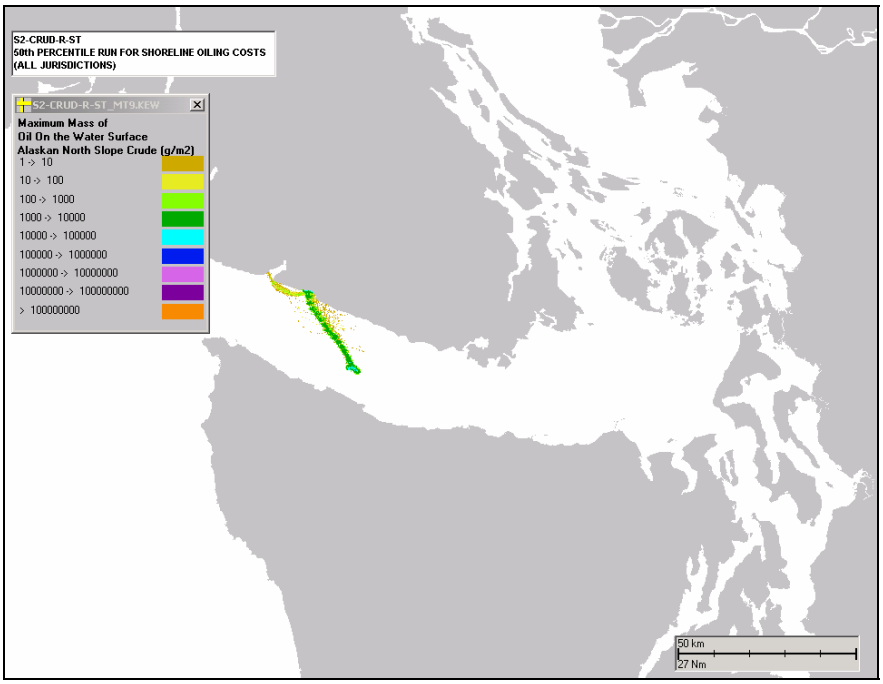

Figure XIII.E-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

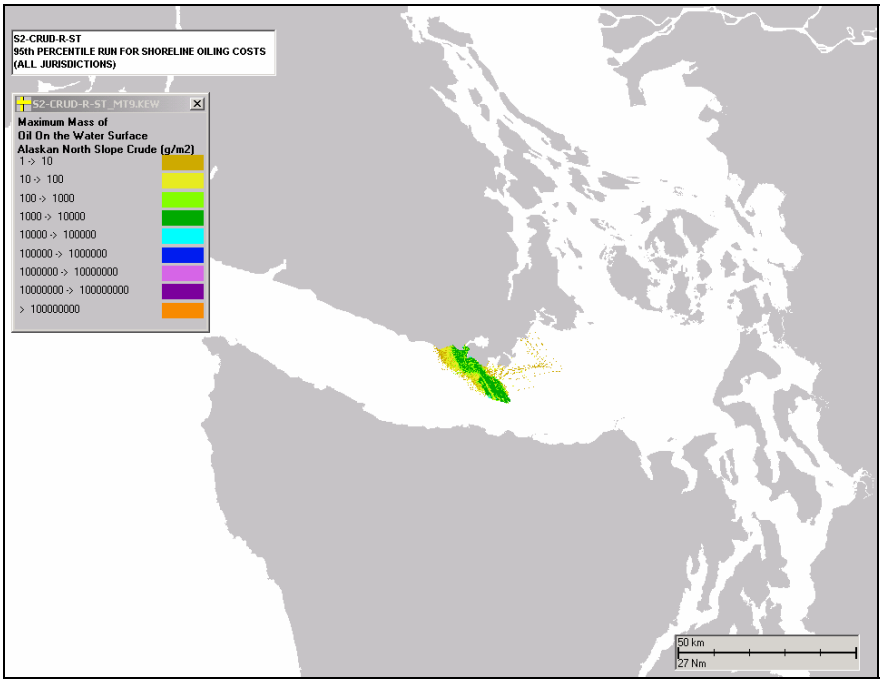

Figure XIII.E-3. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

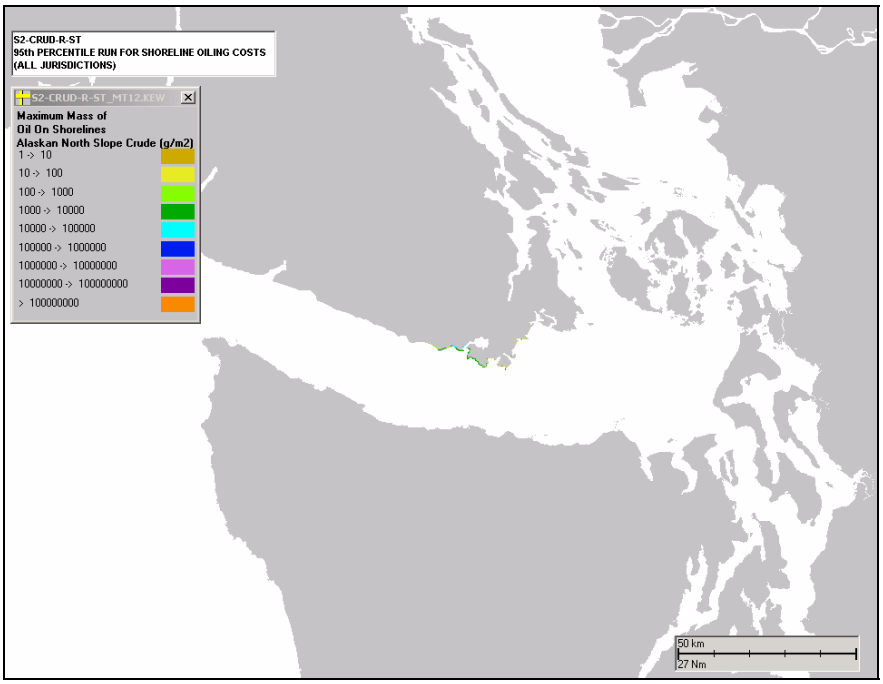

Figure XIII.E-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

Maximum water column exposure of dissolved aromatic concentration does not exceed 1 ppb.

Figure XIII.E-5. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

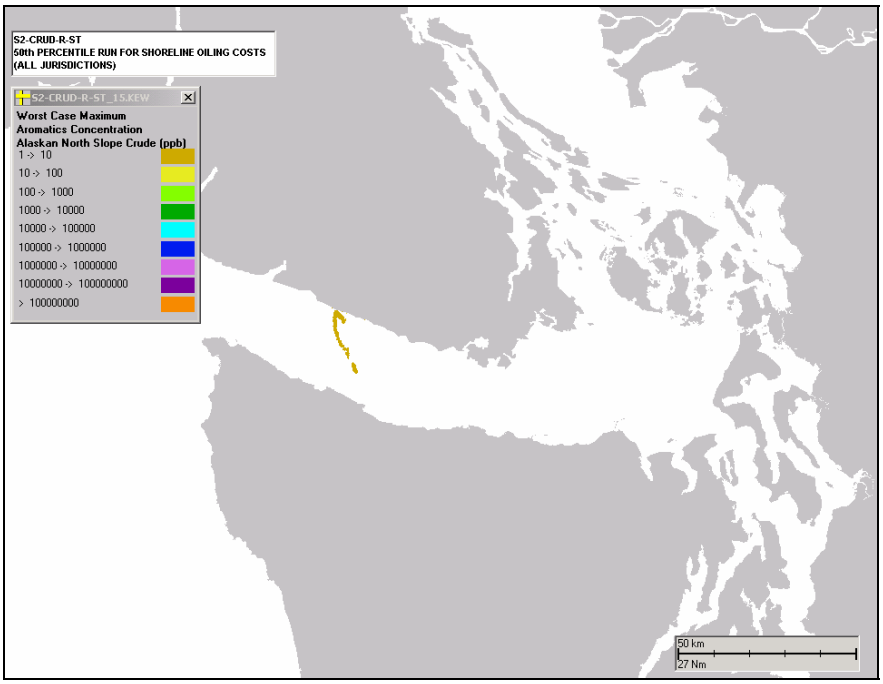

Figure XIII.E-6. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

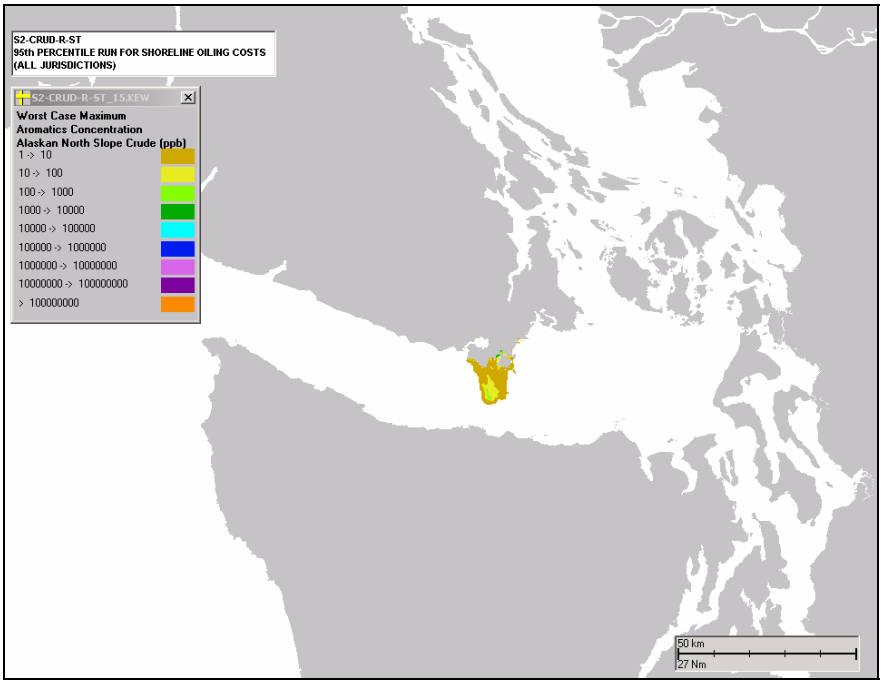

Figure XIII.E-7. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

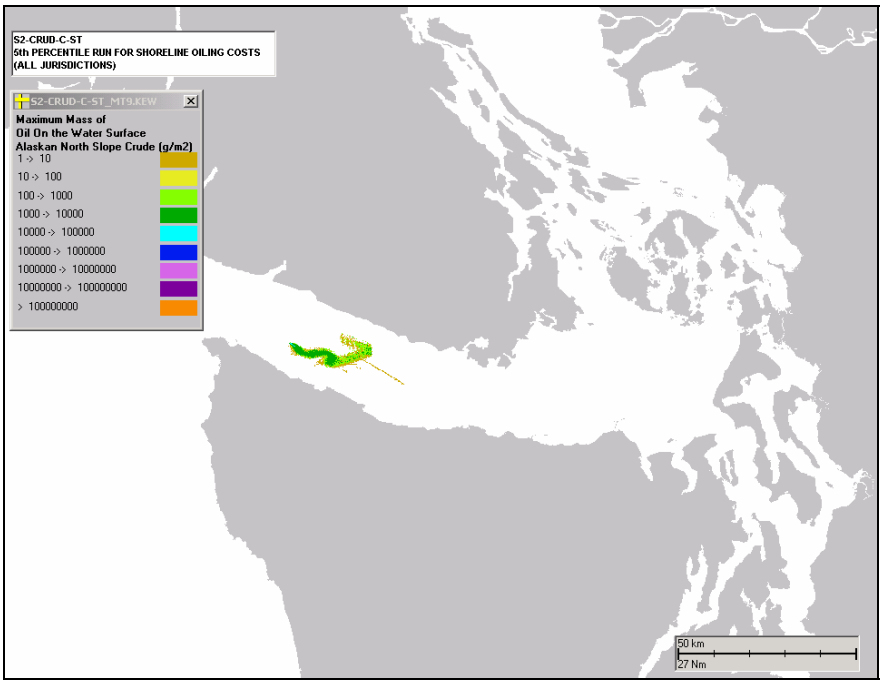

Figure XIII.E-8. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

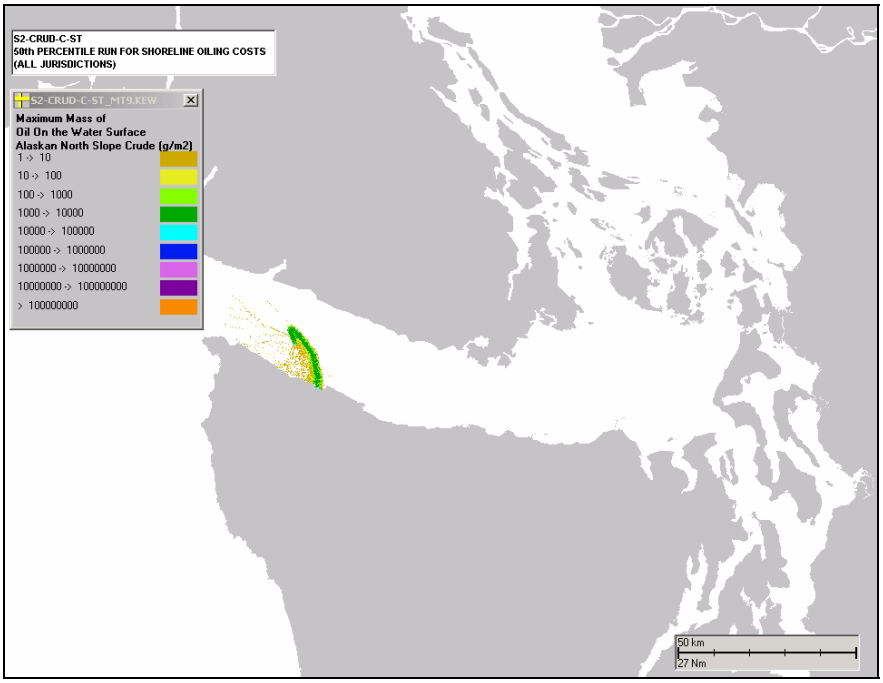

Figure XIII.E-9. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

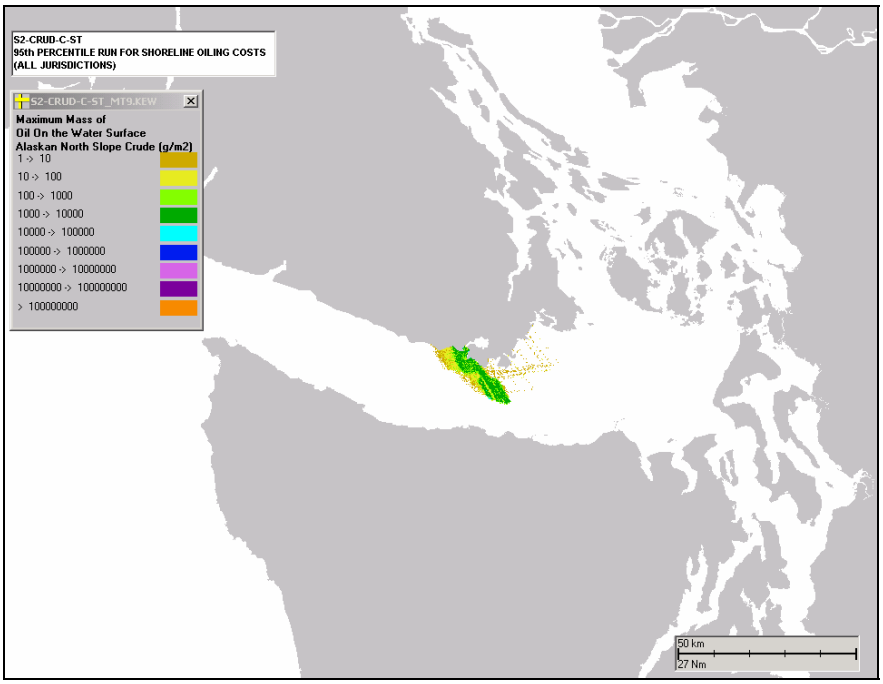

Figure XIII.E-10. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

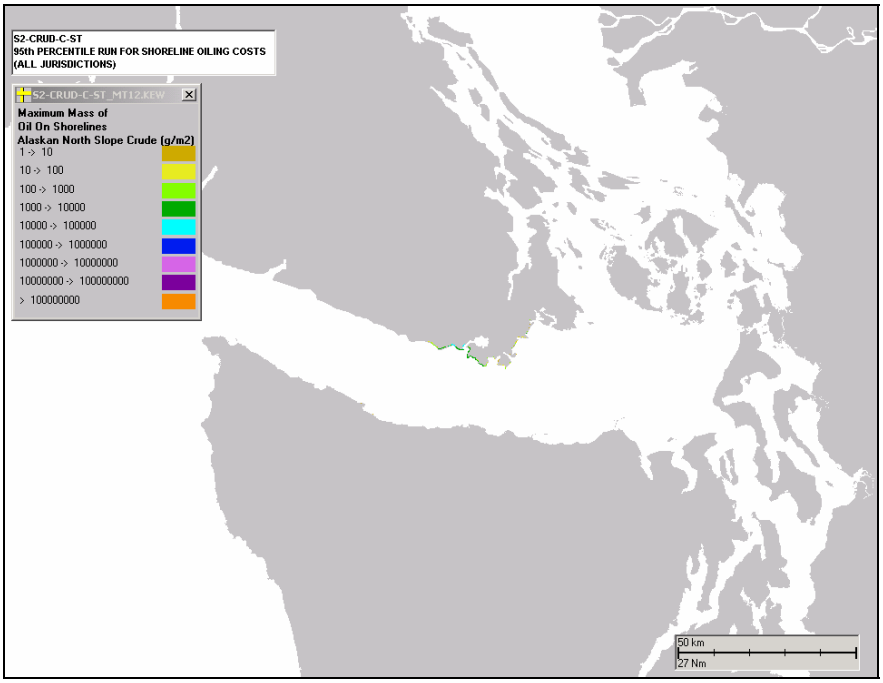

Figure XIII.E-11. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

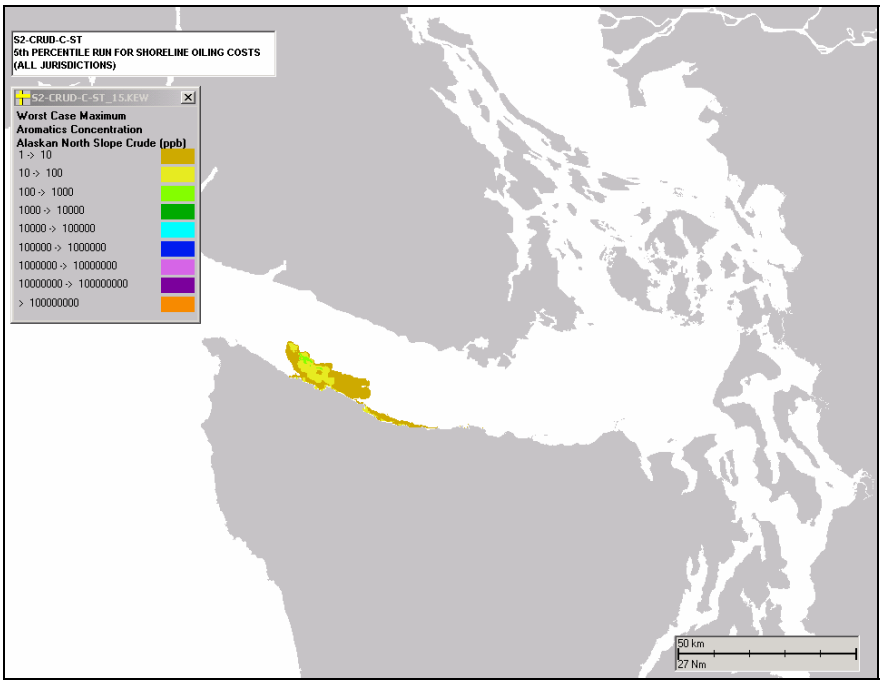

Figure XIII.E-12. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

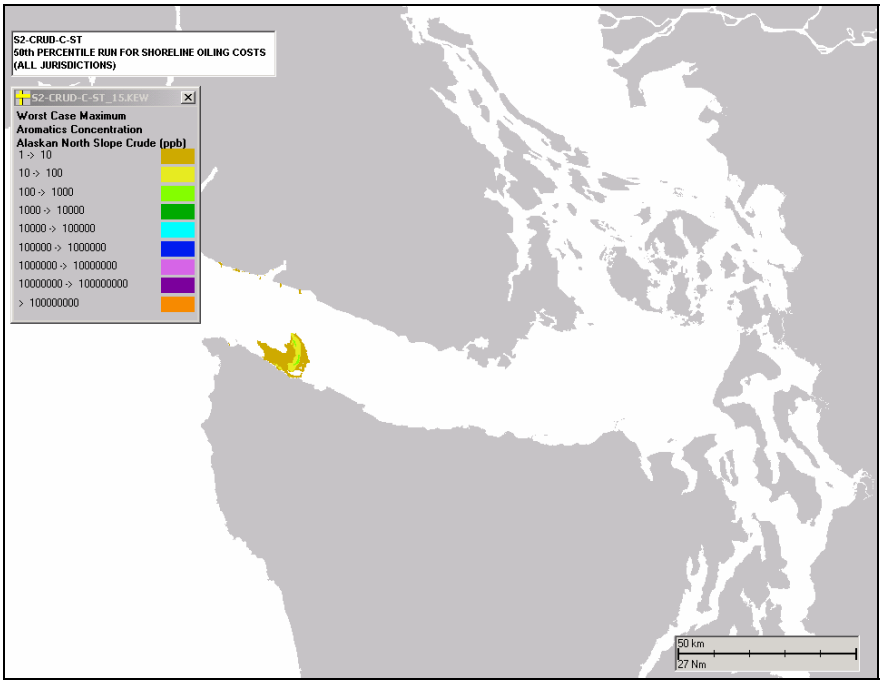

Figure XIII.E-13. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

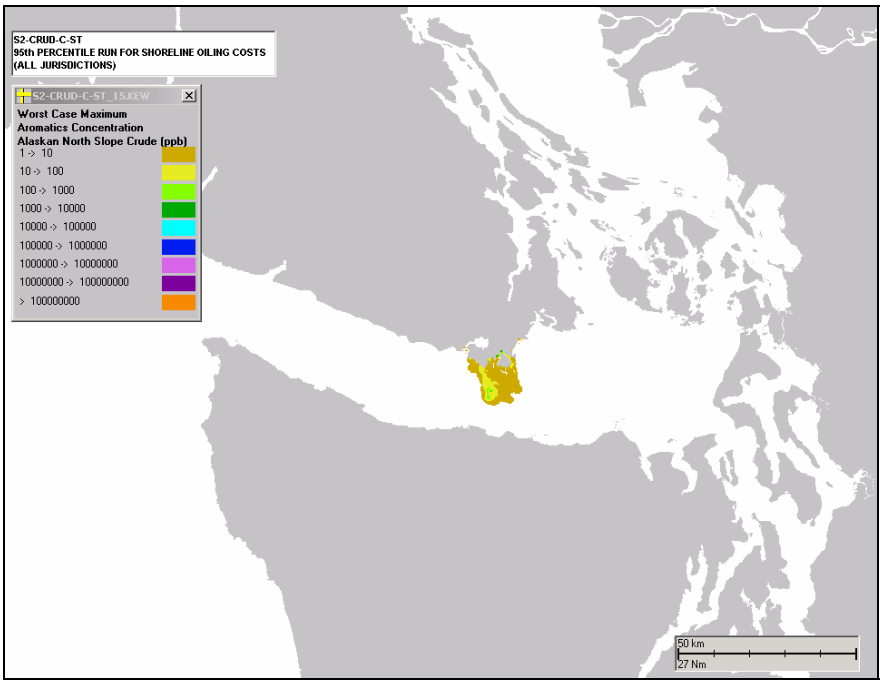

Figure XIII.E-14. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIII.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost.

The wildlife impacts for all 100 runs were estimated from the habitat area occupied by the species group that was oiled, i.e., areas of water swept by oil > 10 g/m^2 and shoreline oiled by >100 g/m^2, using the methods described in Section 2.3 of Volume I. The actual 5th, 50th and 95th percentile results for the 100 estimates of wildlife impact were calculated by sorting only the wildlife group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact indices of a given scenario. Thus, to evaluate the various impact results for different species groups within a single scenario (i.e., different wildlife groups within a single table), the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table XIII.F-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	7,191	1,557	-	-	0	-	1	-	8,749	8,748	1
50th Percentile Run (based on shore cost)	5,617	902	3	186	0	-	1	-	6,709	6,709	1
95th Percentile Run (based on shore cost)	7,260	1,586	6	362	0	-	1	-	9,214	9,213	1
5th Percentile	4,799	562	-	-	0	-	0	-	5,487	5,486	0.48
50th Percentile	7,141	1,536	2	107	0	-	1	-	8,800	8,799	0.67
95th Percentile	12,055	3,582	6	388	0	-	1	-	16,789	16,787	1.07
Mean	7,686	1,763	2	147	0	-	1	-	9,598	9,598	0.71
Std Dev (SD)	2,539	1,057	3	191	0	-	0	-	3,619	3,619	0.21
Mean - 2SD	2,608	-	-	-	0	-	0	-	2,361	2,361	0.30
Mean + 2SD	12,763	3,877	8	528	0	-	1	-	16,836	16,835	1.13

Table XIII.F-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	5,598	894	-	-	0	-	1	-	6,492	6,492	1
50th Percentile Run (based on shore cost)	5,237	744	2	122	0	-	1	-	6,106	6,105	1
95th Percentile Run (based on shore cost)	7,099	1,519	6	374	0	-	1	-	8,999	8,998	1
5th Percentile	4,755	543	-	-	0	-	0	-	5,464	5,463	0.48
50th Percentile	6,965	1,463	2	100	0	-	1	-	8,495	8,494	0.66
95th Percentile	11,993	3,556	6	365	0	-	1	-	15,552	15,551	1.07
Mean	7,459	1,669	2	134	0	-	1	-	9,264	9,264	0.70
Std Dev (SD)	2,346	976	3	169	0	-	0	-	3,357	3,357	0.19
Mean - 2SD	2,767	-	-	-	0	-	0	-	2,550	2,549	0.32
Mean + 2SD	12,150	3,621	7	472	0	-	1	-	15,979	15,978	1.08

XIII.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because fish and invertebrate impacts are not necessarily correlated with shore cost, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run by shore cost.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the habitat area occupied by the species group that was contaminated using the methods described in Section 2.3 of Volume I. The actual 5th, 50th and 95th percentile results for the 100 estimates of fish and invertebrate impact were calculated by sorting only the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact indices of a given scenario. Thus, to evaluate the various impact results for different species groups within a single scenario (i.e., different fish and invertebrate groups within a single table), the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table XIII.G-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	-	-	-	-	904.2	-	904
50th Percentile Run (shore cost)	-	-	1.9	1.0	1,025.2	-	1,028
95th Percentile Run (shore cost)	2,759.1	6,692.1	35.2	7.2	1,450.8	1,360	12,304
5th Percentile	-	-	-	-	904.8	-	905
50th Percentile	1,477.6	3,657.3	21.2	4.6	1,272.0	-	6,433
95th Percentile	7,214.3	17,243.6	83.9	16.2	2,072.3	1,004	27,634
Mean	2,137.9	5,169.5	26.9	5.5	1,329.5	198	8,867
Std Dev (SD)	2,672.4	6,371.0	30.5	5.8	404.0	355	9,838
Mean - 2SD	-	-	-	-	521.5	-	521
Mean + 2SD	7,482.7	17,911.4	87.9	17.0	2,137.4	907	28,544

Table XIII.G-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	5,906.2	14,145.6	69.6	13.5	1,889.8	-	22,025
50th Percentile Run (shore cost)	2,467.8	6,002.4	32.0	6.6	1,410.2	1,101	11,020
95th Percentile Run (shore cost)	4,071.0	9,799.1	49.6	9.8	1,633.8	1,392	16,955
5th Percentile	-	-	3.4	1.3	1,044.5	-	1,049
50th Percentile	4,688.4	11,261.4	56.3	11.1	1,719.9	-	17,737
95th Percentile	15,643.4	37,206.4	176.1	33.2	3,248.2	947	57,254
Mean	5,838.5	13,975.6	68.6	13.3	1,874.9	185	21,956
Std Dev (SD)	4,647.0	11,017.7	51.1	9.5	655.6	347	16,728
Mean - 2SD	-	-	-	-	563.7	-	564
Mean + 2SD	15,132.5	36,011.0	170.9	32.3	3,186.2	880	55,413

XIII.H. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All weights are as wet weight; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

NRDA costs were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because impacts are not necessarily correlated with shore cost, the results for NRDA costs may not be in increasing order from 5th to 95th percentile run by shore cost.

The NRDA costs for all 100 runs were estimated from the wildlife, fish and invertebrate impact estimates for each run. The actual 5th, 50th and 95th percentile results for the 100 estimates were calculated by sorting by NRDA cost for the specific group. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for the species group (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact groups of a given scenario. Thus, to evaluate the various NRDA cost contributions for different species groups within a single scenario (i.e., different fish and invertebrate groups within a single table), the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table XIII.H-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:									
Small pelagic fish	-	-	2,759.1	-	1,477.6	7,214.3	2,137.9	-	7,482.7
Large pelagic fish	-	-	6,692.1	-	3,657.3	17,243.6	5,169.5	-	17,911.4
Demersal fish	-	1.9	35.2	-	21.2	83.9	26.9	-	87.9
Decapods	-	1.0	7.2	-	4.6	16.2	5.5	-	17.0
Molluscs	904	1,025	2,811	905	1,272	3,076	1,528	521	3,045
Birds:									
Waterfowl (# * kg each)	5,609	4,381	5,663	3,744	5,570	9,403	5,995	2,034	9,955
Seabirds (# * kg each)	1,962	1,137	1,998	708	1,936	4,513	2,221	-	4,884
Waders (# * kg each)	-	4	7	-	2	8	3	-	11
Shorebirds (# * kg each)	-	6	11	-	3	12	4	-	16
Raptors (# * kg each)	0	0	0	0	0	0	0	0	0
Other wildlife:									
Sea otters, other mammals	-	-	-	-	-	-	-	-	-
Pinnipeds	67	55	68	48	67	107	71	30	113
Cetaceans	-	-	-	-	-	-	-	-	-
Totals:									
Subtotal fish and invertebrates	904	1,028	12,304	905	6,433	27,634	8,867	521	28,544
Subtotal birds	7,571	5,528	7,679	4,451	7,511	13,935	8,224	2,035	14,866
Subtotal other wildlife	67	55	68	48	67	107	71	30	113
Total all species	8,543	6,610	20,051	5,404	14,011	41,676	17,163	2,586	43,522

Table XIII.H-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	23	16	44	12	34	98	41	4	104
Saltmarsh Area (acres)	56	39	108	29	84	243	101	11	256
Saltmarsh Cost (millions of 2004$)	10.5	7.2	20.3	5.5	15.7	45.5	19.0	2.0	48.0
Eelgrass Area (m2)	14	10	27	7	21	61	26	3	65
Eelgrass Area (acres)	35	24	68	18	52	152	63	7	160
Eelgrass Cost (millions of 2004$)	4.2	2.9	8.1	2.2	6.2	18.1	7.6	0.8	19.1

Table XIII.H-3. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:									
Small pelagic fish	5,906.2	2,467.8	4,071.0	-	4,688.4	15,643.4	5,838.5	-	15,132.5
Large pelagic fish	14,145.6	6,002.4	9,799.1	-	11,261.4	37,206.4	13,975.6	-	36,011.0
Demersal fish	69.6	32.0	49.6	3.4	56.3	176.1	68.6	-	170.9
Decapods	13.5	6.6	9.8	1.3	11.1	33.2	13.3	-	32.3
Molluscs	1,890	2,511	3,026	1,045	1,720	4,195	2,060	564	4,066
Birds:									
Waterfowl (# * kg each)	4,366	4,085	5,537	3,709	5,432	9,354	5,818	2,159	9,477
Seabirds (# * kg each)	1,126	937	1,914	684	1,843	4,481	2,103	-	4,563
Waders (# * kg each)	-	2	8	-	2	7	3	-	10
Shorebirds (# * kg each)	-	4	11	-	3	11	4	-	14
Raptors (# * kg each)	0	0	0	0	0	0	0	0	0
Other wildlife:									
Sea otters, other mammals	-	-	-	-	-	-	-	-	-
Pinnipeds	55	52	67	48	66	107	70	32	108
Cetaceans	-	-	-	-	-	-	-	-	-
Totals:									
Subtotal fish and invertebrates	22,025	11,020	16,955	1,049	17,737	57,254	21,956	564	55,413
Subtotal birds	5,493	5,029	7,470	4,393	7,281	13,853	7,927	2,159	14,064
Subtotal other wildlife	55	52	67	48	66	107	70	32	108
Total all species	27,572	16,100	24,492	5,490	25,084	71,214	29,953	2,754	69,584

Table XIII.H-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	59.0	32.4	52.7	11.6	56.4	159.4	67.0	4.6	156.5
Saltmarsh Area (acres)	145.7	80.1	130.3	28.7	139.3	393.9	165.6	11.3	386.6
Saltmarsh Cost (millions of 2004$)	27.3	15.0	24.4	5.4	26.1	73.8	31.0	2.1	72.4
Eelgrass Area (m2)	36.8	20.3	32.9	7.3	35.2	99.6	41.9	2.9	97.8
Eelgrass Area (acres)	91.0	50.1	81.4	17.9	87.1	246.2	103.5	7.1	241.6
Eelgrass Cost (millions of 2004$)	10.9	6.0	9.7	2.1	10.4	29.4	12.4	0.8	28.8

XIII.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table XIII.I-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	20.788	20.788	20.788	20.788	22.688	21.026	19.720	22.332
% Removed by 24 hours	6.9	17.9	7.8	1.8	7.4	22.5	9.3	-	22.4
Compensation (millions $)	52.8	46.6	52.3	55.8	52.5	48.0	52.0	48.7	55.4

Table XIII.I-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	22.688	20.788	20.788	20.788	22.688	20.818	16.414	25.221
% Removed by 24 hours	21.5	23.1	7.8	1.8	7.5	22.6	9.3	-	22.3
Compensation (millions $)	44.5	47.6	52.3	55.7	52.5	48.0	51.5	40.3	62.8

Phase 1: Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XIV: Results of Alternative Response Scenarios for Strait of Juan de Fuca – Alaskan North Slope Crude

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XIV.A. INTRODUCTION

The results of the alternate response scenarios for the Strait of Juan de Fuca – Alaskan North Slope Crude are contained in this volume. There were two main stochastic scenarios for this location, oil type and spill volume:

1. Mechanical removal under Washington state Caps standards
2. Mechanical removal under Washington state Caps standards plus dispersant application

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps) or to include in situ burning (ISB). The geographic data, current data, and model inputs are the same for each of the alternate response scenarios as was described in Volume XII for the main stochastic scenarios. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup. The figures and tables in this volume summarize the model results for the alternate response scenarios, as well as corresponding 3 runs (of the same start date and time) from the main response scenario.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs (termed the base case runs). The 100 main stochastic scenario runs of the base case scenario were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shoreline cleanup costs are presented. Because each impact index is not necessarily correlated with shoreline cleanup cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th, and 95th percentile runs for shoreline cleanup costs using the base case stochastic scenario were used when comparing one

response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. Note that in Section II.2, the individual runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs (and their dates and times) varied from one stochastic scenario to the next, and for the alternate scenarios other than the base case, they are not the same runs as those reported in this volume. Thus, in this volume, the alternate response scenarios are labeled with "-base". This indicates the base case 5th, 50th, and 95th percentile runs for shoreline costs were rerun with the same start date and time but with the alternate response. (For scenarios other than the base case, the 5th, 50th, and 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this volume.)

In this volume (Section B), the results for the 5th, 50th, and 95th percentile runs based on shoreline oiling costs (using the base case scenario for sorting) are shown, as plots of the following measures of exposure:

- Water surface exposure to floating hydrocarbons (g/m^2)
- Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill

These figures are followed by additional sections with tables of the wildlife, fish and invertebrate impacts and the NRDA costs (damages).

XIV.B. EXPOSURE FOR INDIVIDUAL MODEL RUNS

XIV.B.1. No Removal, Scenario S2-Crud-N

The response for this scenario includes the use of protection booms only, and no mechanical removal using the three runs as identified as 5th, 50th and 95th percentile in the base case.

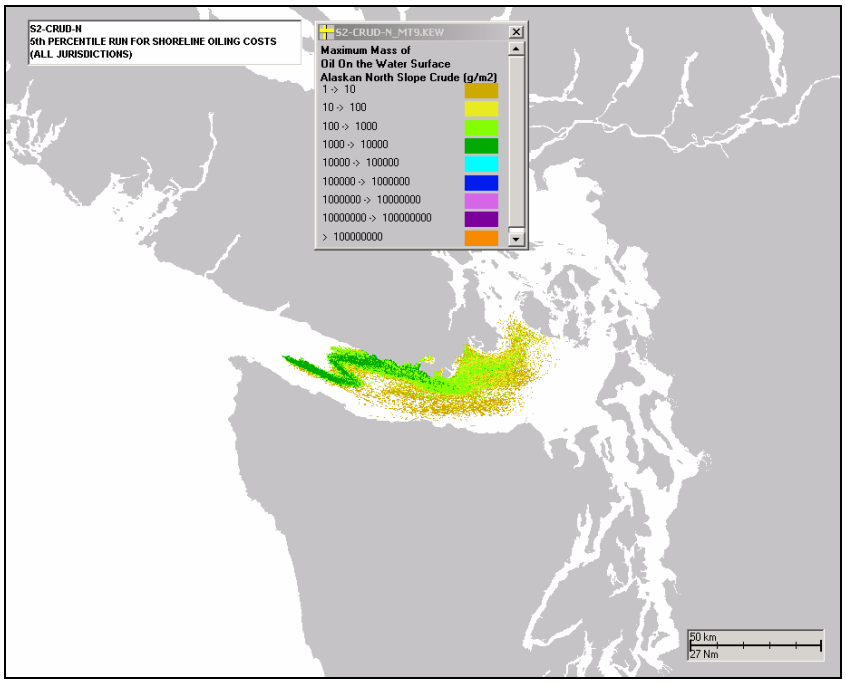


Figure XIV.B.1-1. Strait of Juan de Fuca, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

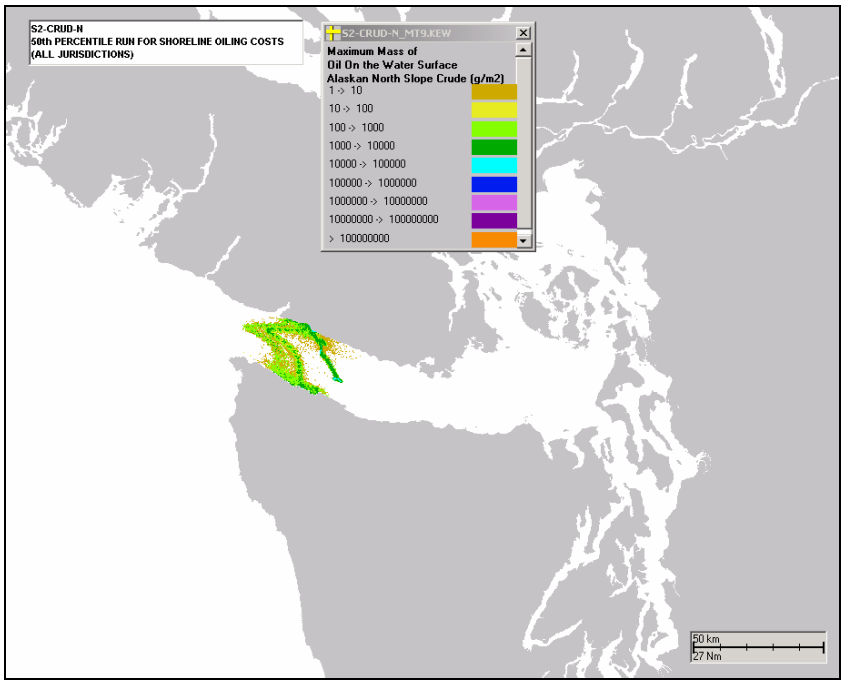


Figure XIV.B.1-2. Strait of Juan de Fuca, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

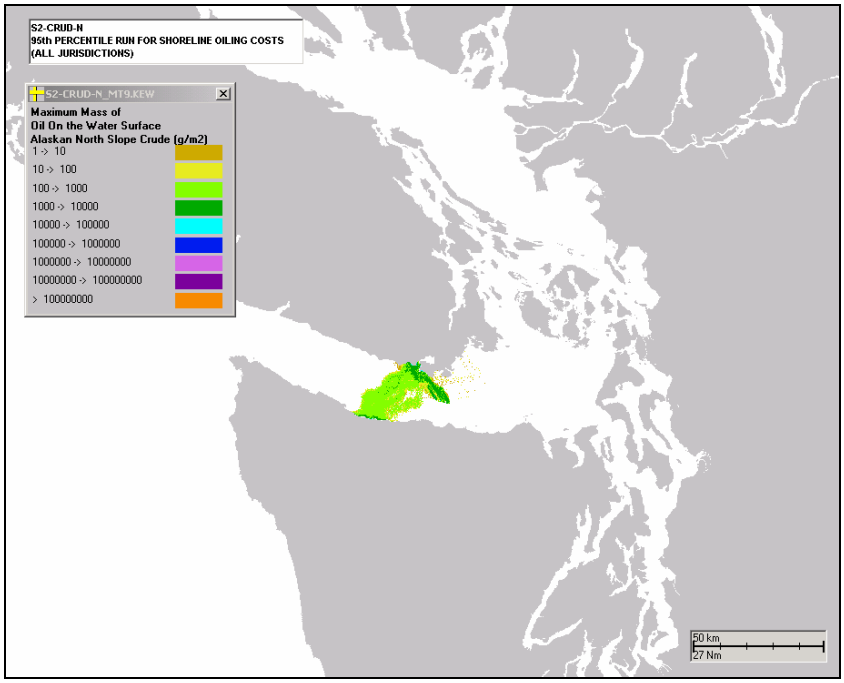


Figure XIV.B.1-3. Strait of Juan de Fuca, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

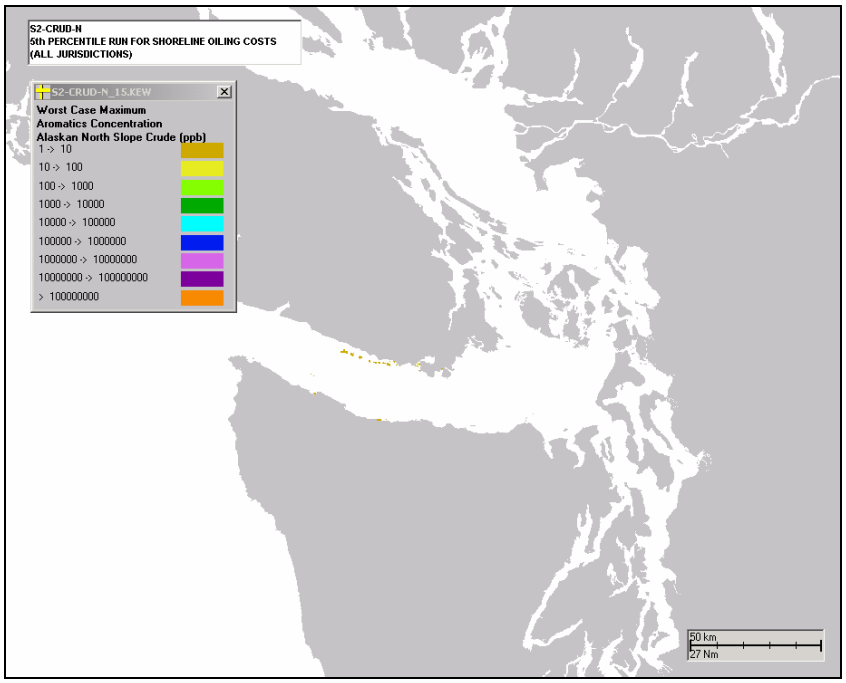


Figure XIV.B.1-4. Strait of Juan de Fuca, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

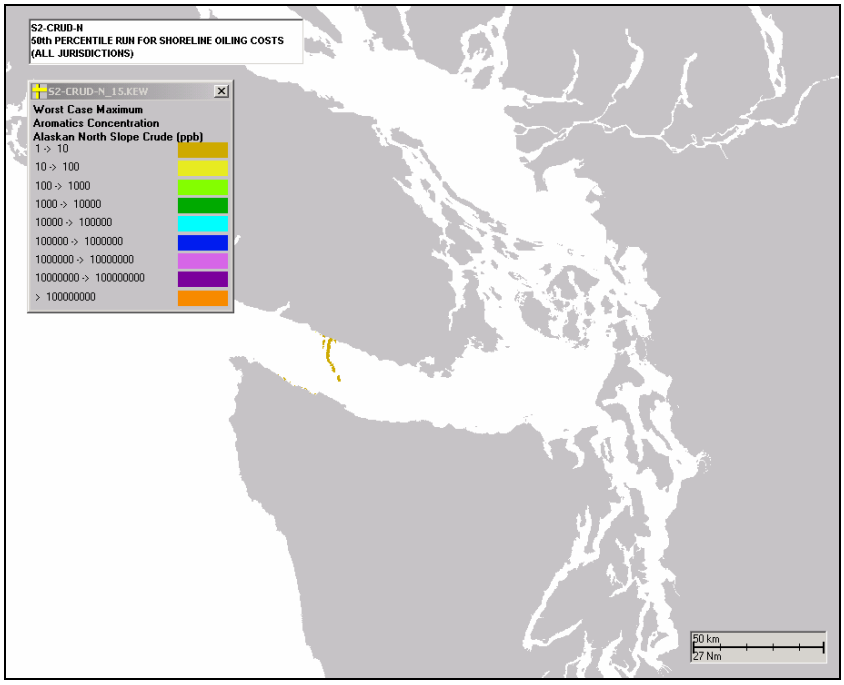


Figure XIV.B.1-5. Strait of Juan de Fuca, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

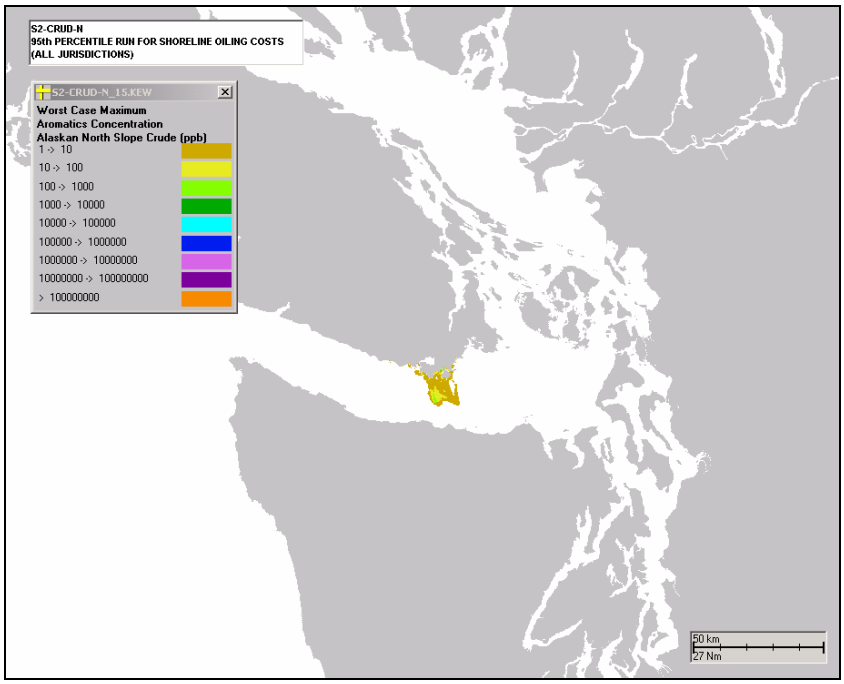


Figure XIV.B.1-6. Strait of Juan de Fuca, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIV.B.2. State Mechanical Removal, Scenario S2-Crud-R-ST

The response for this scenario includes the use of mechanical removal based on state standards and protection booming. These results as the same as those shown in Volume XIII, Section XIII.E. This scenario was used to identify the 5th, 50th and 95th percentile based on total shoreline cost, referred to as the " base case".

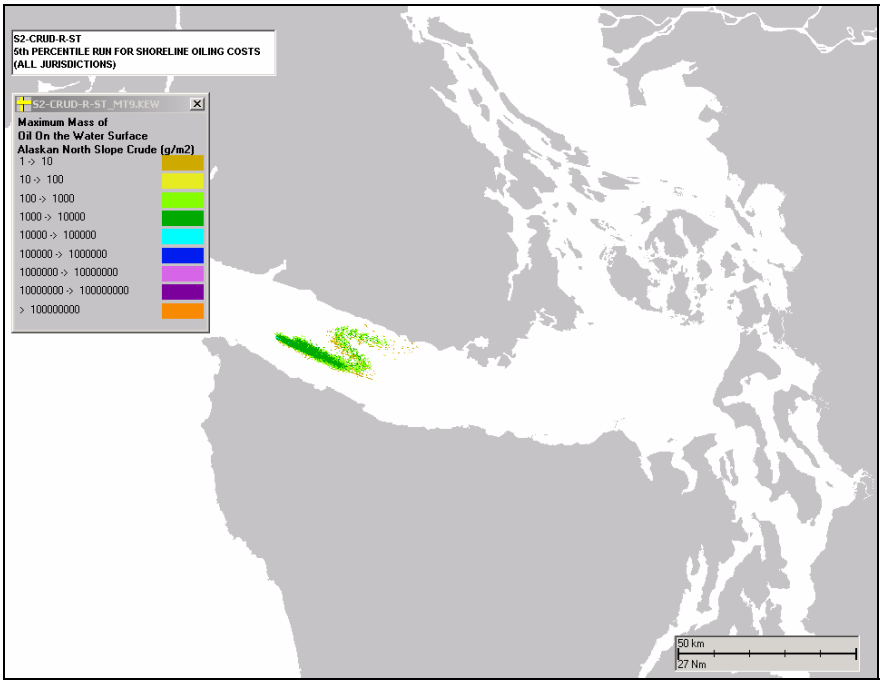


Figure XIV.B.2-1. Strait of Juan de Fuca, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

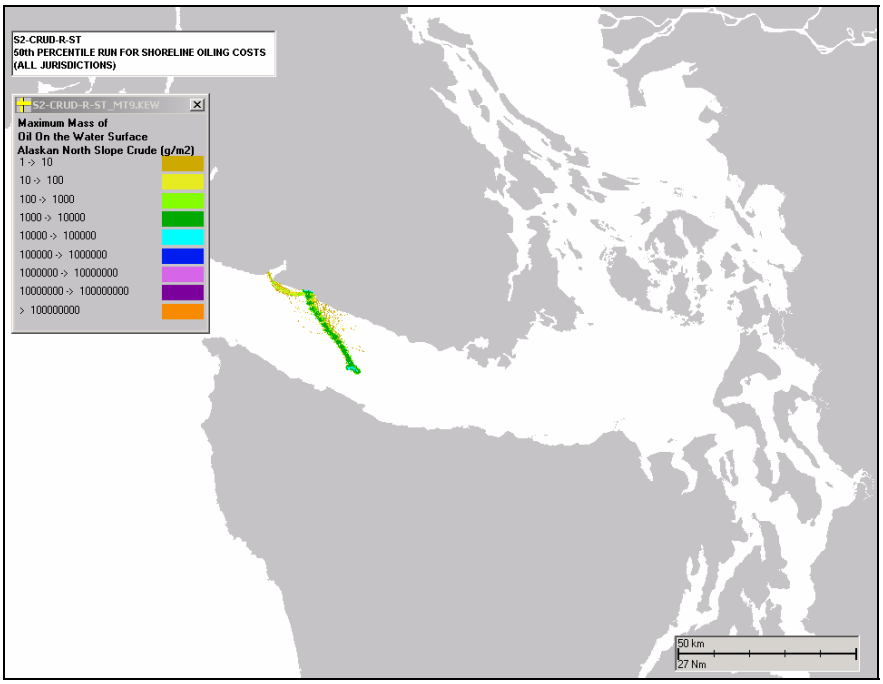


Figure XIV. B.2-2. Strait of Juan de Fuca, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

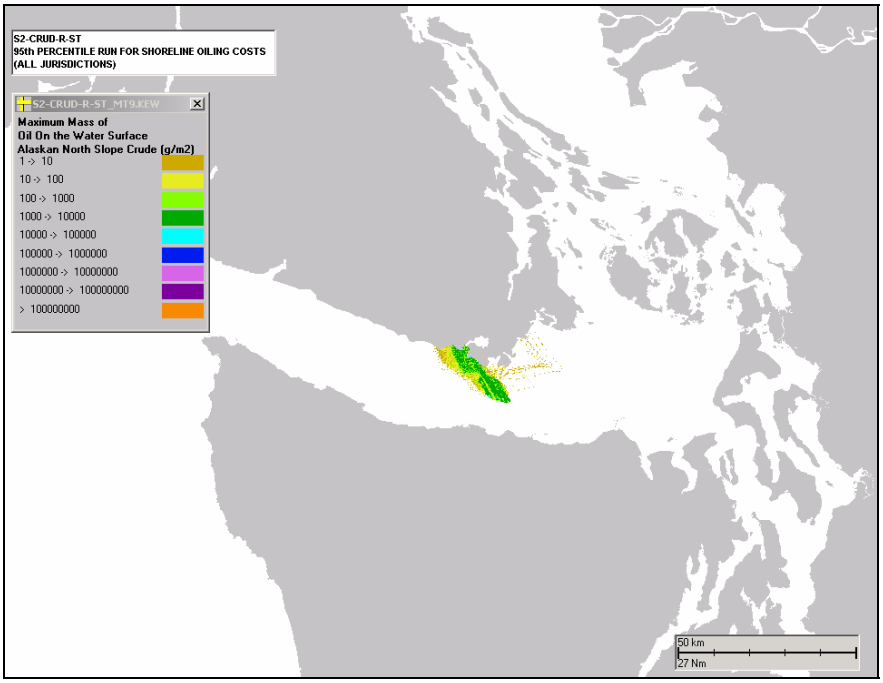


Figure XIV. B.2-3. Strait of Juan de Fuca, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

Maximum water column exposure of dissolved aromatic concentration does not exceed 1 ppb.

Figure XIV. B.2-4. Strait of Juan de Fuca, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

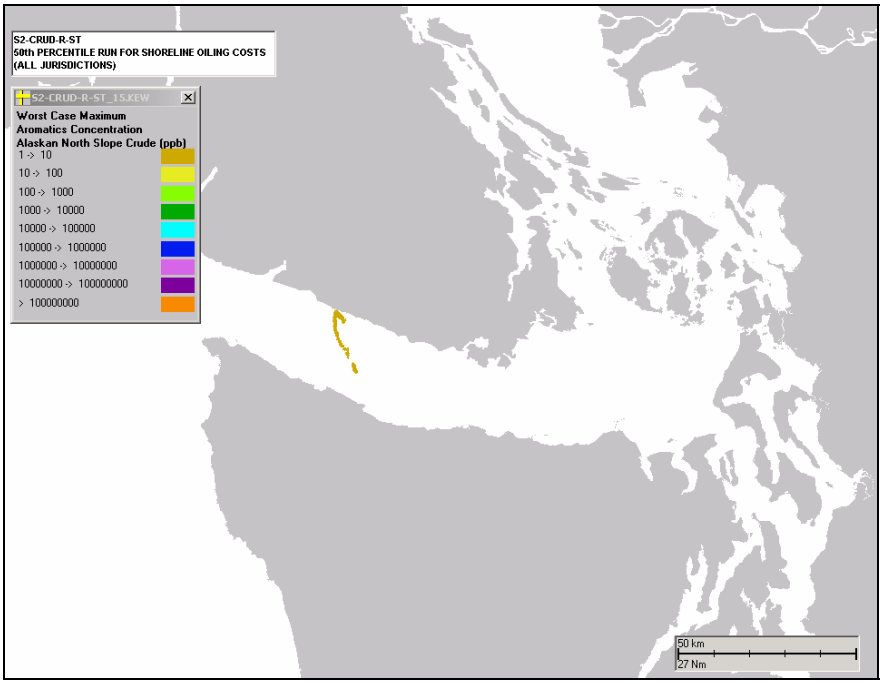


Figure XIV. B.2-5. Strait of Juan de Fuca, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

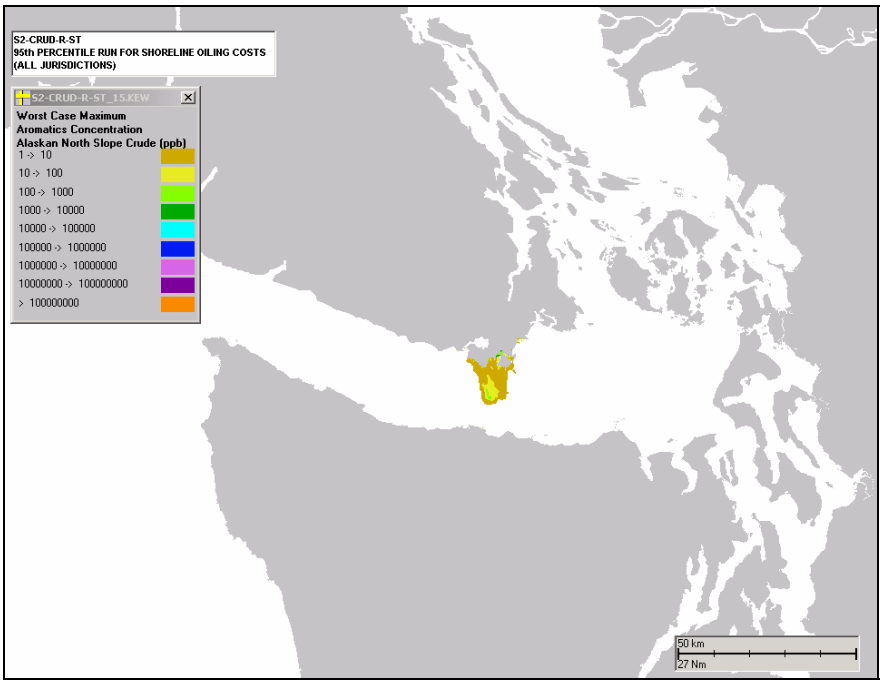


Figure XIV. B.2-6. Strait of Juan de Fuca, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIV.B.3. Federal Mechanical Removal, Scenario S2-Crud-R-Fed

The response for this scenario includes the use of mechanical removal based on federal standards and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case.

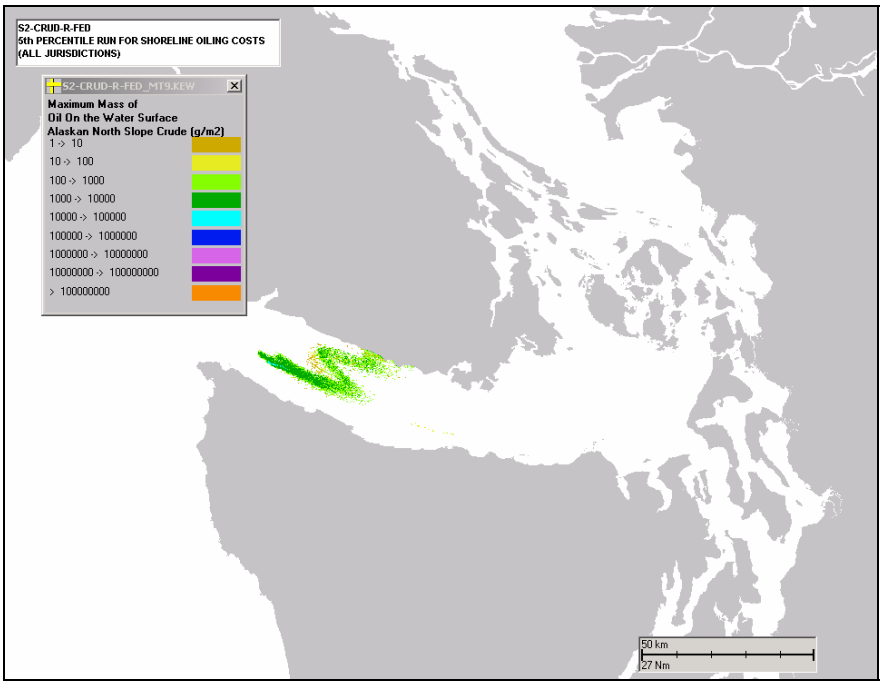


Figure XIV.B.3-1. Strait of Juan de Fuca, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

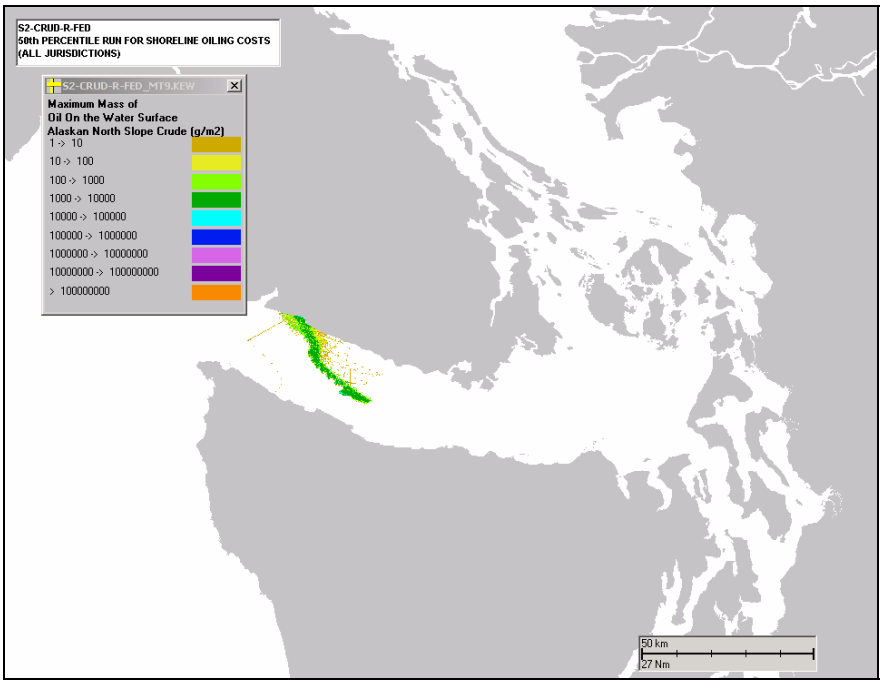


Figure XIV. B.3-2. Strait of Juan de Fuca, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

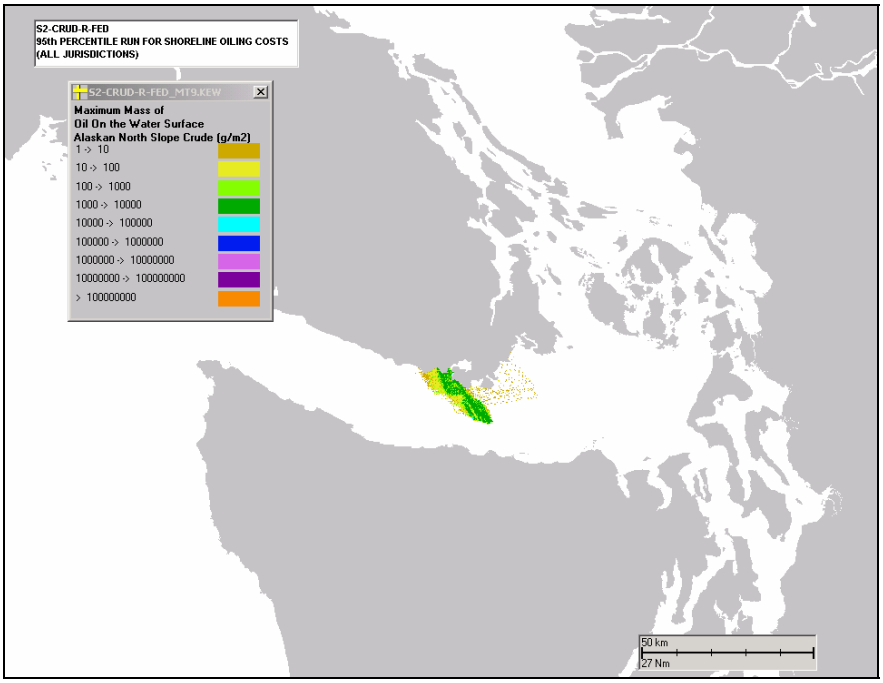


Figure XIV. B.3-3. Strait of Juan de Fuca, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

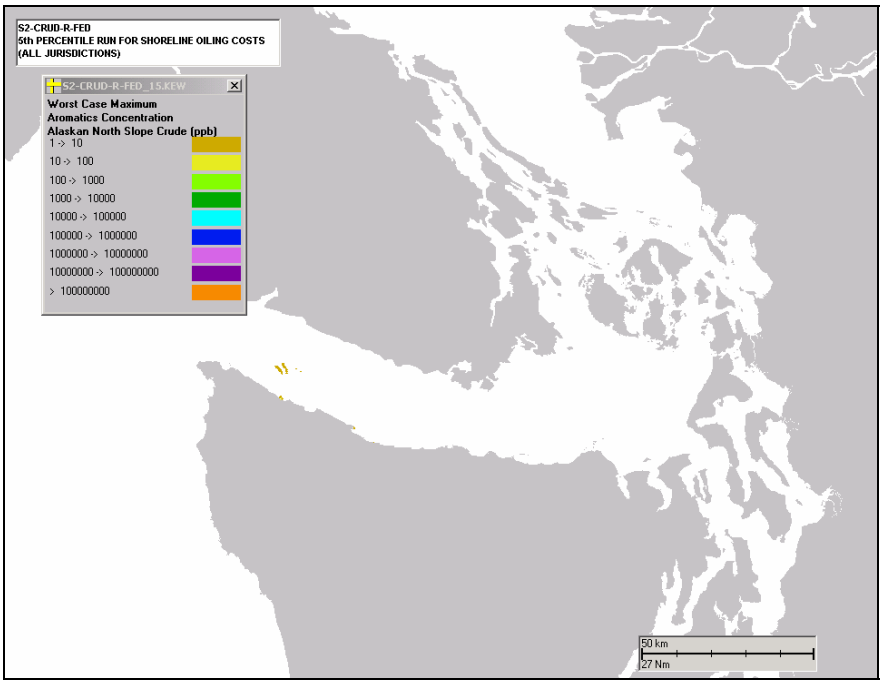


Figure XIV.B.3-4. Strait of Juan de Fuca, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

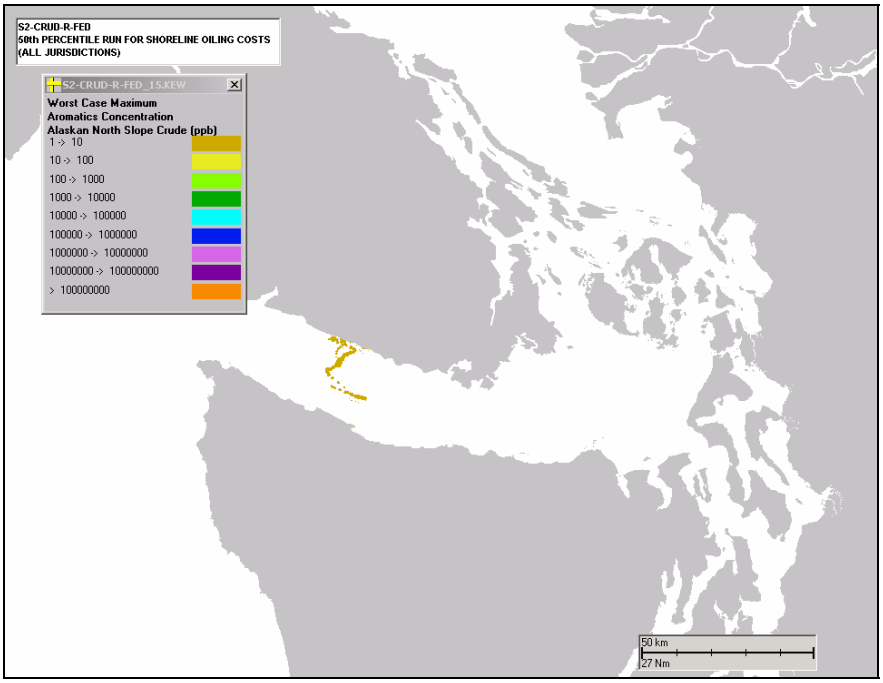


Figure XIV.B.3-5. Strait of Juan de Fuca, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

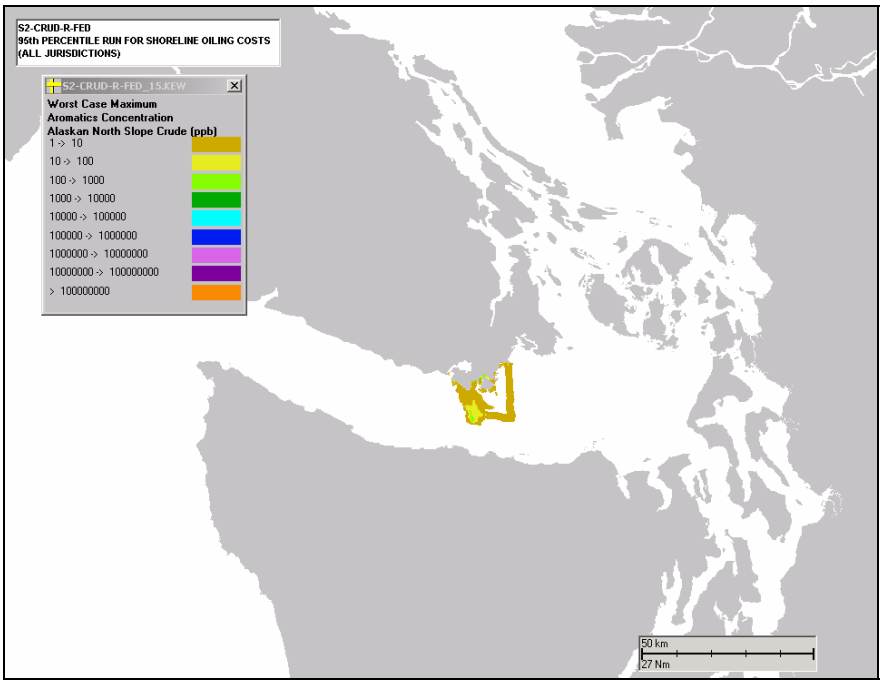


Figure XIV.B.3-6. Strait of Juan de Fuca, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIV.B.4. 3rd Alternative Mechanical Removal, Scenario S2-Crud-R-3

The response for this scenario includes the use of mechanical removal based on the 3rd alternative standards and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case.

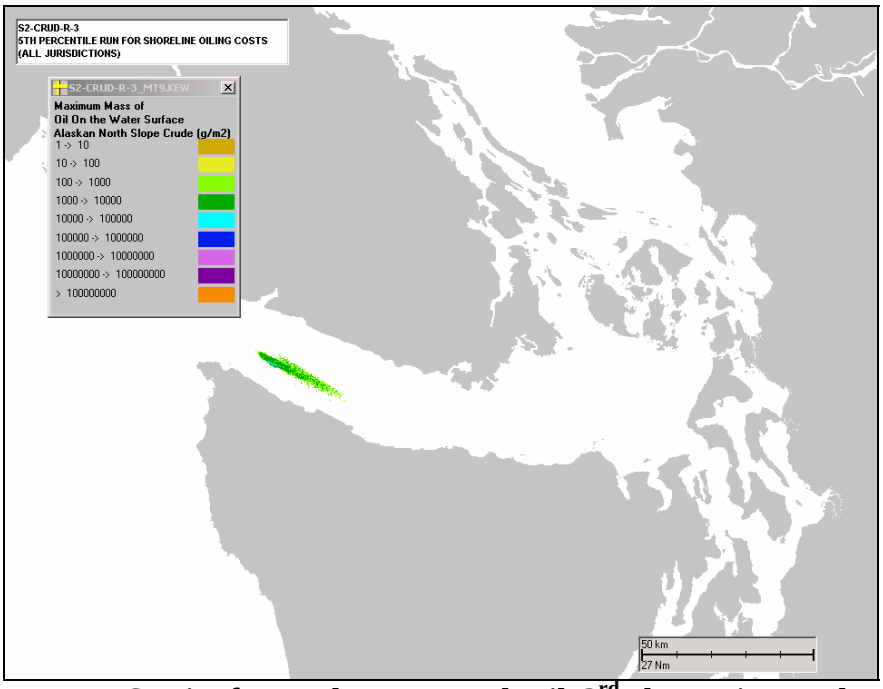


Figure XIV.B.4-1. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

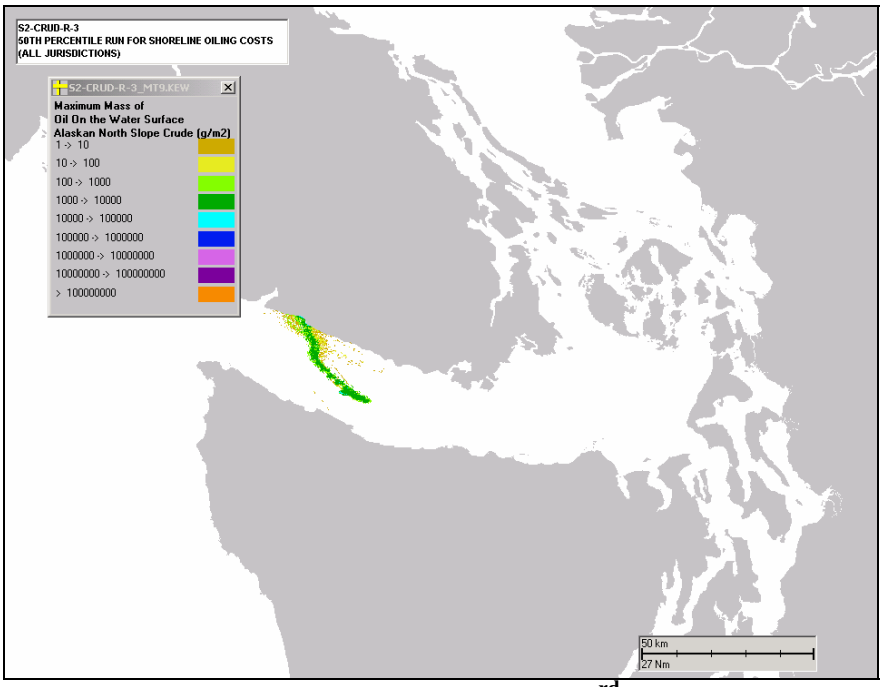


Figure XIV.B.4-2. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

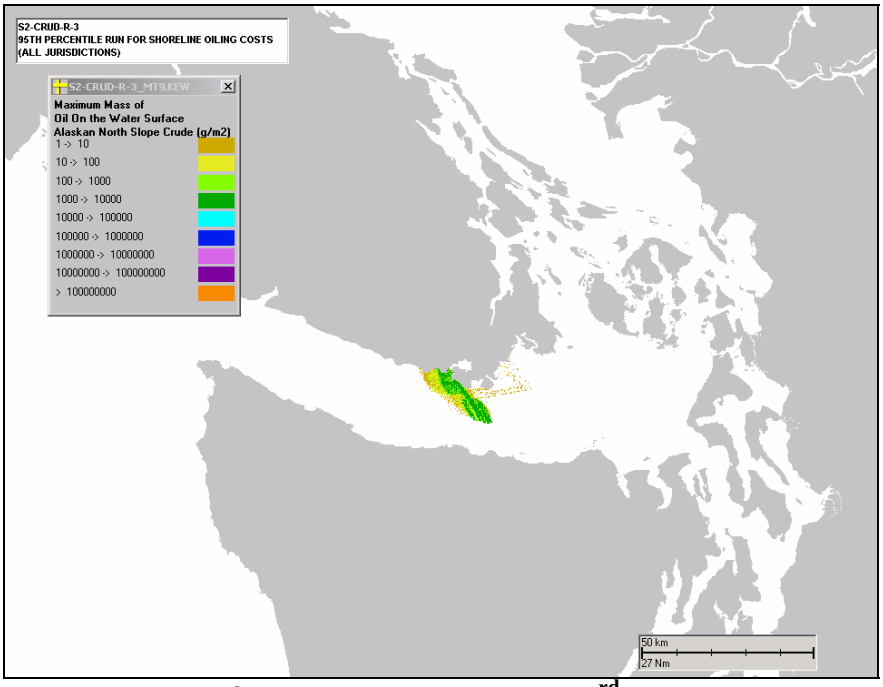


Figure XIV.B.4-3. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

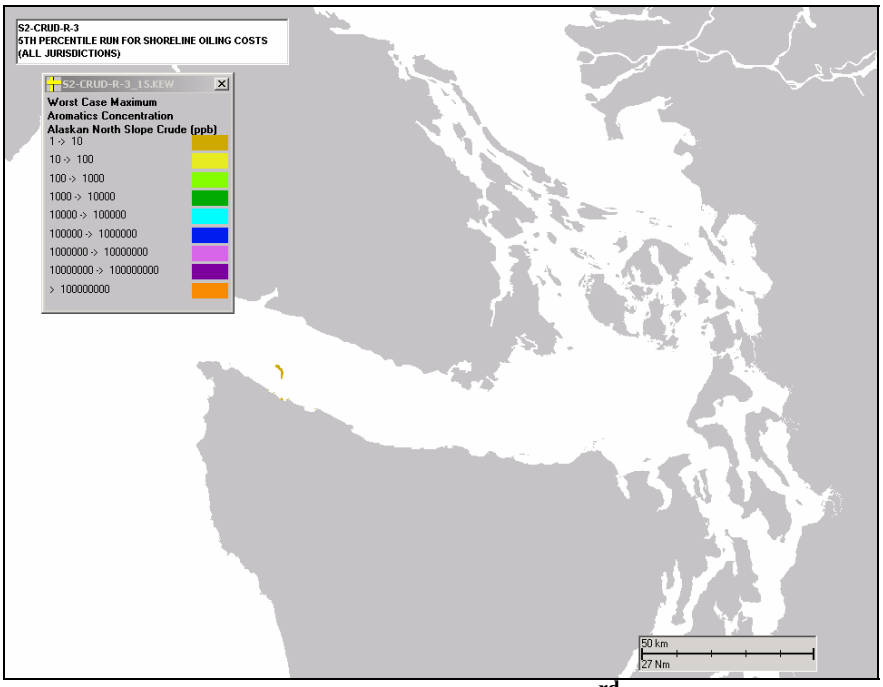


Figure XIV.B.4-4. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

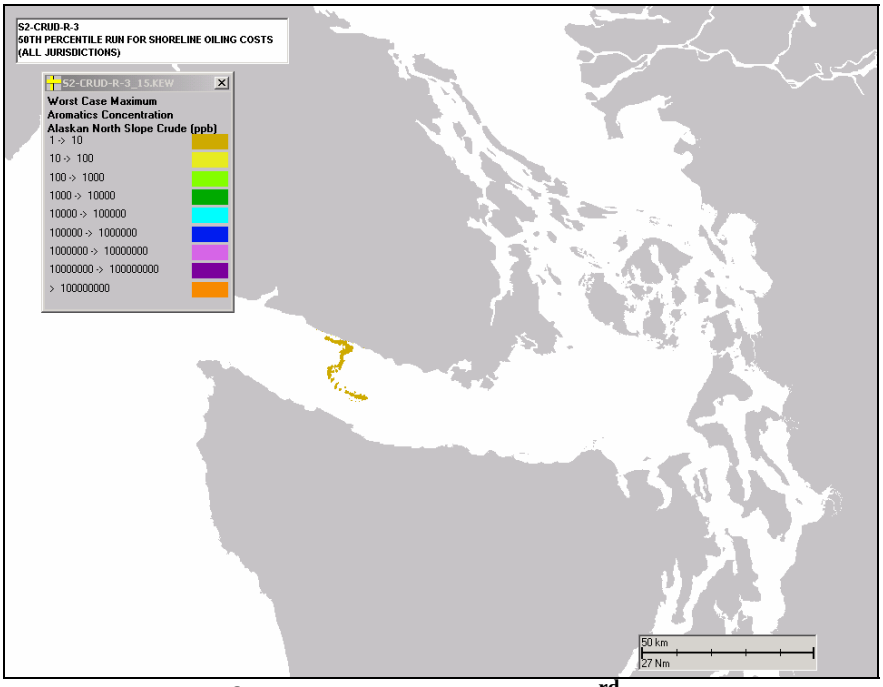


Figure XIV.B.4-5. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

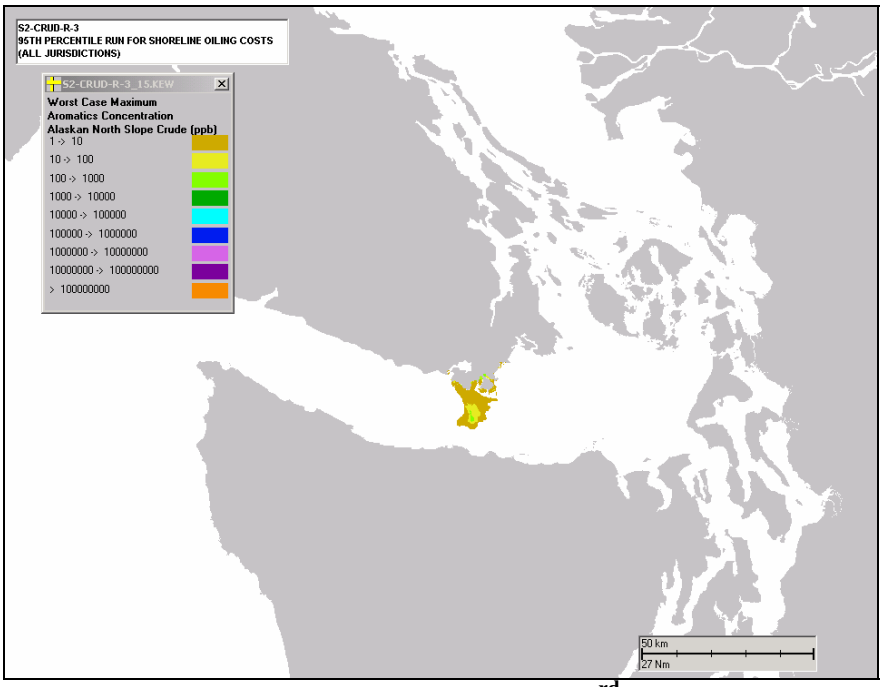


Figure XIV.B.4-6. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIV.B.5. State Mechanical Removal and dispersant, Scenario S2-Crud-C-ST

The response for this scenario includes the use of mechanical removal based on state standards, dispersant and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case where no dispersant was applied.

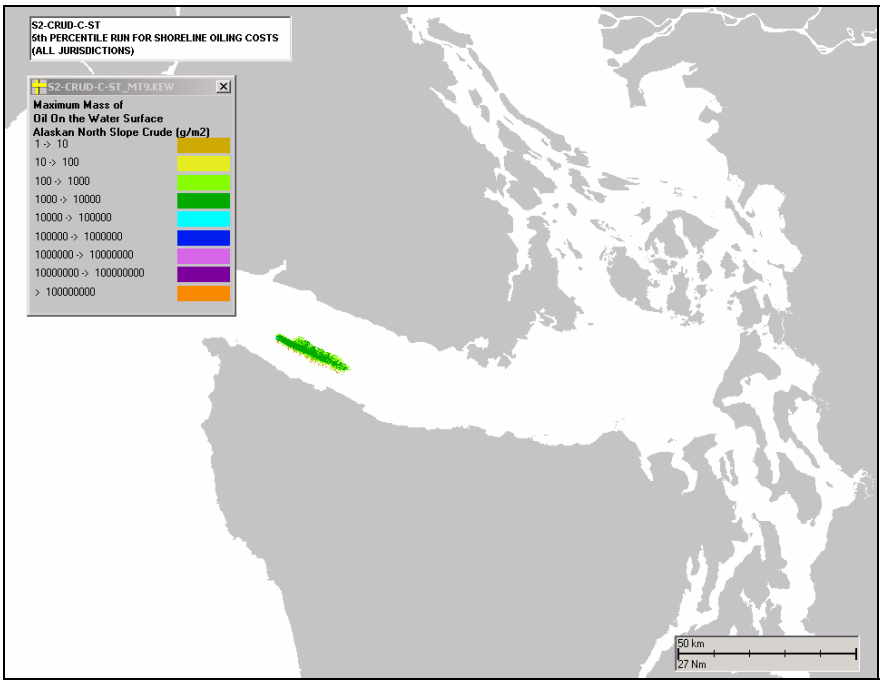


Figure XIV.B.5-1. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

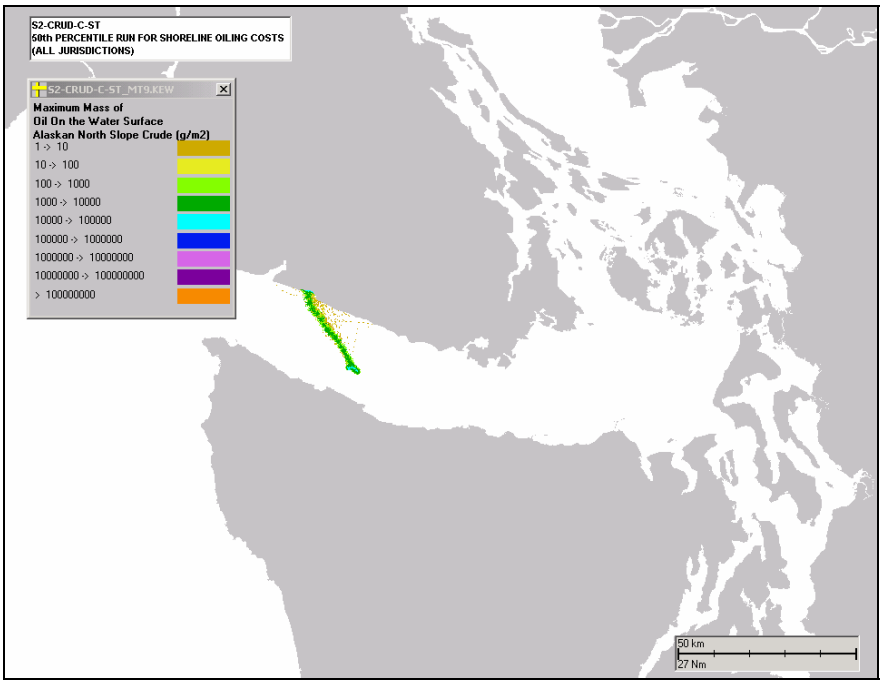


Figure XIV.B.5-2. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

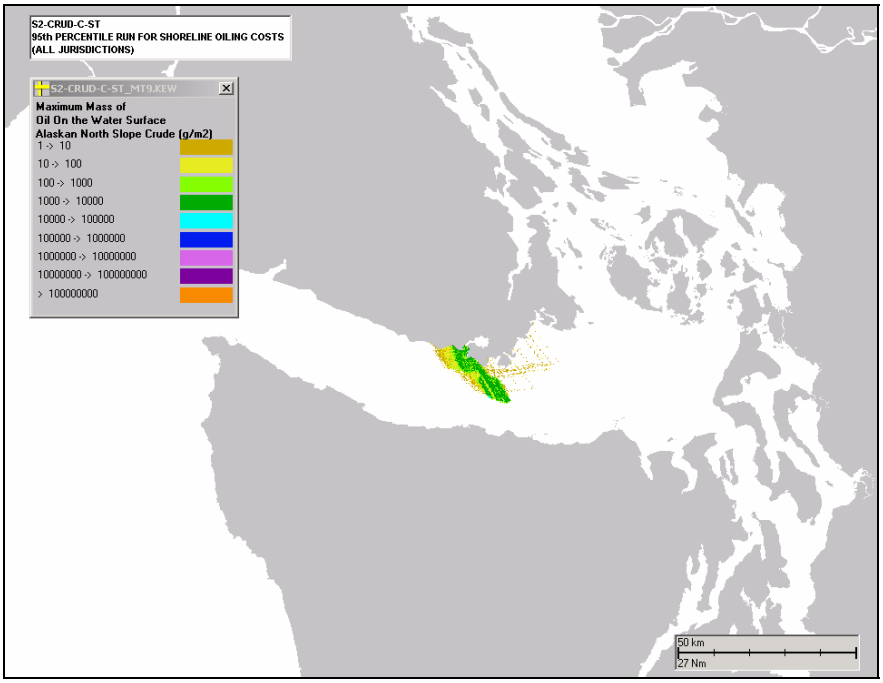


Figure XIV.B.5-3. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

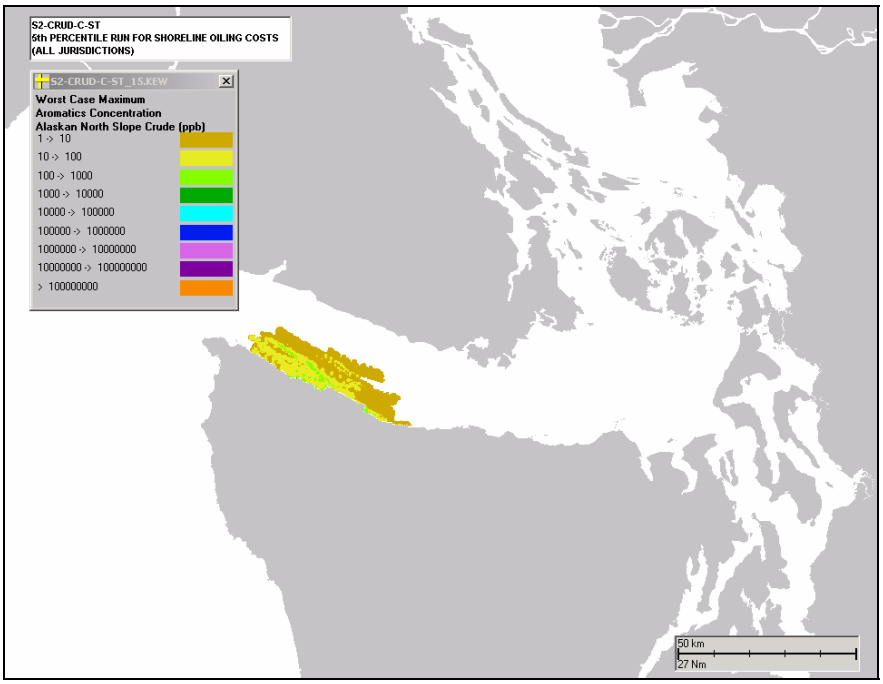


Figure XIV.B.5-4. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

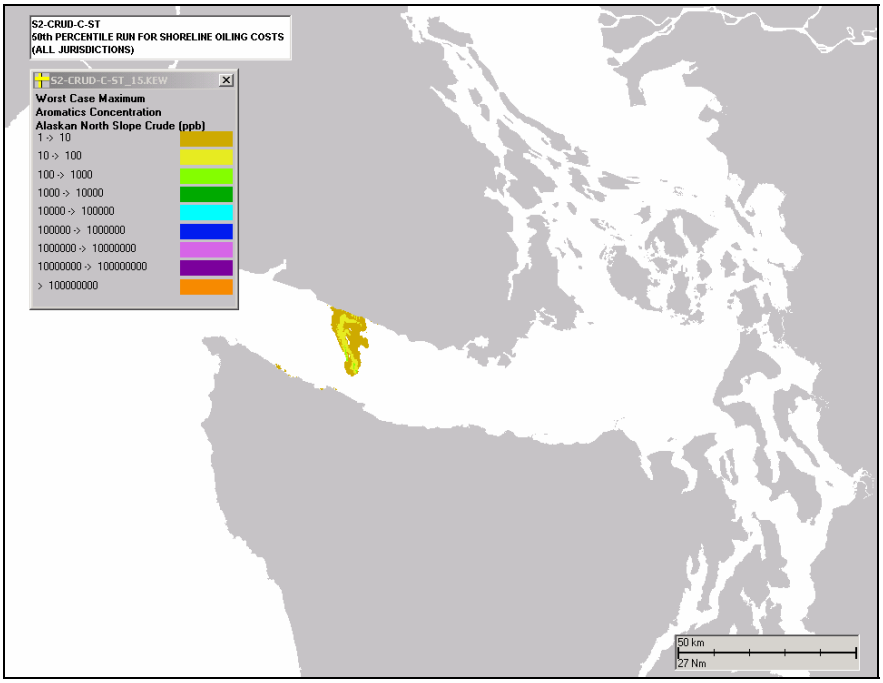


Figure XIV.B.5-5. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

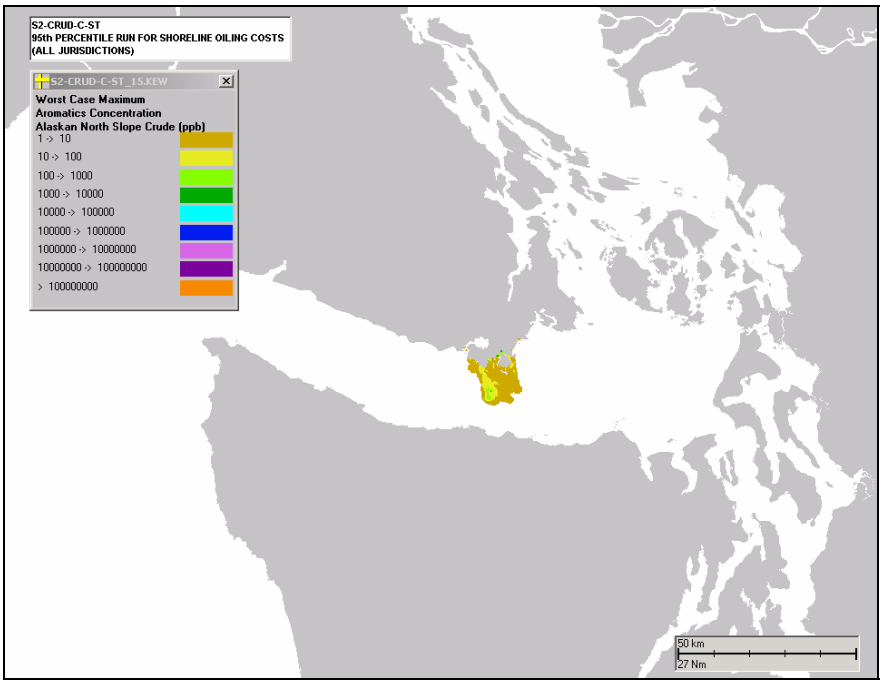


Figure XIV.B.5-6. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIV.B.6. Federal Mechanical Removal and dispersant, Scenario S2-Crud-C-Fed

The response for this scenario includes the use of mechanical removal based on federal standards, dispersant and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case where no dispersant was applied.

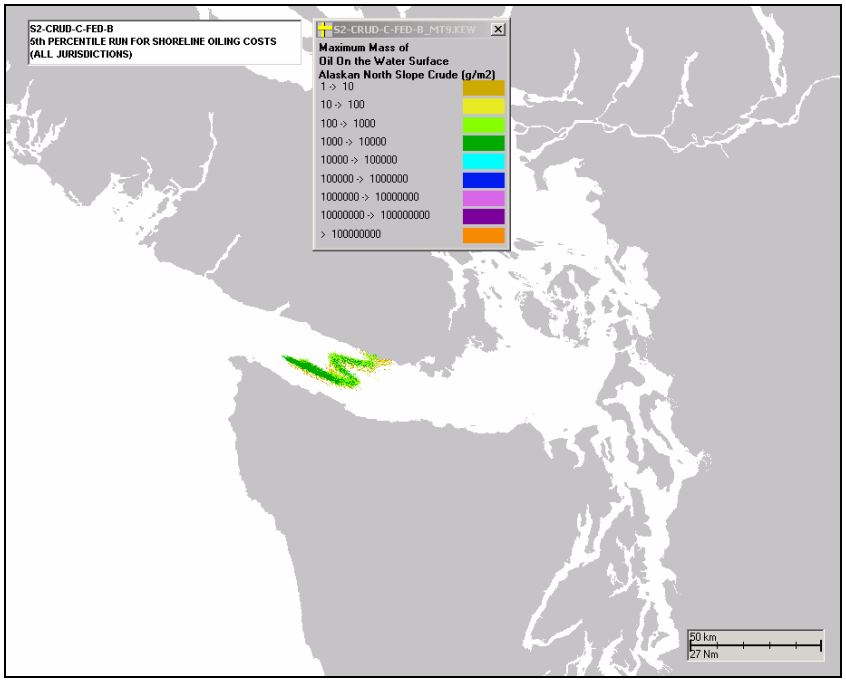


Figure XIV.B.6-1. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

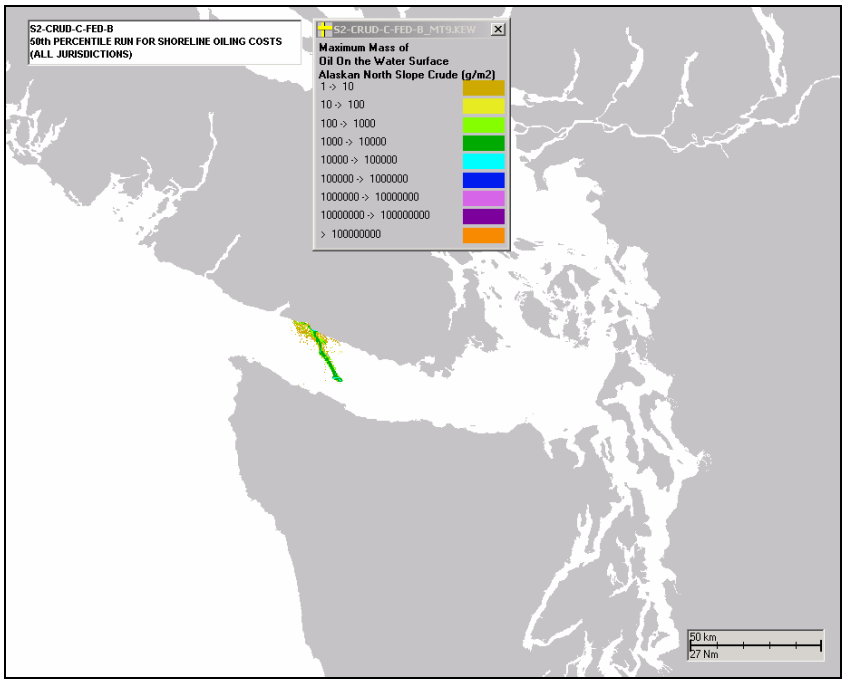


Figure XIV.B.6-2. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

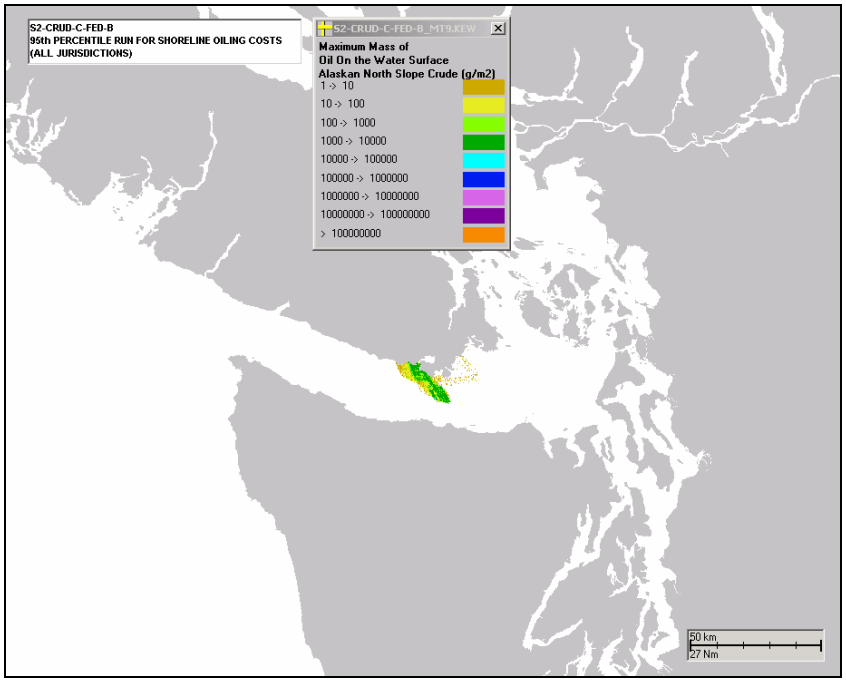


Figure XIV.B.6-3. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

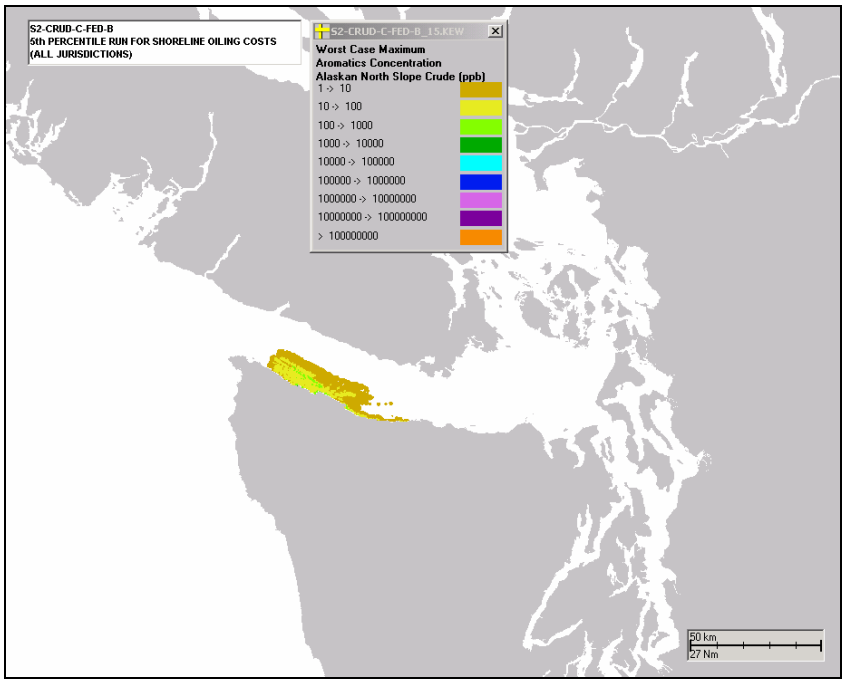


Figure XIV.B.6-4. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

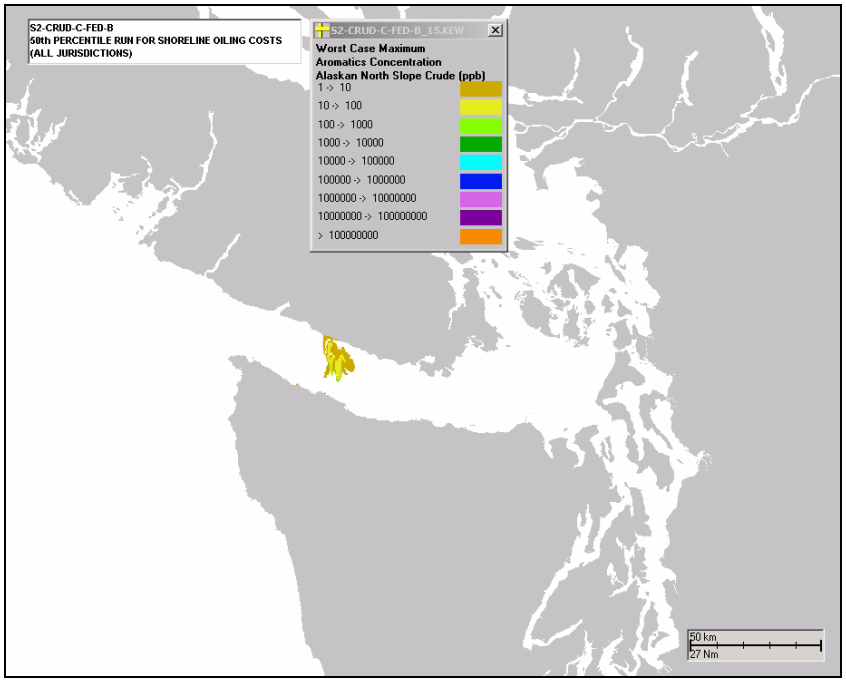


Figure XIV.B.6-5. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

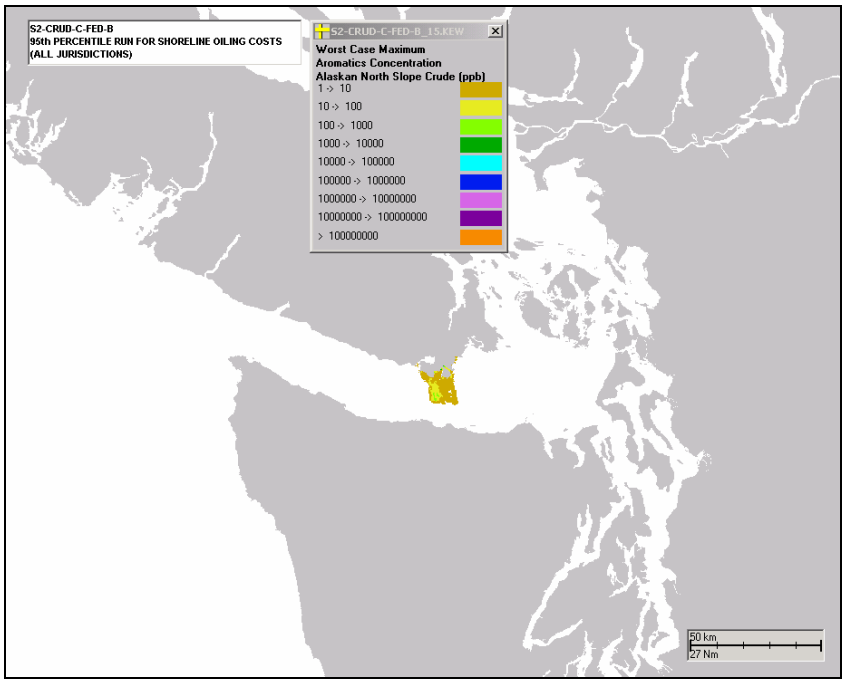


Figure XIV.B.6-6. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIV.B.7. 3rd Alternative Mechanical Removal and dispersant, Scenario S2-Crud-C-3

The response for this scenario includes the use of mechanical removal based on the 3rd alternative standards, dispersant and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case where no dispersant was applied.

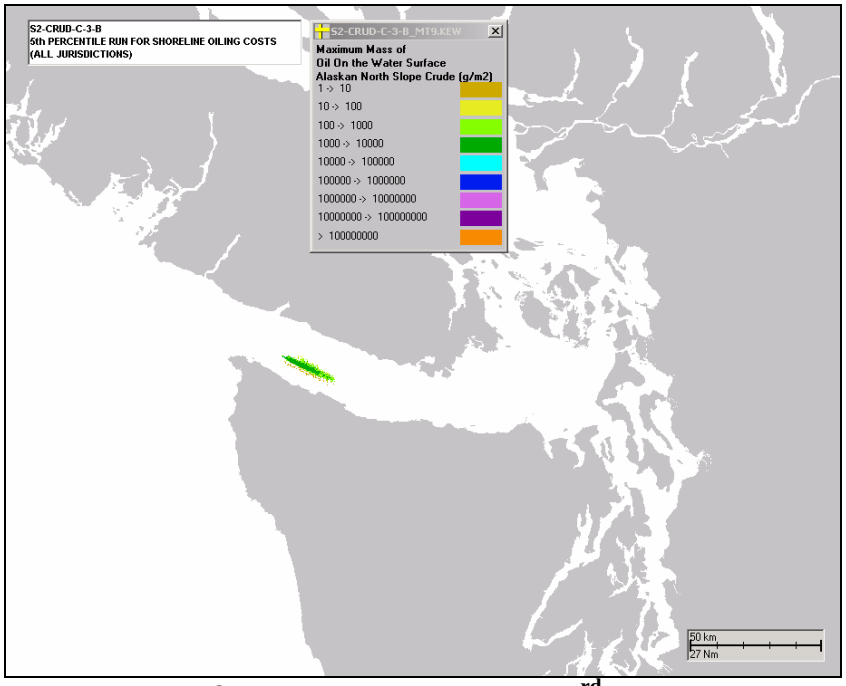


Figure XIV.B.7-1. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

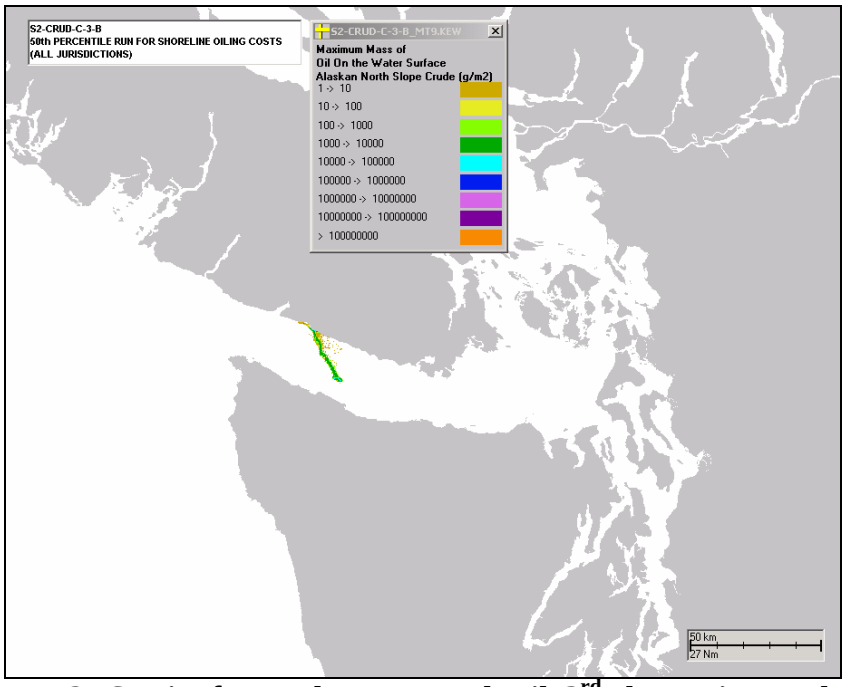


Figure XIV.B.7-2. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

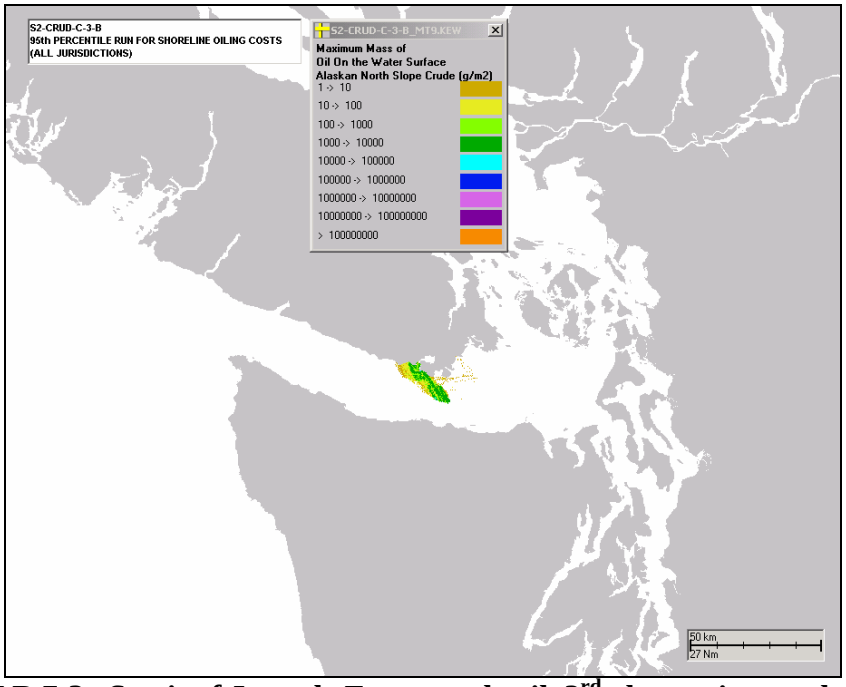


Figure XIV.B.7-3. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

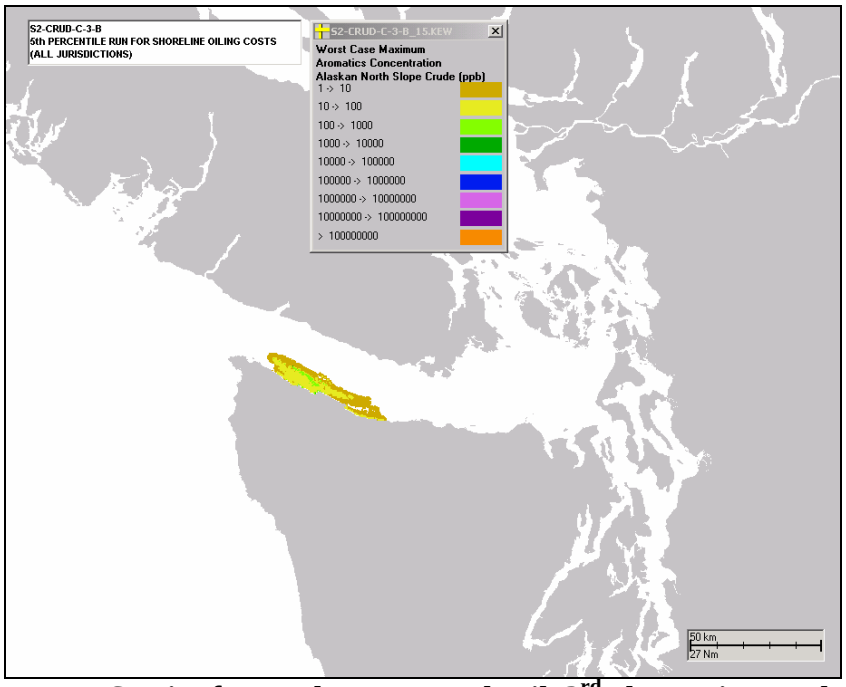


Figure XIV.B.7-4. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

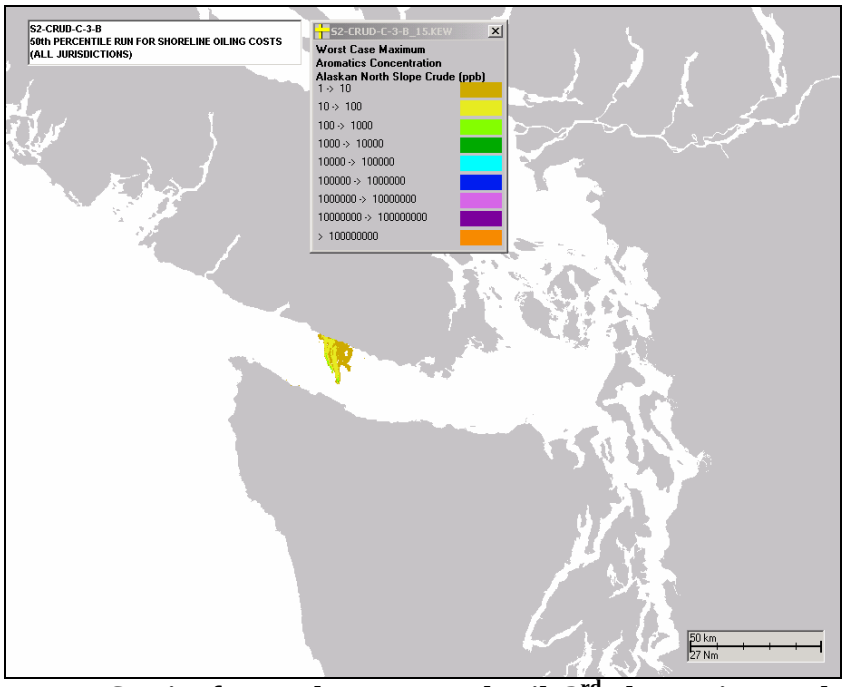


Figure XIV.B.7-5. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

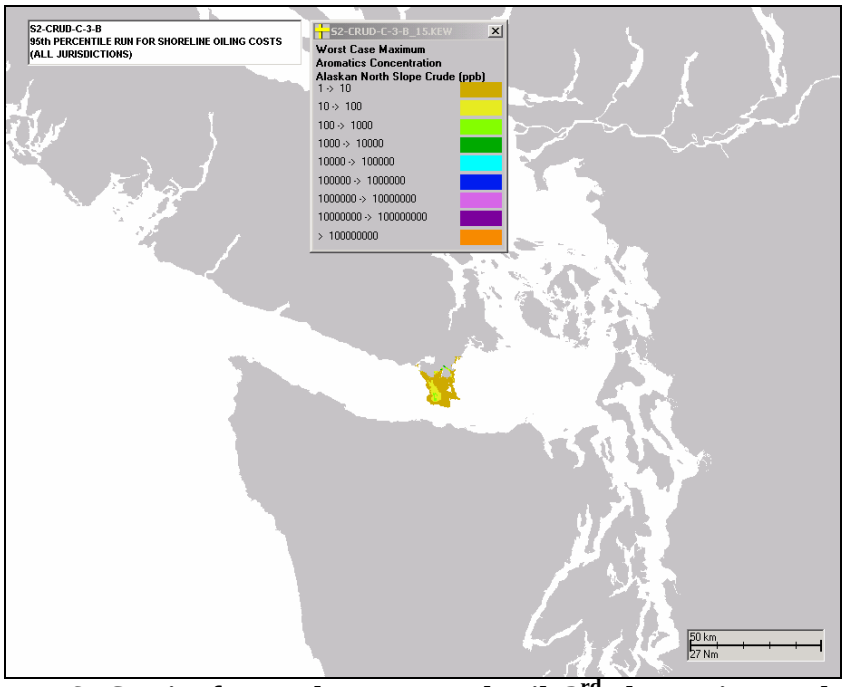


Figure XIV.B.7-6. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIV.B.8. State Mechanical Removal and In-situ Burning, Scenario S2-Crud-R-ISB

The response for this scenario includes the use of mechanical removal based on state standards, protection booms, and in-situ burning using the three runs as identified as 5th, 50th and 95th percentile in the base case.

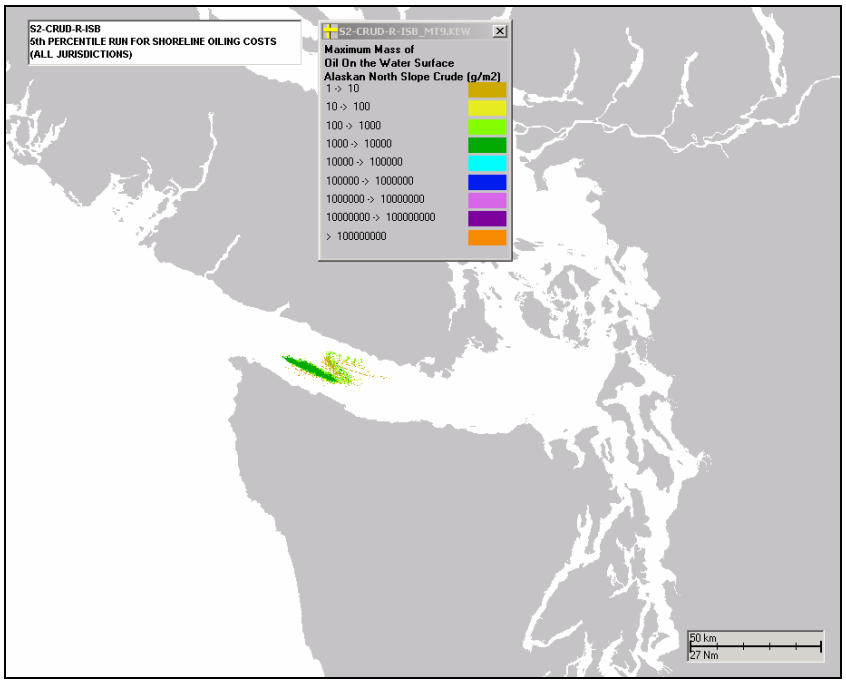


Figure XIV.B.8-1. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

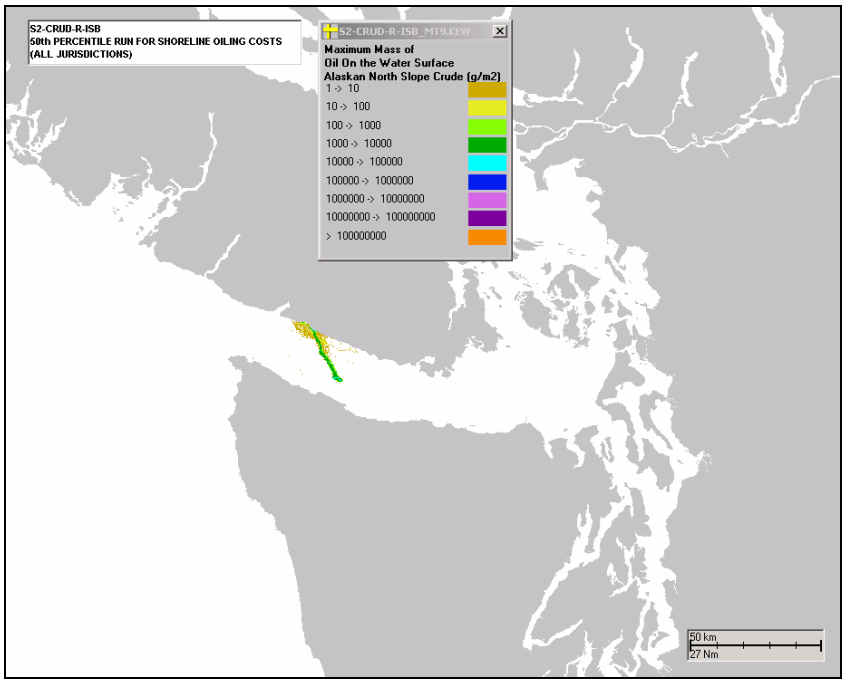


Figure XIV.B.8-2. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

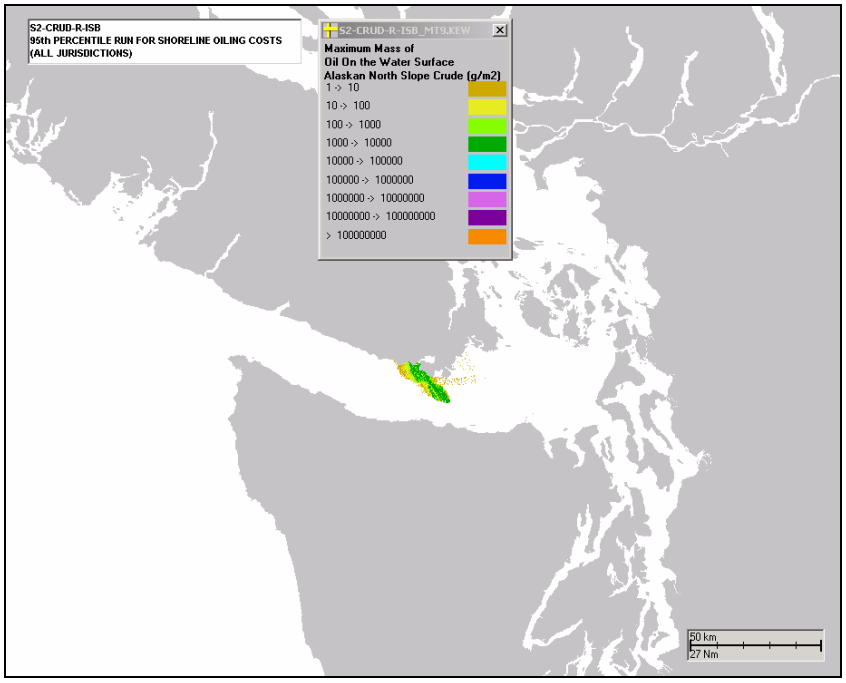


Figure XIV.B.8-3. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

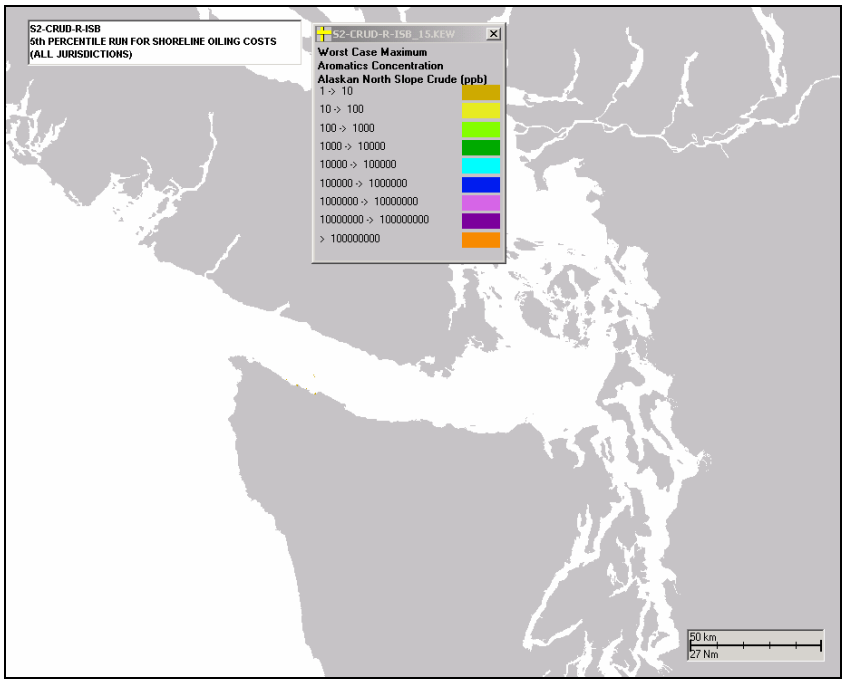


Figure XIV.B.8-4. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

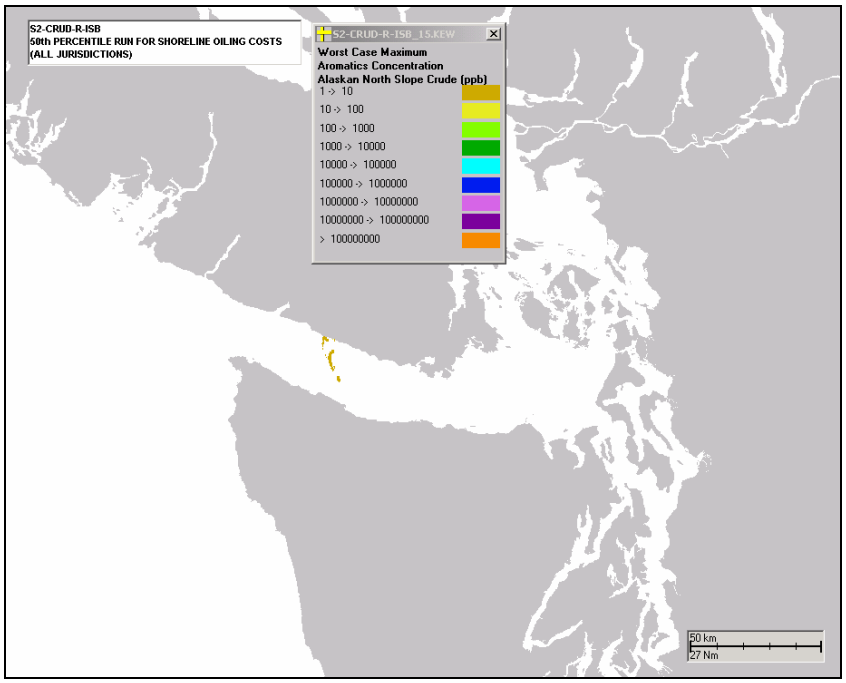


Figure XIV.B.8-5. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

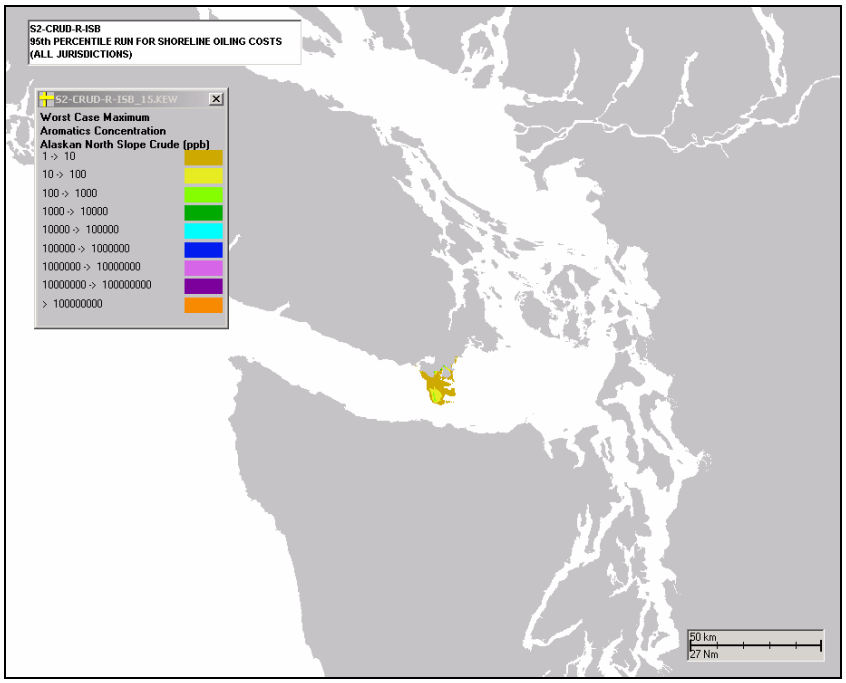


Figure XIV.B.8-6. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIV.B.9 Oil Fate Over Time

The figures in this section summarize the fate of the oil over time for alternate response scenarios of the 5th, 50th and 95th percentile runs. Figures XIV.B.9-1 to XIV.B.9-21 list the mass balance of oil as a function of time. The oil on the water surface is floating oil (thick, sheen or tar balls) within the model grid. Oil in the water column is either entrained oil droplets or dissolved. The percent removed is by mechanical removal during the response to the spill. Figures XIV.B.9-22 to XIV.B.9-39 summarize the results, showing comparisons of the alternative responses for each of the individual runs.

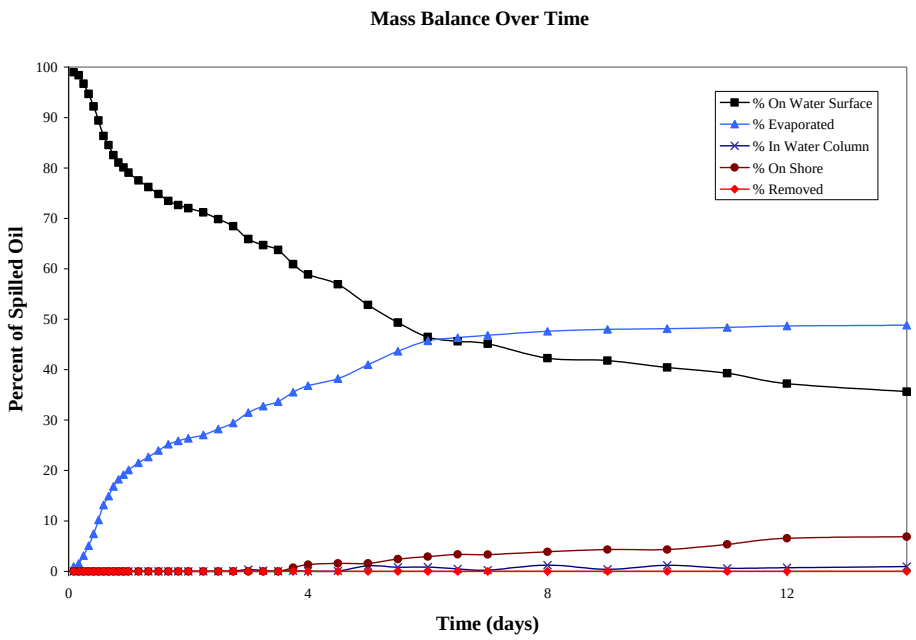


Figure XIV.B.9-1 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

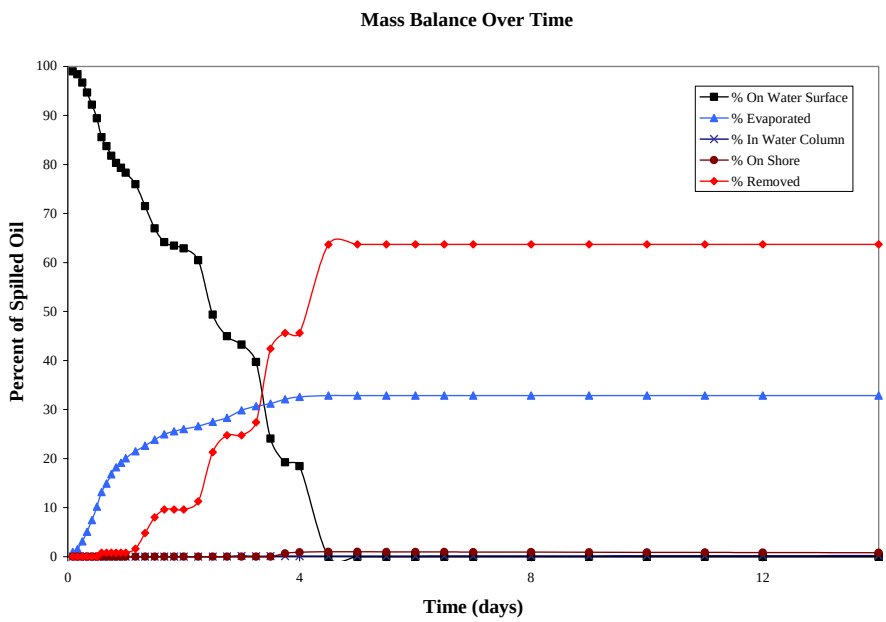


Figure XIV.B.9-2 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

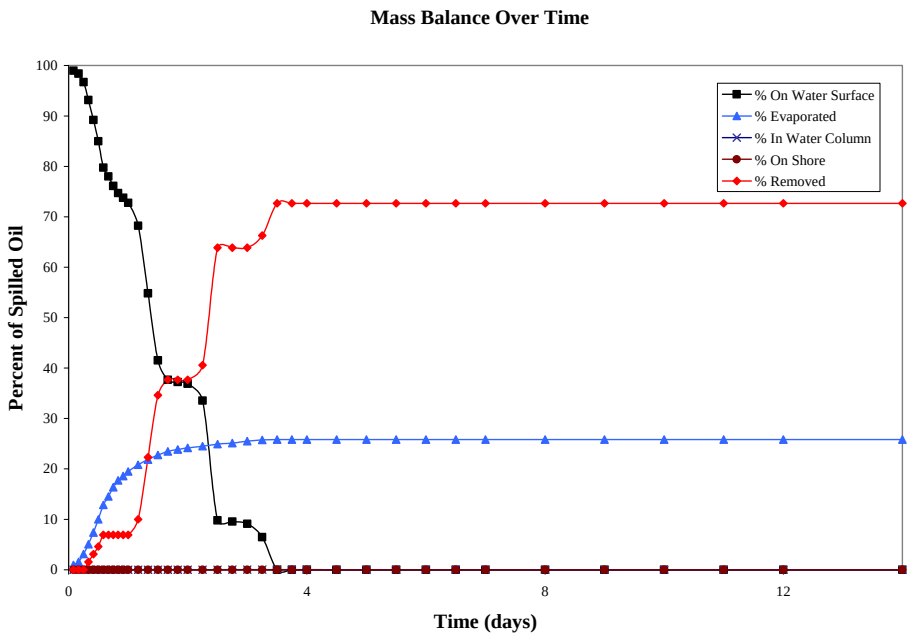


Figure XIV.B.9-3 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

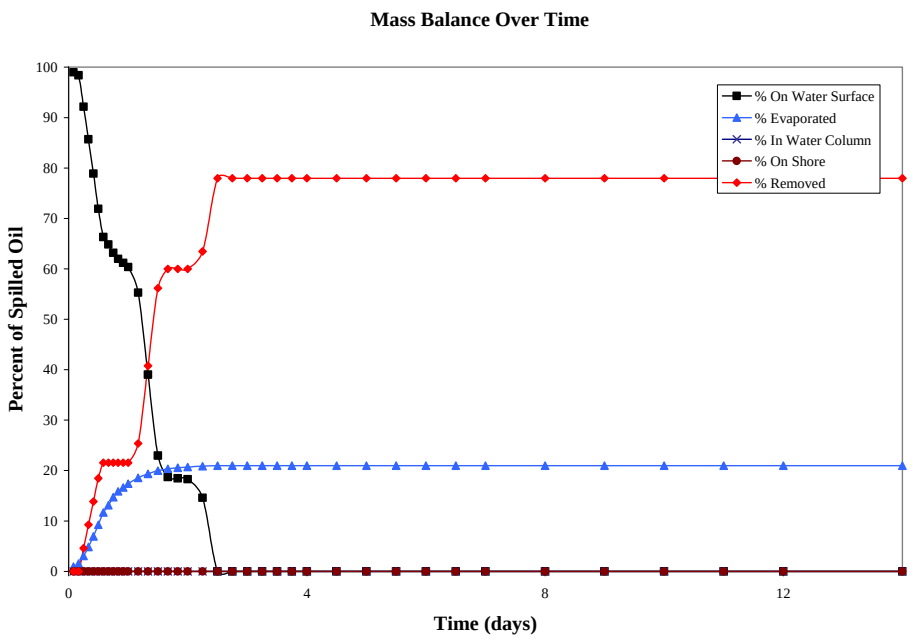


Figure XIV.B.9-4 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

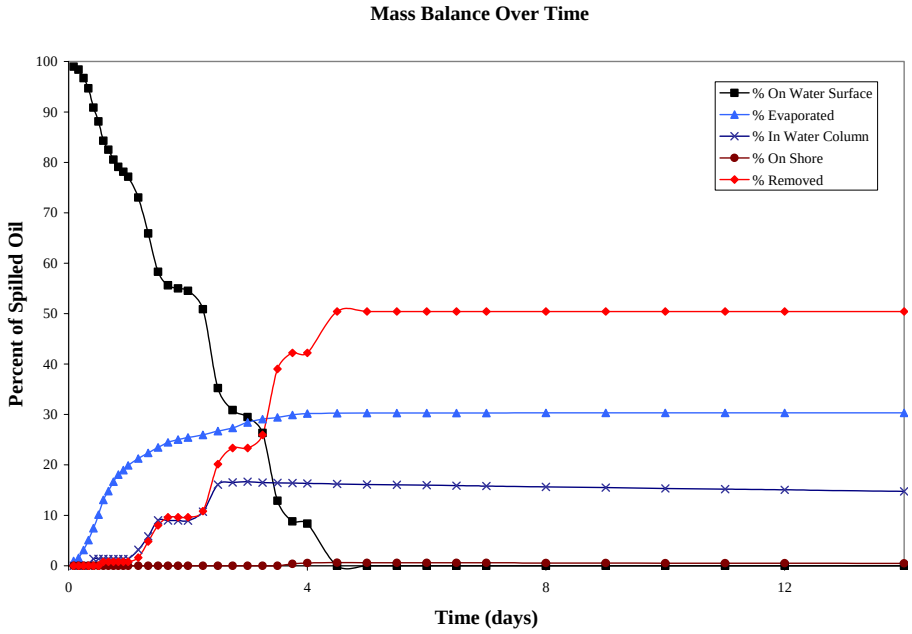


Figure XIV.B.9-5 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

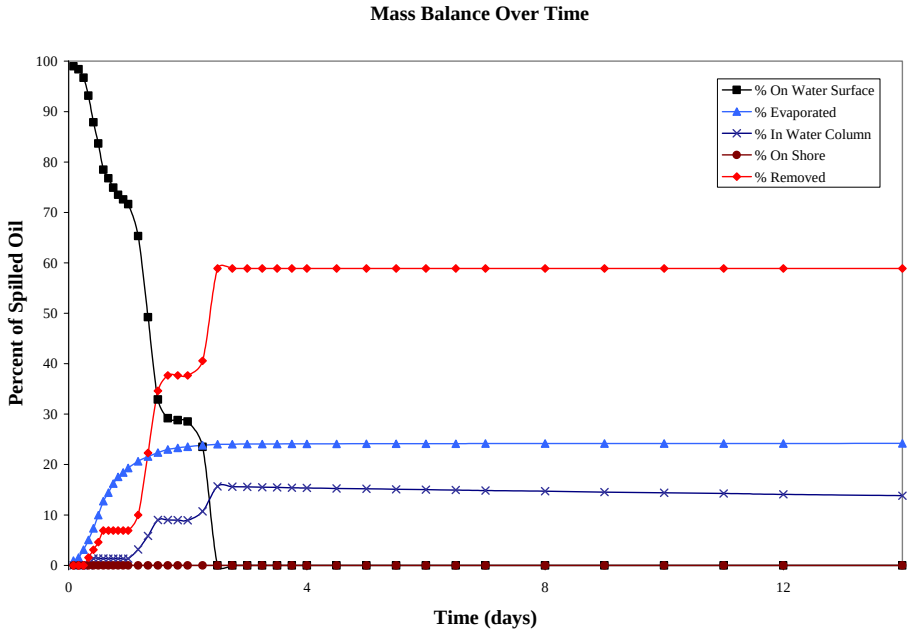


Figure XIV.B.9-6 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

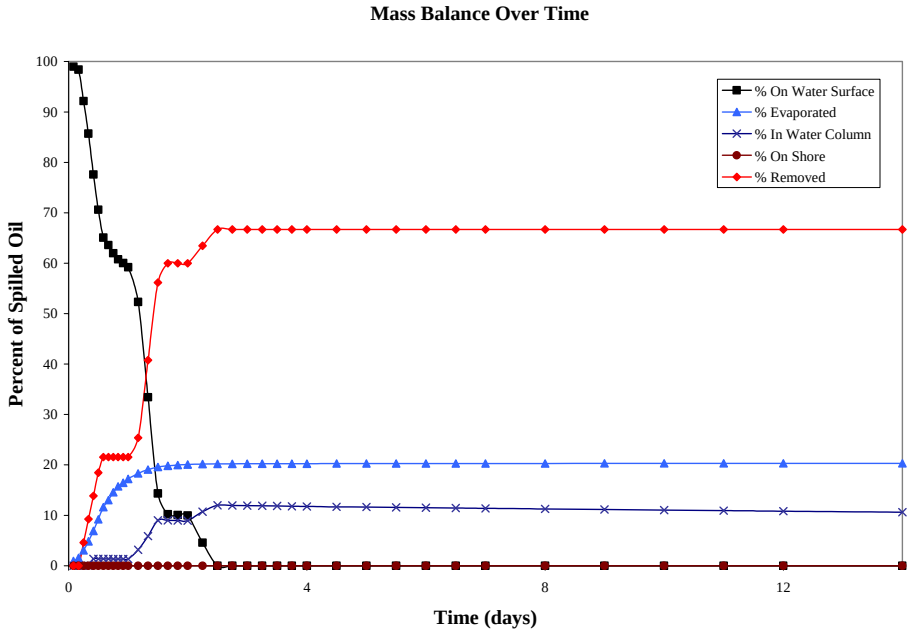


Figure XIV.B.9-7 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

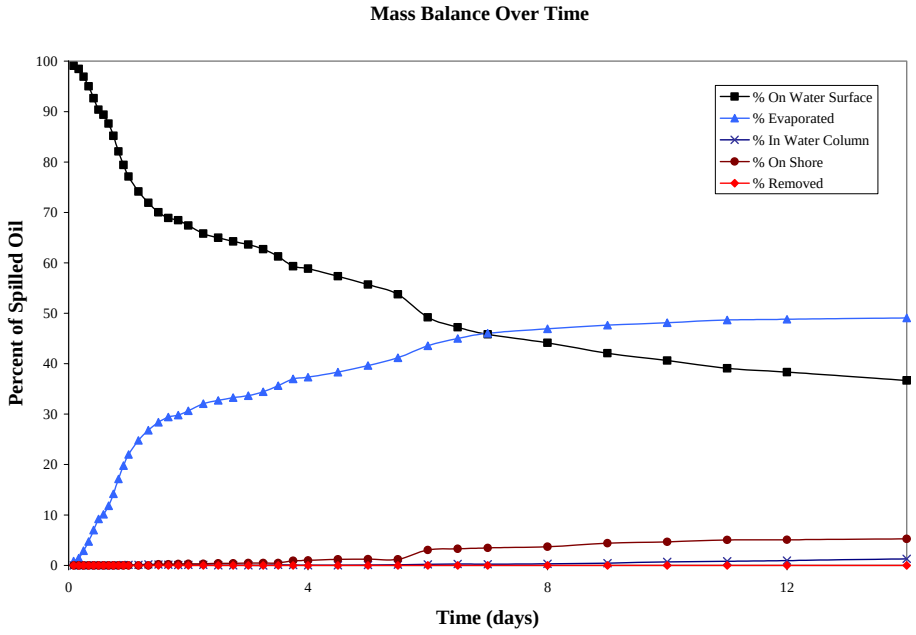


Figure XIV.B.9-8 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

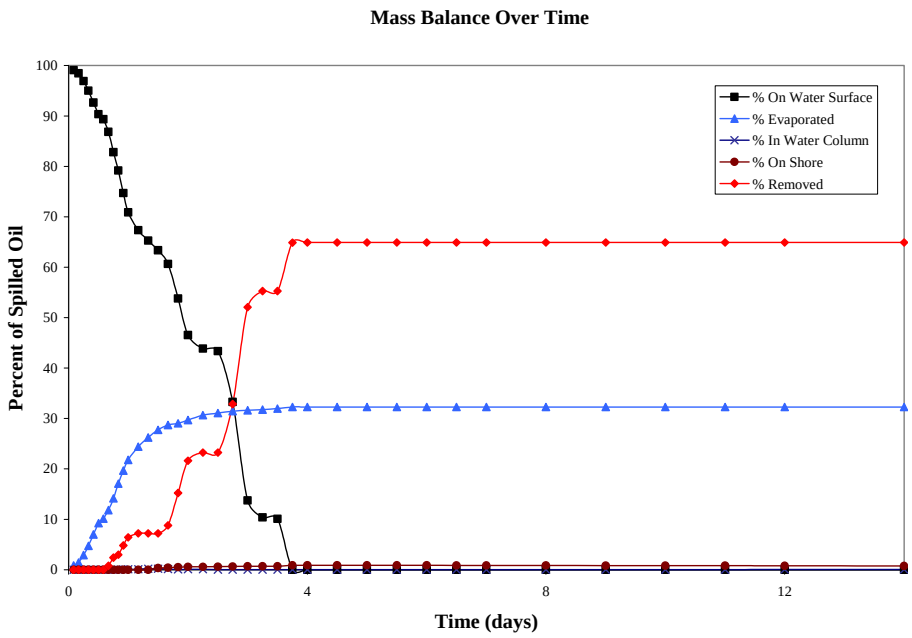


Figure XIV.B.9-9 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

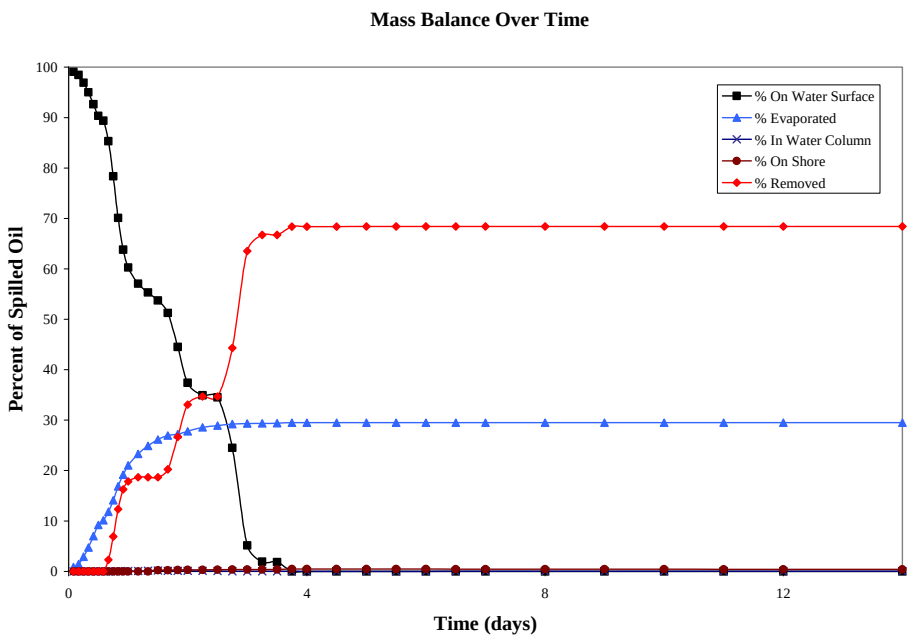


Figure XIV.B.9-10 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

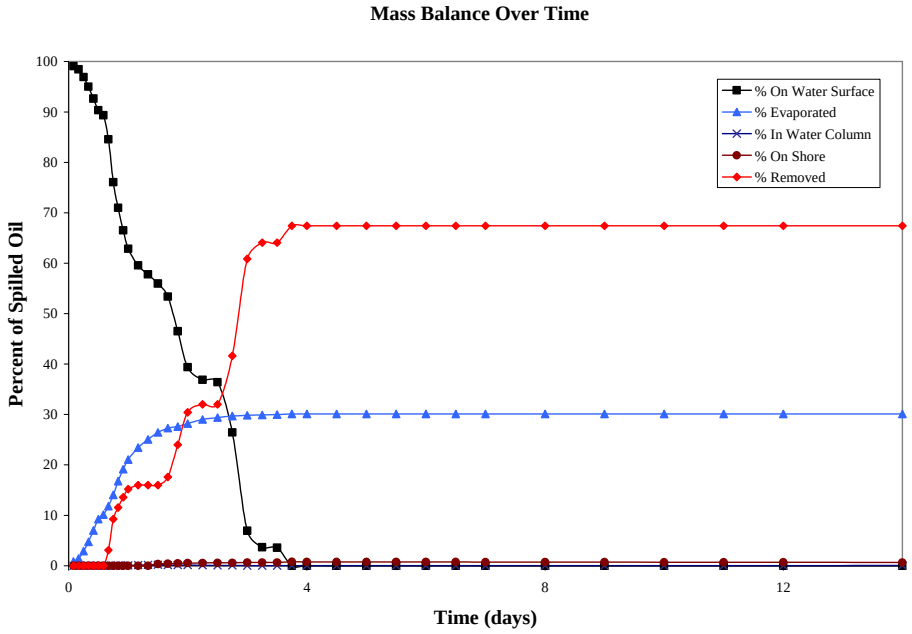


Figure XIV.B.9-11 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

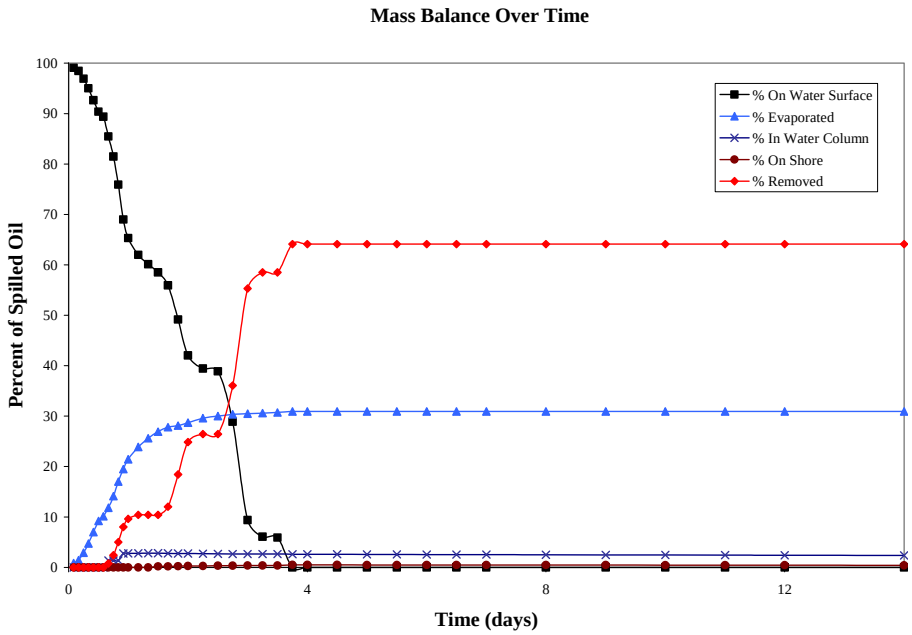


Figure XIV.B.9-12 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

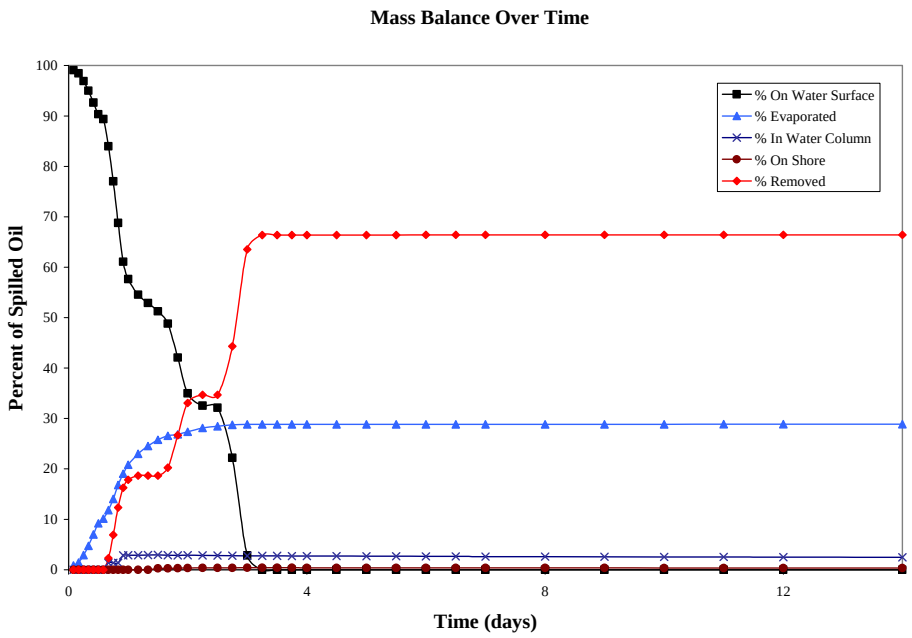


Figure XIV.B.9-13 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

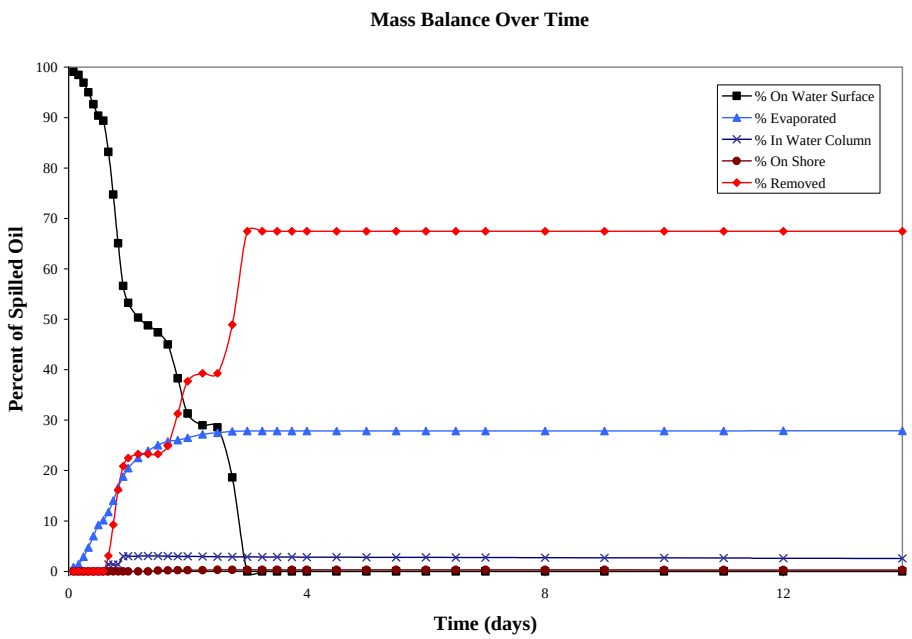


Figure XIV.B.9-14 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

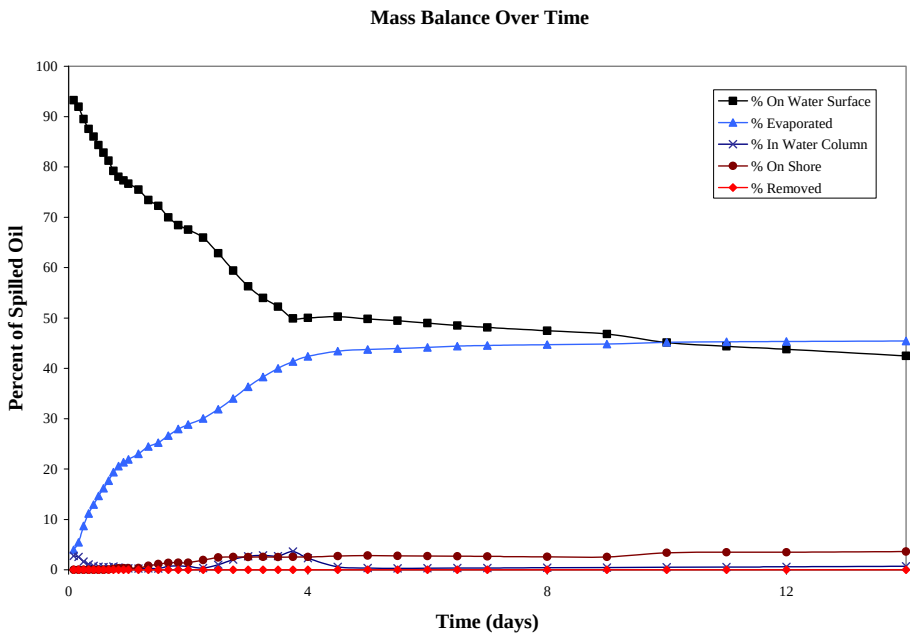


Figure XIV.B.9-15 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

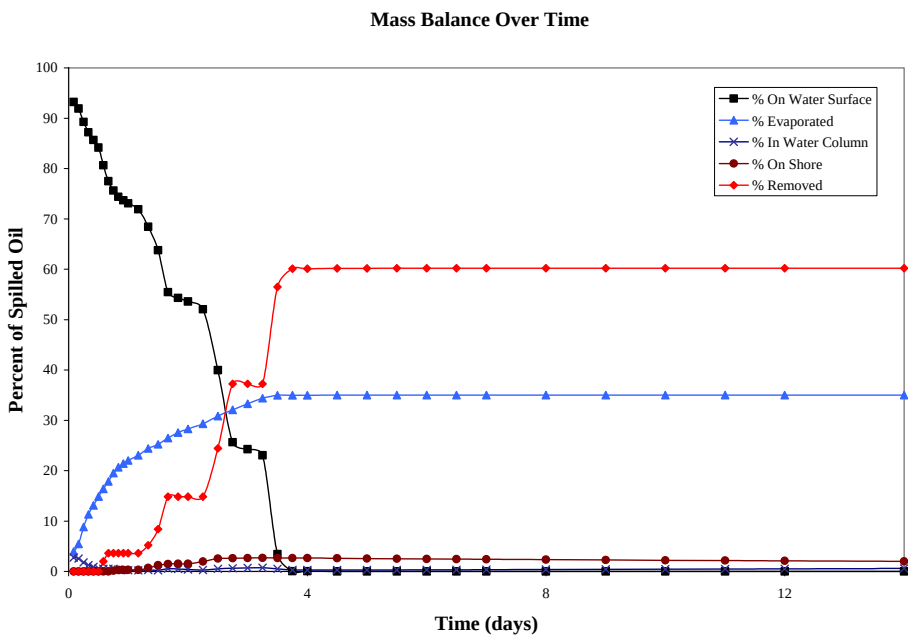


Figure XIV.B.9-16 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

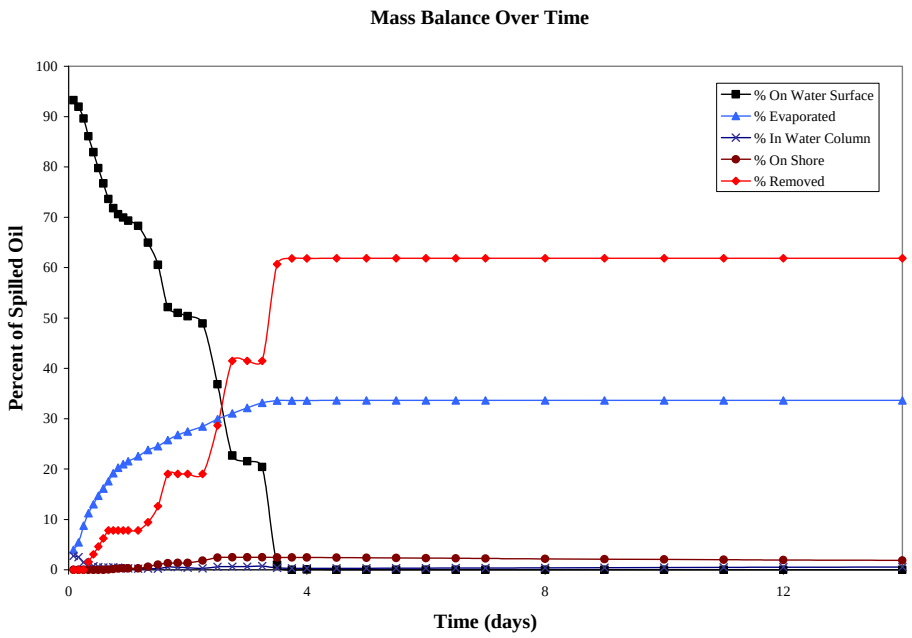


Figure XIV.B.9-17 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

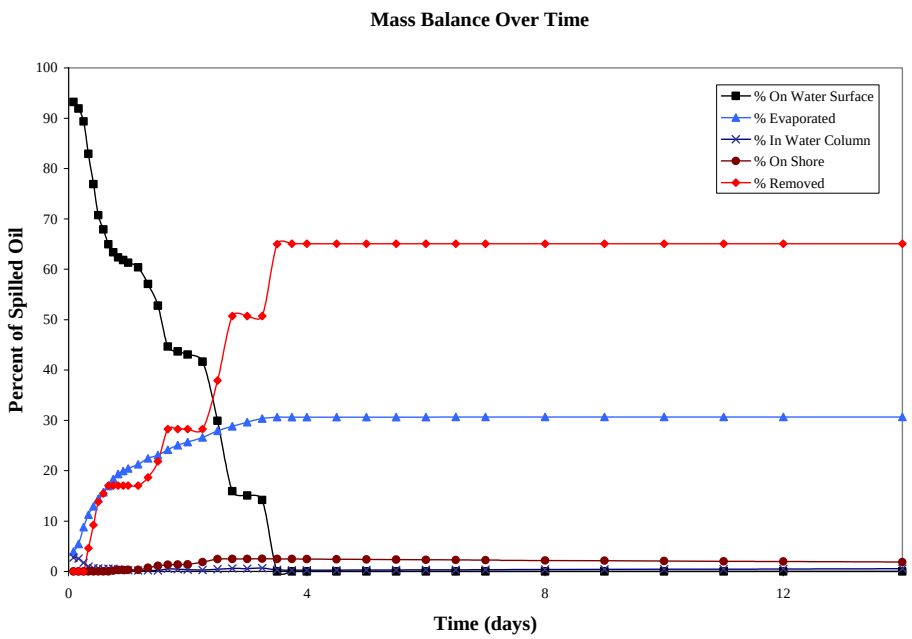


Figure XIV.B.9-18 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

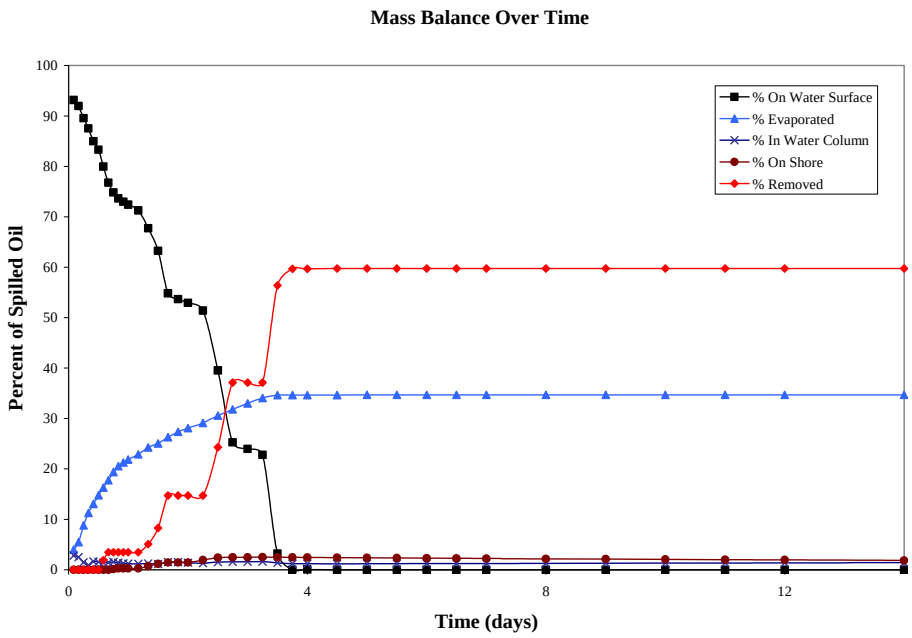


Figure XIV.B.9-19 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

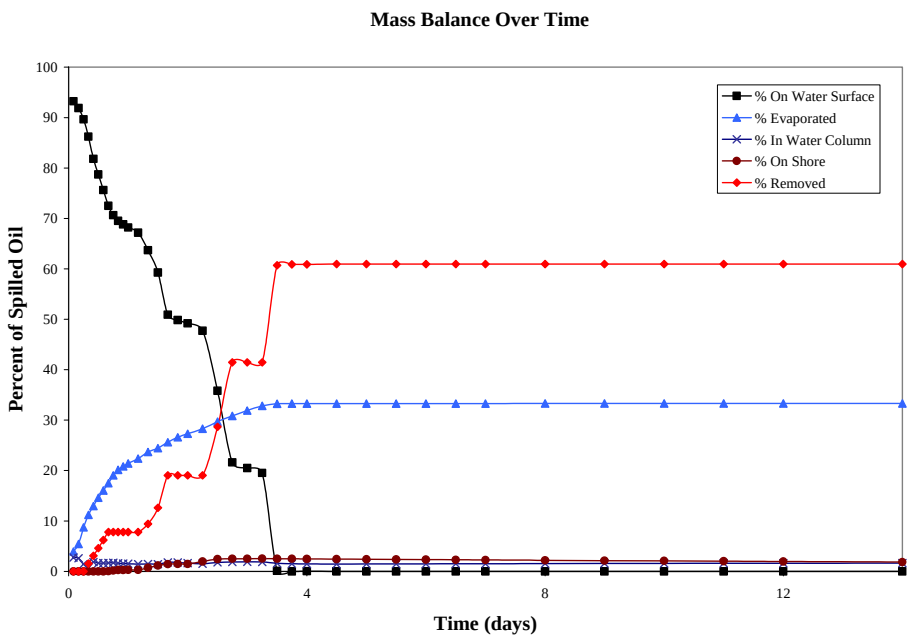


Figure XIV.B.9-20 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

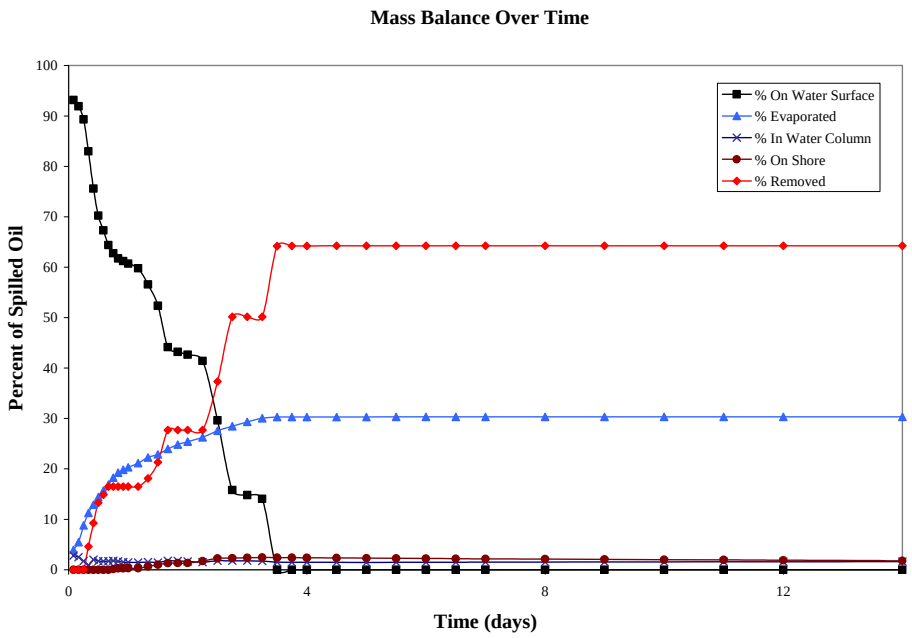
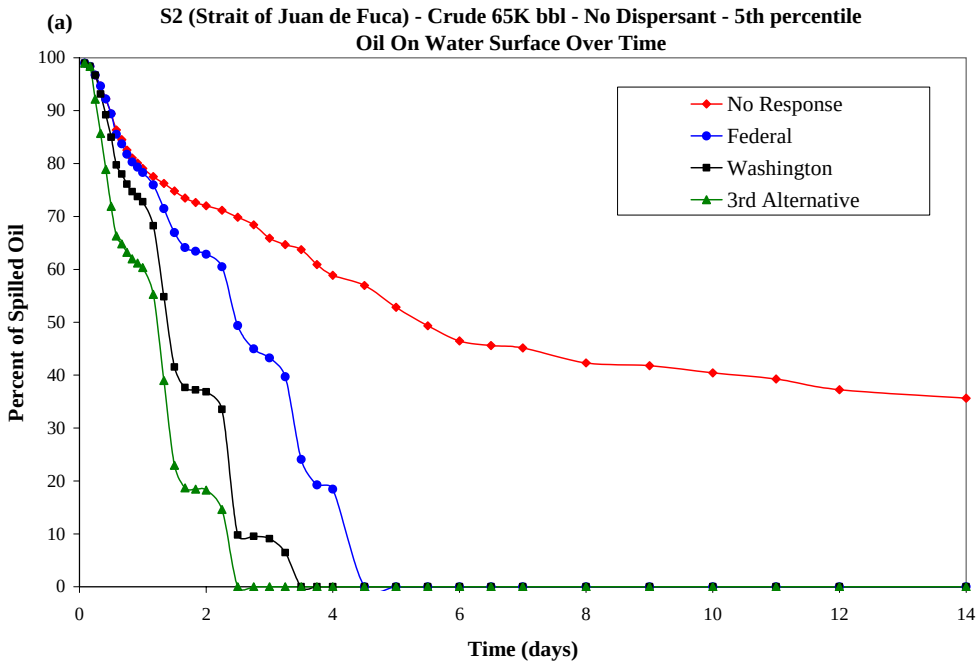


Figure XIV.B.9-21 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).



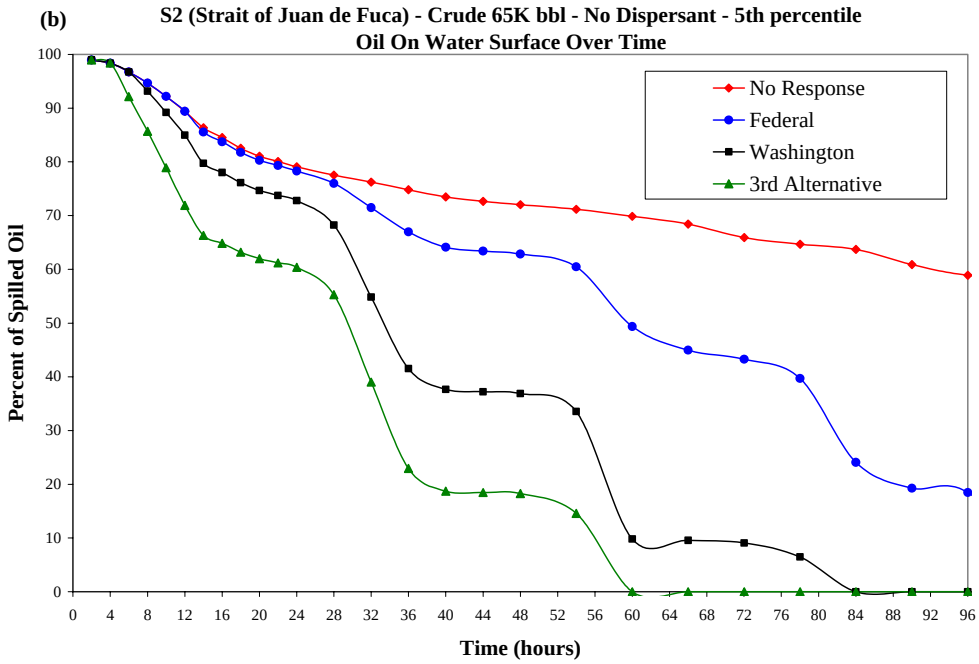
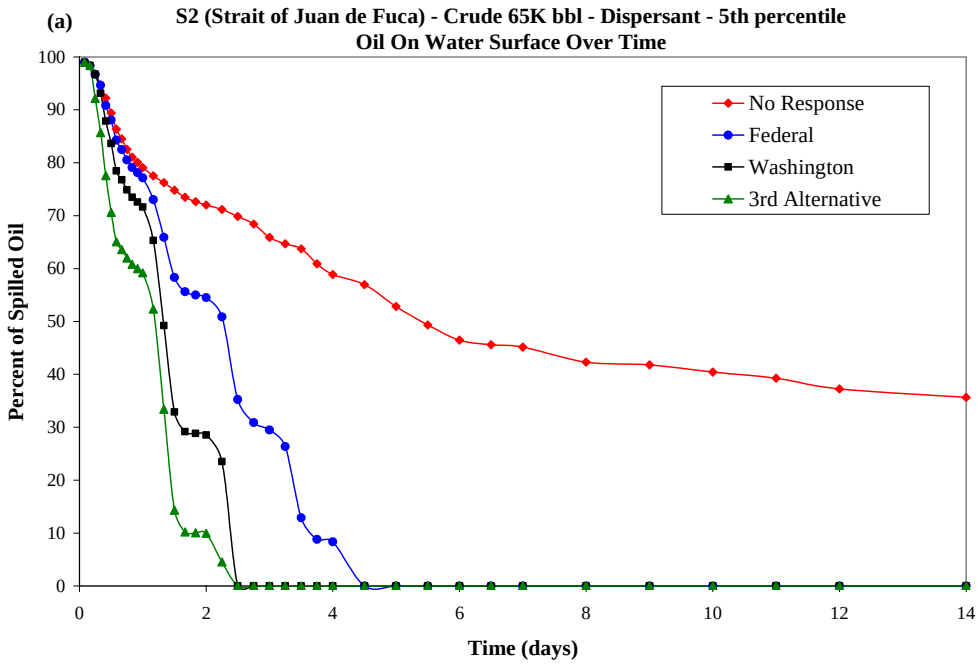


Figure XIV.B.9-22 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



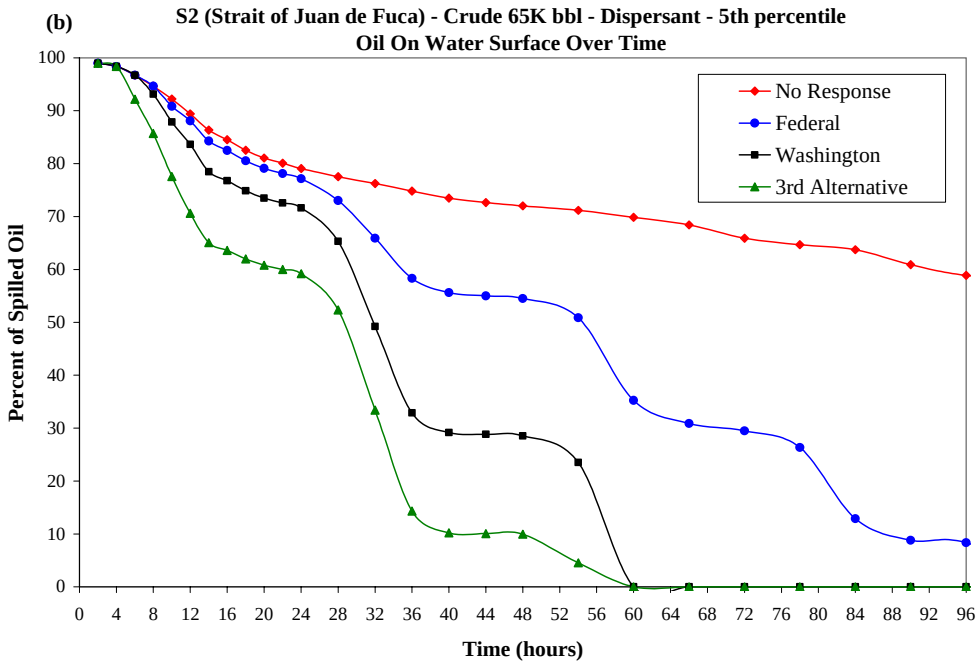
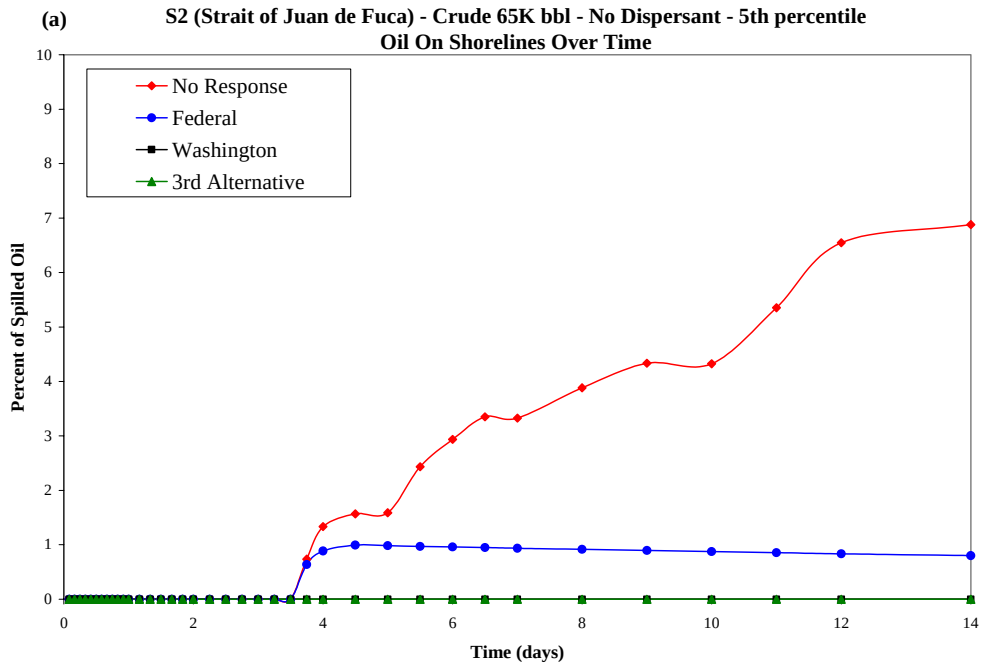


Figure XIV.B.9-23Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



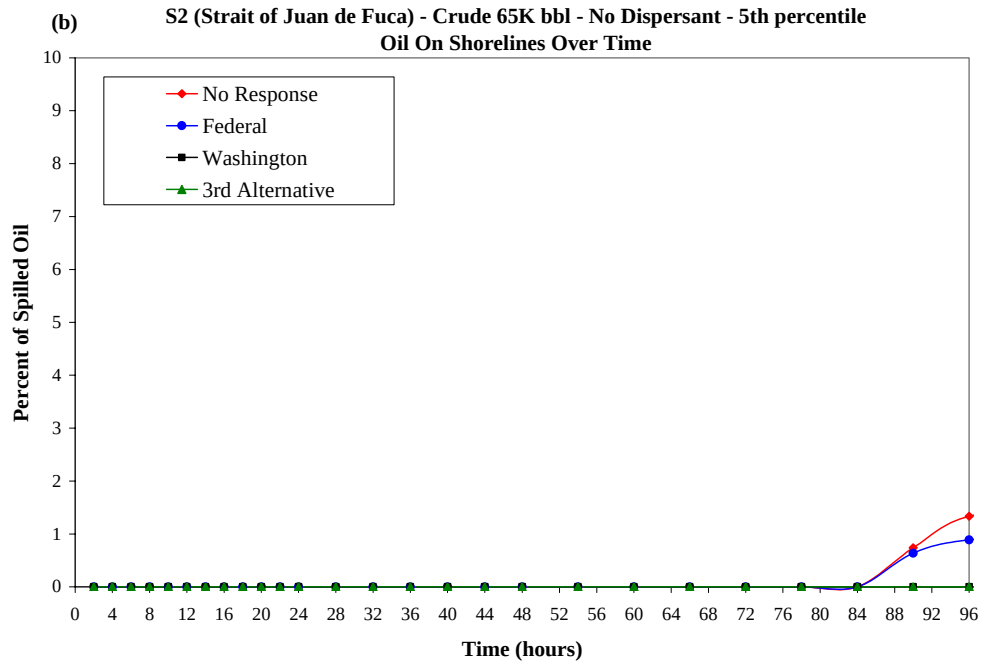
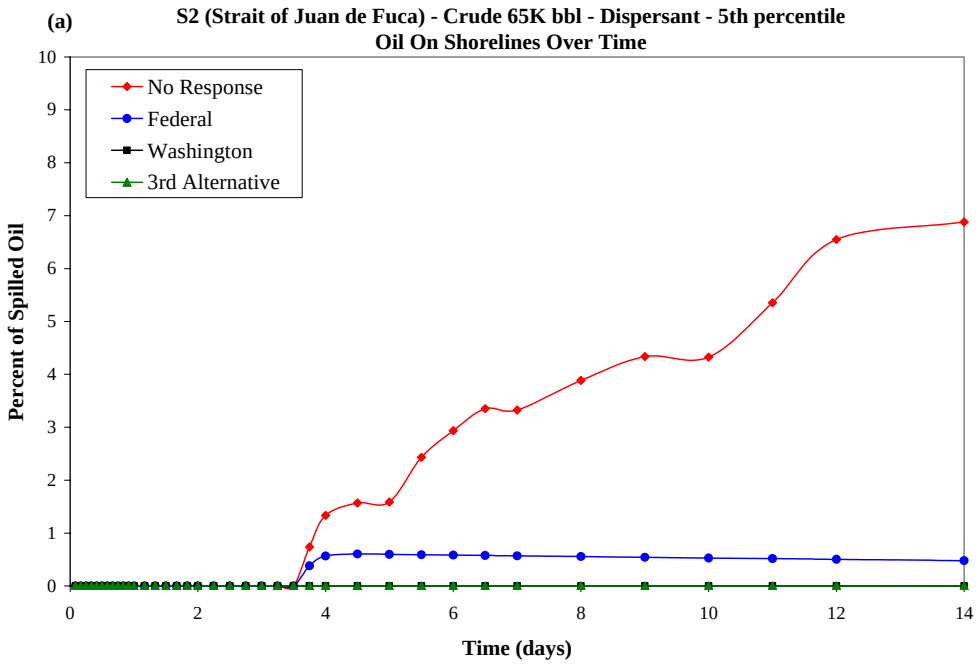


Figure XIV.B.9-24 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



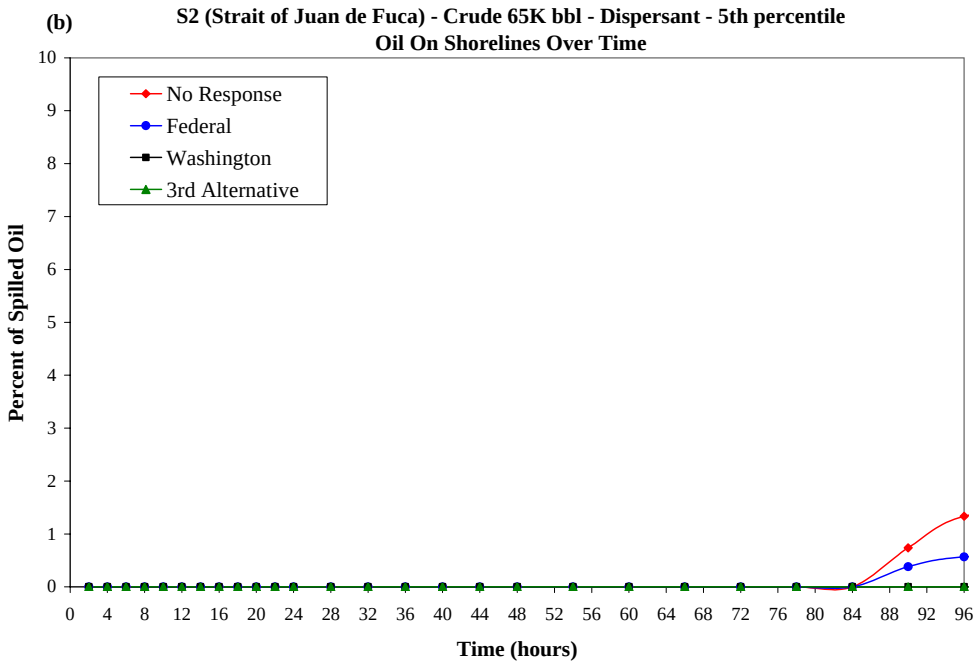
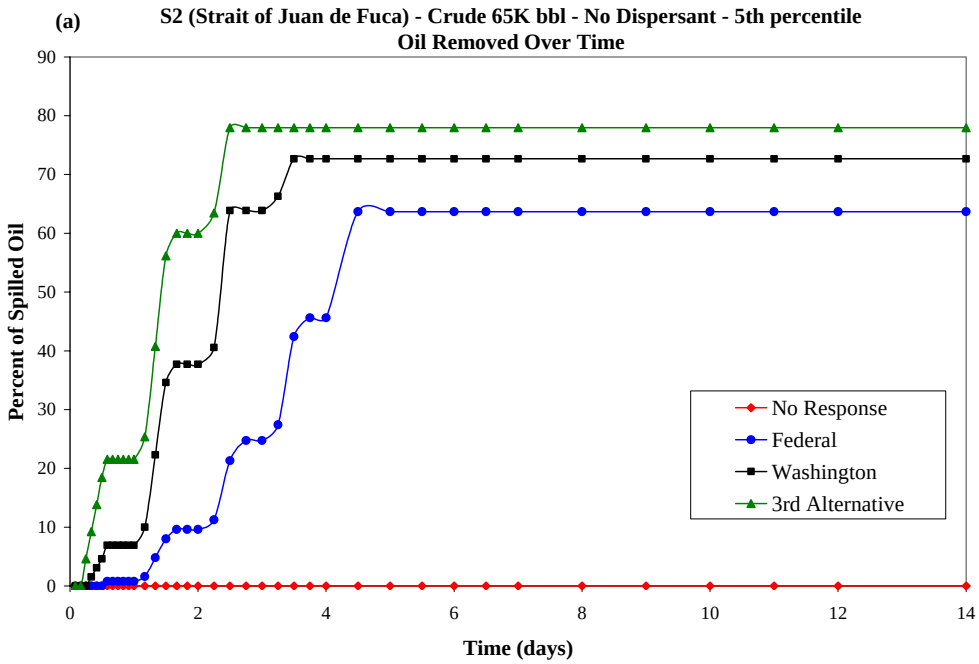


Figure XIV.B.9-25 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



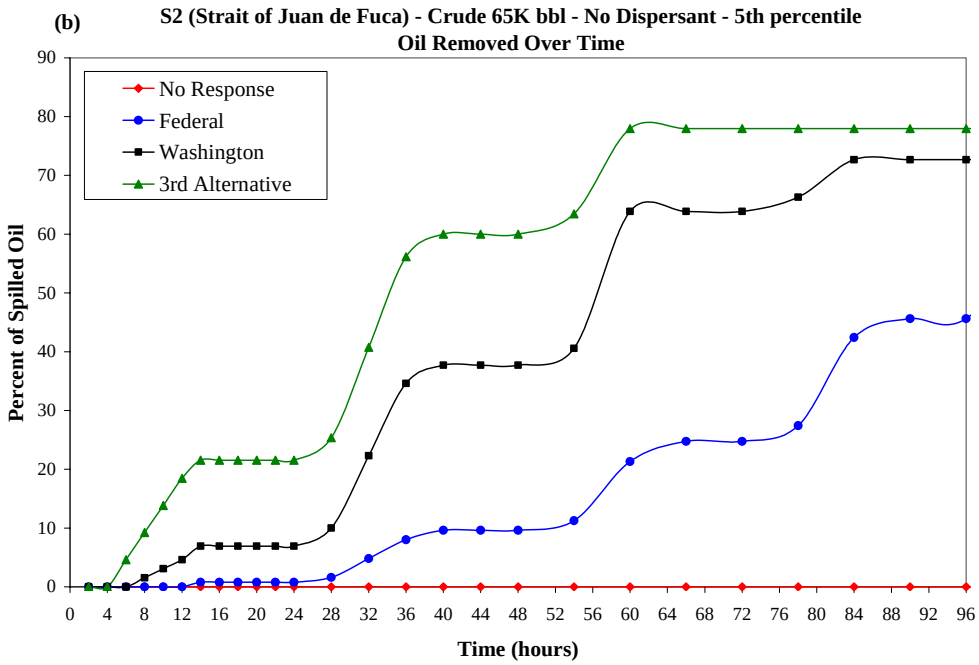
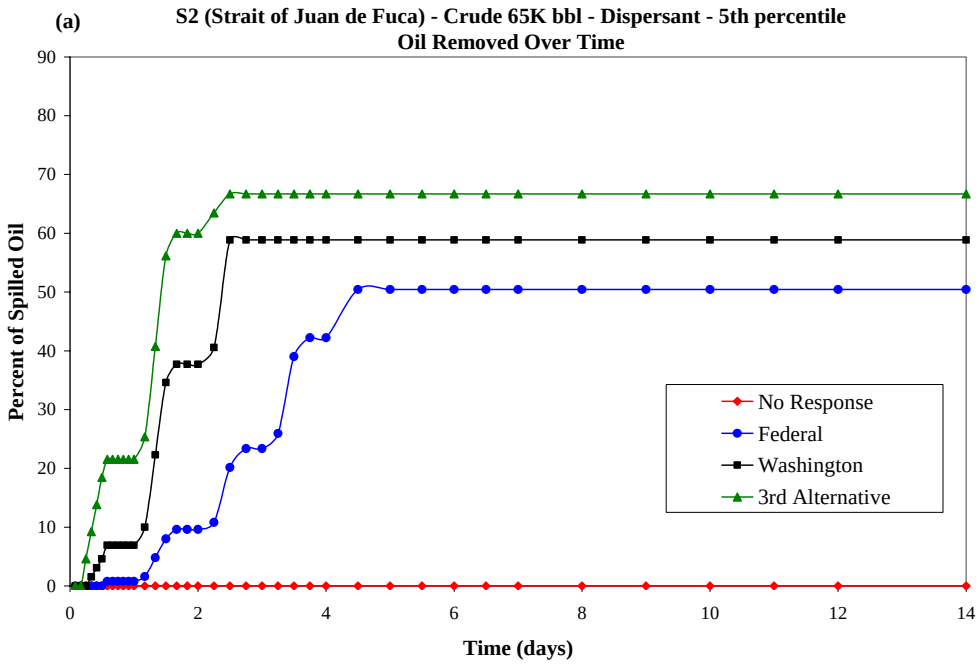


Figure XIV.B.9-26 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



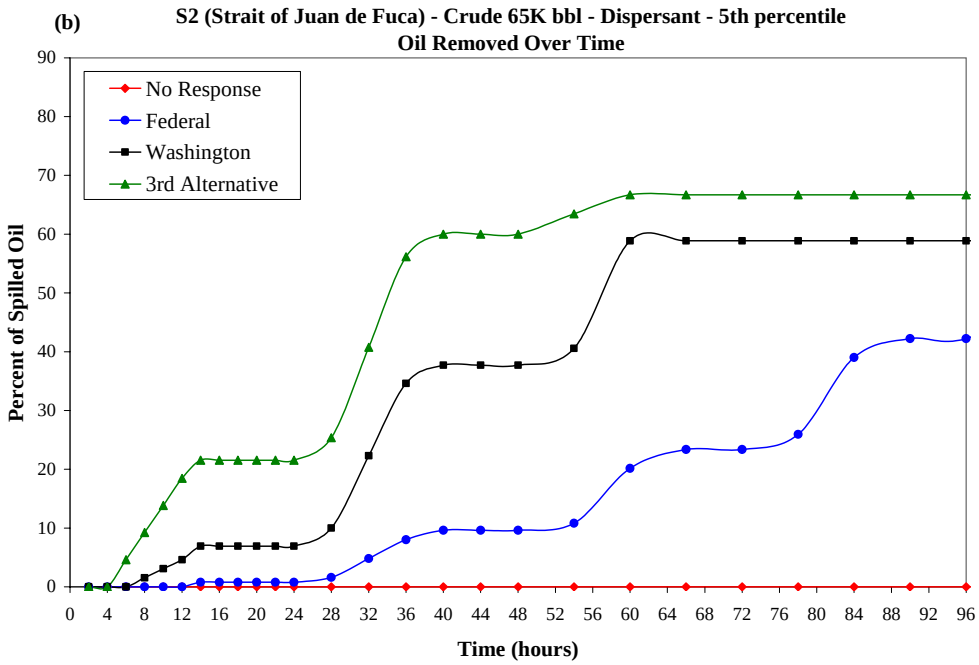
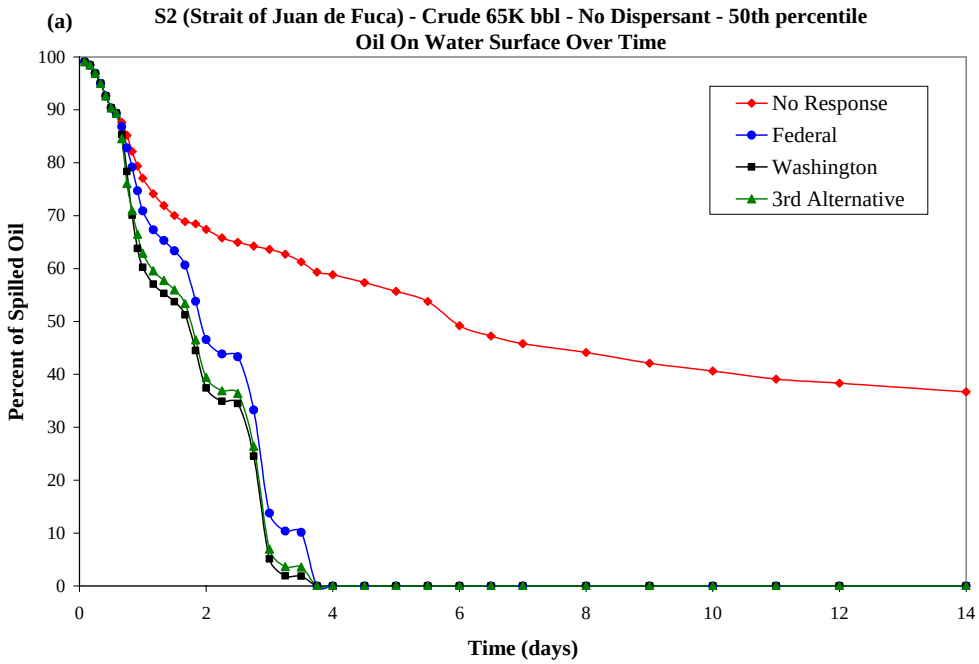


Figure XIV.B.9-27 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



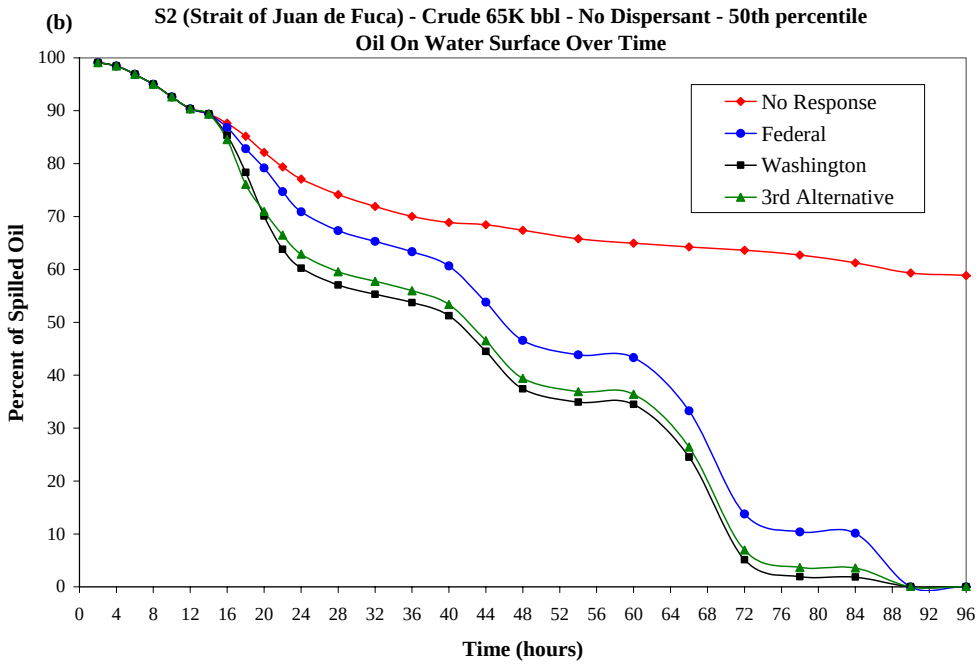
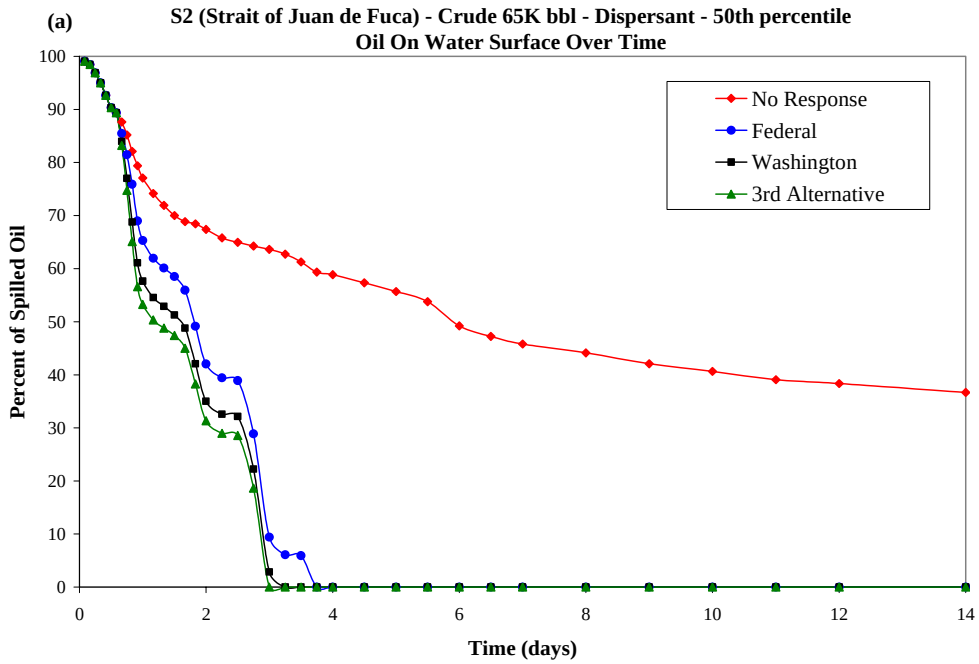


Figure XIV.B.9-28 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



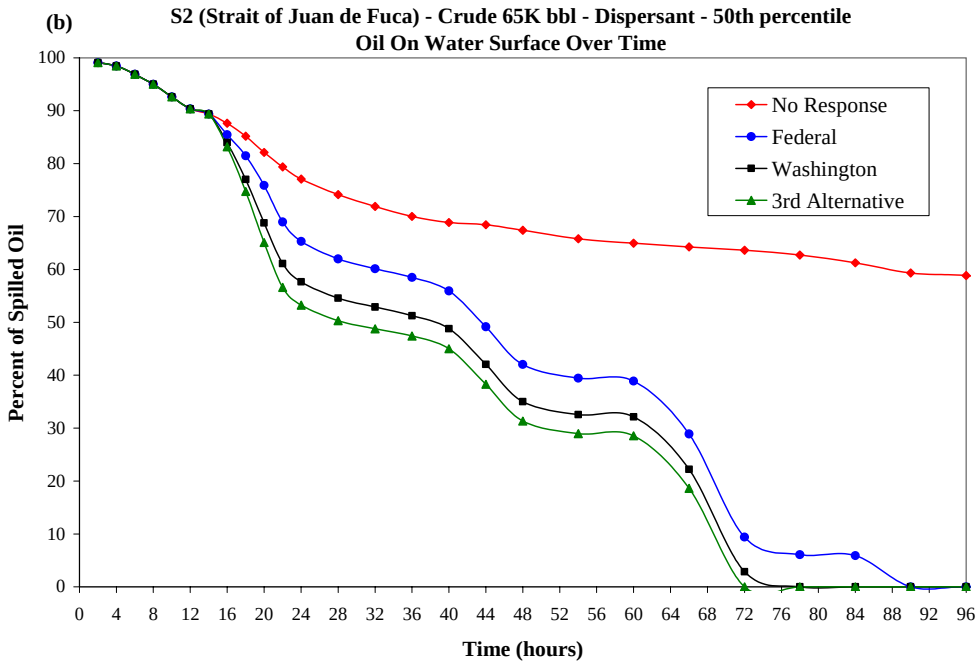
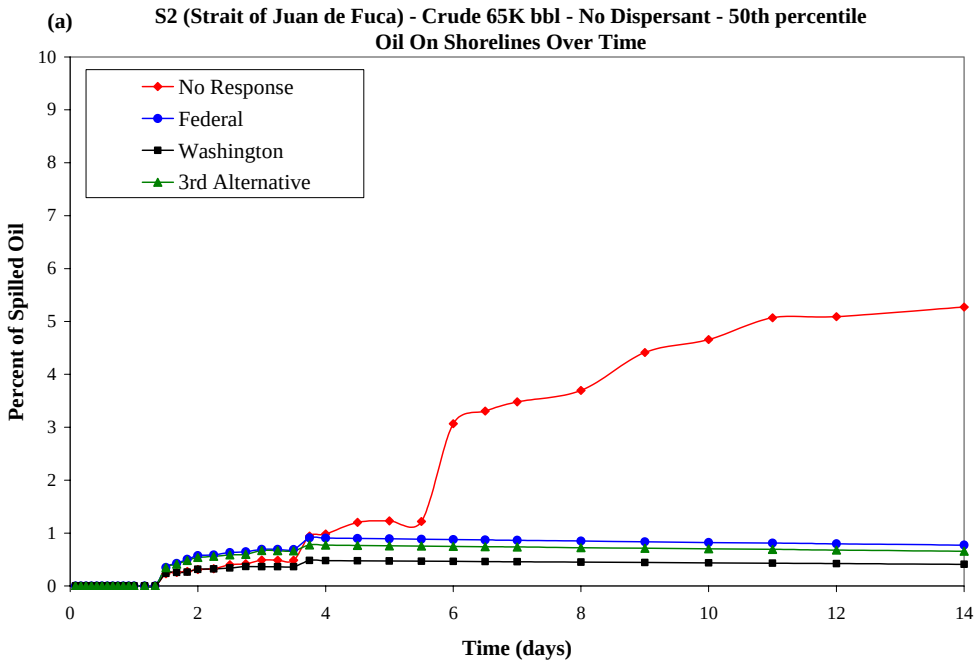


Figure XIV.B.9-29 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



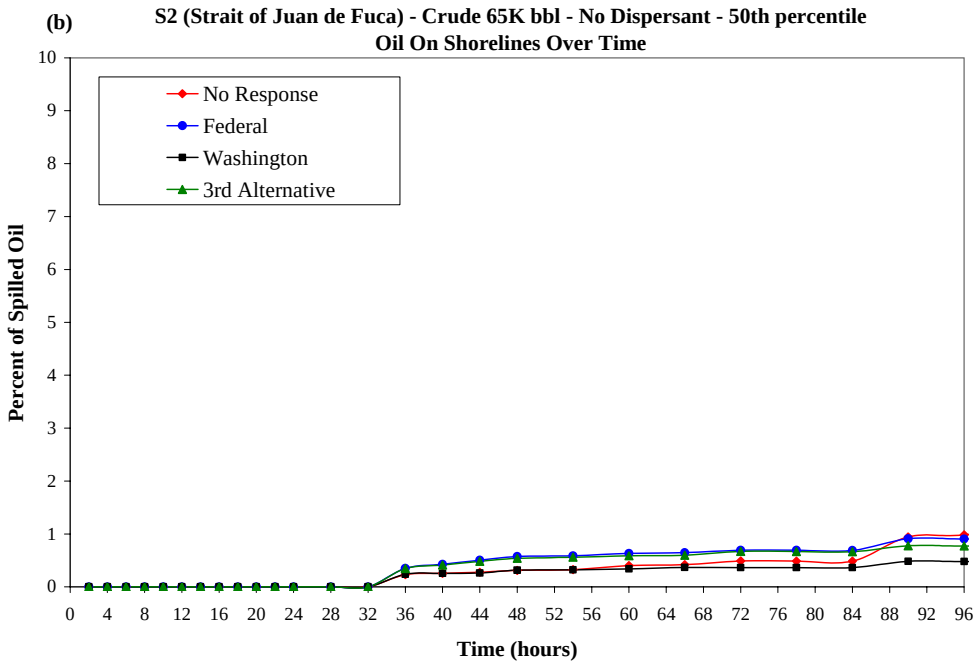
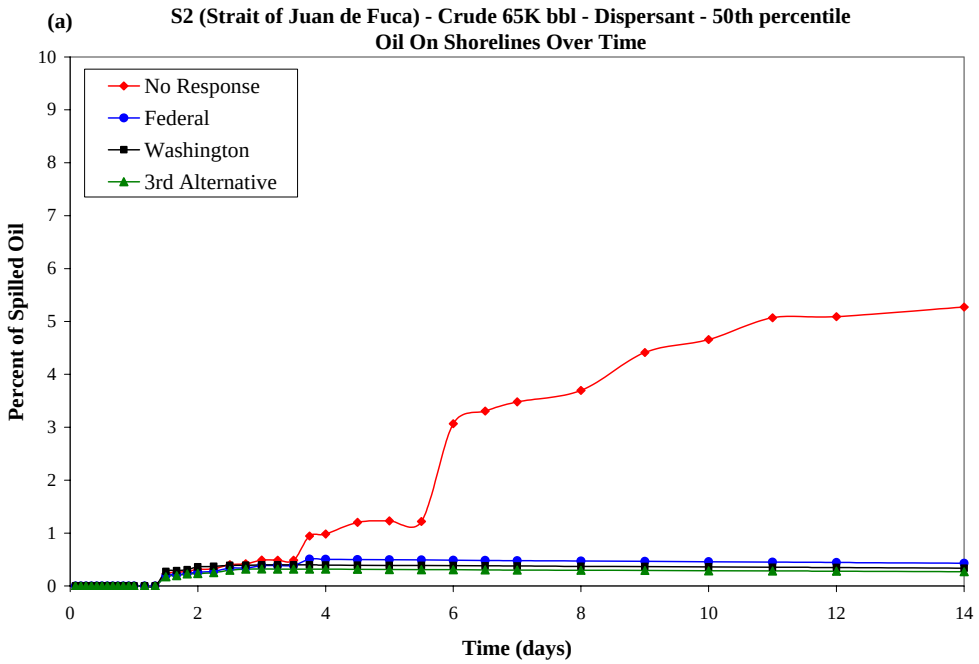


Figure XIV.B.9-30 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



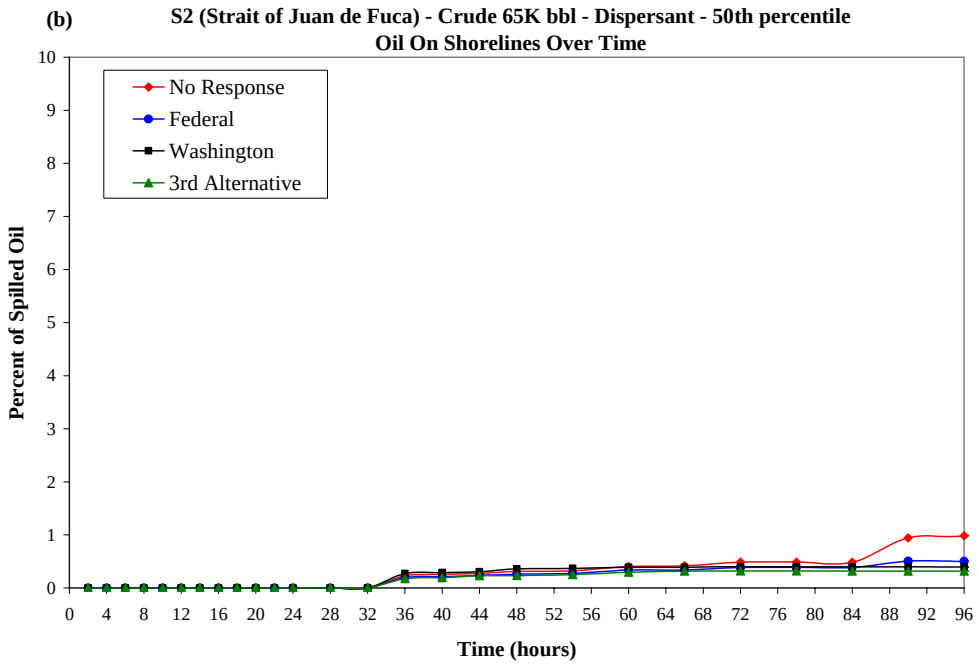
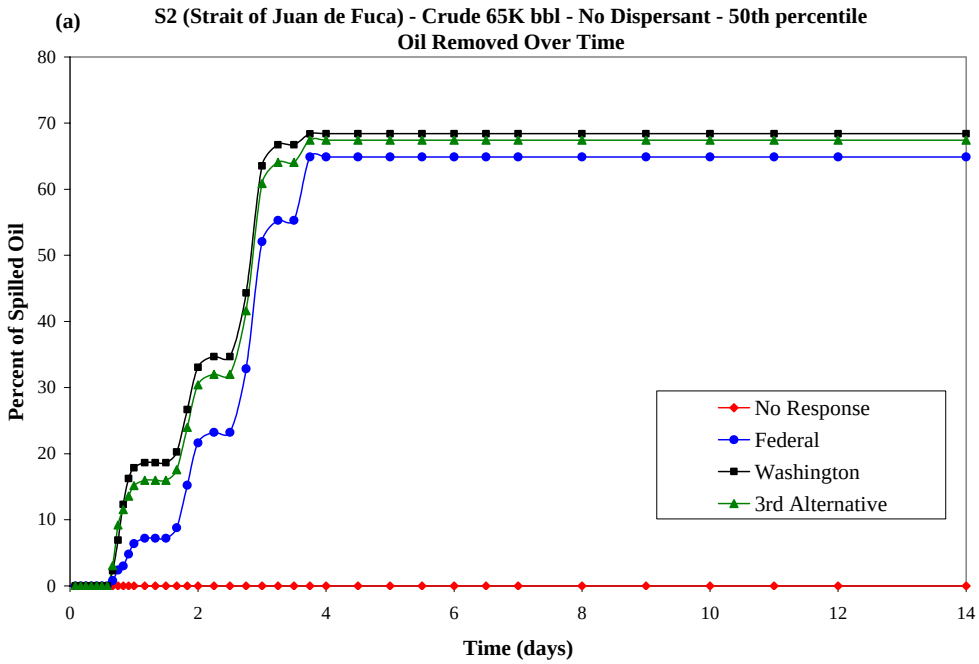


Figure XIV.B.9-31 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



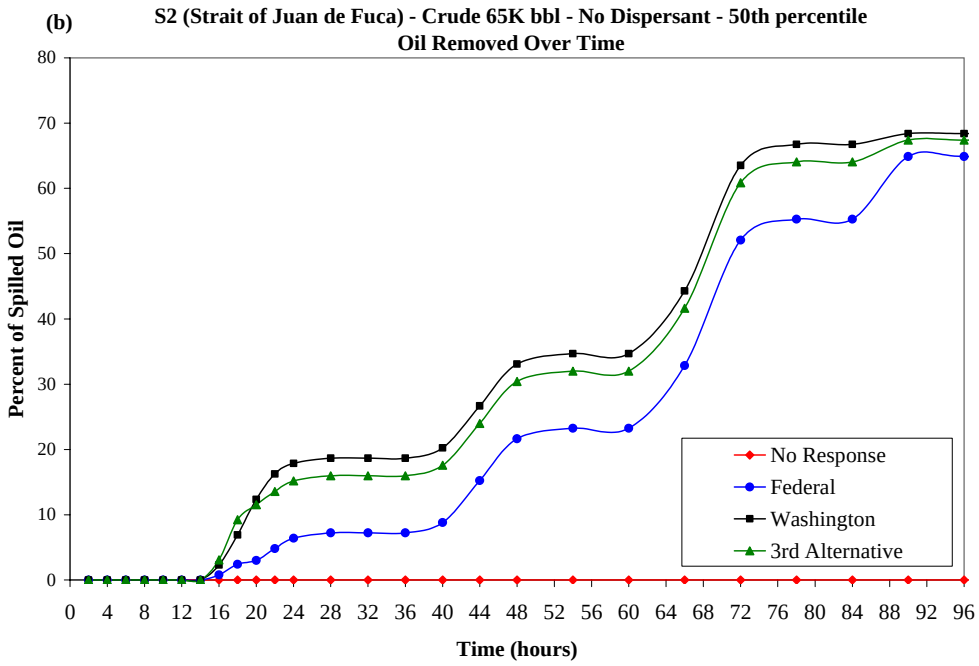
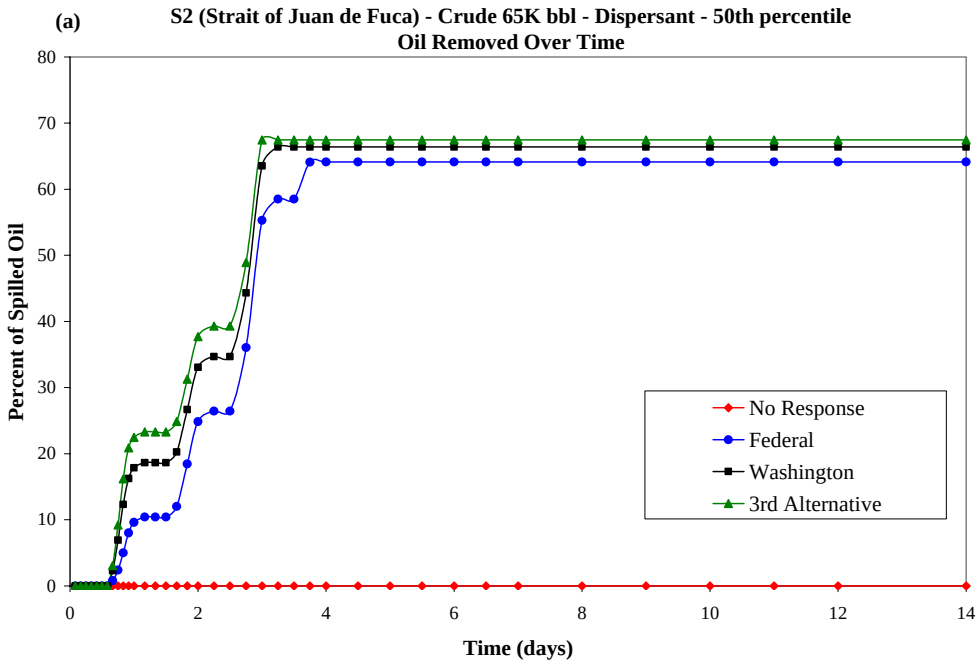


Figure XIV.B.9-32 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



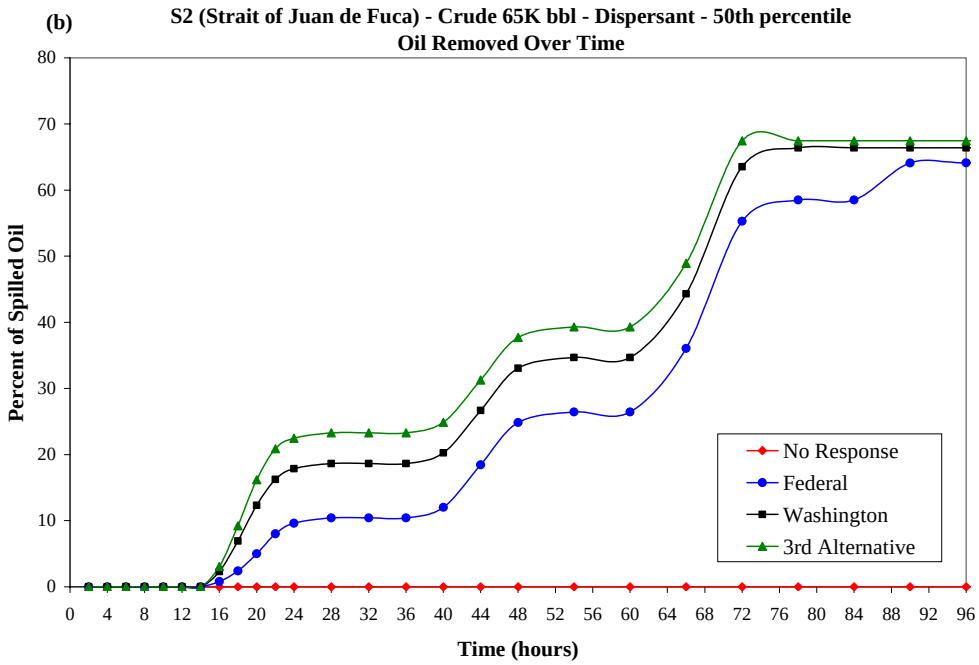
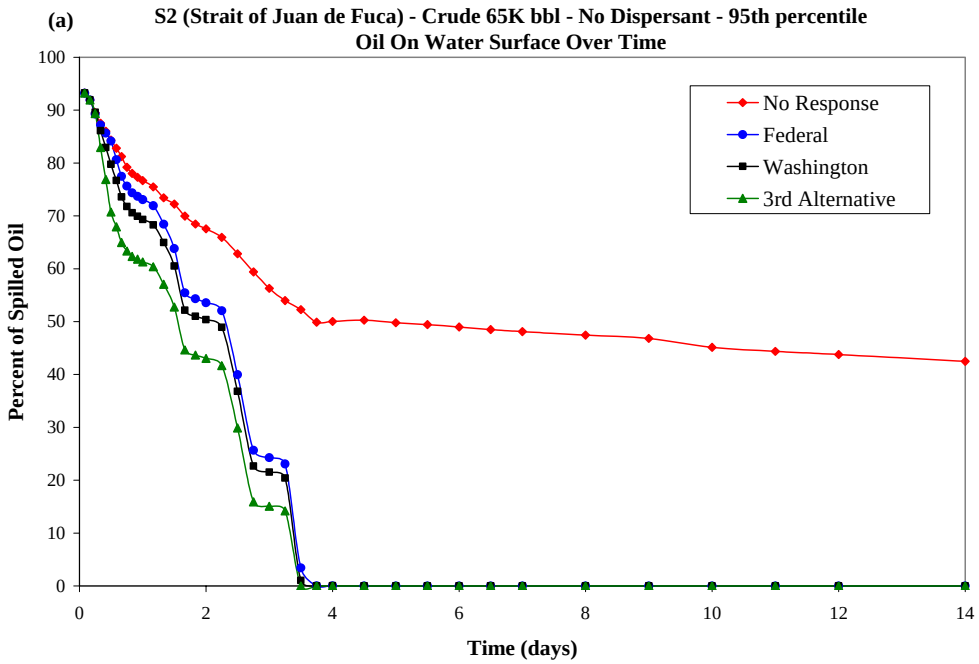


Figure XIV.B.9-33 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



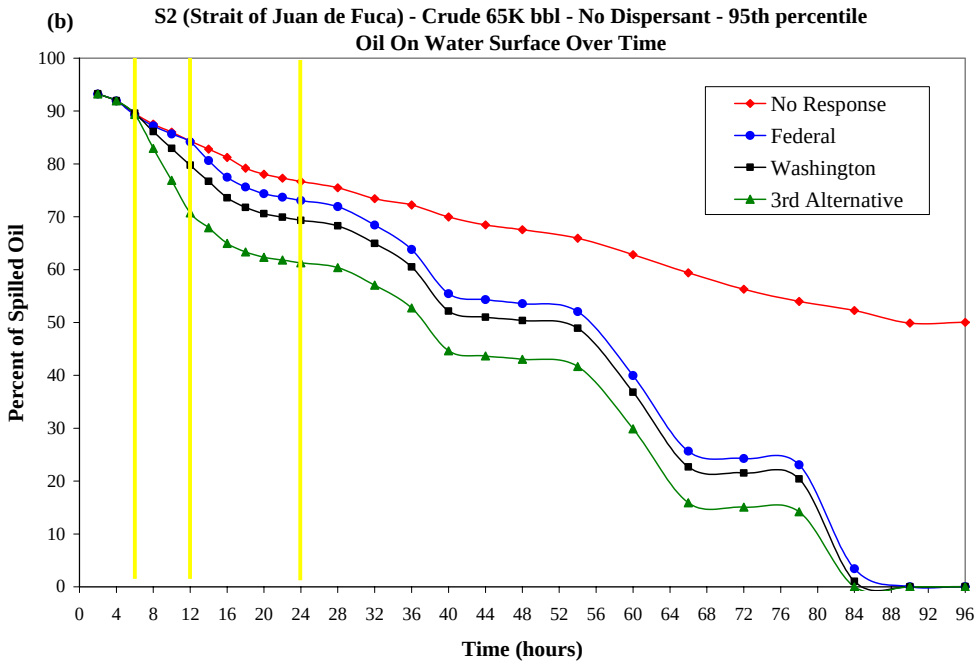
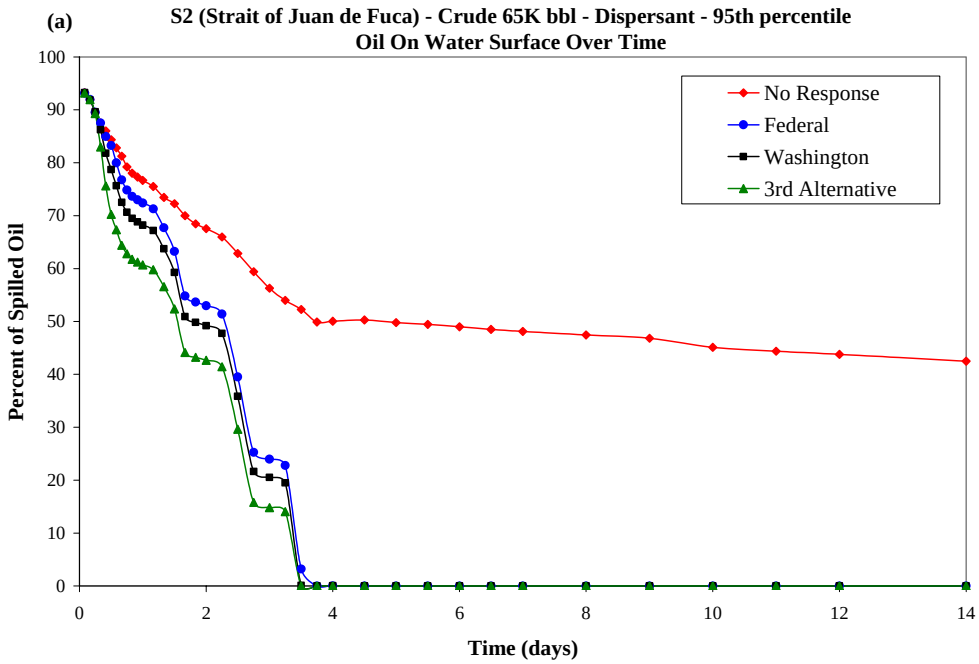


Figure XIV.B.9-34 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



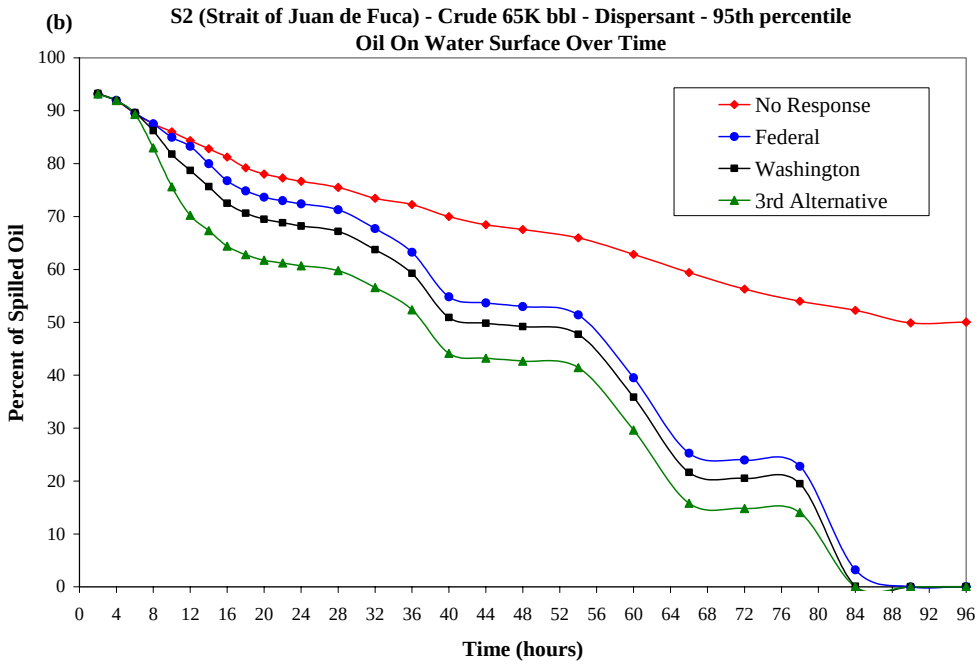
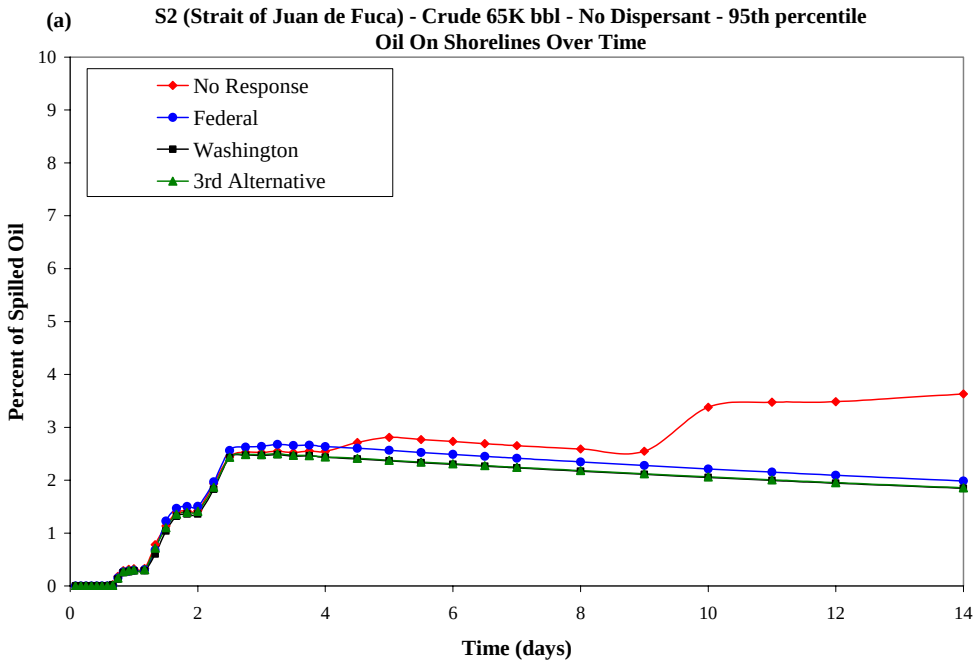


Figure XIV.B.9-35 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



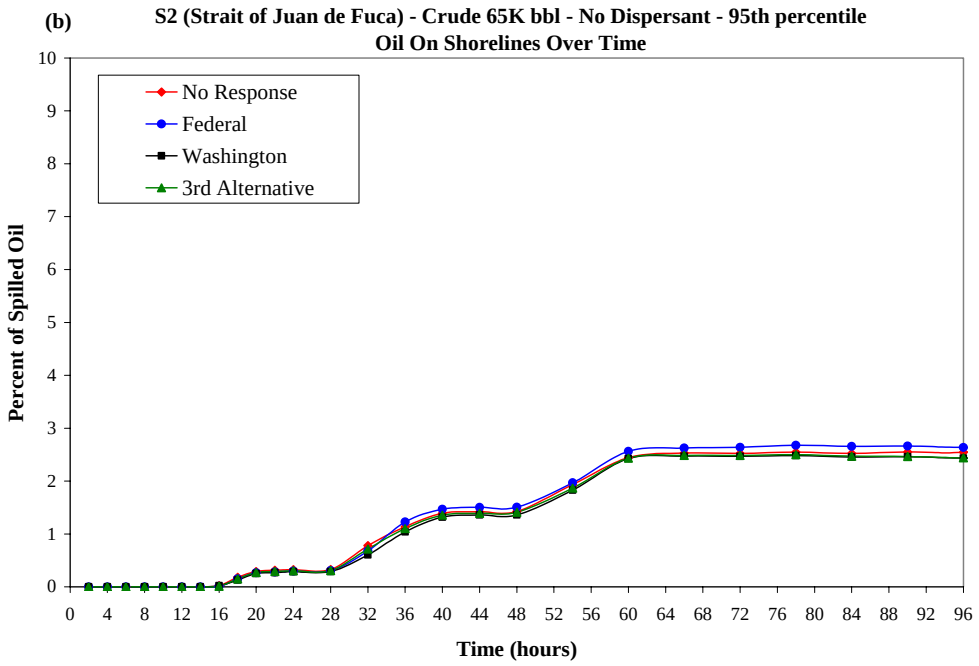
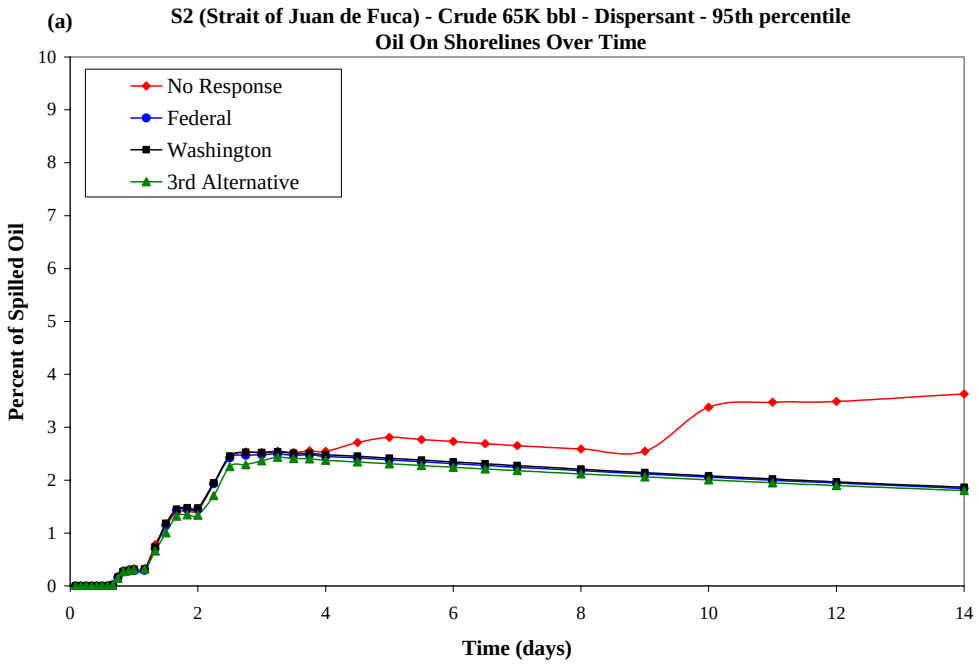


Figure XIV.B.9-36 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



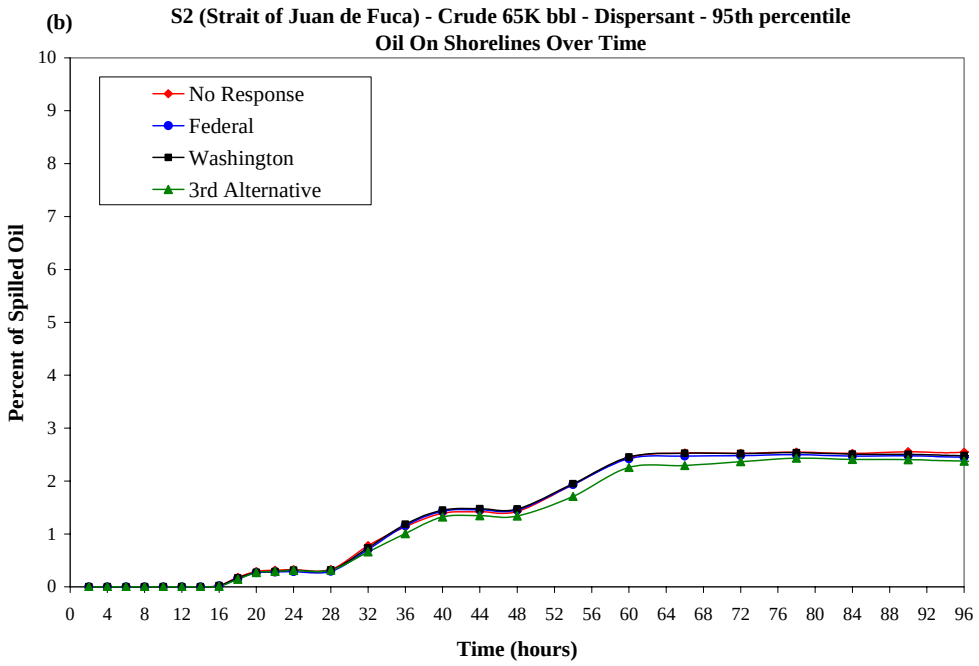
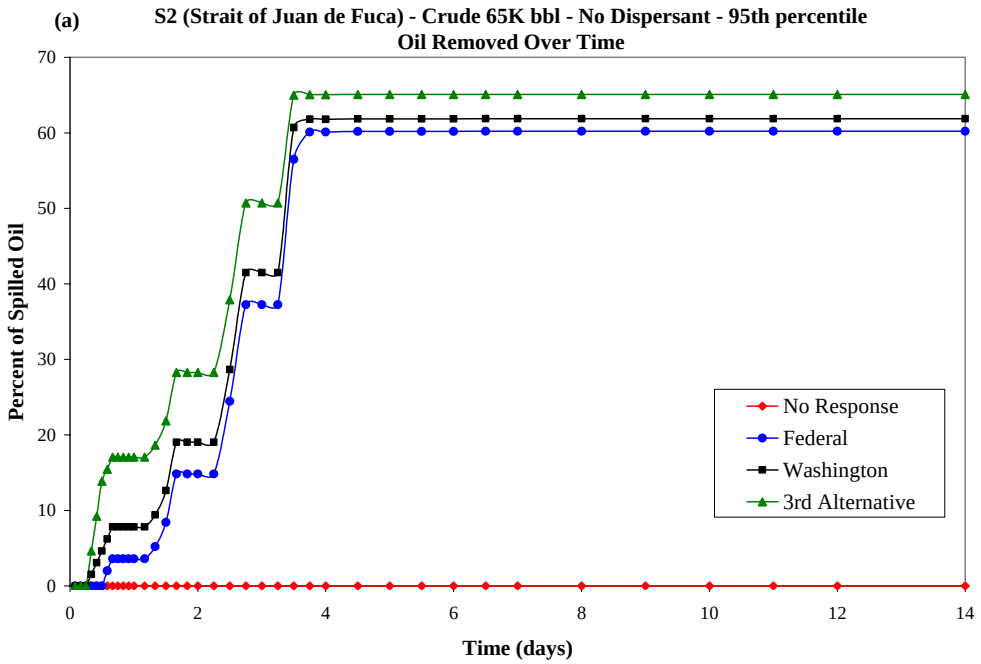


Figure XIV.B.9-37 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



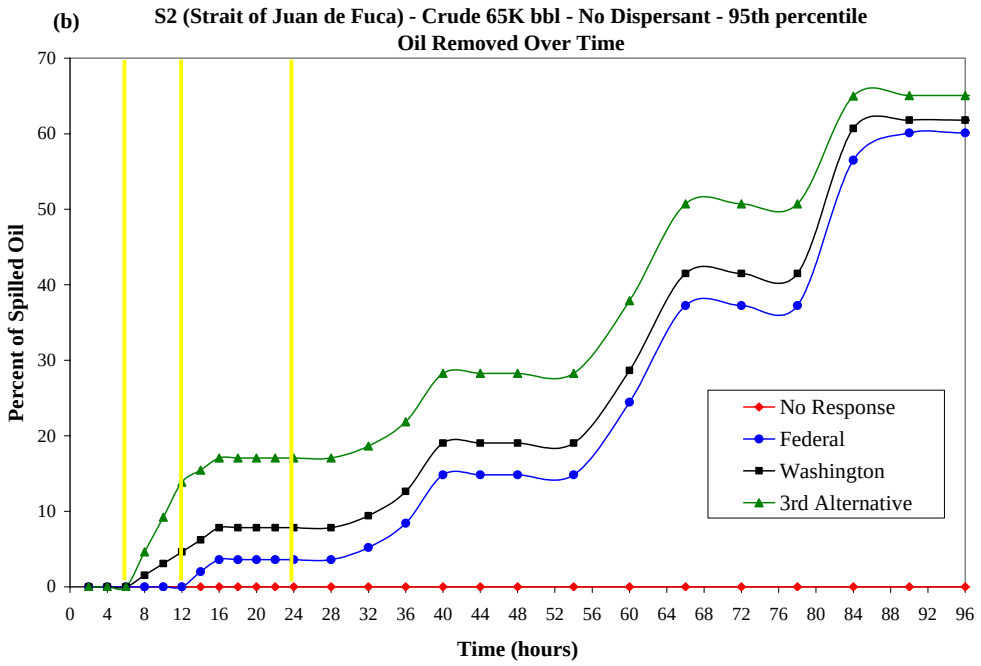
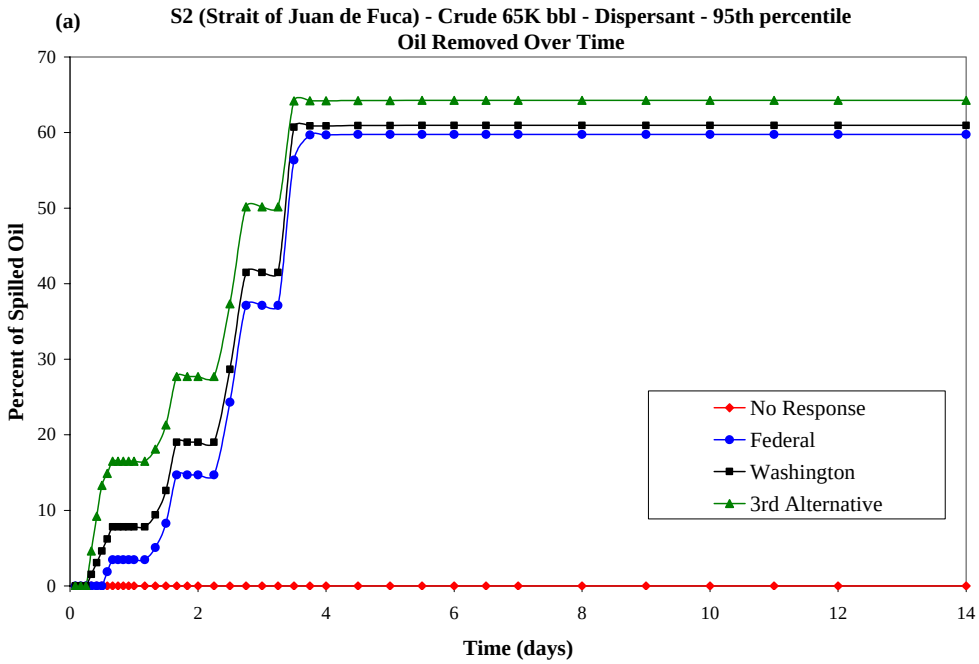


Figure XIV.B.9-38 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run. Part b is a subset of Part a.



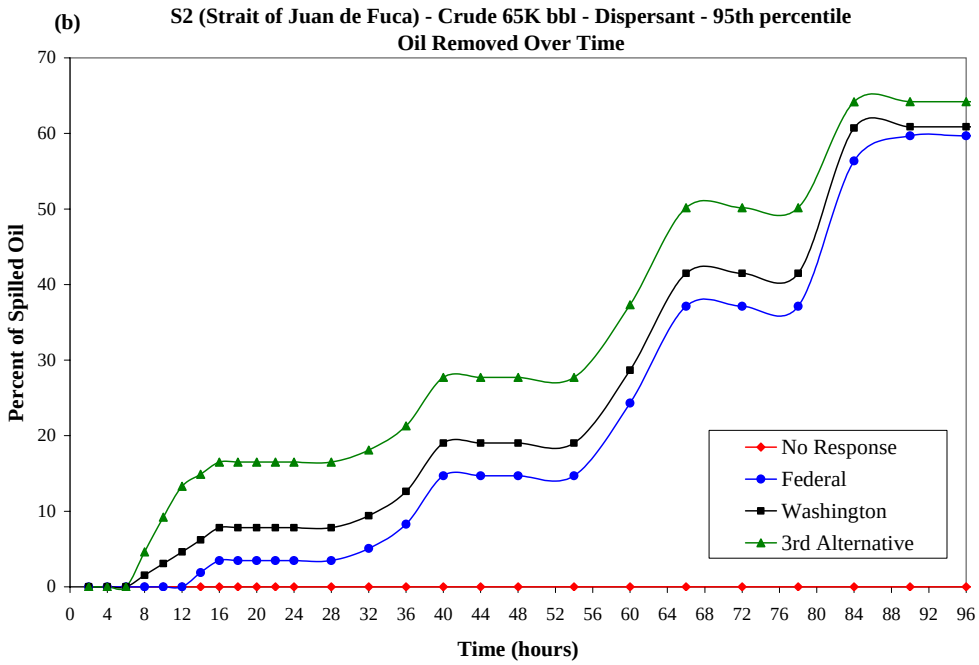


Figure XIV.B.9-39 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run. Part b is a subset of Part a.

XIV.C. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the appropriate seasonal abundance for each of the 5th, 50th and 95th percentile run dates. Impacts are proportional to pre-spill abundance. Thus, for the runs the results were corrected to use the annual mean abundance. Thus, all results are based on annual mean abundance. Note that the statistical data in the shaded cells are based only on 3 runs and so are highly uncertain.

Table IXIV.C-1 Strait of Juan de Fuca – Alaskan North Slope Crude, no removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	32,342	12,027	172	10,990	0	-	3	-	55,535	55,532	3
50th Percentile Run (based on shore cost)	12,820	3,900	14	910	0	-	1	-	17,646	17,645	1
95th Percentile Run (based on shore cost)	16,984	5,634	12	742	0	-	1	-	23,373	23,371	1
Mean	20,715	7,187	66	4,214	0	-	2	-	32,184	32,183	2
Std Dev (SD)	10,282	4,280	92	5,869	0	-	1	-	20,423	20,423	1
Mean - 2SD	151	-	-	-	0	-	0	-	-	-	0
Mean + 2SD	41,280	15,747	250	15,952	0	-	3	-	73,031	73,028	3

Table IXIV.C-2 Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	7,191	1,557	-	-	0	-	1	-	8,749	8,748	1
50th Percentile Run (based on shore cost)	5,617	902	3	186	0	-	1	-	6,709	6,709	1
95th Percentile Run (based on shore cost)	7,260	1,586	6	362	0	-	1	-	9,214	9,213	1
Mean	7,686	1,763	2	147	0	-	1	-	9,598	9,598	0.71
Std Dev (SD)	2,539	1,057	3	191	0	-	0	-	3,619	3,619	0.21
Mean - 2SD	2,608	-	-	-	0	-	0	-	2,361	2,361	0.30
Mean + 2SD	12,763	3,877	8	528	0	-	1	-	16,836	16,835	1.13

Table IXIV.C-3 Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	10,021	2,735	3	189	0	-	1	-	12,949	12,948	1
50th Percentile Run (based on shore cost)	6,949	1,456	4	238	0	-	1	-	8,648	8,647	1
95th Percentile Run (based on shore cost)	7,279	1,594	6	389	0	-	1	-	9,268	9,267	1
Mean	8,083	1,928	4	272	0	-	1	-	10,288	10,288	1
Std Dev (SD)	1,687	702	2	104	0	-	0	-	2,325	2,325	0
Mean - 2SD	4,709	524	1	64	0	-	0	-	5,638	5,638	0
Mean + 2SD	11,456	3,333	8	480	0	-	1	-	14,938	14,937	1

Table IXIV.C-4 Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	5,686	931	-	-	0	-	1	-	6,617	6,616	1
50th Percentile Run (based on shore cost)	6,510	1,274	3	218	0	-	1	-	8,007	8,006	1
95th Percentile Run (based on shore cost)	7,097	1,518	6	362	0	-	1	-	8,983	8,982	1
Mean	6,431	1,241	3	193	0	-	1	-	7,869	7,868	1
Std Dev (SD)	709	295	3	182	0	-	0	-	1,189	1,189	0
Mean - 2SD	5,013	651	-	-	0	-	0	-	5,490	5,490	0
Mean + 2SD	7,849	1,831	9	558	0	-	1	-	10,247	10,247	1

Table IXIV.C-5 Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	5,680	928	-	-	0	-	1	-	6,609	6,609	1
50th Percentile Run (based on shore cost)	5,356	793	2	102	0	-	1	-	6,254	6,254	1
95th Percentile Run (based on shore cost)	7,099	1,519	6	374	0	-	1	-	8,999	8,998	1
Mean	6,045	1,080	2	159	0	-	1	-	7,287	7,287	1
Std Dev (SD)	927	386	3	193	0	-	0	-	1,493	1,493	0
Mean - 2SD	4,191	309	-	-	0	-	0	-	4,302	4,302	0
Mean + 2SD	7,899	1,852	9	545	0	-	1	-	10,273	10,272	1

Table IXIV.C-6 Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	9,455	2,500	2	134	0	-	1	-	12,093	12,092	1
50th Percentile Run (based on shore cost)	5,427	823	2	152	0	-	1	-	6,405	6,404	1
95th Percentile Run (based on shore cost)	7,190	1,557	6	369	0	-	1	-	9,122	9,122	1
Mean	7,358	1,627	3	218	0	-	1	-	9,207	9,206	1
Std Dev (SD)	2,019	841	2	131	0	-	0	-	2,845	2,845	0
Mean - 2SD	3,319	-	-	-	0	-	0	-	3,517	3,517	0
Mean + 2SD	11,396	3,308	8	480	0	-	1	-	14,896	14,895	1

Table IXIV.C-7 Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	5,392	808	-	-	0	-	1	-	6,201	6,201	1
50th Percentile Run (based on shore cost)	4,850	583	1	70	0	-	0	-	5,505	5,504	0
95th Percentile Run (based on shore cost)	7,051	1,499	5	342	0	-	1	-	8,898	8,897	1
Mean	5,765	963	2	137	0	-	1	-	6,868	6,868	1
Std Dev (SD)	1,147	477	3	181	0	-	0	-	1,792	1,792	0
Mean - 2SD	3,471	9	-	-	0	-	0	-	3,284	3,283	0
Mean + 2SD	8,058	1,918	8	499	0	-	1	-	10,452	10,452	1

Table IXIV.C-8 Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and in situ burning: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	6,613	1,317	-	-	0	-	1	-	7,930	7,930	1
50th Percentile Run (based on shore cost)	5,161	712	2	120	0	-	1	-	5,995	5,995	1
95th Percentile Run (based on shore cost)	7,097	1,518	5	342	0	-	1	-	8,963	8,962	1
Mean	6,290	1,182	2	154	0	-	1	-	7,630	7,629	1
Std Dev (SD)	1,007	419	3	174	0	-	0	-	1,506	1,506	0
Mean - 2SD	4,276	344	-	-	0	-	0	-	4,617	4,616	0
Mean + 2SD	8,305	2,021	8	501	0	-	1	-	10,643	10,642	1

XIV.D. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates were calculated using the seasonal abundance for each of the spill dates included in the 3 runs. Note that the statistical data in the shaded cells are based only on 3 runs and so are highly uncertain.

Table XIV.D-1. Strait of Juan de Fuca – Alaskan North Slope Crude, no removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	0.0	0.0	0.0	0.3	979.5	4,565	5,545
50th Percentile Run (shore cost)	0.0	0.0	3.2	1.2	1041.9	2,396	3,442
95th Percentile Run (shore cost)	3944.9	9500.5	48.2	9.6	1616.2	1,683	16,803
Mean	1315.0	3166.8	17.1	3.7	1212.5	2,881	8,597
Std Dev (SD)	2277.6	5485.1	27.0	5.1	351.0	1,501	9,647
Mean - 2SD	0.0	0.0	0.0	0.0	510.6	-	511
Mean + 2SD	5870.1	14137.0	71.0	13.9	1914.5	5,883	27,890

Table XIV.D-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	-	-	-	-	904.2	-	904
50th Percentile Run (shore cost)	-	-	1.9	1.0	1,025.2	-	1,028
95th Percentile Run (shore cost)	2,759.1	6,692.1	35.2	7.2	1,450.8	1,360	12,304
Mean	2,137.9	5,169.5	26.9	5.5	1,329.5	198	8,867
Std Dev (SD)	2,672.4	6,371.0	30.5	5.8	404.0	355	9,838
Mean - 2SD	-	-	-	-	521.5	-	521
Mean + 2SD	7,482.7	17,911.4	87.9	17.0	2,137.4	907	28,544

Table XIV.D-3. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	0.0	0.0	0.0	0.0	935.7	-	936
50th Percentile Run (shore cost)	322.3	921.0	8.6	2.2	1110.8	-	2,365
95th Percentile Run (shore cost)	4394.7	10565.9	53.1	10.5	1679.0	1,424	18,128
Mean	1572.3	3829.0	20.6	4.2	1241.8	475	7,143
Std Dev (SD)	2449.6	5852.5	28.5	5.5	388.6	822	9,547
Mean - 2SD	0.0	0.0	0.0	0.0	464.7	-	465
Mean + 2SD	6471.5	15534.0	77.6	15.3	2019.0	2,120	26,237

Table XIV.D-4. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	0.0	0.0	0.0	0.0	926.9	-	927
50th Percentile Run (shore cost)	400.1	1105.4	9.4	2.4	1121.7	-	2,639
95th Percentile Run (shore cost)	2845.2	6896.0	36.2	7.3	1462.8	1,489	12,737
Mean	1081.8	2667.1	15.2	3.2	1170.5	496	5,434
Std Dev (SD)	1540.2	3703.8	18.8	3.7	271.3	860	6,398
Mean - 2SD	0.0	0.0	0.0	0.0	627.9	-	628
Mean + 2SD	4162.2	10074.7	52.7	10.7	1713.0	2,216	18,229

Table XIV.D-5. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	15631.4	37177.9	175.9	33.2	3246.5	-	56,265
50th Percentile Run (shore cost)	3469.5	8374.6	43.0	8.6	1549.9	-	13,446
95th Percentile Run (shore cost)	4071.0	9799.1	49.6	9.8	1633.8	1,392	16,955
Mean	7723.9	18450.5	89.5	17.2	2143.4	464	28,889
Std Dev (SD)	6854.7	16234.0	74.9	13.9	956.3	804	24,937
Mean - 2SD	0.0	0.0	0.0	0.0	230.9	-	231
Mean + 2SD	21433.3	50918.6	239.4	45.0	4055.9	2,072	78,764

Table XIV.D-6. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	16179.5	38476.1	181.9	34.3	3323.0	-	58,195
50th Percentile Run (shore cost)	3696.5	8912.3	45.5	9.1	1581.6	-	14,245
95th Percentile Run (shore cost)	4001.2	9634.0	48.8	9.7	1624.1	1,457	16,775
Mean	7959.1	19007.5	92.1	17.7	2176.2	486	29,738
Std Dev (SD)	7120.7	16864.2	77.8	14.4	993.4	841	25,912
Mean - 2SD	0.0	0.0	0.0	0.0	189.4	-	189
Mean + 2SD	22200.6	52735.8	247.8	46.5	4163.0	2,168	81,562

Table XIV.D-7. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	11470.3	27323.0	130.5	24.8	2666.0	-	41,615
50th Percentile Run (shore cost)	3622.6	8737.3	44.7	8.9	1571.3	-	13,985
95th Percentile Run (shore cost)	4233.6	10184.3	51.3	10.1	1656.5	1,424	17,560
Mean	6442.2	15414.9	75.5	14.6	1964.6	475	24,387
Std Dev (SD)	4365.2	10338.1	47.7	8.8	609.0	822	16,191
Mean - 2SD	0.0	0.0	0.0	0.0	746.7	-	747
Mean + 2SD	15172.5	36091.1	170.9	32.3	3182.5	2,120	56,769

Table XIV.D-8. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and in situ burning: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	0.0	0.0	0.0	0.0	907.0	-	907
50th Percentile Run (shore cost)	0.0	0.0	0.0	0.6	999.9	-	1,001
95th Percentile Run (shore cost)	2988.8	7236.1	37.7	7.6	1482.8	1,392	13,145
Mean	996.3	2412.0	12.6	2.8	1129.9	464	5,018
Std Dev (SD)	1725.6	4177.8	21.8	4.2	309.1	804	7,042
Mean - 2SD	0.0	0.0	0.0	0.0	511.7	-	512
Mean + 2SD	4447.4	10767.6	56.2	11.2	1748.2	2,072	19,102

XIV.E. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All weights are as wet weight; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

NRDA costs were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because impacts are not necessarily correlated with shore cost, the results for NRDA costs may not be in increasing order from 5th to 95th percentile run by shore cost.

Table XIV.E-1. Strait of Juan de Fuca – Alaskan North Slope Crude, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	-	3,944.9	1,315.0	-	5,870.1
Large pelagic fish	-	-	9,500.5	3,166.8	-	14,137.0
Demersal fish	-	3.2	48.2	17.1	-	71.0
Decapods	0.3	1.2	9.6	3.7	-	13.9
Molluscs	5,544	3,438	3,300	4,094	511	7,798
Birds:						
Waterfowl (# * kg each)	27,814	5,128	13,247	15,397	-	38,386
Seabirds (# * kg each)	11,786	5,461	7,098	8,115	1,549	14,681
Waders (# * kg each)	224	19	15	86	-	325
Shorebirds (# * kg each)	-	-	22	7	-	33
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	272	155	147	191	51	331
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	5,545	3,442	16,803	8,597	511	27,890
Subtotal birds	39,825	10,607	20,383	23,605	1,549	53,426
Subtotal other wildlife	272	155	147	191	51	331
Total all species	45,642	14,204	37,333	32,393	2,111	81,647

Table XIV.E-2. Strait of Juan de Fuca – Alaskan North Slope Crude, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	123	49	97	90	12	201
Saltmarsh Area (acres)	304	121	240	222	31	497
Saltmarsh Cost (millions of 2004$)	57.0	22.7	45.1	41.6	5.8	93.1
Eelgrass Area (m2)	77	31	61	56	8	126
Eelgrass Area (acres)	190	76	150	139	19	311
Eelgrass Cost (millions of 2004$)	22.7	9.0	17.9	16.5	2.3	37.1

Table XIV.E-3. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	-	2,759.1	2,137.9	-	7,482.7
Large pelagic fish	-	-	6,692.1	5,169.5	-	17,911.4
Demersal fish	-	1.9	35.2	26.9	-	87.9
Decapods	-	1.0	7.2	5.5	-	17.0
Molluscs	904	1,025	2,811	1,528	521	3,045
Birds:						
Waterfowl (# * kg each)	5,609	4,381	5,663	5,995	2,034	9,955
Seabirds (# * kg each)	1,962	1,137	1,998	2,221	-	4,884
Waders (# * kg each)	-	4	7	3	-	11
Shorebirds (# * kg each)	-	6	11	4	-	16
Raptors (# * kg each)	0	0	0	0	0	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	67	55	68	71	30	113
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	904	1,028	12,304	8,867	521	28,544
Subtotal birds	7,571	5,528	7,679	8,224	2,035	14,866
Subtotal other wildlife	67	55	68	71	30	113
Total all species	8,543	6,610	20,051	17,163	2,586	43,522

Table XIV.E-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	23	16	44	41	4	104
Saltmarsh Area (acres)	56	39	108	101	11	256
Saltmarsh Cost (millions of 2004$)	10.5	7.2	20.3	19.0	2.0	48.0
Eelgrass Area (m2)	14	10	27	26	3	65
Eelgrass Area (acres)	35	24	68	63	7	160
Eelgrass Cost (millions of 2004$)	4.2	2.9	8.1	7.6	0.8	19.1

Table XIV.E-5. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	322.3	4,394.7	1,572.3	-	6,471.5
Large pelagic fish	-	921.0	10,565.9	3,829.0	-	15,534.0
Demersal fish	-	8.6	53.1	20.6	-	77.6
Decapods	-	2.2	10.5	4.2	-	15.3
Molluscs	936	1,111	3,103	1,717	465	4,139
Birds:						
Waterfowl (# * kg each)	8,618	2,779	5,677	5,692	-	11,530
Seabirds (# * kg each)	2,681	2,039	2,008	2,242	1,483	3,002
Waders (# * kg each)	4	5	8	6	1	10
Shorebirds (# * kg each)	-	-	12	4	-	17
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	90	89	68	83	58	108
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	936	2,365	18,128	7,143	465	26,237
Subtotal birds	11,303	4,823	7,705	7,944	1,484	14,560
Subtotal other wildlife	90	89	68	83	58	108
Total all species	12,329	7,278	25,901	15,169	2,007	40,904

Table XIV.E-6. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	32	24	56	37	12	87
Saltmarsh Area (acres)	79	59	138	92	31	214
Saltmarsh Cost (millions of 2004$)	14.9	11.1	25.9	17.3	5.8	40.2
Eelgrass Area (m2)	20	15	35	23	8	54
Eelgrass Area (acres)	50	37	86	58	19	134
Eelgrass Cost (millions of 2004$)	5.9	4.4	10.3	6.9	2.3	16.0

Table XIV.E-7. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	400.1	2,845.2	1,081.8	-	4,162.2
Large pelagic fish	-	1,105.4	6,896.0	2,667.1	-	10,074.7
Demersal fish	-	9.4	36.2	15.2	-	52.7
Decapods	-	2.4	7.3	3.2	-	10.7
Molluscs	927	1,122	2,952	1,667	628	3,929
Birds:						
Waterfowl (# * kg each)	4,890	2,604	5,536	4,343	1,263	7,424
Seabirds (# * kg each)	912	1,783	1,913	1,536	447	2,625
Waders (# * kg each)	-	4	7	4	-	11
Shorebirds (# * kg each)	-	-	11	4	-	16
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	55	85	67	69	39	98
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	927	2,639	12,737	5,434	628	18,229
Subtotal birds	5,801	4,392	7,467	5,887	1,710	10,076
Subtotal other wildlife	55	85	67	69	39	98
Total all species	6,784	7,116	20,270	11,390	2,377	28,404

Table XIV.E-8. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	15	23	44	27	7	62
Saltmarsh Area (acres)	37	56	108	67	16	154
Saltmarsh Cost (millions of 2004$)	6.9	10.4	20.3	12.5	3.1	28.8
Eelgrass Area (m2)	9	14	27	17	4	39
Eelgrass Area (acres)	23	35	68	42	10	96
Eelgrass Cost (millions of 2004$)	2.7	4.2	8.1	5.0	1.2	11.5

Table XIV.E-9. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	15,631.4	3,469.5	4,071.0	7,723.9	-	21,433.3
Large pelagic fish	37,177.9	8,374.6	9,799.1	18,450.5	-	50,918.6
Demersal fish	175.9	43.0	49.6	89.5	-	239.4
Decapods	33.2	8.6	9.8	17.2	-	45.0
Molluscs	3,247	1,550	3,026	2,607	231	6,127
Birds:						
Waterfowl (# * kg each)	4,885	2,142	5,537	4,188	585	7,791
Seabirds (# * kg each)	910	1,111	1,914	1,311	249	2,374
Waders (# * kg each)	-	2	8	3	-	11
Shorebirds (# * kg each)	-	-	11	4	-	17
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	55	72	67	65	48	81
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	56,265	13,446	16,955	28,889	231	78,764
Subtotal birds	5,795	3,255	7,470	5,507	834	10,193
Subtotal other wildlife	55	72	67	65	48	81
Total all species	62,115	16,773	24,492	34,460	1,113	89,038

Table XIV.E-10. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	129	39	53	74	5	186
Saltmarsh Area (acres)	319	98	130	182	13	459
Saltmarsh Cost (millions of 2004$)	59.8	18.3	24.4	34.2	2.4	86.0
Eelgrass Area (m2)	81	25	33	46	3	116
Eelgrass Area (acres)	199	61	81	114	8	287
Eelgrass Cost (millions of 2004$)	23.8	7.3	9.7	13.6	0.9	34.2

Table XIV.E-11. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	16,179.5	3,696.5	4,001.2	7,959.1	-	22,200.6
Large pelagic fish	38,476.1	8,912.3	9,634.0	19,007.5	-	52,735.8
Demersal fish	181.9	45.5	48.8	92.1	-	247.8
Decapods	34.3	9.1	9.7	17.7	-	46.5
Molluscs	3,323	1,582	3,081	2,662	189	6,331
Birds:						
Waterfowl (# * kg each)	8,132	2,171	5,608	5,304	-	11,288
Seabirds (# * kg each)	2,450	1,152	1,962	1,855	544	3,165
Waders (# * kg each)	3	3	8	4	-	10
Shorebirds (# * kg each)	-	-	11	4	-	16
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	86	72	67	75	56	94
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	58,195	14,245	16,775	29,738	189	81,562
Subtotal birds	10,584	3,326	7,588	7,166	544	14,479
Subtotal other wildlife	86	72	67	75	56	94
Total all species	68,865	17,644	24,430	36,980	789	96,135

Table XIV.E-12. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	148	41	53	81	7	201
Saltmarsh Area (acres)	366	102	130	200	17	497
Saltmarsh Cost (millions of 2004$)	68.6	19.2	24.4	37.4	3.1	93.1
Eelgrass Area (m2)	93	26	33	50	4	126
Eelgrass Area (acres)	229	64	81	125	10	310
Eelgrass Cost (millions of 2004$)	27.3	7.6	9.7	14.9	1.2	37.1

Table XIV.E-13. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	11,470.3	3,622.6	4,233.6	6,442.2	-	15,172.5
Large pelagic fish	27,323.0	8,737.3	10,184.3	15,414.9	-	36,091.1
Demersal fish	130.5	44.7	51.3	75.5	-	170.9
Decapods	24.8	8.9	10.1	14.6	-	32.3
Molluscs	2,666	1,571	3,081	2,439	747	5,302
Birds:						
Waterfowl (# * kg each)	4,637	1,940	5,500	4,026	312	7,740
Seabirds (# * kg each)	792	816	1,889	1,166	-	2,418
Waders (# * kg each)	-	1	7	3	-	10
Shorebirds (# * kg each)	-	-	10	3	-	15
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	53	66	66	62	46	77
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	41,615	13,985	17,560	24,387	747	56,769
Subtotal birds	5,430	2,757	7,406	5,198	312	10,184
Subtotal other wildlife	53	66	66	62	46	77
Total all species	47,097	16,808	25,033	29,646	1,105	67,030

Table XIV.E-14. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	98	38	54	63	3	140
Saltmarsh Area (acres)	241	94	133	156	8	346
Saltmarsh Cost (millions of 2004$)	45.2	17.7	24.9	29.3	1.5	64.8
Eelgrass Area (m2)	61	24	34	39	2	87
Eelgrass Area (acres)	151	59	83	98	5	216
Eelgrass Cost (millions of 2004$)	18.0	7.0	9.9	11.7	0.6	25.8

Table XIV.E-15. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and in situ burning: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	-	2,988.8	996.3	-	4,447.4
Large pelagic fish	-	-	7,236.1	2,412.0	-	10,767.6
Demersal fish	-	-	37.7	12.6	-	56.2
Decapods	-	0.6	7.6	2.8	-	11.2
Molluscs	907	1,000	2,875	1,594	512	3,820
Birds:						
Waterfowl (# * kg each)	5,687	2,064	5,536	4,429	331	8,528
Seabirds (# * kg each)	1,290	997	1,913	1,400	465	2,335
Waders (# * kg each)	-	2	7	3	-	10
Shorebirds (# * kg each)	-	-	10	3	-	15
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	63	70	67	66	60	73
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	907	1,001	13,145	5,018	512	19,102
Subtotal birds	6,977	3,064	7,466	5,836	796	10,888
Subtotal other wildlife	63	70	67	66	60	73
Total all species	7,947	4,134	20,678	10,920	1,367	30,064

Table XIV.E-16. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and in situ burning: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	19	13	45	25	7	62
Saltmarsh Area (acres)	46	32	111	63	17	154
Saltmarsh Cost (millions of 2004$)	8.6	5.9	20.8	11.8	3.2	28.9
Eelgrass Area (m2)	12	8	28	16	4	39
Eelgrass Area (acres)	29	20	69	39	11	96
Eelgrass Cost (millions of 2004$)	3.4	2.4	8.3	4.7	1.3	11.5

XIV.F. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

The Washington Compensation Schedule was applied to the model results for the hypothetical spills simulated. The methods are described in Section 6.2 of Volume I. Note that the Compensation Schedule is designed to be a simplified procedure for small spills. Thus, for spills the size of those considered here, the OPA procedures using restoration costs (listed in section XIV.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table XIV.F-1. Strait of Juan de Fuca – Alaskan North Slope Crude, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	22.688	22.688	22.688	22.688	22.688	22.688
% Removed by 24 hours	-	-	-	-	-	-
Compensation (millions $)	61.9	61.9	61.9	61.9	61.9	61.9

Table XIV.F-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	20.788	20.788	21.026	19.720	22.332
% Removed by 24 hours	6.9	17.9	7.8	9.3	-	22.4
Compensation (millions $)	52.8	46.6	52.3	52.0	48.7	55.4

Table XIV.F-3. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	20.788	20.788	20.788	20.788	20.788
% Removed by 24 hours	0.80	6.41	3.61	3.61	-	9.22
Compensation (millions $)	56.3	53.1	54.7	54.7	54.7	54.7

Table XIV.F-4. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	20.788	20.788	20.788	20.788	20.788
% Removed by 24 hours	21.5	15.2	17.1	17.9	11.4	24.5
Compensation (millions $)	44.5	48.1	47.1	46.6	46.6	46.6

Table XIV.F-5. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	20.788	20.788	20.818	16.414	25.221
% Removed by 24 hours	6.9	17.9	7.8	9.3	-	22.3
Compensation (millions $)	52.8	46.6	52.3	51.5	40.3	62.8

Table XIV.F-6. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	20.788	20.788	20.788	20.788	20.788
% Removed by 24 hours	0.8	9.6	3.5	4.6	-	13.7
Compensation (millions $)	56.3	51.3	54.8	54.1	54.1	54.1

Table XIV.F-7. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	20.788	20.788	20.788	20.788	20.788
% Removed by 24 hours	21.5	22.5	16.5	20.2	13.7	26.6
Compensation (millions $)	44.5	44.0	47.4	45.3	45.3	45.3

Table XIV.F-8. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and in situ burning: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	20.788	20.788	20.788	20.788	20.788
% Removed by 24 hours	8.1	19.3	7.8	11.7	-	24.8
Compensation (millions $)	52.2	45.8	52.3	50.1	50.1	50.1

Draft Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XV: Model Inputs for San Juan Islands – Alaskan North Slope Crude

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XV.A. INTRODUCTION

This appendix contains model input data (in maps, figures and tables) for the modeled locations and the sources for that information. The approach and sources applicable to all modeled locations are described in Volume I, Section 3 of this technical report. Specifics to this model location are below. Thus, the reader should refer to Volume I, Section 3 for background and the context within which these data are used.

XV.B. GEOGRAPHICAL DATA

Geographic data for the modeled location are presented in this section. The sources for these data are described in Volume I, Section 3. Maps are also presented below showing areas where mechanical removal, dispersant application (as applicable), and in situ burning (ISB, as applicable) were assumed to occur in the model simulations. The assumptions for the response scenarios are in Volume I, Section 3.

XV.B.1. Maps of the Vicinity of the Modeled Spill Locations

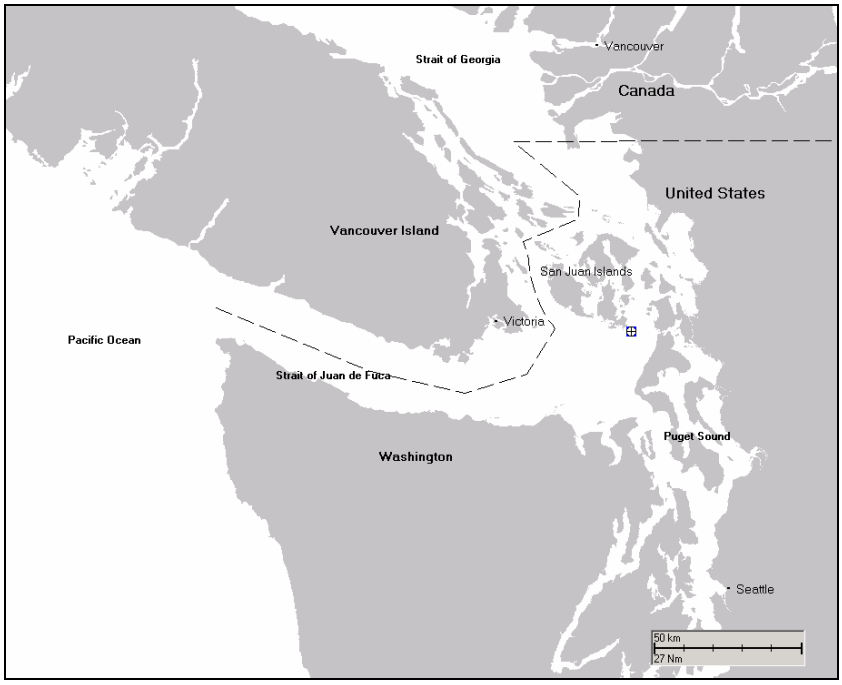

Figure XV.B.1-1 Map of the vicinity of the potential spill locations.

XV.B.2. Gridded Habitat Mapping

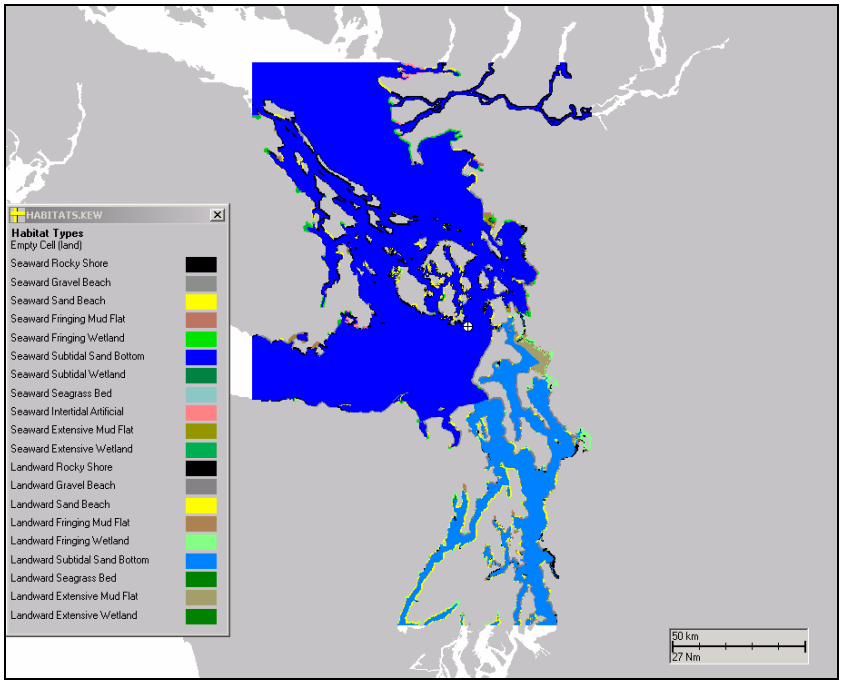

Figure XV.B.2-1 Habitat grid used for modeling the potential spills.

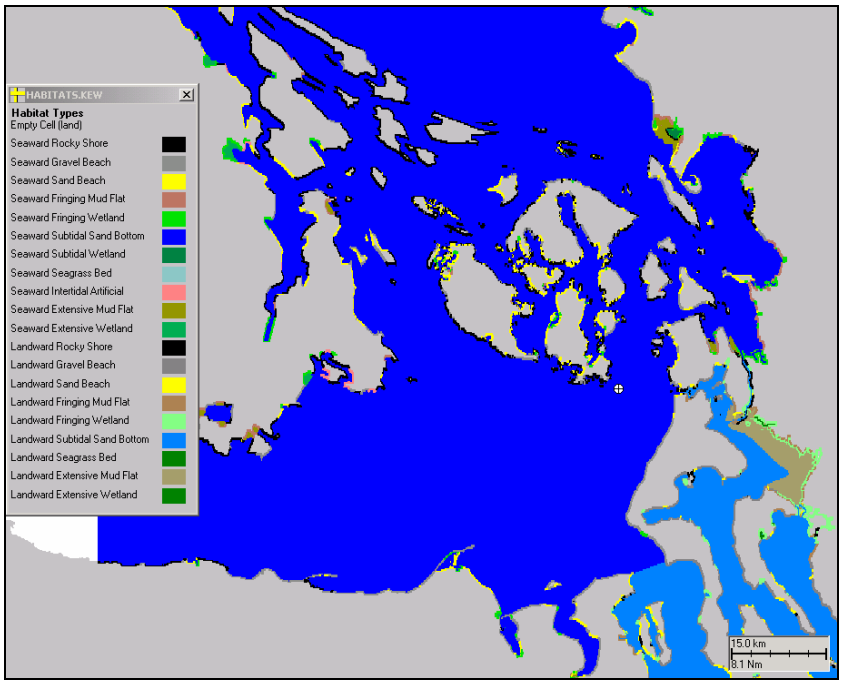

Figure XV.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XV.B-3. Gridded Depth Data

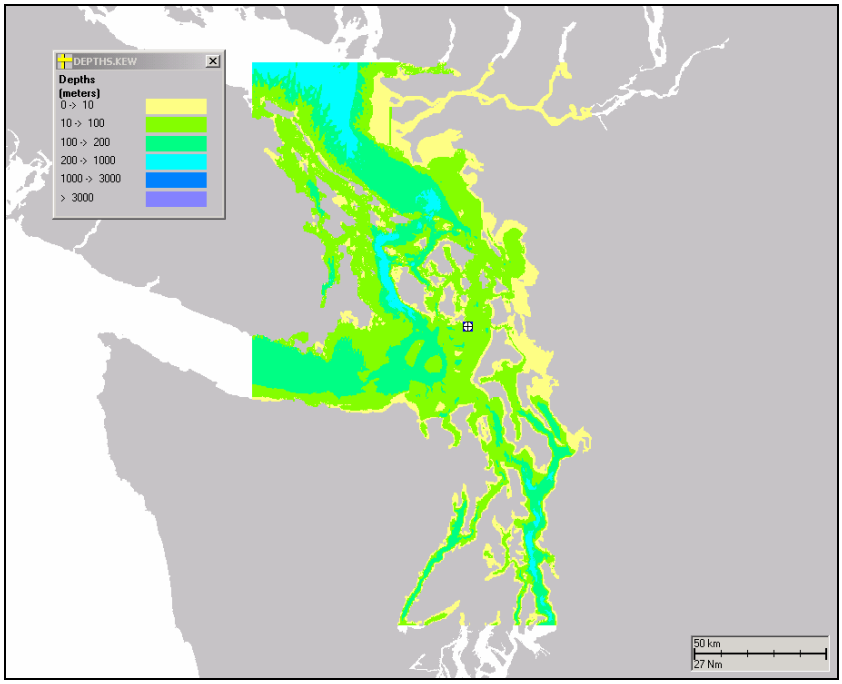

Figure XV.B.3-1 Depth grid used for modeling the potential spills.

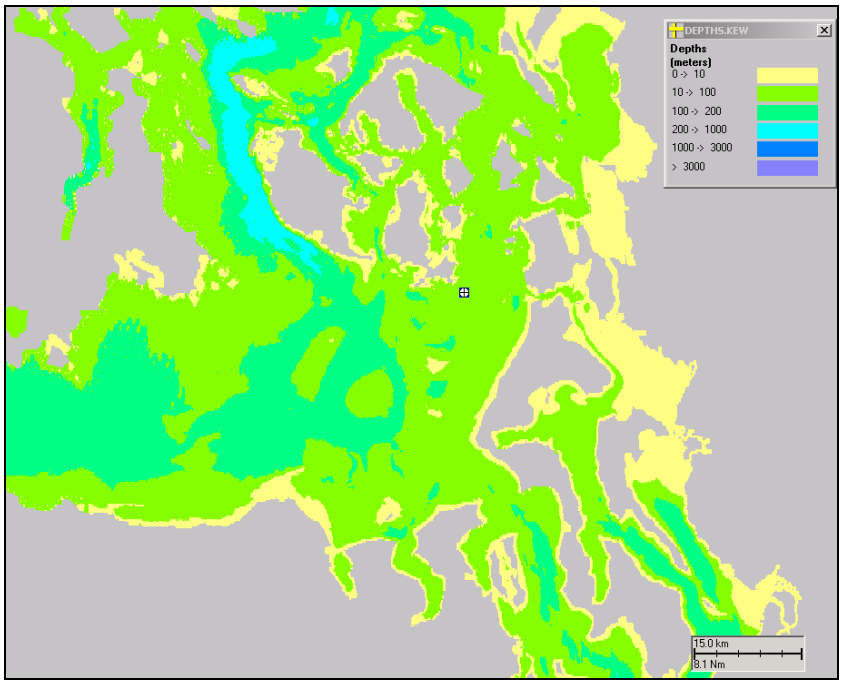

Figure XV.B.3-2 Depth grid used for modeling the potential spills (closer view).

XV.B-4. Areas Where Response Actions Assumed

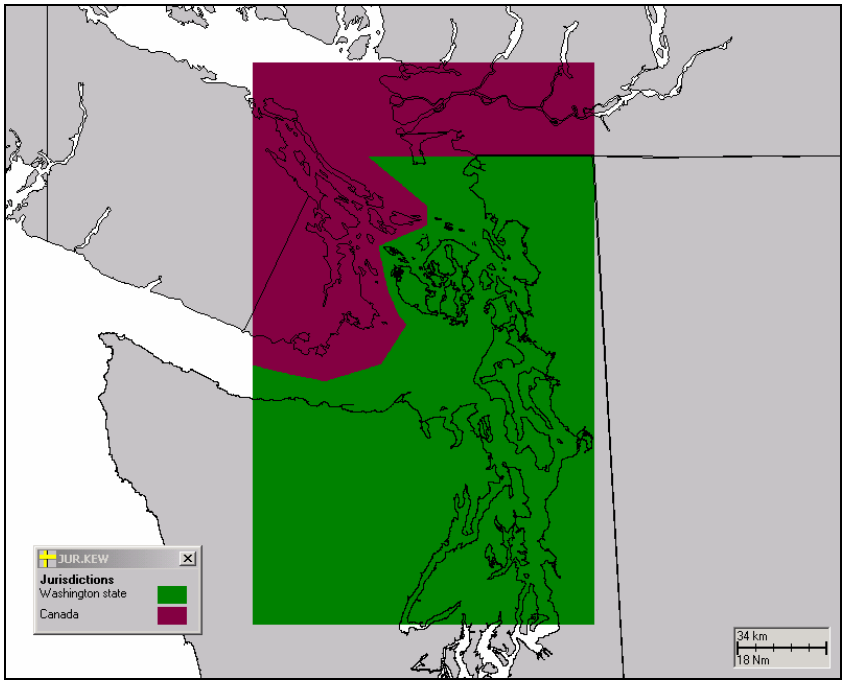

Figure XV.B.4-1 Jurisdictions in the area of the potential spills.

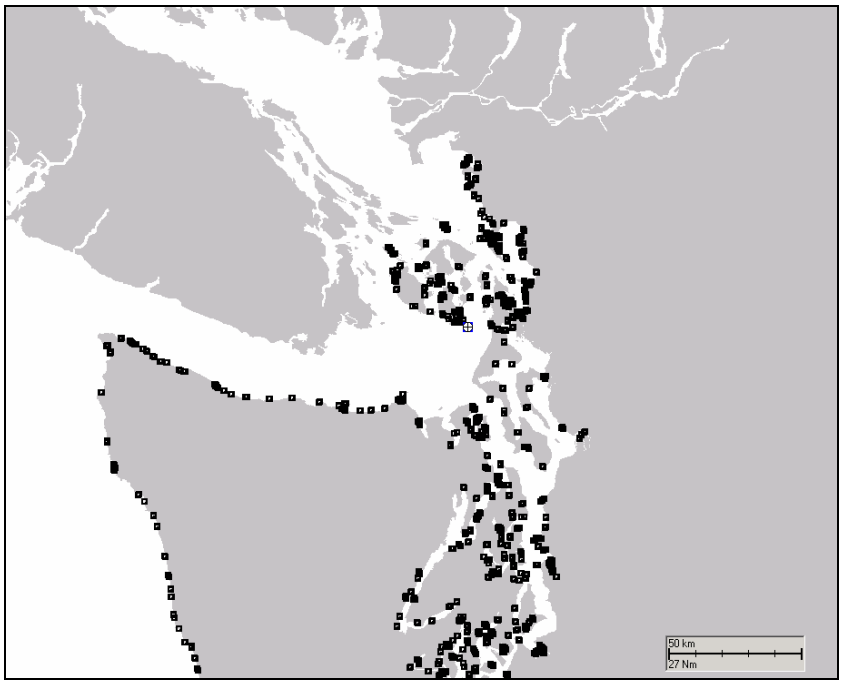

Figure XV.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

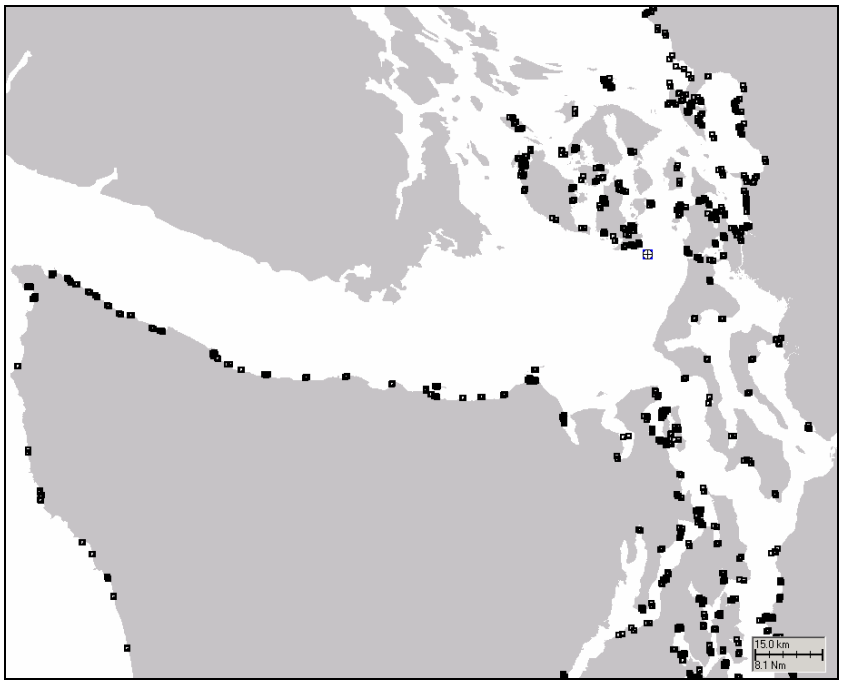

Figure XV.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

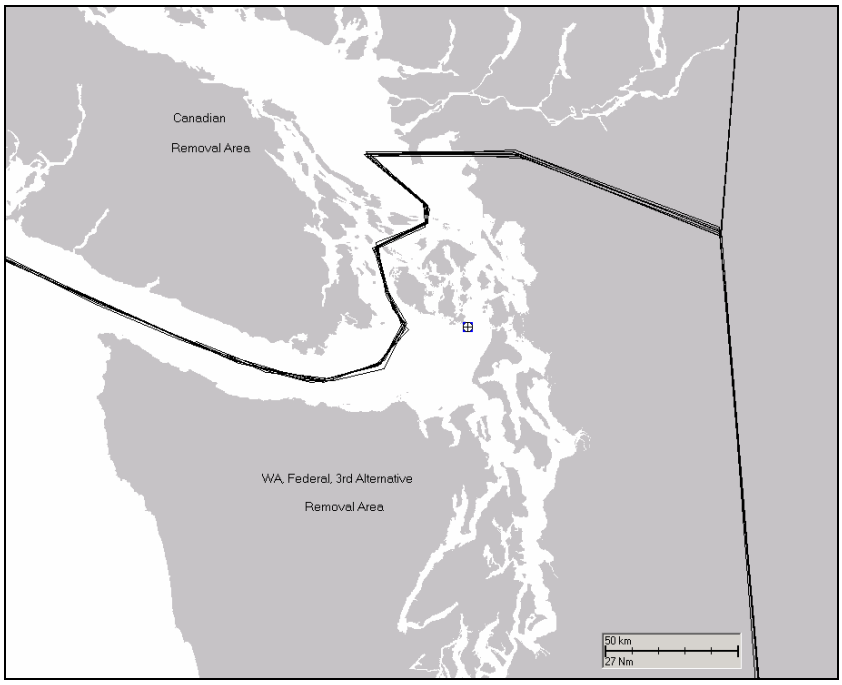

Figure XV.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

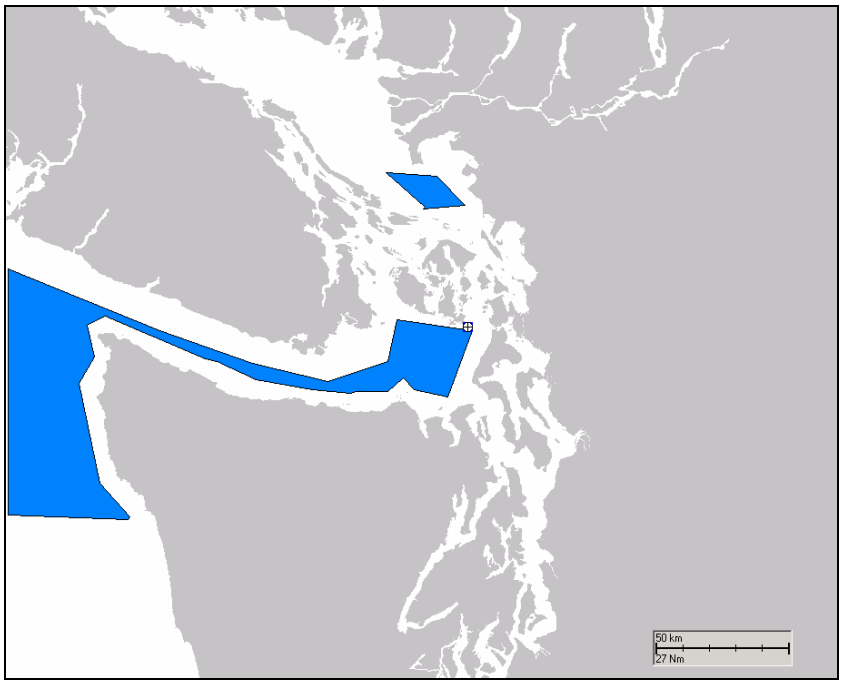

Figure XV.B.4-5 Areas where dispersant application was assumed to occur in modeling the potential spills.

XV.C. CURRENT DATA

XV.C.1. Basis of Current Data

Currents were based on hydrodynamic model data from D.O. Hodgins (1998; Seaconsult Marine Research Ltd, 8805 Osler Street, Vancouver V6P 4G1, Canada), who simulated currents in the Strait of Georgia. The surface currents from Hodgins' three-dimensional model outputs were formatted for use in SIMAP. The tidal forcing functions applied were the 9 harmonic constituents (M_2, S_2, N_2, K_2, MF, Q_1, K_1, O_1 and P_1).

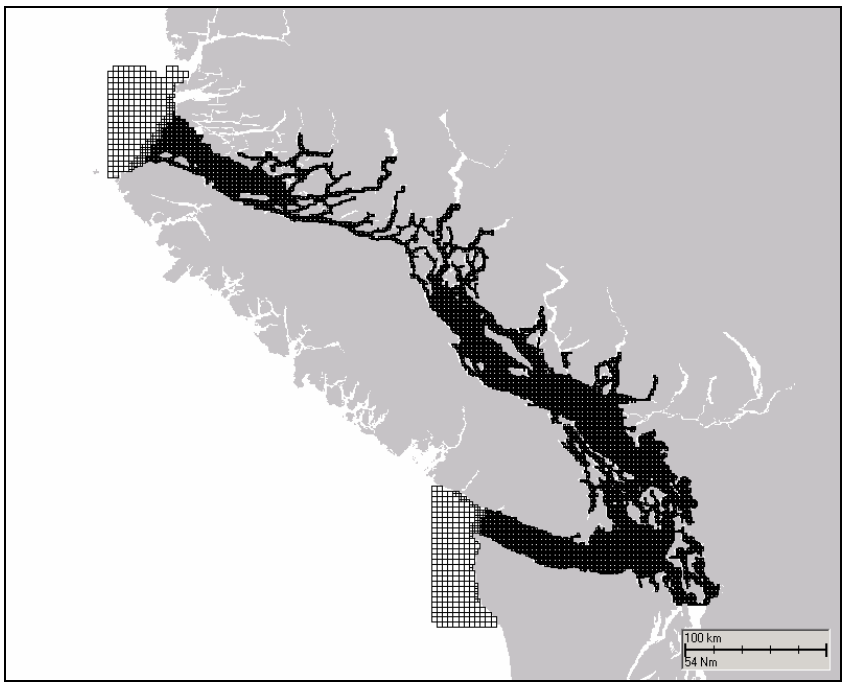

Figure XV.C.1-1 Grid used for the hydrodynamic model-generated current data.

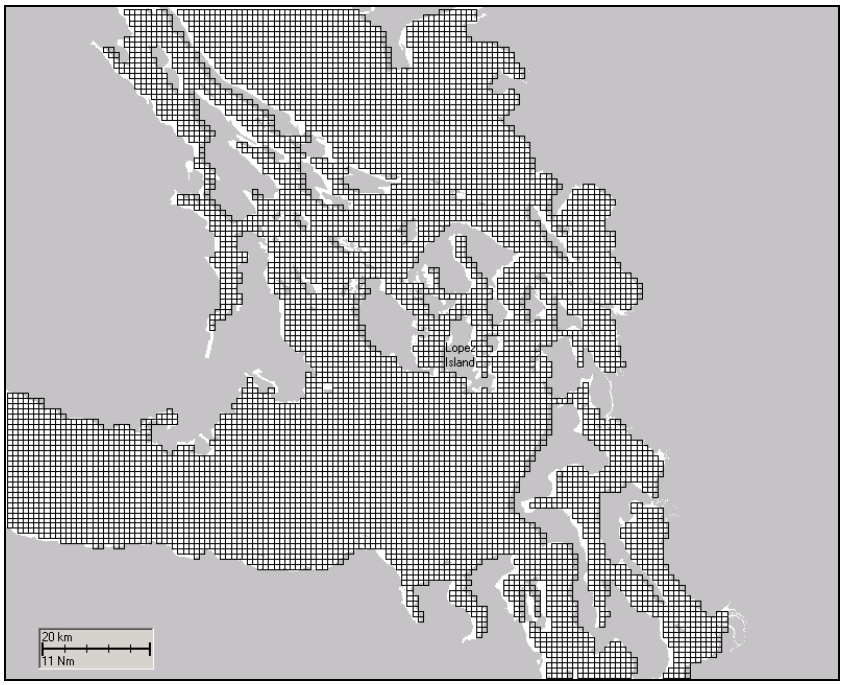

Figure XV.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island).

XV.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations

The figures below show the maximum flood and ebb of the M_2 and K_1 component. Note that 0.5 m/sec = 1 knot.

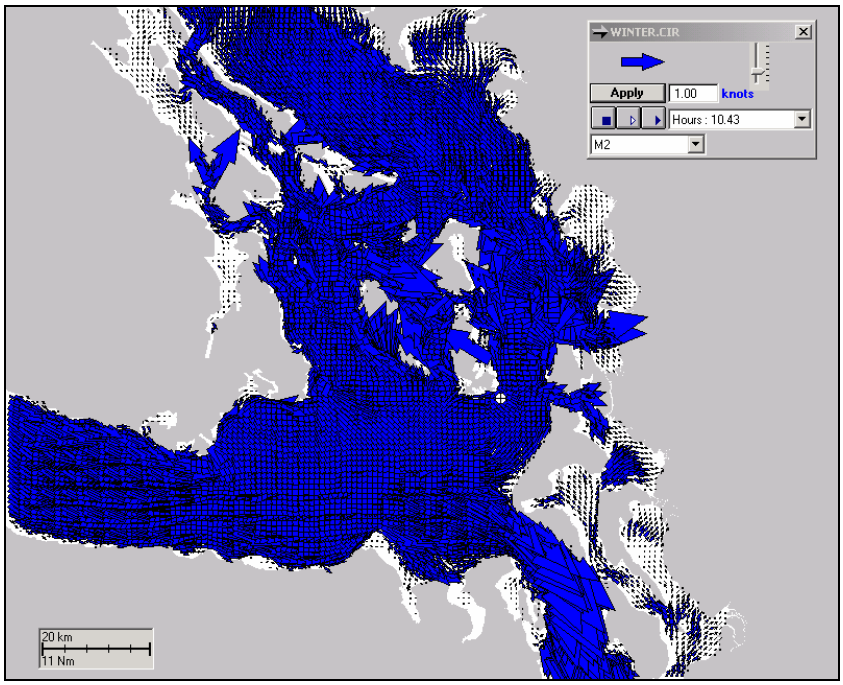

Figure XV.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Lopez Island.

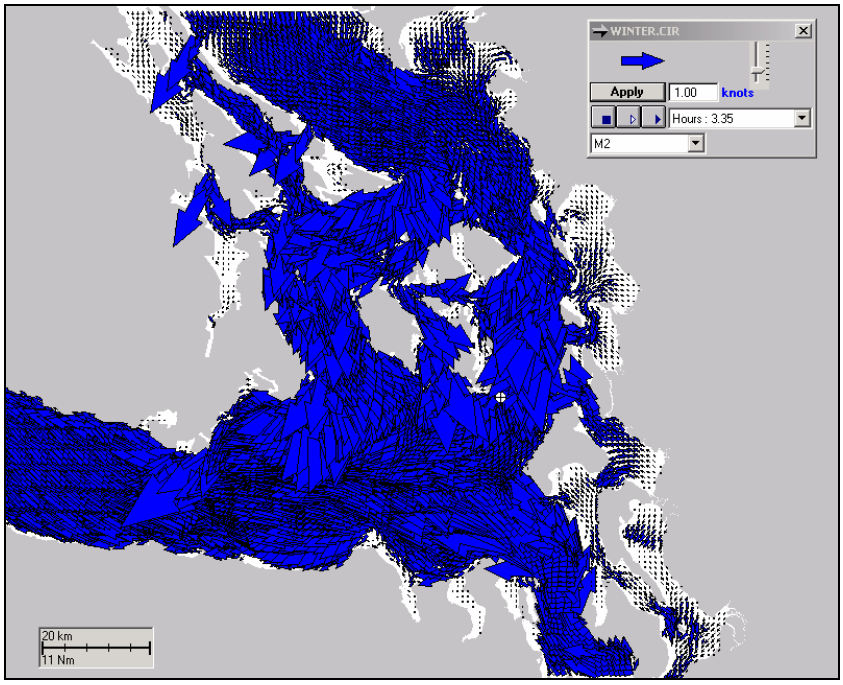

Figure XV.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Lopez Island.

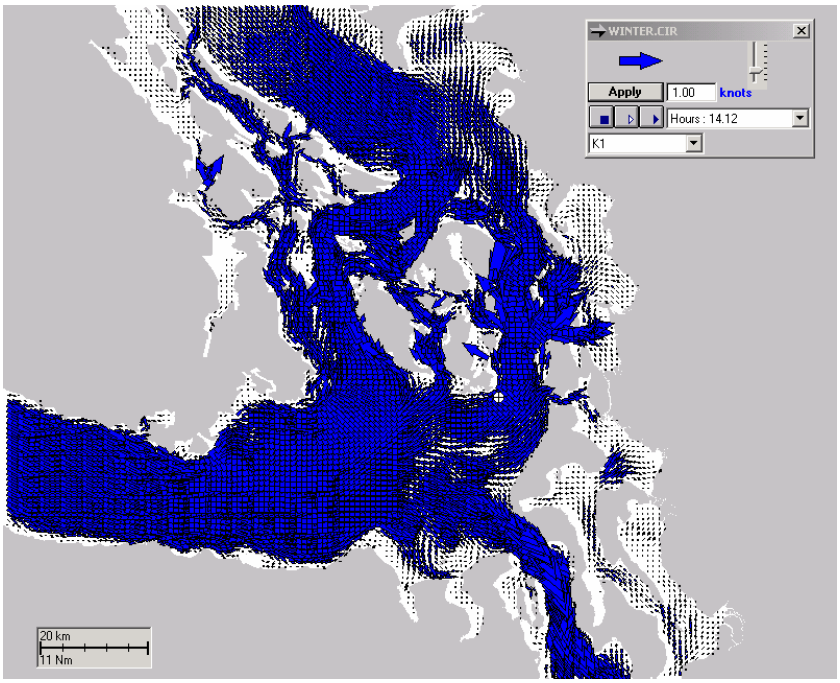

Figure XV.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Lopez Island.

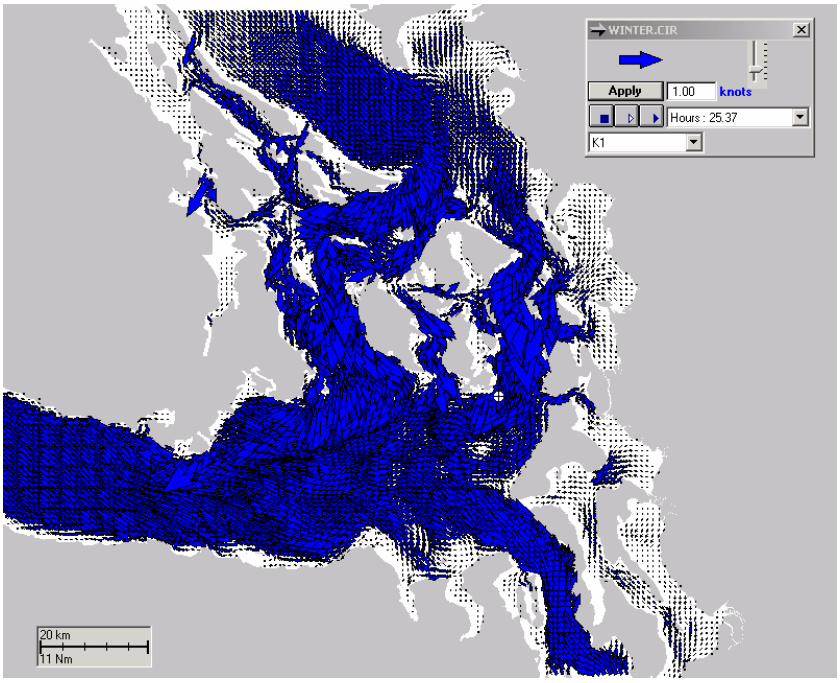

Figure XV.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Lopez Island.

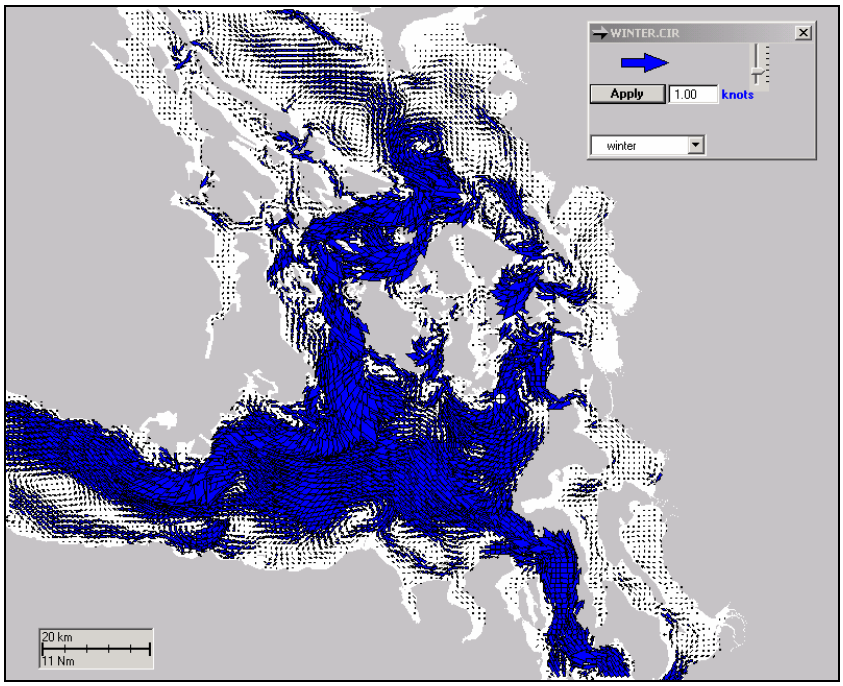

Figure XV.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction.

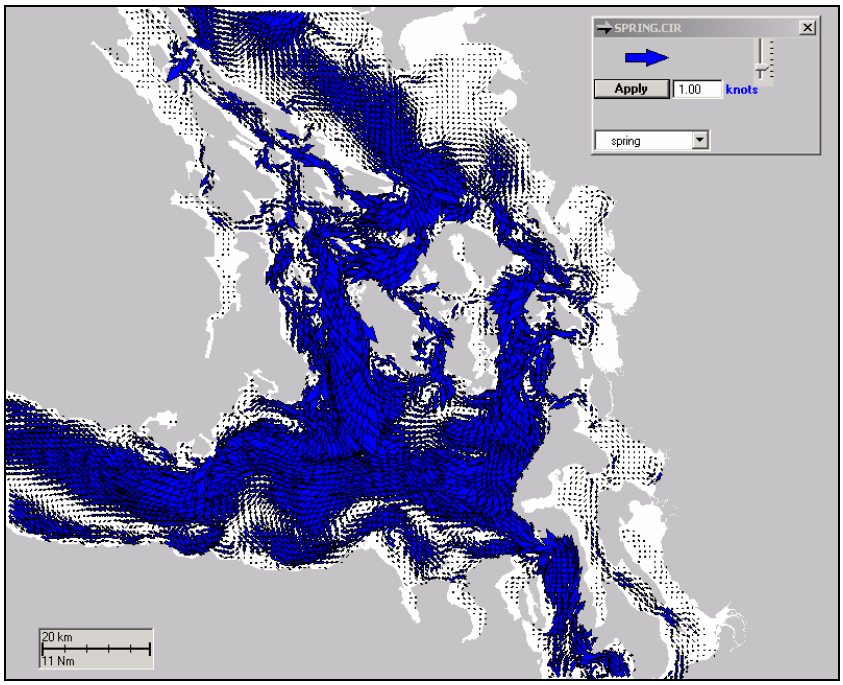

Figure XV.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction.

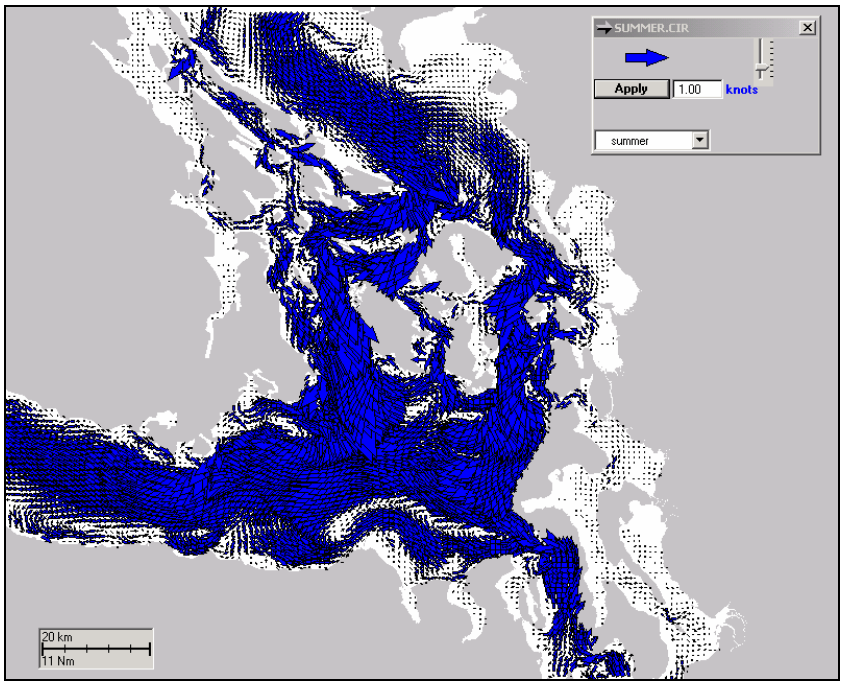

Figure XV.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.

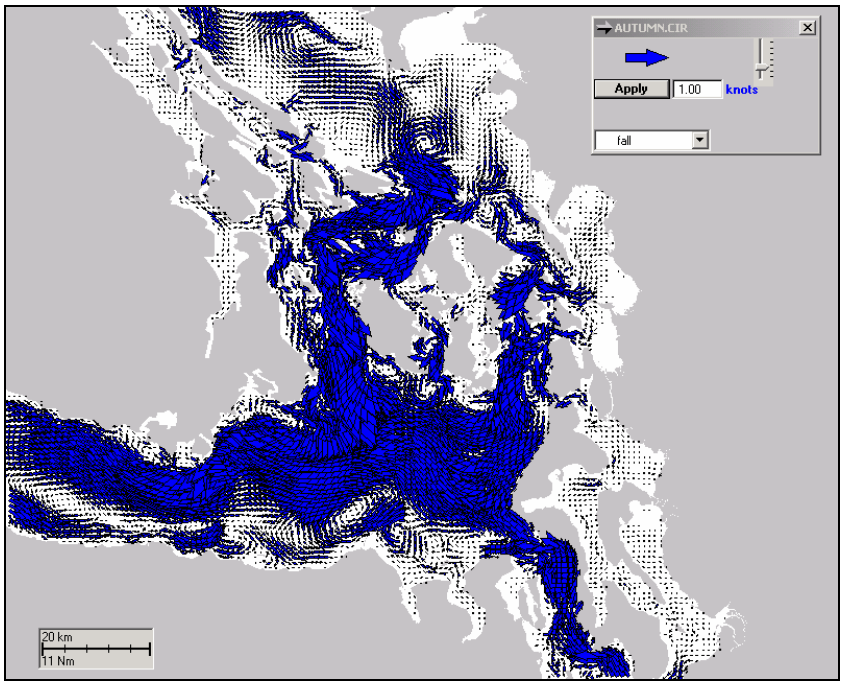

Figure XV.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction.

XV.D: OIL PROPERTIES

Table XV.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.8761	Wang et al. (1999)
Viscosity @ 25 deg. C (cp)	16	Wang et al. (1999)
Surface Tension (dyne/cm)	27	Wang et al. (1999)
Pour Point (deg. C)	-54	Wang et al. (1999)
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.030662	Wang et al. (1999)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.010372	A.D. Little (1996)
Fraction 2-ring aromatics (included in PAHs above)	0.00375	A.D. Little (1996)
Fraction 3-ring aromatics (included in PAHs above)	0.006622	A.D. Little (1996)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.189338	Wang et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.13325	Wang et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.200378	Wang et al. (1999)[1]
Minimum Oil Thickness (m)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	70	Wang et al. (1999)[2]; NOAA (2000)[2]
Mousse Water Content as Spilled (%)	0	-
Water content of fuel (not in mousse, %)	0	-
Degradation Rate (/day), Surface & Shore	0.01	National Research Council (1985)
Degradation Rate (/day), Hydrocarbons in Water	0.01	National Research Council (1985)
Degradation Rate (/day), Oil in Sediment	0.001	Haines and Atlas (1982)
Degradation Rate (/day), Aromatics in Water	0.01	French et al. (1996b)
Degradation Rate (/day), Aromatics in Sediment	0.001	French et al. (1996b)

[1] – Wang et al. (1999) provided total hydrocarbon data. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.
[2] – Mid-value used.

Table XV.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil.

Aromatic	Log(K_{ow})*	Concentration (mg/kg)
benzene	2.13	0.0
Toluene	2.69	0.0
Ethylbenzene	3.13	0.0
o-Xylene	3.15	0.0
p-Xylene	3.18	0.0
m-Xylene	3.2	0.0
Xylenes	3.18	0.0
styrene	3.05	0.0
methylstyrenes	3.35	0.0
1,2,3-Trimethylbenzene	3.55	0.0
1,2,4-Trimethylbenzene	3.6	0.0
1,3,4-Trimethylbenzene	3.6	0.0
1,3,5-Trimethylbenzene	3.58	0.0
Trimethylbenzenes	3.58	0.0
n-propylbenzene	3.69	0.0
iso-propylbenzene	3.63	0.0
ethyl-methylbenzenes	3.63	0.0
iso-propyl-4-methylbenzene	4.10	0.0
butylbenzenes	4.12	0.0
tetramethylbenzenes	4.01	0.0
tetralin	3.83	0.0
diphenylmethane	4.14	0.0
naphthalene	3.37	650
C1-naphthalenes	3.87	1,300
C2-naphthalenes	4.37	1,800
C3-naphthalenes	5.00	1,400
C4-naphthalenes	5.55	850
biphenyls	3.9	180
acenaphthylene	4.07	0.0
acenaphthene	3.92	0.0
dibenzofuran	4.31	0.0
Fluorene	4.18	82
C1-fluorenes	4.97	220
C2-fluorenes	5.20	260
C3-fluorenes	5.50	280

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

Table XV.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	200
C1-dibenzothiophene	4.86	360
C2-dibenzothiophene	5.50	540
C3-dibenzothiophene	5.73	460
phenanthrene	4.57	230
anthracene	4.54	0.0
C1-phenanthrenes/anthracenes	5.14	430
C2-phenanthrenes/anthracenes	5.25	490
C3-phenanthrenes/anthracenes	6.00	380
C4-phenanthrenes/anthracenes	6.51	260
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total log(K_{ow})$\leq$5.6	-	9,272

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

XV.E: INPUTS TO THE SIMAP PHYSICAL FATES MODEL

This section summarizes the model input data for the scenarios run and the sources for that information. The approach and sources applicable to all modeled locations are described in Volume I, Section 3 of this technical report. Specifics to this model location are below. Thus, the reader should refer to Volume I, Section 3 for background and the context within which these data are used.

The model grid and cell size were set to provide the maximum resolution (minimum cell size) possible within the memory constraints of the model, while also providing sufficient geographic coverage to encompass the maximum extent of oiling possible for the scenario. Test runs (randomizing weather conditions) were made to estimate the maximum extent of surface oiling and the grid size was set to cover that area.

Table XV.E-1. Inputs to the Fates Model for Stochastic Scenarios

Name	Description	Units	Source(s) of Information	Value(s)
Spill Site	Location of the spill site	-	Washington DOE	Rosario Strait/Georgia Strait from the south end of Lopez Island to off Cherry Point
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure XV.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure XV.E-1)
Depth of release	Depth below the water surface of the release or 0 for surface release	m	Washington DOE	0 m
Start time and date	Randomized over selected months of the year	Date, hr,min	(randomized)	Jan-Dec
Spill duration	Hours over which the release occurs	Hours	(assumed)	4 hours
Total spill amount	Total volume (or weight) released (maximum if range)	bbl	Washington DOE	65,000 bbl
Model time step	Time step used for model calculations	Hours	-	0.25
Model duration	Length of each model simulation	Days	-	14 days

Table XV.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	320
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table XV.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Salinity	Surface water salinity	ppt	French et al. (1996b) province 51	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XV.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XV.E-4)
Air Temperature	Air water temperature at water surface	Degrees C	(assume = water temperature)	(= water temperature)
Fetch	Fetch = distance to land to N, S, E, W (if landfall not in model domain)	km	Chart	(calculated from model grid)
Wind drift speed	Speed oil moves down wind relative to wind	% of wind speed	Youssef (1993); Youssef and Spaulding (1993)	(model calculated)
Wind drift angle	Angle to right of wind (in northern hemisphere) that oil drifts	Deg. to right of down wind	Youssef (1993); Youssef and Spaulding (1993, 1994)	(model calculated)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y	m^2/sec	French et al. (1996, 1999a) based on Okubo (1971)	1 m^2/sec (estuaries and low energy coastal areas)
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z	m^2/sec	French et al. (1996, 1999) based on Okubo (1971)	0.0001 m^2/sec
Suspended sediment concentration	Average suspended sediment concentration during spill period	mg/l	French et al. (1996b)	10 mg/l
Suspended sediment settling rate	Net settling rate for suspended sediments	m/day	French et al. (1996b)	1 m/day

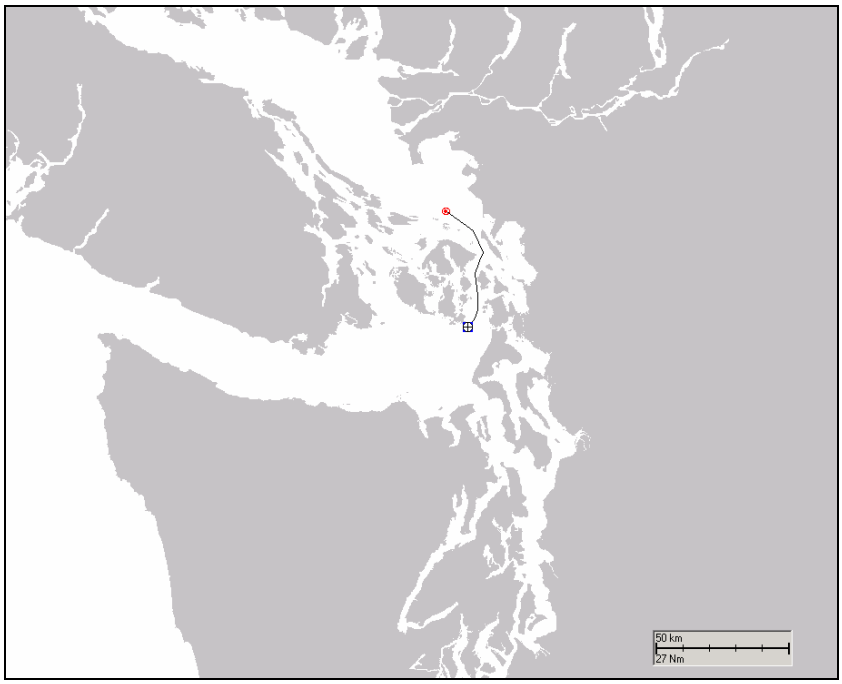

Figure XV.E-1 Varied range of spill site, Rosario Strait/Georgia Strait from the south end of Lopez Island to off Cherry Point.

Table XV.E-2. Time, date and location inputs for each of the 100 stochastic runs.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	2002	10	25	3	48.79085	122.8576
2	1992	5	12	8	48.63506	122.7353
3	1993	10	23	20	48.54226	122.7459
4	1999	3	7	5	48.61182	122.7485
5	1993	11	18	11	48.81049	122.8989
6	1998	11	21	3	48.51369	122.7412
7	1998	5	29	20	48.77623	122.8268
8	1996	6	15	9	48.80529	122.888
9	1995	5	31	18	48.41553	122.7824
10	2000	12	5	17	48.58387	122.7532
11	1999	4	23	14	48.48296	122.738
12	2003	8	3	10	48.44713	122.7527
13	2003	12	15	9	48.43967	122.759
14	1997	1	9	7	48.54966	122.7472
15	1997	1	12	14	48.54472	122.7463
16	2001	11	13	6	48.66917	122.7128
17	2002	8	28	23	48.7191	122.746
18	2002	1	21	20	48.43344	122.765
19	1996	11	4	22	48.5928	122.7548
20	1999	12	18	14	48.63166	122.7372
21	1994	6	20	10	48.5304	122.7438
22	1992	10	31	6	48.63742	122.734
23	1994	3	12	7	48.76853	122.8106
24	2001	11	5	14	48.43426	122.7642
25	2000	10	20	22	48.52842	122.7434
26	1995	11	9	1	48.77577	122.8259
27	2001	7	11	4	48.41615	122.7818
28	1993	5	26	4	48.73642	122.7575
29	1992	6	17	18	48.80195	122.881
30	1993	2	7	18	48.75351	122.779
31	2002	2	20	10	48.51136	122.7409
32	1993	5	23	17	48.72731	122.7514
33	1997	1	6	21	48.64153	122.7317
34	1995	3	28	12	48.66311	122.7169
35	1992	8	8	18	48.61361	122.7475
36	1993	8	21	16	48.50145	122.7399
37	1994	3	17	20	48.62929	122.7386
38	1995	6	3	17	48.5179	122.7416
39	1993	11	30	23	48.66429	122.7161
40	1993	3	16	5	48.59597	122.7554
41	2000	8	30	13	48.5145	122.7412
42	1995	9	5	14	48.7494	122.7704
43	2002	3	10	13	48.74996	122.7715
44	1997	4	24	5	48.77132	122.8165
45	1999	7	31	5	48.53325	122.7443
46	1998	9	4	1	48.577	122.752
47	1994	7	21	19	48.4921	122.7389
48	1996	11	9	16	48.50862	122.7406
49	2002	6	10	20	48.70258	122.735
50	1999	3	15	21	48.7546	122.7813
51	2000	8	30	18	48.65939	122.7195

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
52	1998	1	15	10	48.67227	122.7149
53	1996	4	19	3	48.43198	122.7664
54	2000	3	7	12	48.50174	122.7399
55	1995	7	17	21	48.72907	122.7526
56	2001	3	30	8	48.59129	122.7545
57	1994	6	15	8	48.47271	122.7395
58	1996	3	9	17	48.75243	122.7767
59	1992	12	1	17	48.75869	122.7899
60	1998	2	24	8	48.61583	122.7462
61	2003	4	30	12	48.50673	122.7404
62	1996	3	2	19	48.43837	122.7602
63	1994	11	8	17	48.53302	122.7442
64	1998	4	12	18	48.68127	122.7208
65	2000	7	9	21	48.76229	122.7975
66	1998	12	8	18	48.57396	122.7515
67	2003	1	17	18	48.6074	122.751
68	1992	12	23	2	48.80341	122.8841
69	2001	11	17	7	48.80557	122.8886
70	1998	1	12	19	48.72387	122.7491
71	1993	7	18	23	48.46932	122.7412
72	1993	5	7	6	48.51317	122.7411
73	1998	10	21	22	48.43058	122.7678
74	1994	4	11	21	48.79472	122.8658
75	1993	11	1	1	48.68985	122.7265
76	1992	4	22	6	48.75858	122.7897
77	1999	6	8	0	48.52494	122.7428
78	1998	2	27	20	48.75238	122.7766
79	2002	6	22	16	48.60842	122.7504
80	2000	4	8	6	48.5786	122.7523
81	2000	11	16	7	48.46533	122.7433
82	1992	1	28	9	48.43696	122.7616
83	2000	6	22	0	48.74442	122.7628
84	2002	12	29	3	48.74872	122.7689
85	1994	4	24	4	48.62067	122.7435
86	1995	6	19	4	48.75866	122.7899
87	2002	3	3	4	48.76675	122.8069
88	1994	2	27	2	48.64845	122.727
89	2000	11	9	13	48.41859	122.7795
90	1997	2	13	16	48.63328	122.7363
91	2003	4	30	12	48.59886	122.7558
92	1994	2	26	1	48.77412	122.8224
93	1998	7	7	18	48.58145	122.7528
94	1995	12	28	3	48.45767	122.7472
95	1996	8	8	10	48.78553	122.8464
96	2003	3	24	15	48.76492	122.803
97	2002	10	30	15	48.64107	122.7319
98	2000	10	5	10	48.54698	122.7467
99	2002	9	10	19	48.71212	122.7413
100	1992	5	5	13	48.6987	122.7324

Table XV.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	SI_HABS2.HAB
Grid W edge	123° 57.76'W
Grid S edge	47° 22.01' N
Cell size (^{o}longitude)	0.12^o W
Cell size (^{o}latitude)	0.12^o N
Cell size (m) west-east	150.14
Cell size (m) south-north	221.67
# cells west-east	890
# cells south-north	978
Water cell area (m^2)	33,279.9
Shore cell length (m)	182.43
Shore cell width – Rocky shore (m)	1.0
Shore cell width – Artificial shore (m)	1.0
Shore cell width – Gravel beach (m)	1.0
Shore cell width – Sand beach (m)	1.0
Shore cell width – Mud flat (m)	1.0
Shore cell width – Wetlands (fringing,m)	1.0

Table XV.E-4. Water temperature by month of the year (from French et al., 1996b).

Month	**Surface Water Temperature (^{o}C)**	**Bottom Water Temperature (^{o}C)**	**Pycnocline Depth (m)**
January	10	8	20
February	10	8	20
March	10	8	20
April	11	8	20
May	12	8	20
June	14	8	20
July	14	7	10
August	14	7	10
September	14	7	10
October	13	7	20
November	12	7	20
December	10	7	20

Table XV.E-5. Wind data sources and records used.

File Name	Location	Latitude Longitude	Dates	Data Source
SISW1_1992_2003_ LST.WNE	Station SISW1 - Smith Island, WA	48.32 ºN 122.84 ºW	1991-2003	National Data Buoy Center

The SISW1_1992_2003_LST.WNE wind data were downloaded from one buoy Station SISW1 - Smith Island, WA. Figure XV.E-2 displays where the buoy is located along with surrounding buoys. SISW1_1992_2003_LST.WNE data start on 31 December 1991 and end on 31 December 2003.

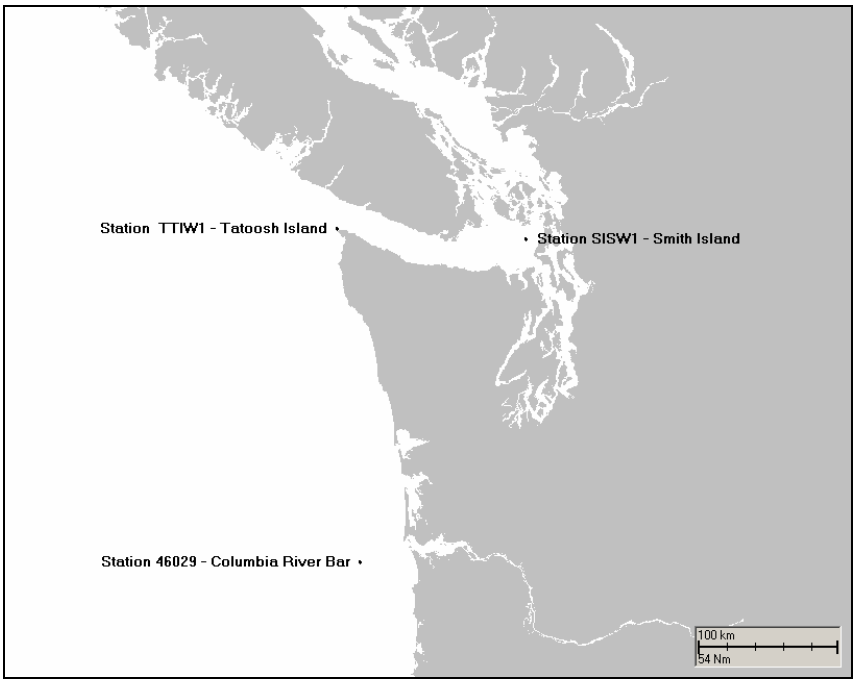

Figure XV.E-2 Wind Station Locations.

Draft Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XVI: Stochastic Model Results for San Juan Islands – Alaskan North Slope Crude

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XVI.A. INTRODUCTION

The results of the main stochastic scenarios for the San Juan Islands – Alaskan North Slope Crude are contained in this volume. There were two main stochastic scenarios:

1. Mechanical removal under Washington state Caps standards
2. Mechanical removal under Washington state Caps standards plus dispersant application

XVI.B. MAPS OF EXPOSURE PROBABILITY, TIME FIRST EXPOSED, AND MAXIMUM POSSIBLE CONTAMINATION

The results of multiple model runs are evaluated to develop the following statistics, for each cell in the model grid ("location") and for each exposure index. Maps of the results summarizing all 100 runs of a scenario are contained in this section.

- Probability of exposure greater than the minimum threshold (probability that the minimum threshold thickness or concentration will be exceeded at each location at any time following the spill). For surface oil, the model records if any oil of greater than that thickness passes through the grid cell, regardless of the aerial coverage of the oil. For concentrations, the average concentration in the grid cell is used to determine if the threshold is exceeded.
- Time (hours) to first exceedance of the minimum threshold at each location (i.e., in teach cell).
- Worst-case maximum exposure (thickness, volume or concentration) at any time after the spill, at a given location (peak exposure at each location delineated by the grid cells). The amounts are averaged over the area of the model grid cell. The worst-case maximum amount is for all possible releases (i.e., maximum peak exposure for all the model runs). This is calculated in two steps: (1) For each individual run (for each spill date run), the maximum amount over all time after the spill is saved for each location (cell) in the model grid. (2) The runs are evaluated to determine the highest amount possible at each location. Note that these *worst-case maximum* amounts are not additive over all locations. These represent maximum possible amounts of oil that could ever reach each site (grid cell), considered individually, and based on the model runs performed. Thus, "worst-case" represents the highest exposure of the most adverse of the runs performed.

Exposure indices and minimum thresholds (i.e., those less than values that might have an impact on any resource) used in the modeling were:

- Surface slick or floating oil: $\geq$ 0.01 g/m^2 (average thickness $\geq$ 0.01 micron)
- Shoreline: average mass loading over the shore segment (length of one grid cell, calculated as the cell diagonal length, times the typical width for the habitat type) $\geq$ 0.01 g/m^2
- Dissolved aromatics: average over the water cell $\geq$ 1 ppb (1 mg/m^3)

- Subsurface oil (entrained in water): average over the water cell $\geq$ 10 ppb (10 mg/m^3)
- Sediment total hydrocarbons: average over the cell $\geq$ 0.0001 g/ m^2
- Sediment dissolved aromatic concentrations: average over the cell $\geq$ 0.0001 g/ m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10 cm, the assumed bioturbation zone)

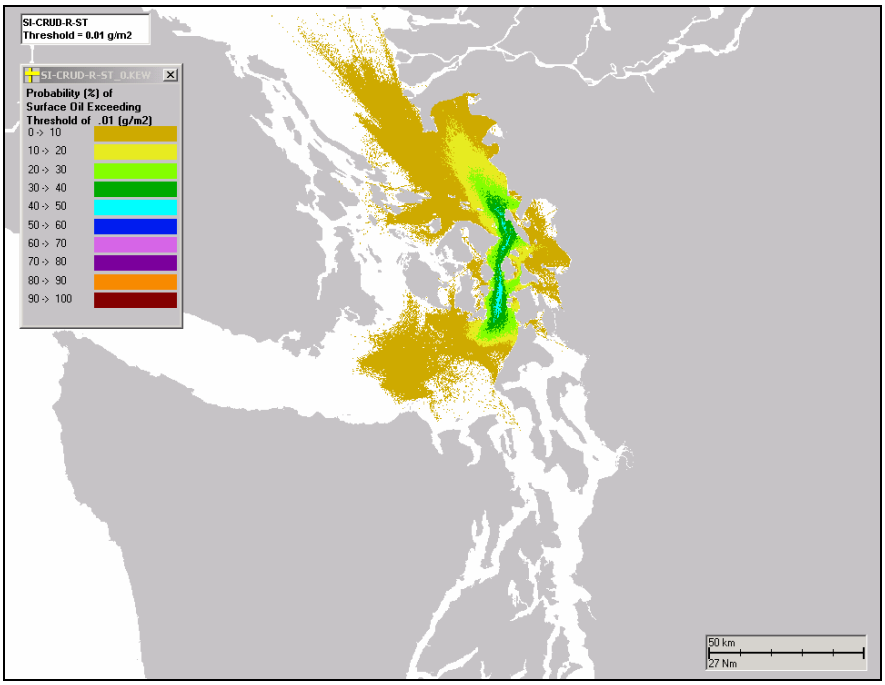

Figure XVI.B-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

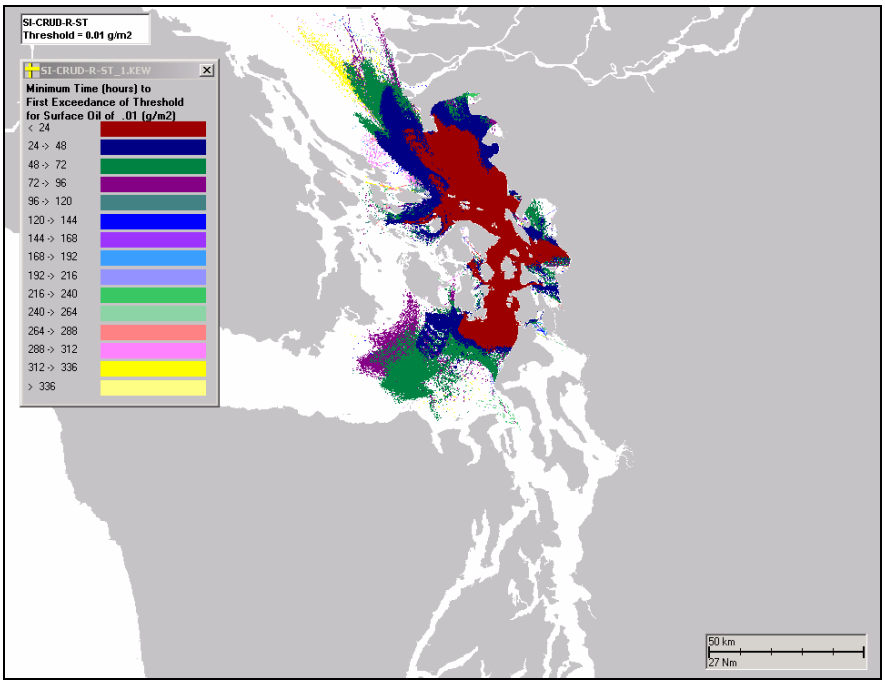

Figure XVI.B-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

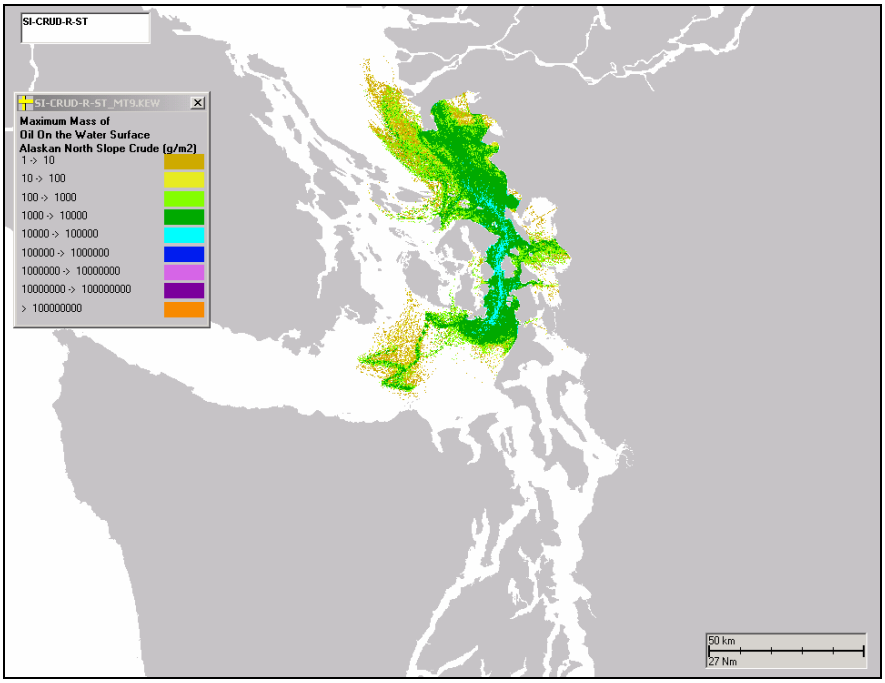

Figure XVI.B-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

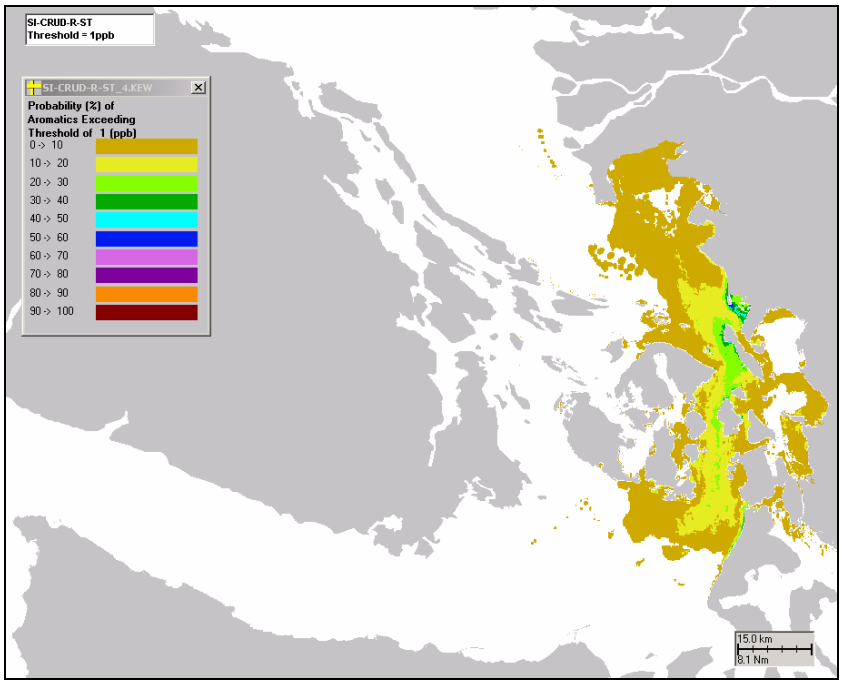

Figure XVI.B-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

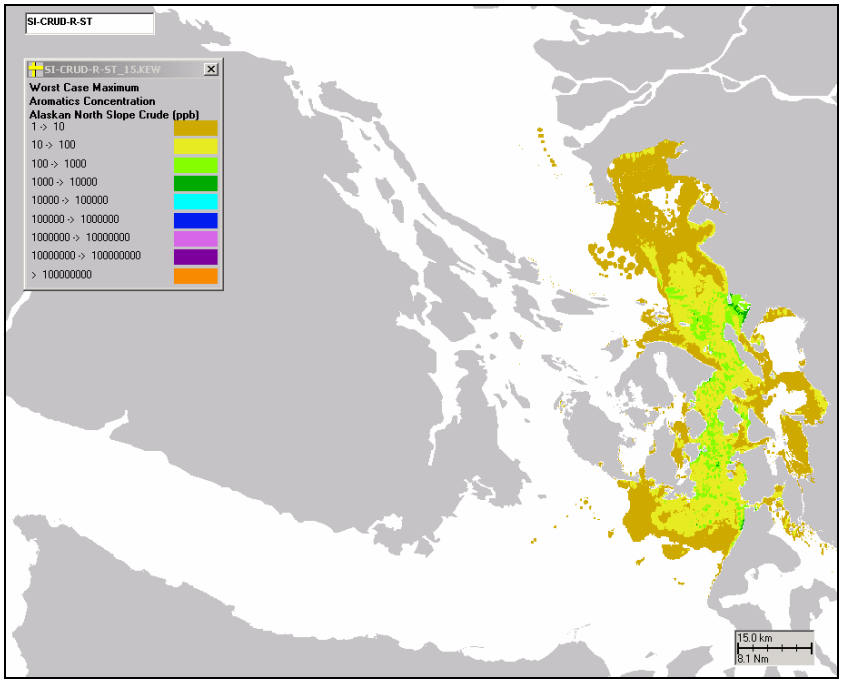

Figure XVI.B-5. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

Sediment exposure to total hydrocarbons does not exceed 0.01 g/m^2

Figure XVI.B-6. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Sediment exposure to total hydrocarbons (g/m^2) under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

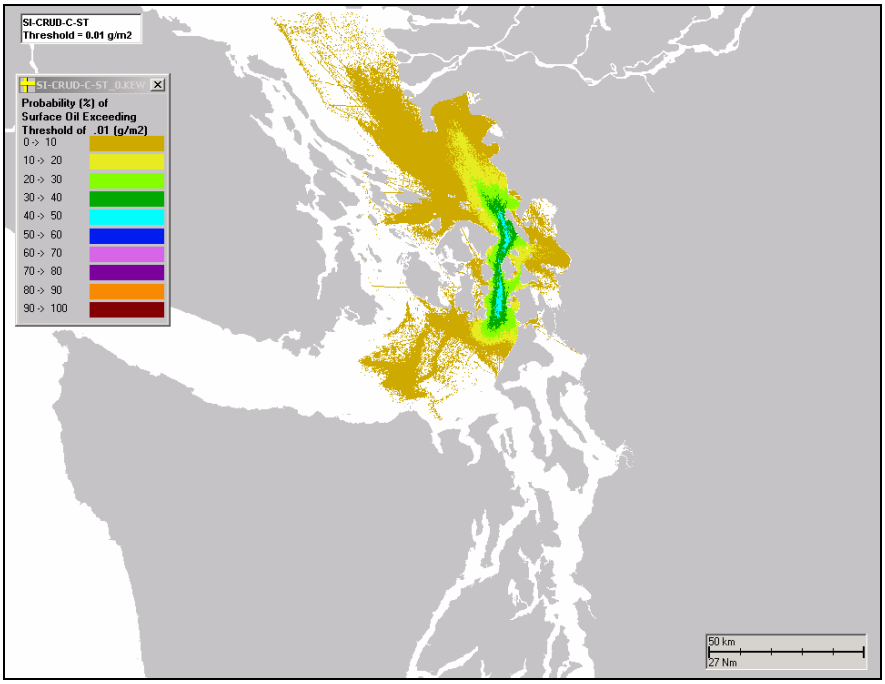

Figure XVI.B-7. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

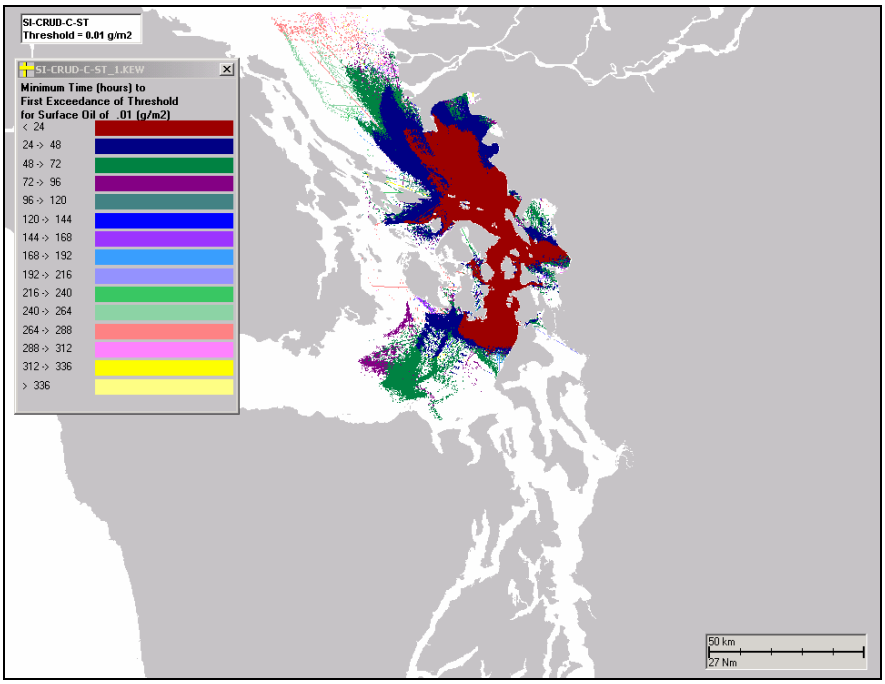

Figure XVI.B-8. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

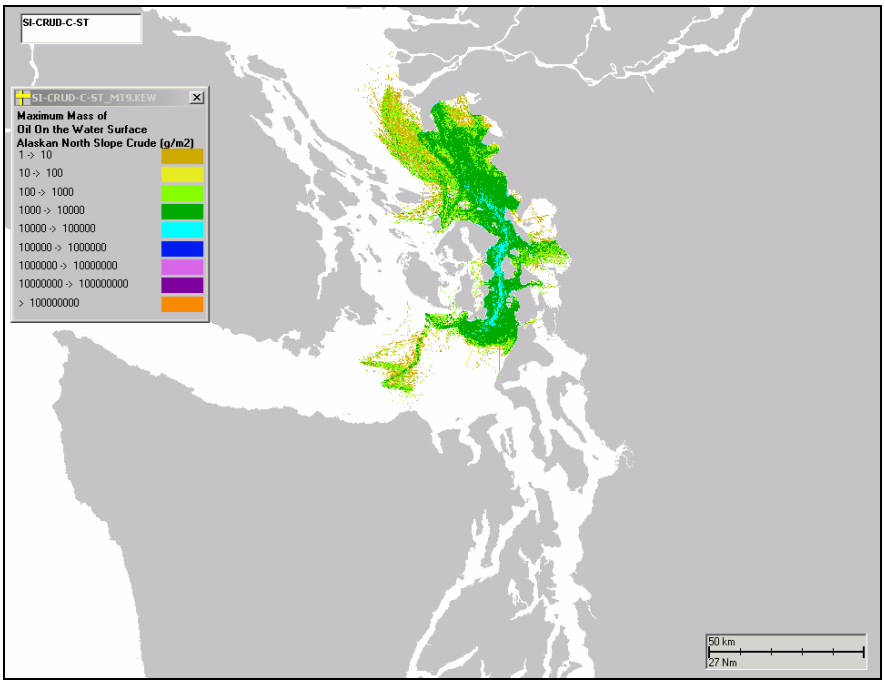

Figure XVI.B-9. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

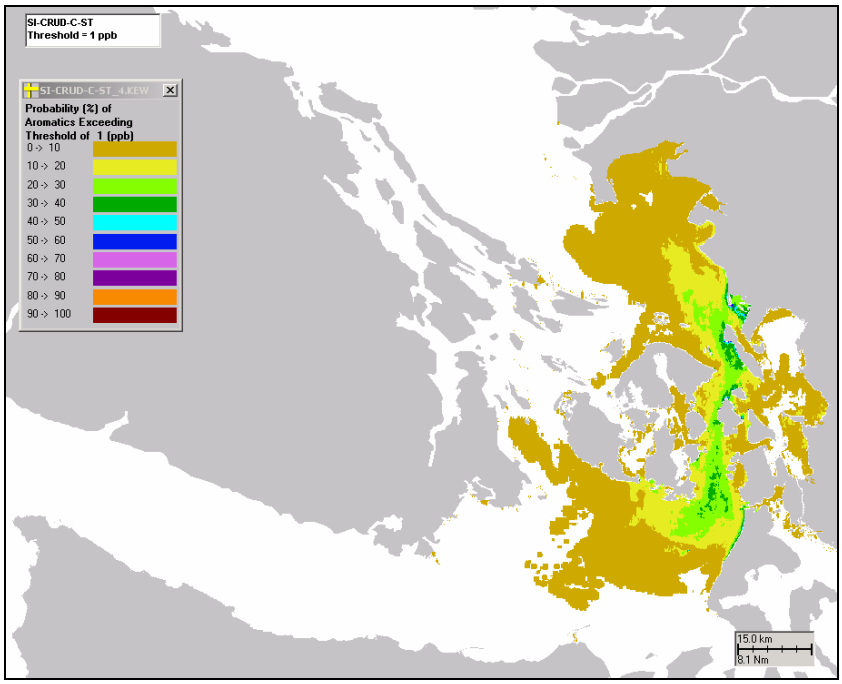

Figure XVI.B-10. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

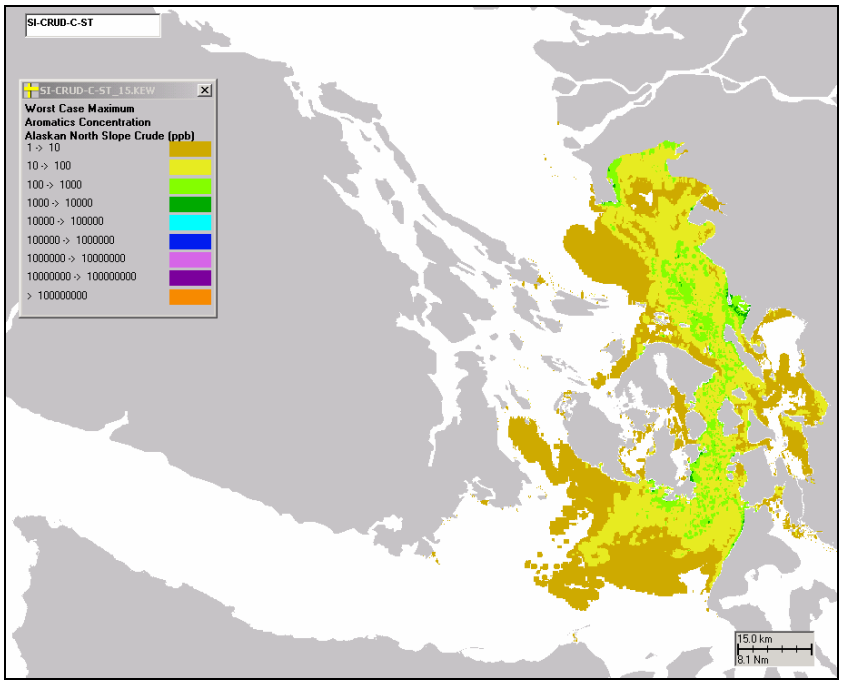

Figure XVI.B-11. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

Sediment exposure to total hydrocarbons does not exceed 0.01 g/m^2

Figure XVI.B-12. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Sediment exposure to total hydrocarbons (g/m^2) under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

XVI.C. RANK ORDER DISTRIBUTIONS FOR ALL MODEL RUNS

In this section, the following impact indices are plotted as rank order distributions:

- Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 (which is sheen) times duration of exposure (in m^2-hrs)
- Shoreline area (m^2) exposed to hydrocarbons of various threshold thicknesses (>0.01, 1, 10, 100, and 1000 g/m^2)
- Water volume exposed to > 1 ppb (>1 mg/m^3) of dissolved aromatic concentration at some time after the spill
- Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill
- Percent of spilled hydrocarbon mass eventually going ashore
- Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats)
- Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill, and
- Percent of spilled hydrocarbon mass removed mechanically an by in situ burning (ISB, if applicable).

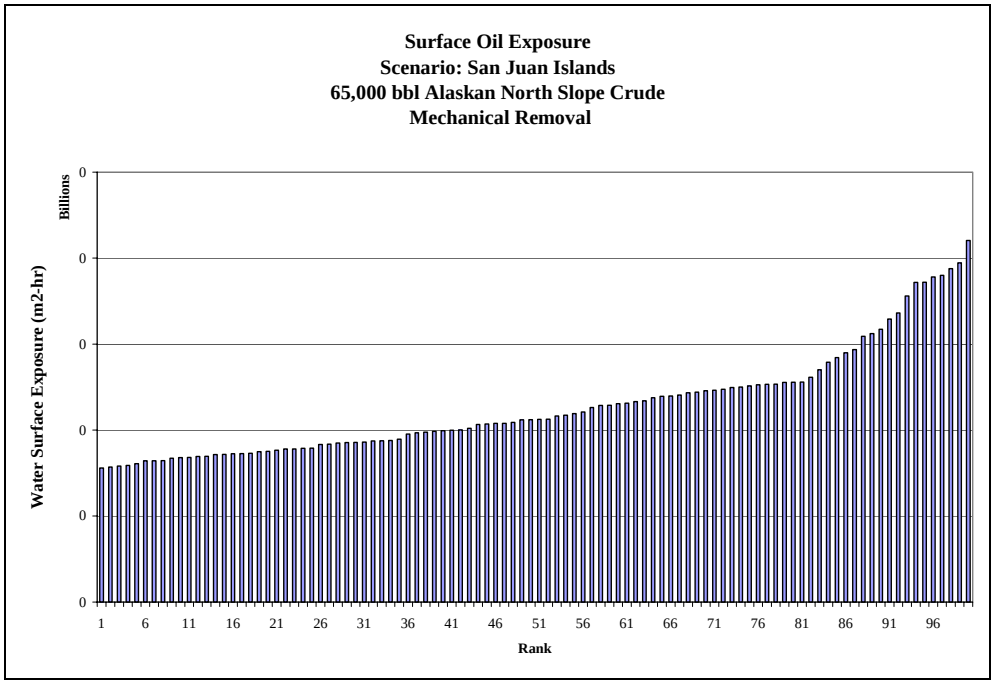

Figure XVI.C-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

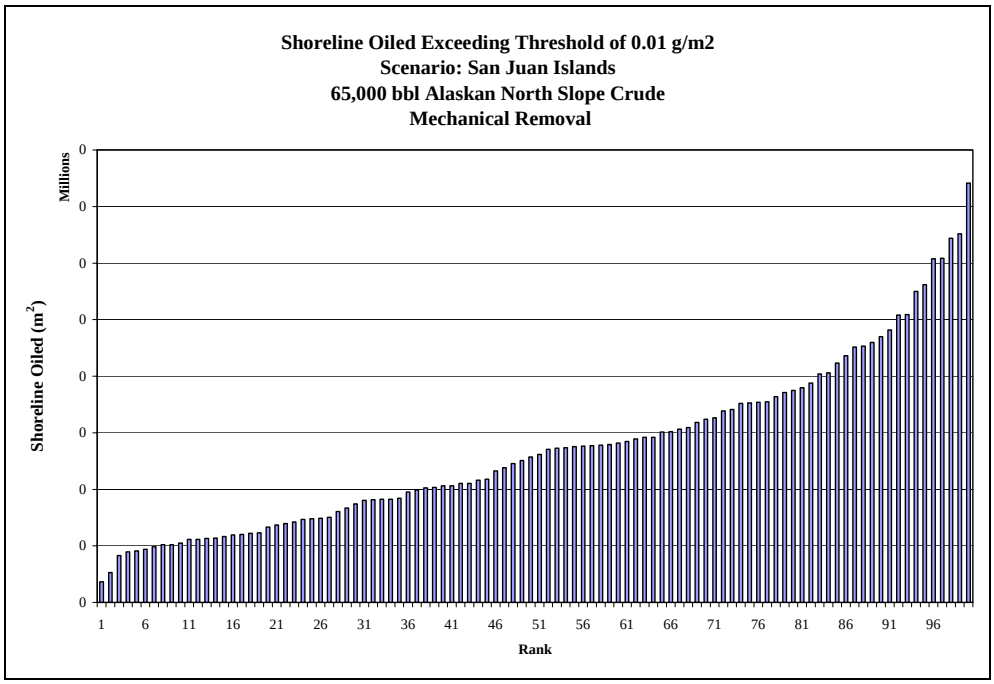

Figure XVI.C-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

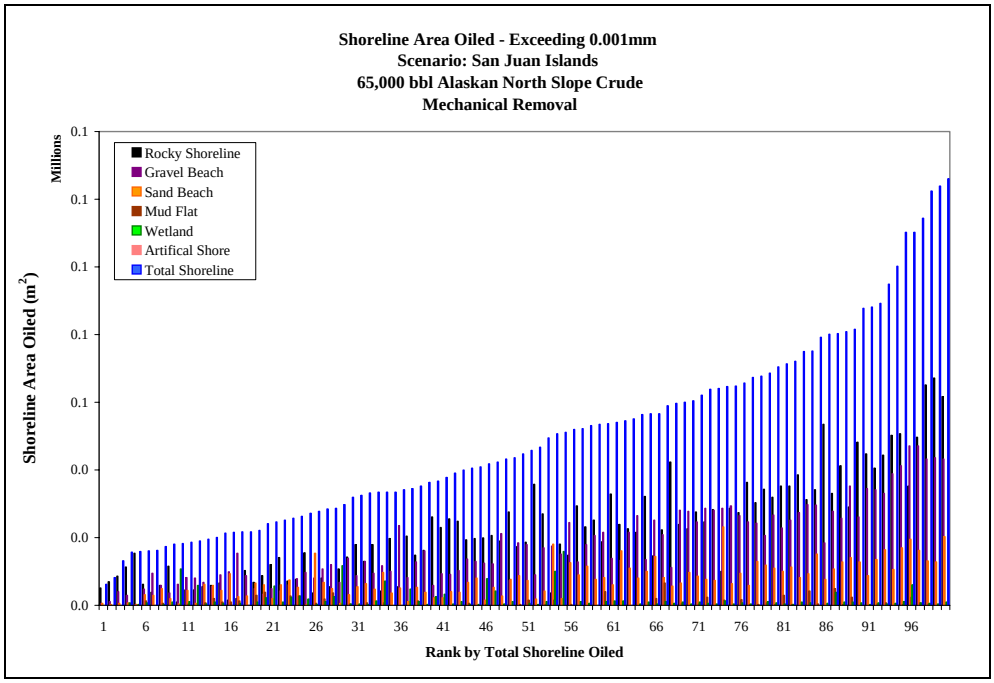

Figure XVI.C-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

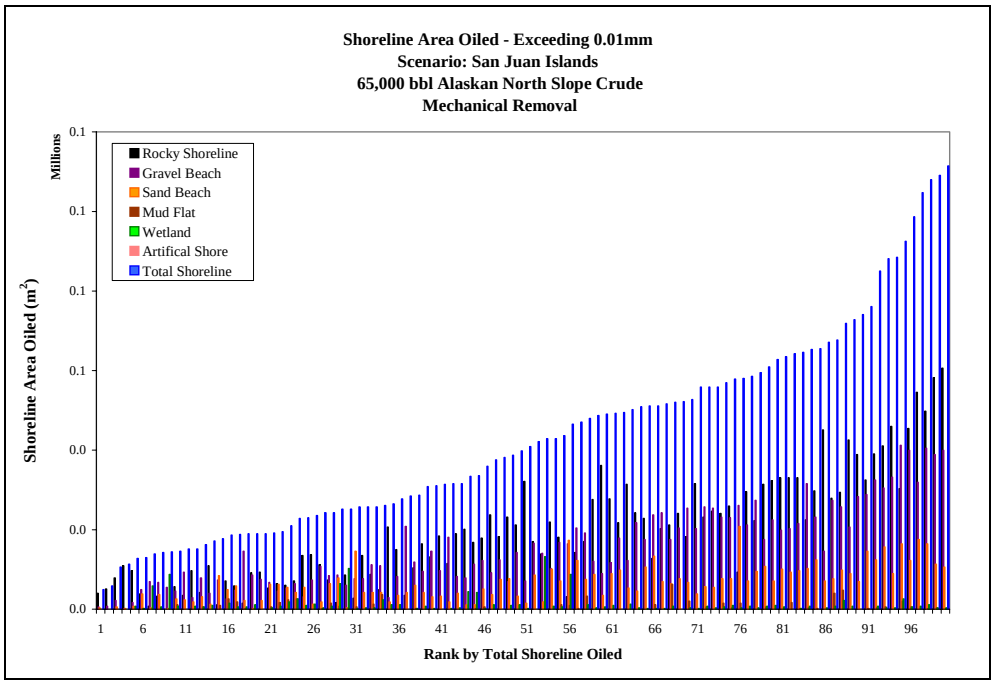

Figure XVI.C-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

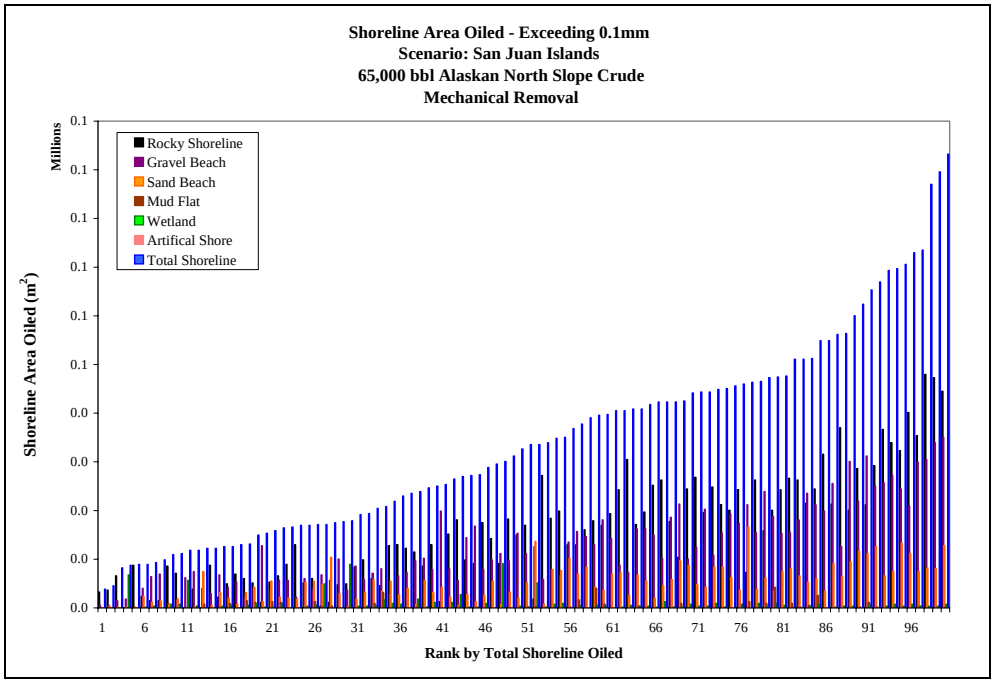

Figure XVI.C-5. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

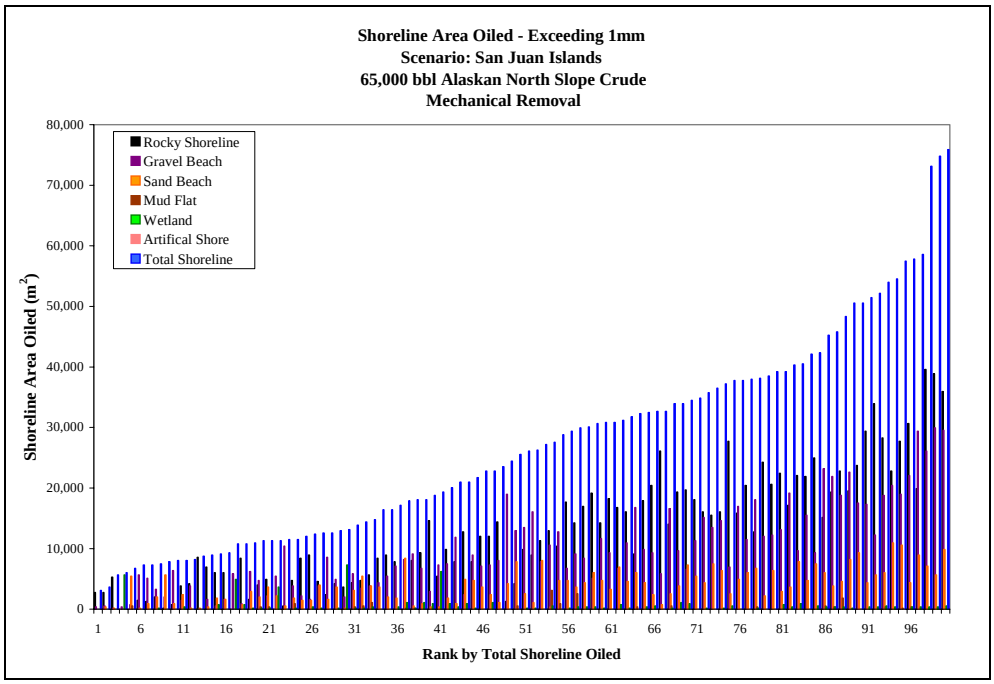

Figure XVI.C-6. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

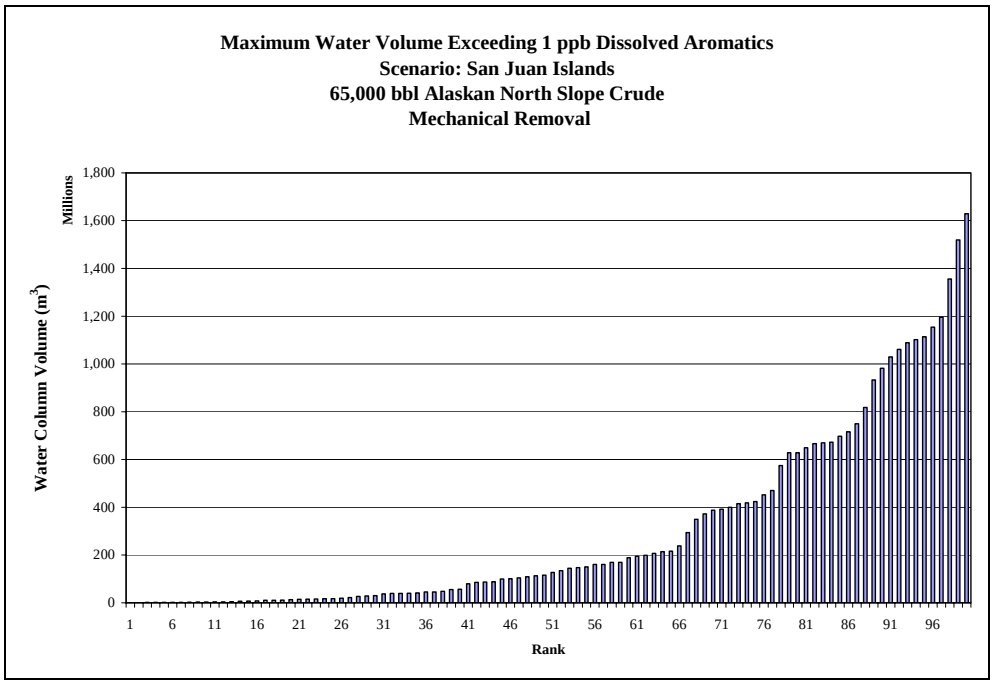

Figure XVI.C-7. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

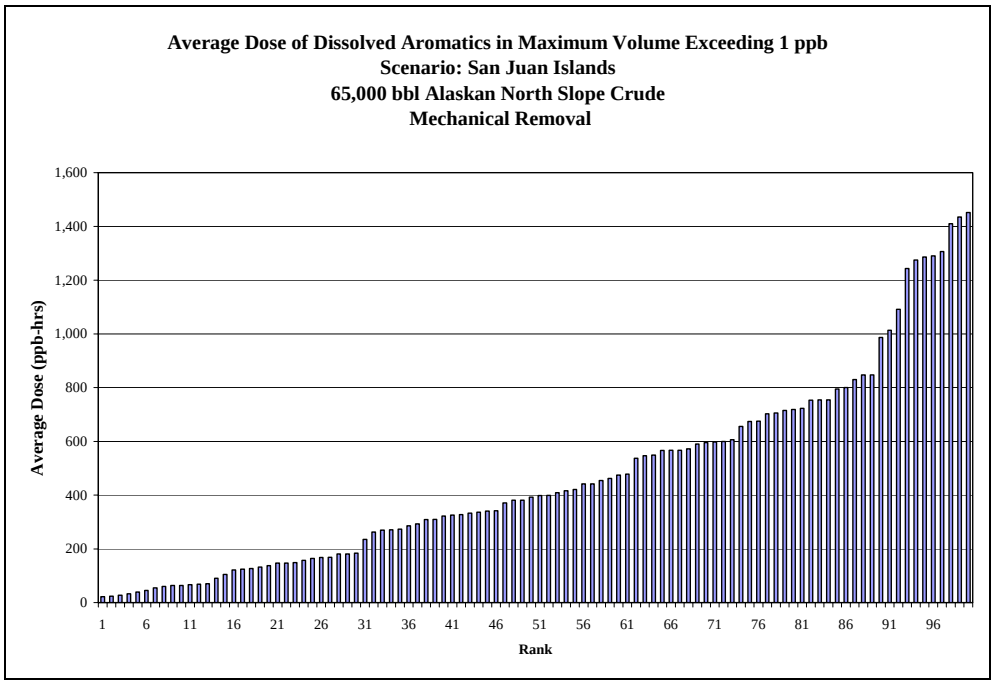

Figure XVI.C-8. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

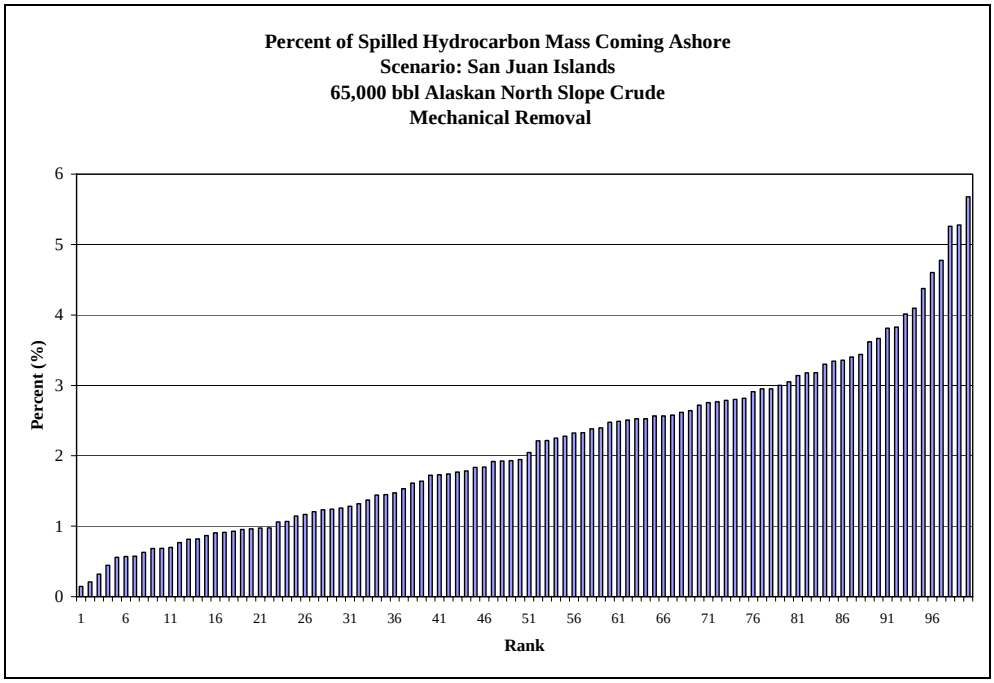

Figure XVI.C-9. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

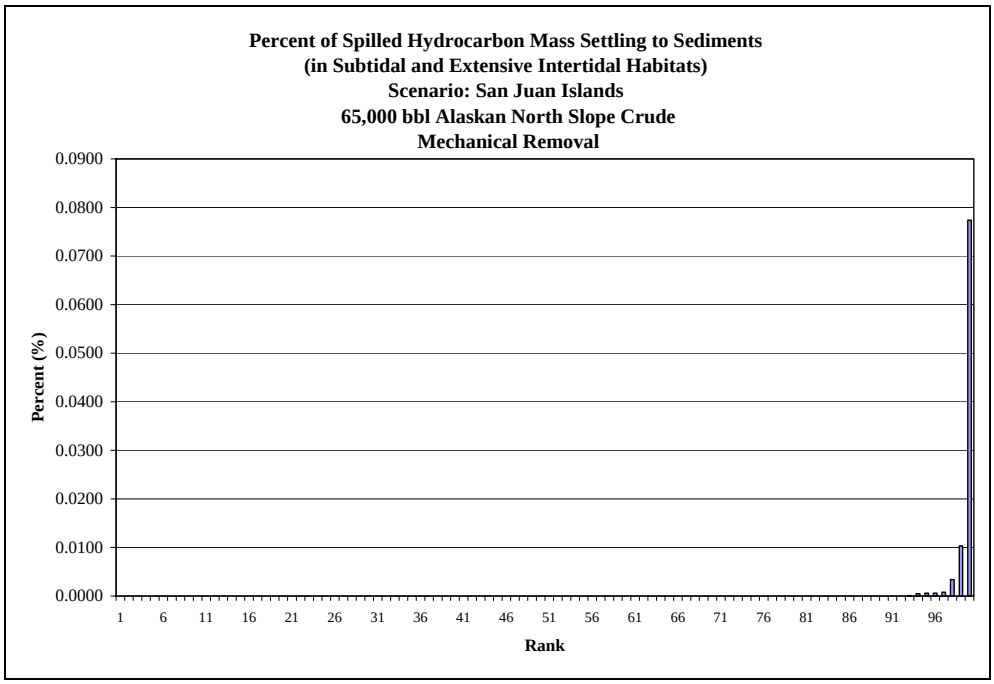

Figure XVI.C-10. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

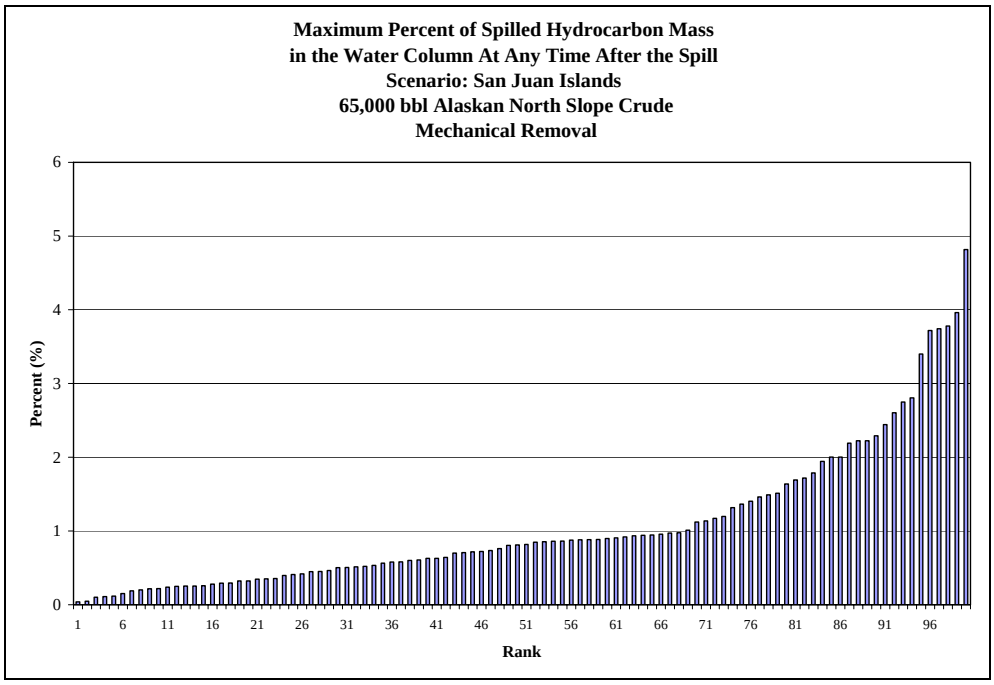

Figure XVI.C-11. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

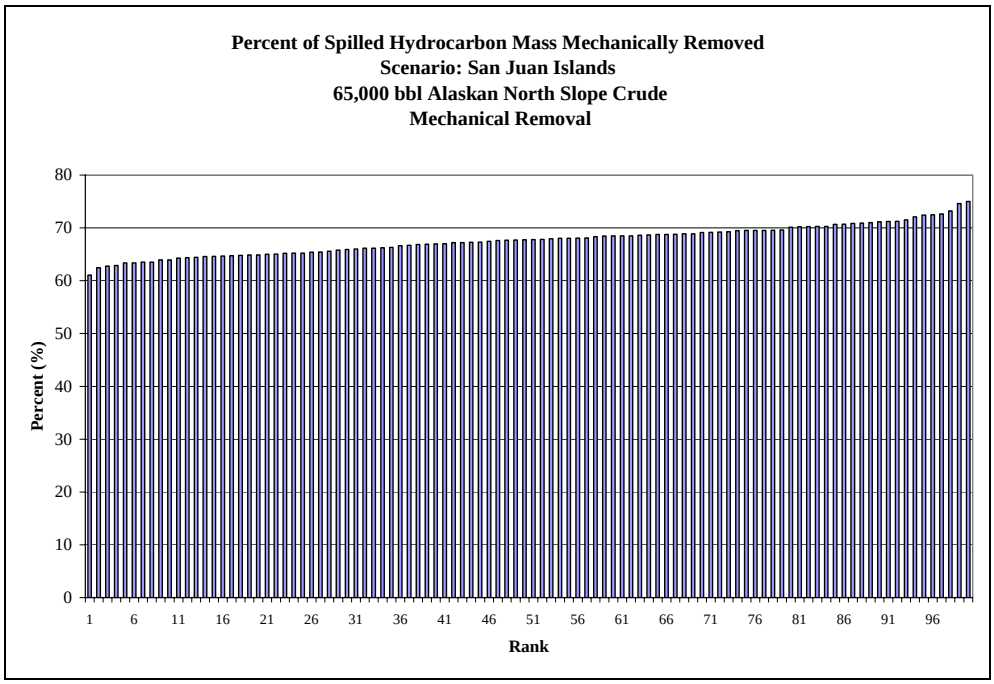

Figure XVI.C-12. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass mechanically removed.

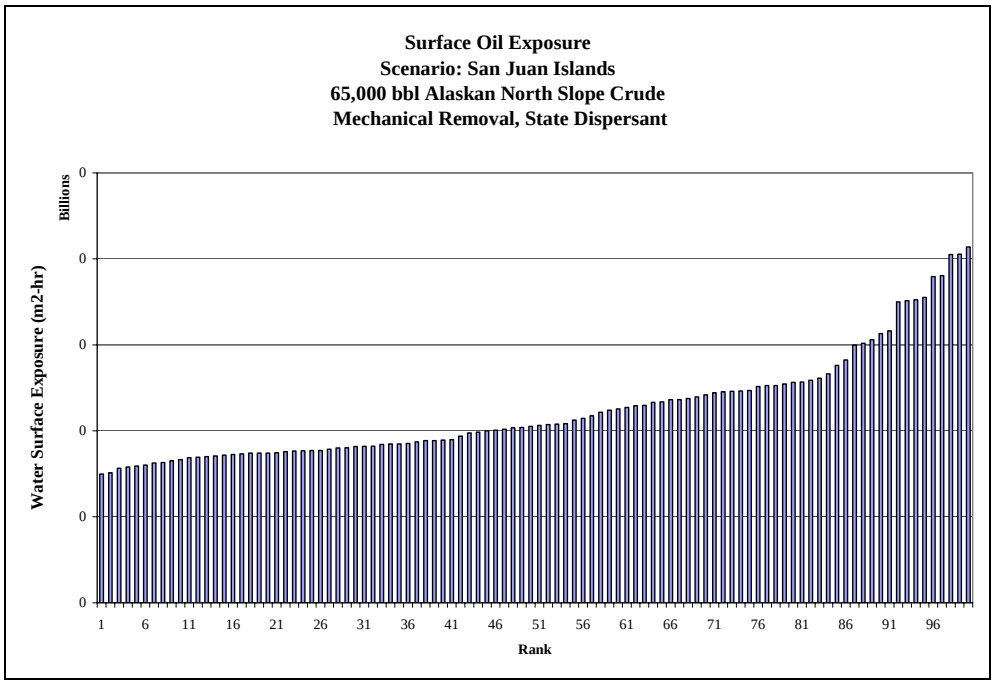

Figure XVI.C-13. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

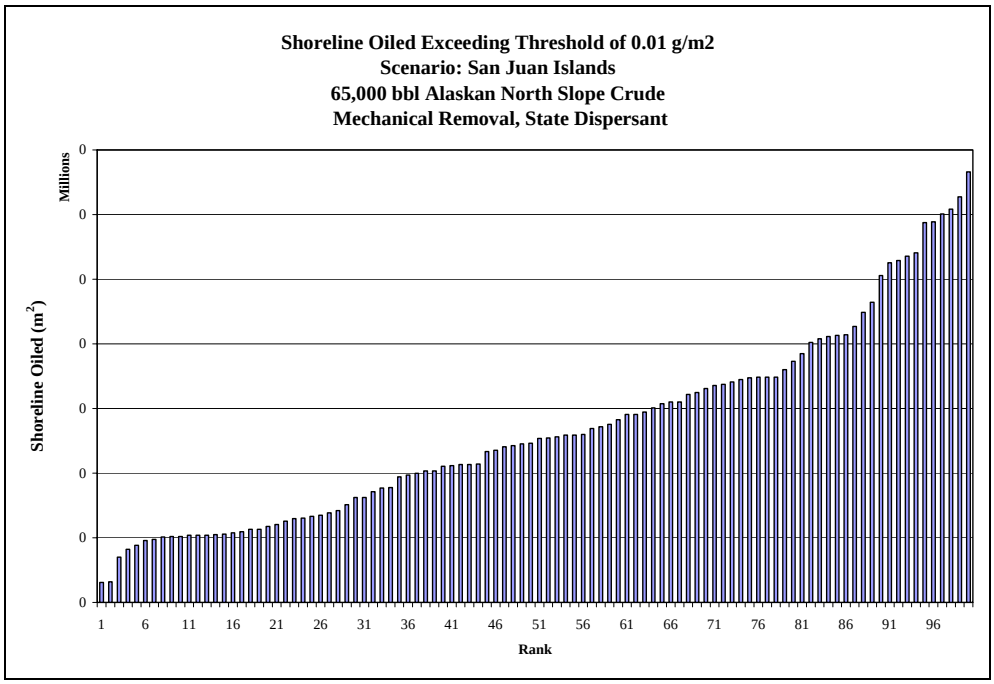

Figure XVI.C-14. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

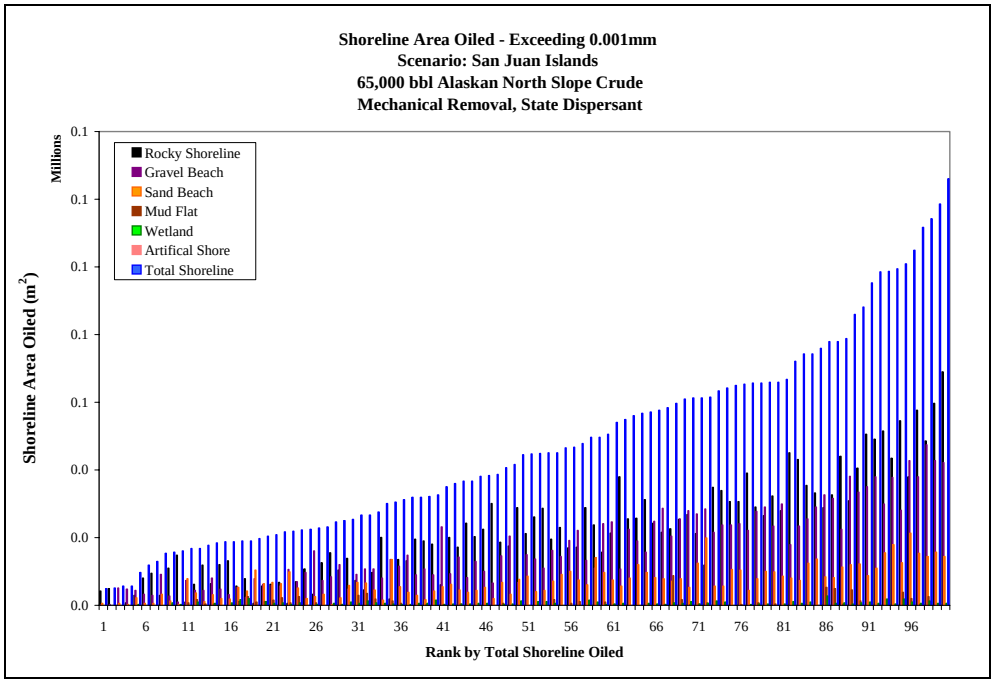

Figure XVI.C-15. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

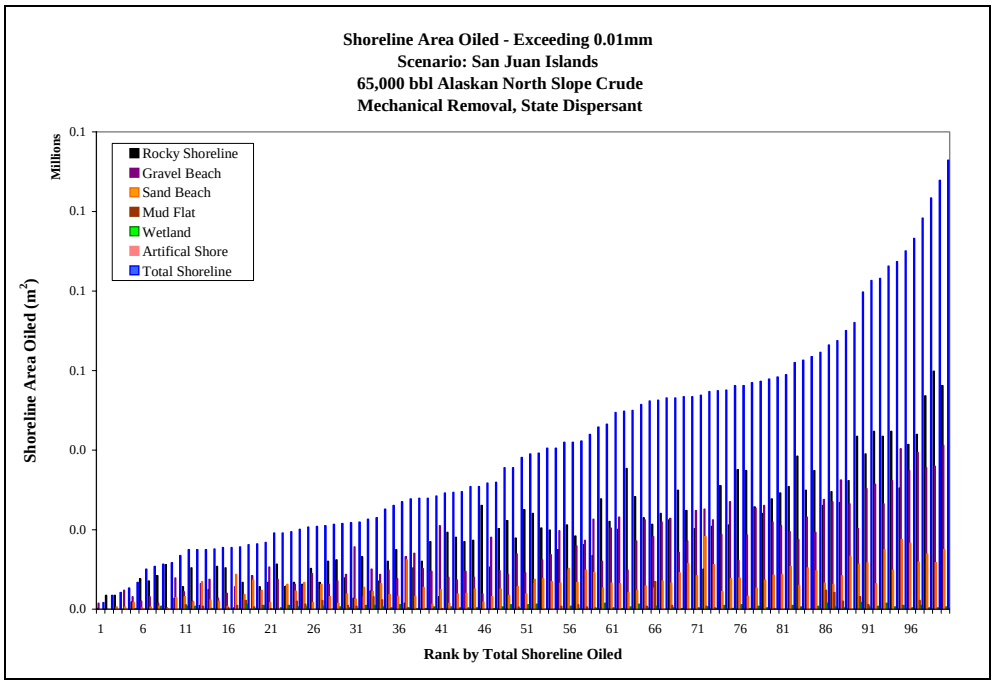

Figure XVI.C-16. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

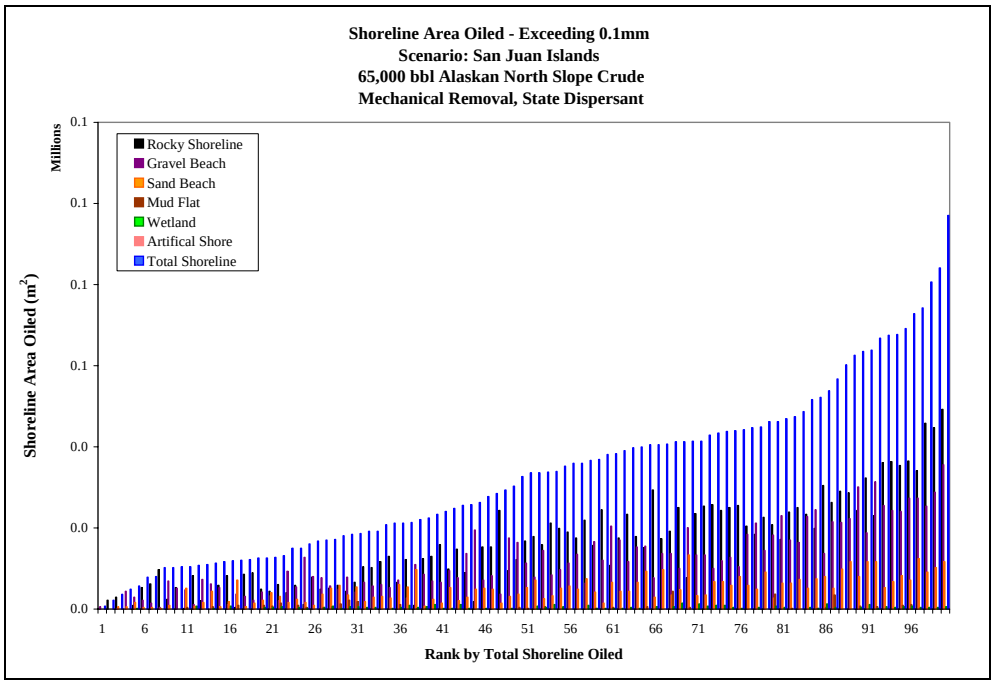

Figure XVI.C-17. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

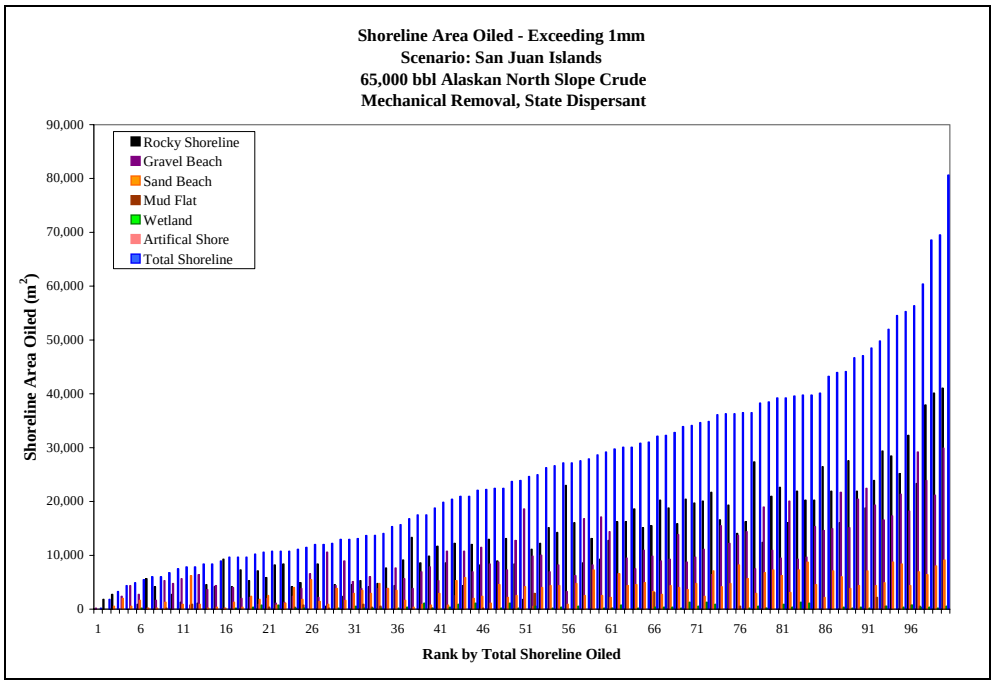

Figure XVI.C-18. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

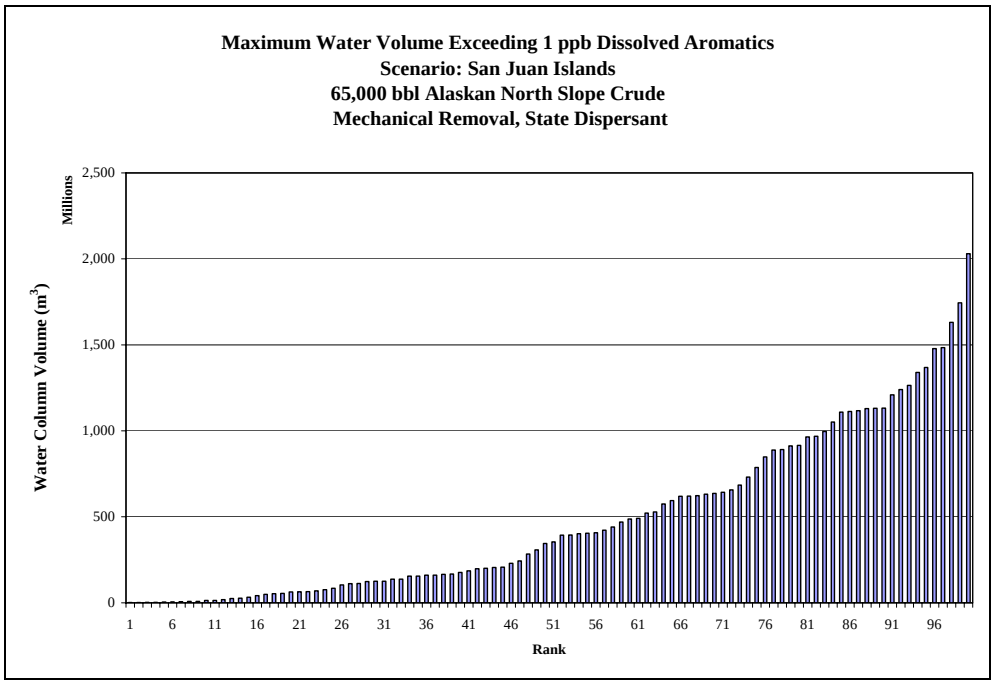

Figure XVI.C-19. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

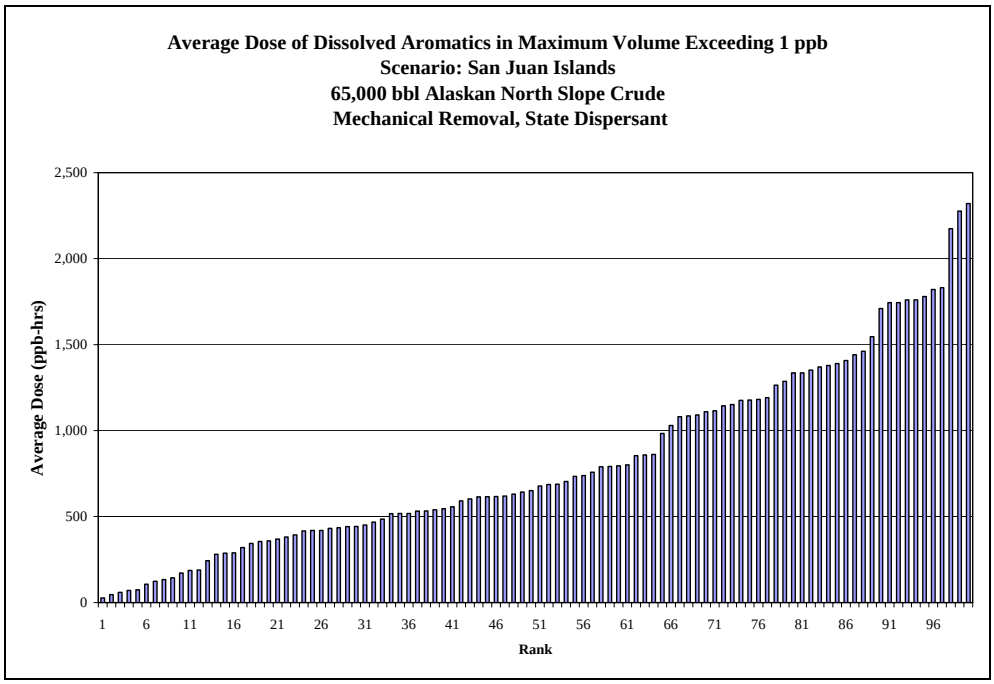

Figure XVI.C-20. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

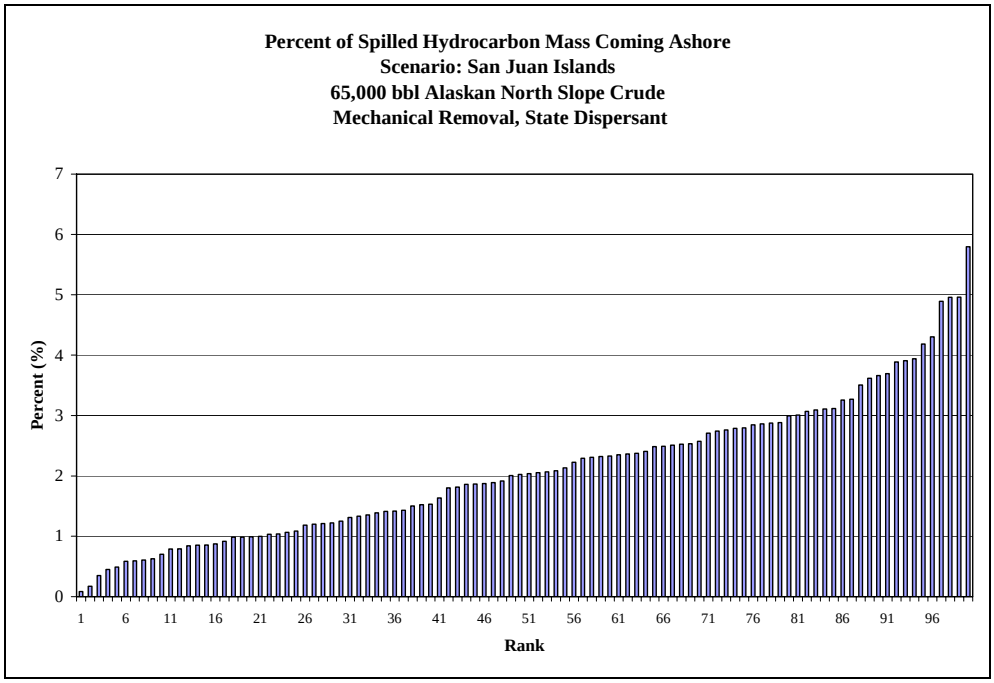

Figure XVI.C-21. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

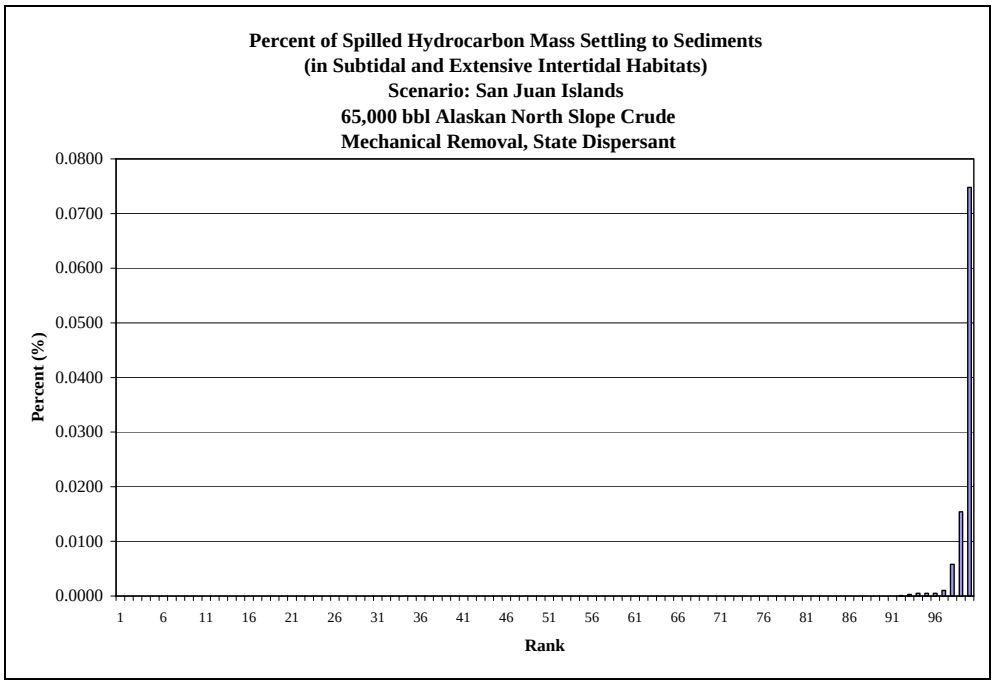

Figure XVI.C-22. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

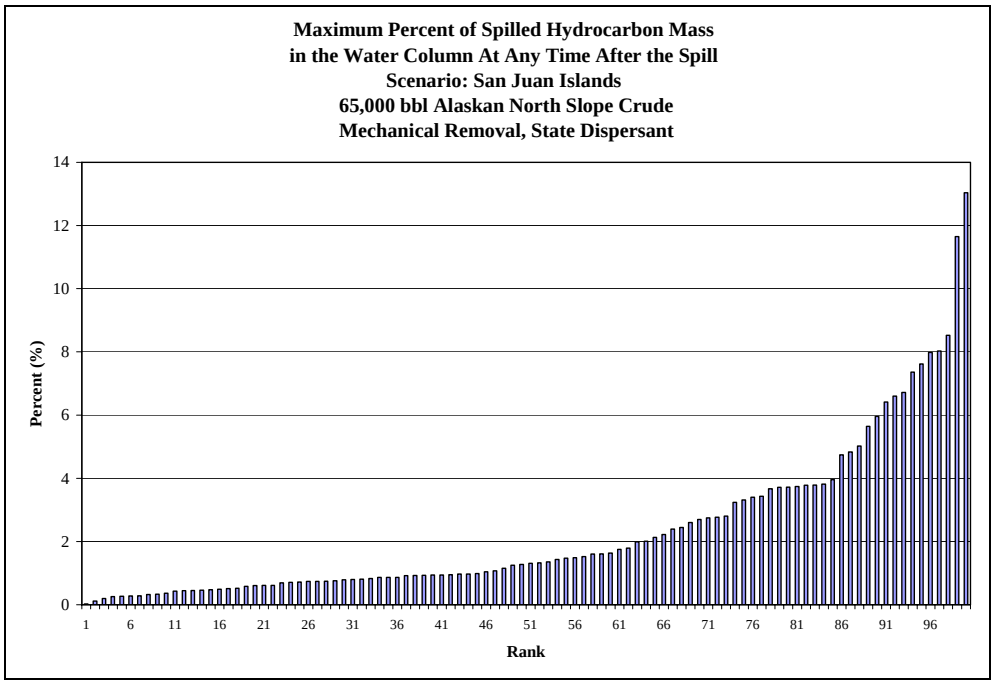

Figure XVI.C-23. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

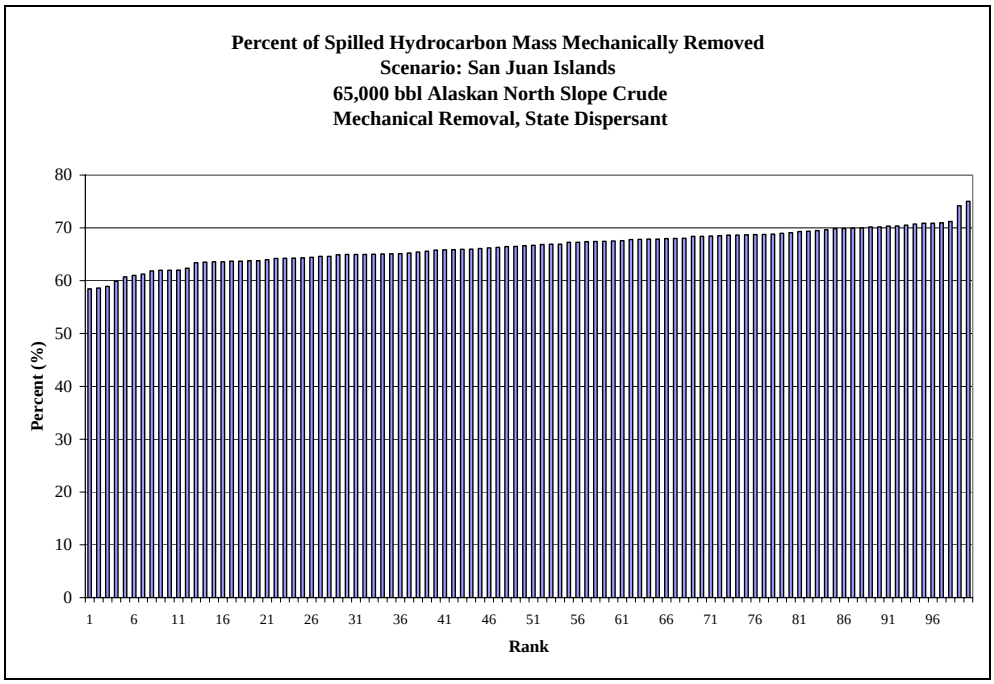

Figure XVI.C-24. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass mechanically removed.

XVI.D. SHORELINE AREAS EXPOSED BY SHORE TYPE

The tables in this section list the areas of shoreline oiled by shore type for the main stochastic scenarios. The 50th and 95th percentile results are sorted by total shoreline oiled at the indicated threshold. Thus, these are not the same runs as those sorted by shoreline cleanup cost (which are reported in Volume II).

Table XVI.D-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	45,789	18,608	17,878	7,297	1,459	547	0
95th	110,188	35,209	47,067	19,520	2,372	6,020	0
Maximum	126,058	67,134	47,067	23,168	6,567	15,871	0
Mean	49,881	22,431	17,593	7,560	737	1,560	0
Std. Dev.	27,787	14,970	11,404	5,048	1,256	2,685	0
Mean + 2 Std. Dev.	105,455	52,371	40,401	17,656	3,249	6,930	0

Table XVI.D-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	40,863	32,107	7,115	1,459	0	182	0
95th	98,694	45,425	39,952	12,223	547	547	0
Maximum	111464	60566	41229	20797	6203	13135	0
Mean	43297	19644	15421	6507	576	1149	0
Std. Dev.	25164	13787	10200	4550	1103	2177	0
Mean + 2 Std. Dev.	93,625	47,218	35,821	15,607	2,782	5,503	0

Table XVI.D-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	33,566	16,966	11,128	5,108	182	182	0
95th	72,971	40,134	20,979	11,128	0	730	0
Maximum	93,221	47,979	35,026	16,601	4,196	9,121	0
Mean	34,355	15,778	12,440	4,989	348	799	0
Std. Dev.	20,261	11,351	8,417	3,622	764	1,629	0
Mean + 2 Std. Dev.	74,877	38,480	29,274	12,233	1,876	4,057	0

Table XVI.D-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	26,087	9,851	13,500	2,554	0	182	0
95th	110,188	30,648	22,074	4,378	2,372	365	0
Maximum	75,889	39,587	29,918	10,946	3,101	7,297	0
Mean	27,100	12,848	9,771	3,774	166	540	0
Std. Dev.	16,826	9,501	7,130	2,728	474	1,224	0
Mean + 2 Std. Dev.	60,752	31,850	24,031	9,230	1,114	2,988	0

Table XVI.D-5. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	44,695	21,162	14,959	8,574	0	0	0
95th	104,896	37,945	42,688	21,344	2,007	912	0
Maximum	126,058	68,958	47,431	21,344	8,757	2,736	0
Mean	47,364	22,039	17,035	7,049	704	536	0
Std. Dev.	28,727	15,139	11,412	4,607	1,387	523	0
Mean + 2 Std. Dev.	104,818	52,317	39,859	16,263	3,478	1,582	0

Table XVI.D-6. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	39,040	24,993	9,121	3,831	0	1,095	0
95th	93,221	41,411	34,844	16,601	0	365	0
Maximum	112923	59837	41229	18243	6932	1642	0
Mean	41345	19372	14850	6148	533	443	0
Std. Dev.	25666	13600	10250	4138	1109	419	0
Mean + 2 Std. Dev.	92,677	46,572	35,350	14,424	2,751	1,281	0

Table XVI.D-7. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	33,566	16,783	11,311	5,290	182	0	0
95th	72,790	36,486	27,364	7,115	1,095	730	0
Maximum	97,051	49,256	35,573	13,317	4,378	1,459	0
Mean	33,087	15,827	11,852	4,756	319	332	0
Std. Dev.	20,449	11,194	8,164	3,226	749	355	0
Mean + 2 Std. Dev.	73,985	38,215	28,180	11,208	1,817	1,042	0

Table XVI.D-8. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	24,628	1,824	18,608	4,196	0	0	0
95th	104,896	32,290	18,243	4,378	2,007	730	0
Maximum	80,632	41,046	29,918	9,121	3,101	1,277	0
Mean	26,036	12,803	9,298	3,512	159	264	0
Std. Dev.	16,618	9,387	6,695	2,439	502	346	0
Mean + 2 Std. Dev.	59,272	31,577	22,688	8,390	1,163	956	0

XVI.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

In this section, the results for the 5th, 50th, and 95th percentile runs based on shoreline oiling costs (using the base case scenario for sorting) are shown, as plots of the following measures of exposure:

- Water surface exposure to floating hydrocarbons (g/m^2)
- Shoreline exposure to hydrocarbons (g/m^2) (for 95th percentile run only)
- Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill

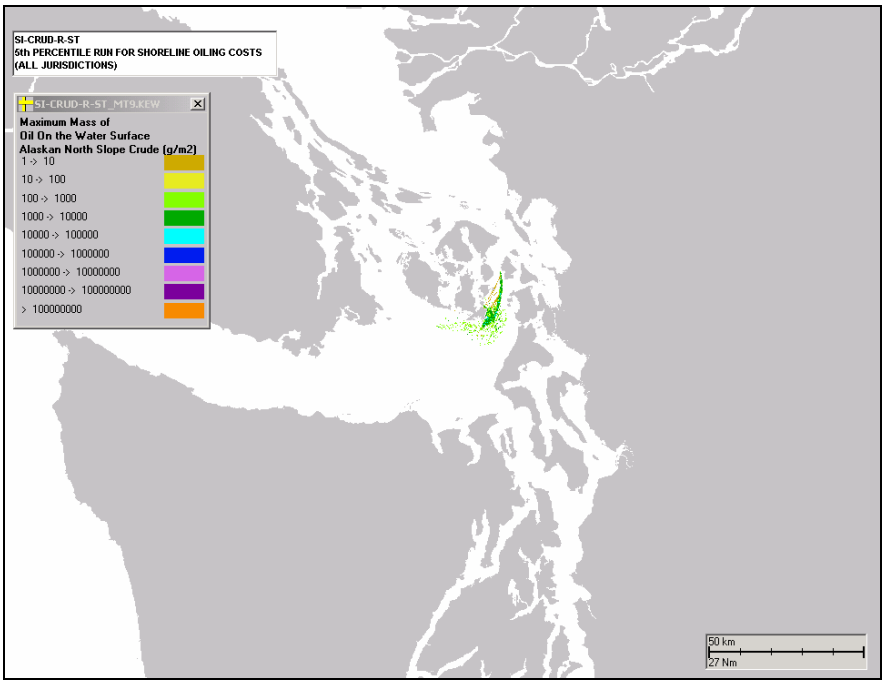

Figure XVI.E-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

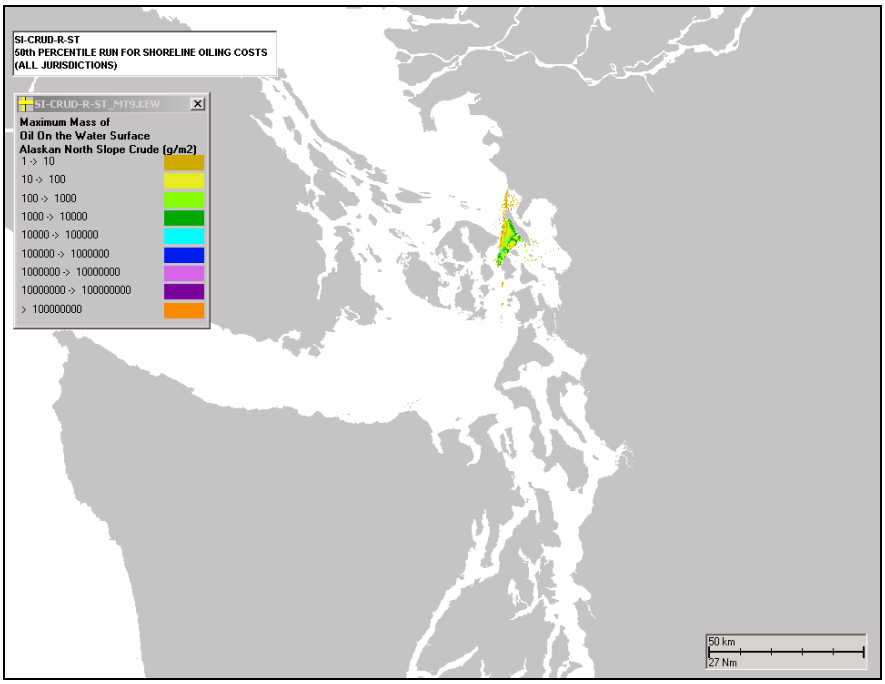

Figure XVI.E-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

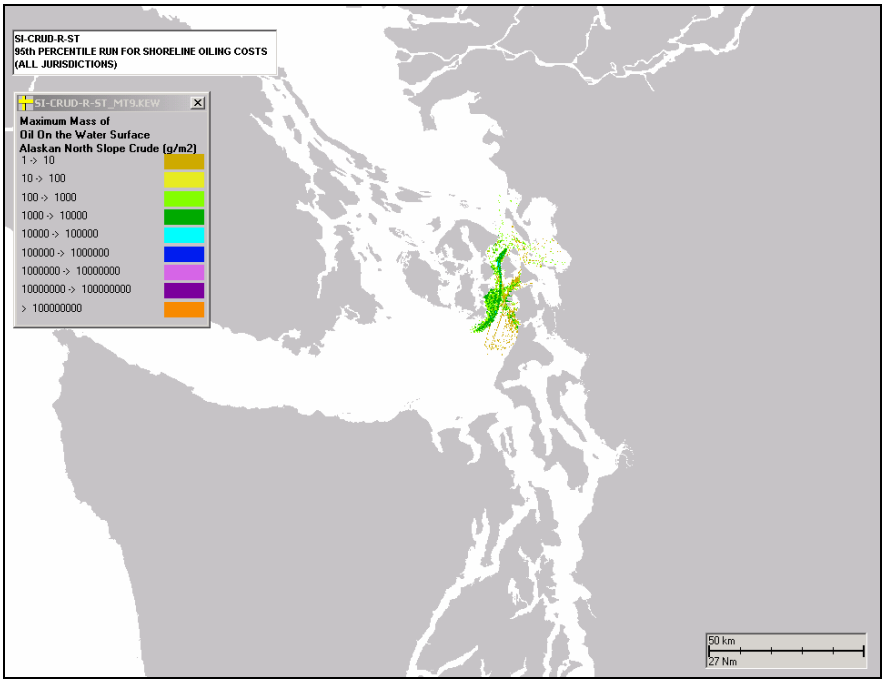

Figure XVI.E-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

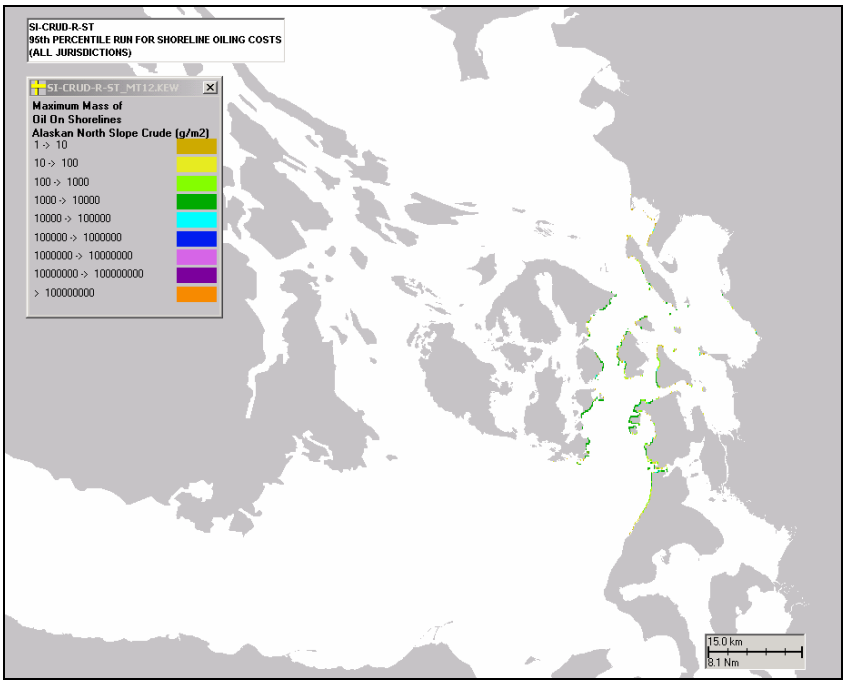

Figure XVI.E-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

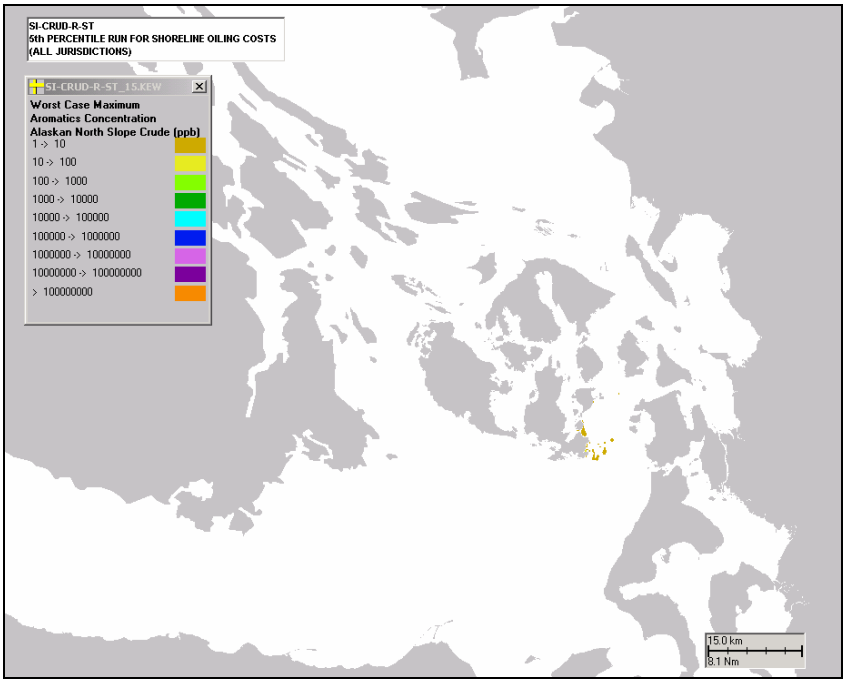

Figure XVI.E-5. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

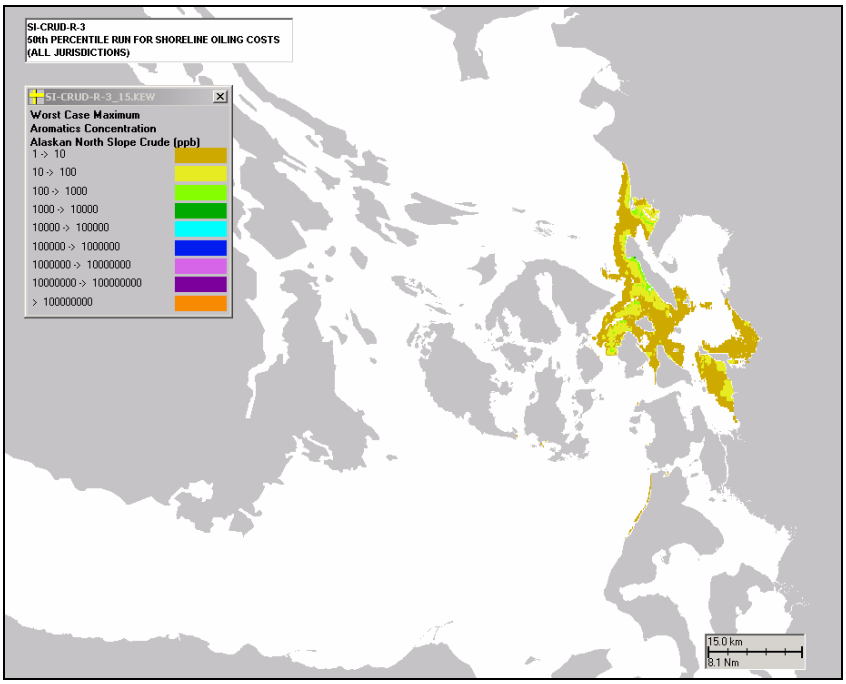

Figure XVI.E-6. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

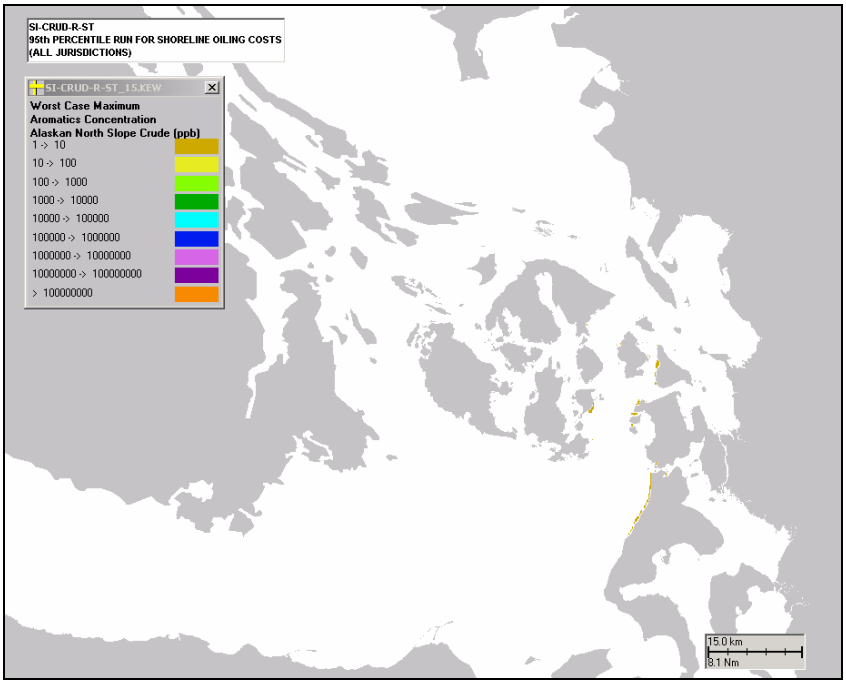

Figure XVI.E-7. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

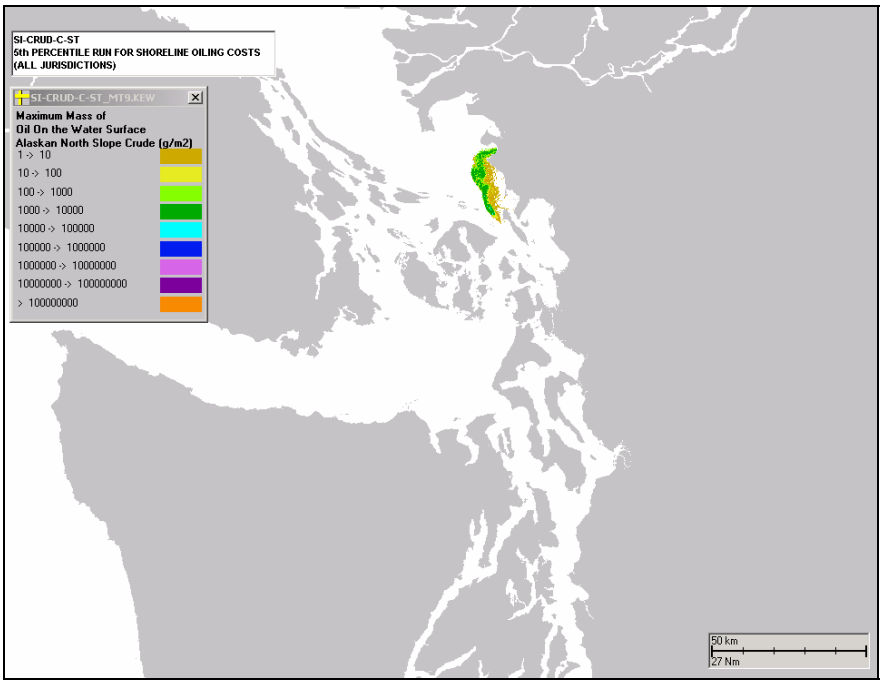

Figure XVI.E-8. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

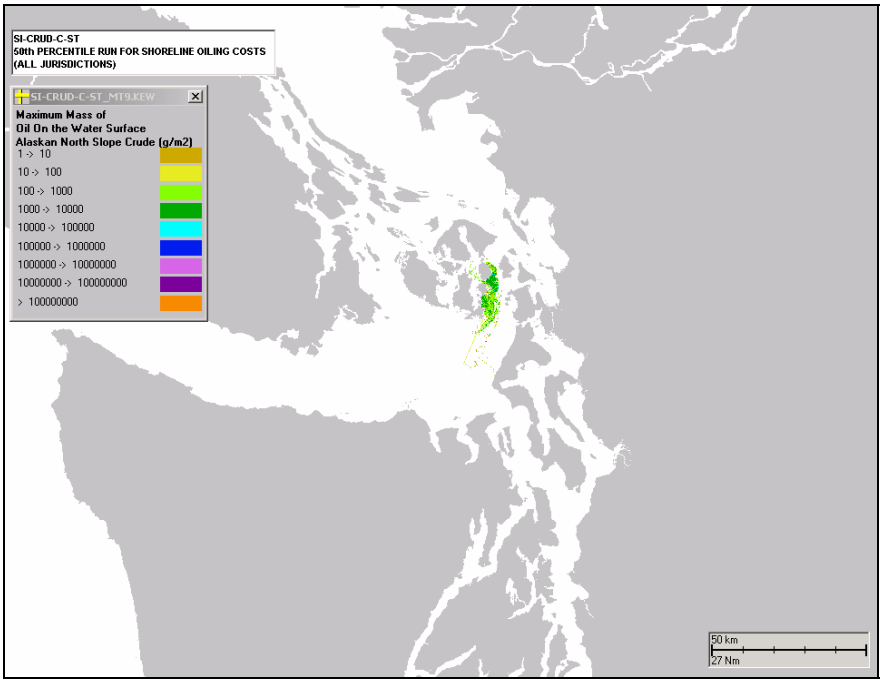

Figure XVI.E-9. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

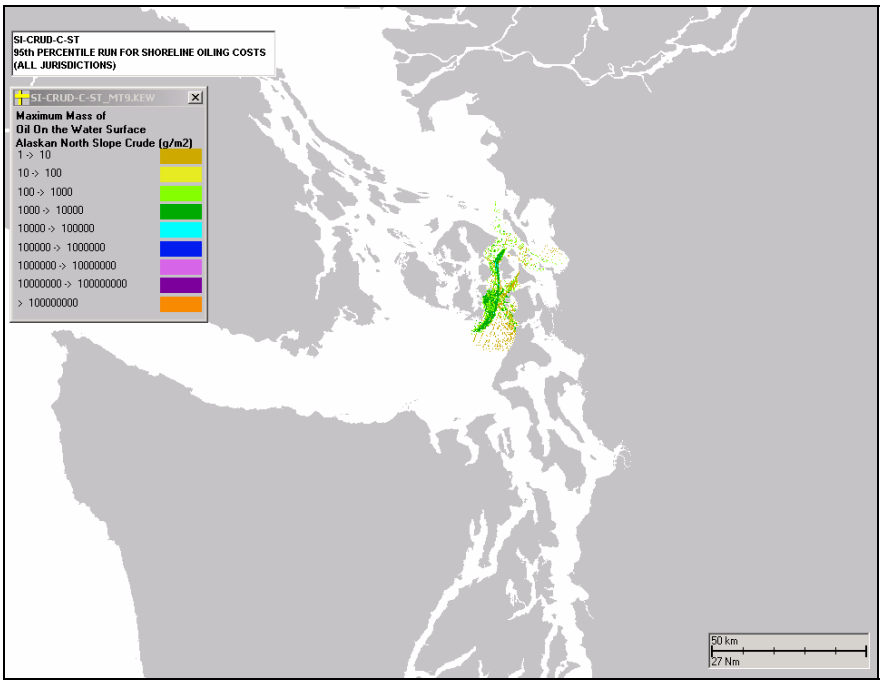

Figure XVI.E-10. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

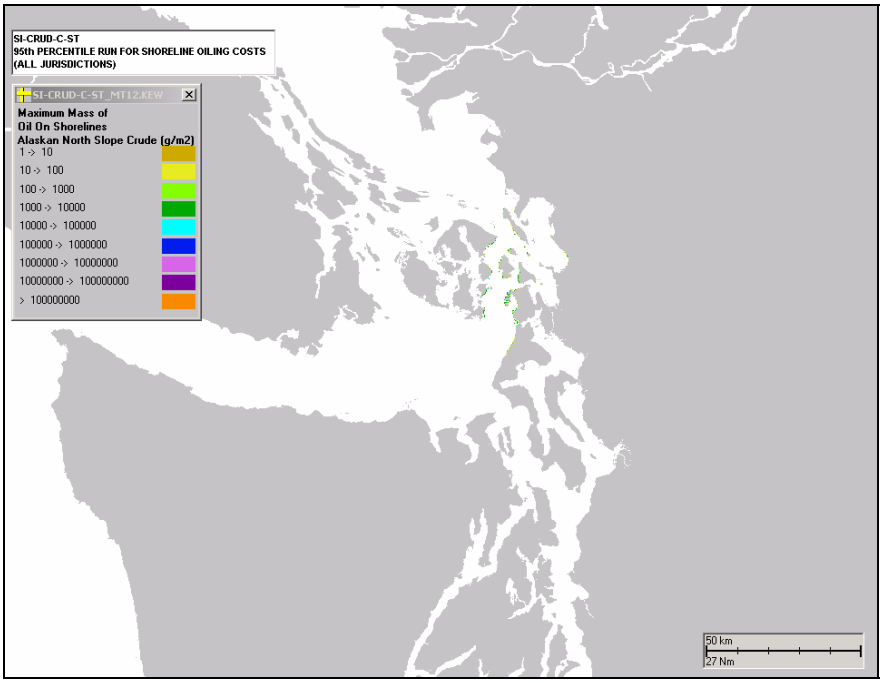

Figure XVI.E-11. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

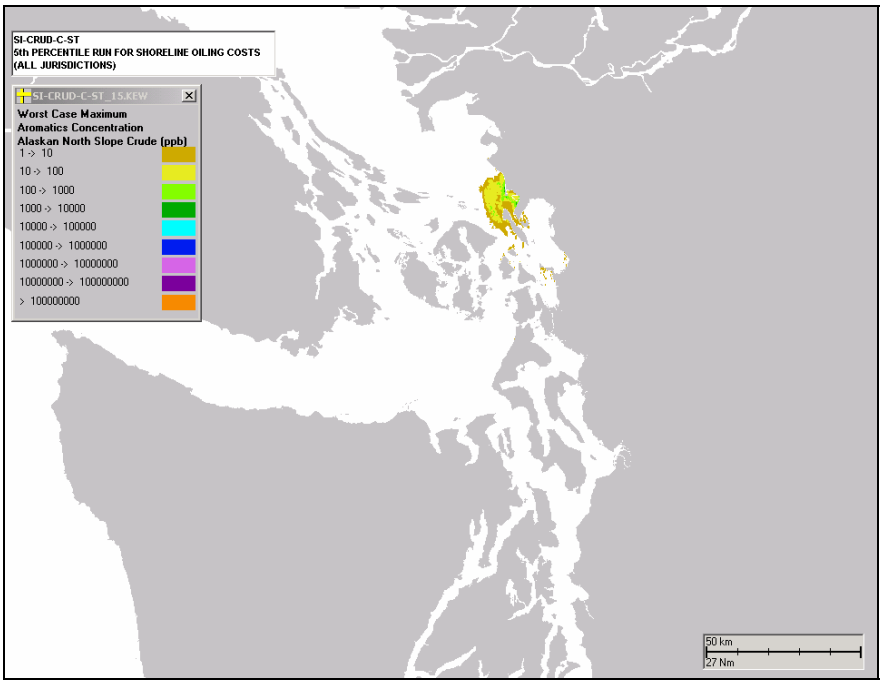

Figure XVI.E-12. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

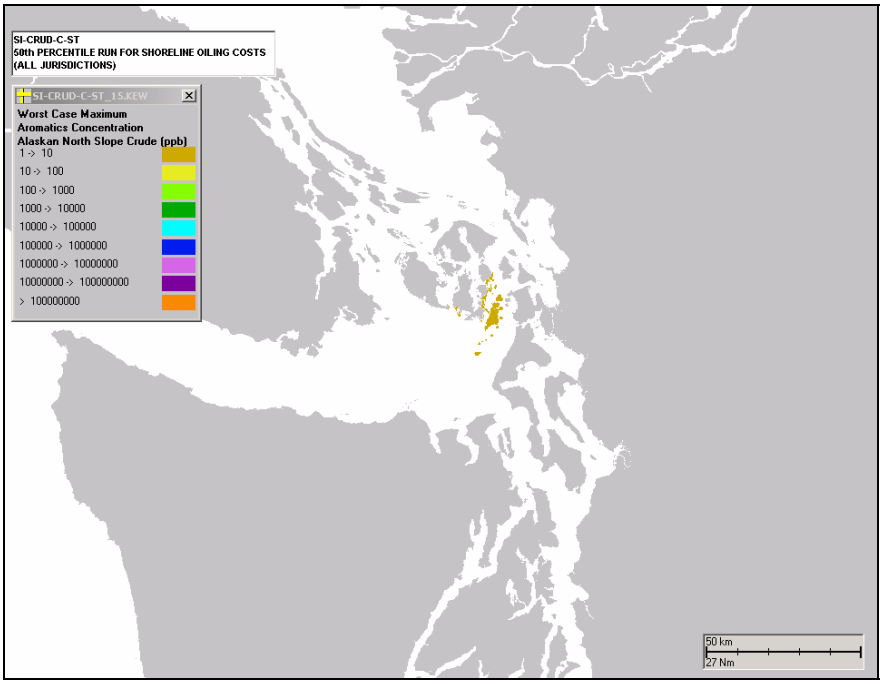

Figure XVI.E-13. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

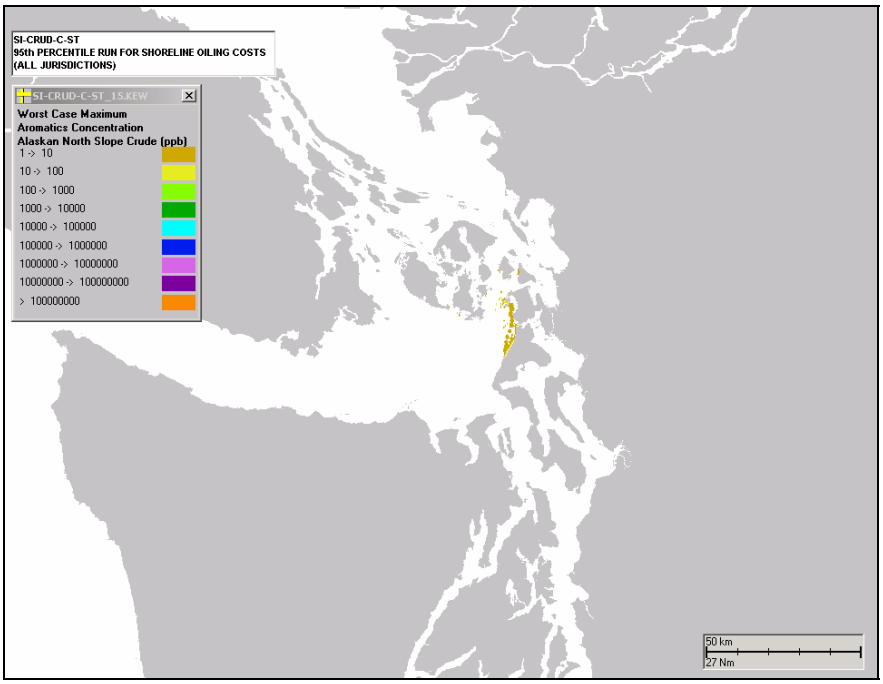

Figure XVI.E-14. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XVI.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost.

The wildlife impacts for all 100 runs were estimated from the habitat area occupied by the species group that was oiled, i.e., areas of water swept by oil > 10 g/m^2 and shoreline oiled by >100 g/m^2, using the methods described in Section 2.3 of Volume I. The actual 5th, 50th and 95th percentile results for the 100 estimates of wildlife impact were calculated by sorting only the wildlife group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact indices of a given scenario. Thus, to evaluate the various impact results for different species groups within a single scenario (i.e., different wildlife groups within a single table), the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table XVI.F-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	2,515	203	1	34	0	-	0	-	2,752	2,752	0
50th Percentile Run (based on shore cost)	2,649	214	2	106	0	-	0	-	2,971	2,971	0
95th Percentile Run (based on shore cost)	5,724	474	4	234	0	-	0	-	6,437	6,437	0
5th Percentile	1,048	79	0	28	0	-	0	-	1,208	1,208	0.14
50th Percentile	3,796	311	2	102	0	-	0	-	4,207	4,206	0.33
95th Percentile	9,075	758	4	222	0	-	1	-	10,042	10,041	0.70
Mean	4,430	365	2	107	0	-	0	-	4,904	4,904	0.38
Std Dev (SD)	2,660	225	1	63	0	-	0	-	2,911	2,911	0.19
Mean - 2SD	-	-	-	-	-	-	0	-	-	-	0.01
Mean + 2SD	9,749	815	4	234	0	-	1	-	10,726	10,725	0.75

Table XVI.F-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	3,700	303	1	40	0	-	0	-	4,044	4,044	0
50th Percentile Run (based on shore cost)	3,005	244	2	106	0	-	0	-	3,357	3,357	0
95th Percentile Run (based on shore cost)	5,559	461	4	230	0	-	0	-	6,254	6,253	0
5th Percentile	1,090	82	0	31	0	-	0	-	1,220	1,220	0.14
50th Percentile	3,833	314	2	105	0	-	0	-	4,219	4,219	0.33
95th Percentile	8,315	694	3	219	0	-	1	-	9,220	9,220	0.65
Mean	4,248	350	2	105	0	-	0	-	4,705	4,705	0.36
Std Dev (SD)	2,438	206	1	62	0	-	0	-	2,671	2,671	0.17
Mean - 2SD	-	-	-	-	-	-	0	-	-	-	0.02
Mean + 2SD	9,124	762	4	230	0	-	1	-	10,047	10,046	0.70

XVI.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because fish and invertebrate impacts are not necessarily correlated with shore cost, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run by shore cost.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the habitat area occupied by the species group that was contaminated using the methods described in Section 2.3 of Volume I. The actual 5th, 50th and 95th percentile results for the 100 estimates of fish and invertebrate impact were calculated by sorting only the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact indices of a given scenario. Thus, to evaluate the various impact results for different species groups within a single scenario (i.e., different fish and invertebrate groups within a single table), the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table XVI.G-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	-	117.6	-	-	967.5	252	1,337
50th Percentile Run (shore cost)	1,453.8	7,636.9	275.2	76.4	5,642.7	566	15,651
95th Percentile Run (shore cost)	-	146.8	-	-	985.7	1,636	2,768
5th Percentile	-	30.9	-	-	913.6	94	1,039
50th Percentile	331.5	2,042.9	48.5	14.9	2,164.6	1,101	5,703
95th Percentile	1,782.4	9,274.7	341.6	94.4	6,661.0	2,395	20,549
Mean	572.7	3,176.9	103.5	29.2	2,869.6	1,134	7,886
Std Dev (SD)	641.8	3,262.3	124.1	34.2	2,028.3	716	6,807
Mean - 2SD	-	-	-	-	-	-	-
Mean + 2SD	1,856.3	9,701.4	351.8	97.6	6,926.3	2,566	21,499

Table XVI.G-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	862.3	4,688.6	155.7	44.0	3,809.6	1,541	11,102
50th Percentile Run (shore cost)	197.8	1,377.0	21.5	7.6	1,750.5	1,478	4,833
95th Percentile Run (shore cost)	126.0	1,019.0	7.0	3.6	1,528.0	1,636	4,319
5th Percentile	-	169.7	-	-	999.9	94	1,264
50th Percentile	822.8	4,491.8	147.7	41.8	3,687.2	991	10,182
95th Percentile	2,626.7	13,482.9	512.1	140.7	9,277.5	2,235	28,275
Mean	998.7	5,345.0	185.8	51.9	4,217.7	1,087	11,887
Std Dev (SD)	882.5	4,425.9	175.4	47.9	2,751.8	648	8,931
Mean - 2SD	-	-	-	-	-	-	-
Mean + 2SD	2,763.7	14,196.8	536.6	147.6	9,721.4	2,383	29,749

XVI.H. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All weights are as wet weight; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

NRDA costs were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because impacts are not necessarily correlated with shore cost, the results for NRDA costs may not be in increasing order from 5th to 95th percentile run by shore cost.

The NRDA costs for all 100 runs were estimated from the wildlife, fish and invertebrate impact estimates for each run. The actual 5th, 50th and 95th percentile results for the 100 estimates were calculated by sorting by NRDA cost for the specific group. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for the species group (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact groups of a given scenario. Thus, to evaluate the various NRDA cost contributions for different species groups within a single scenario (i.e., different fish and invertebrate groups within a single table), the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table XVI.H-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:									
Small pelagic fish	-	1,453.8	-	-	331.5	1,782.4	572.7	-	1,856.3
Large pelagic fish	117.6	7,636.9	146.8	30.9	2,042.9	9,274.7	3,176.9	-	9,701.4
Demersal fish	-	275.2	-	-	48.5	341.6	103.5	-	351.8
Decapods	-	76.4	-	-	14.9	94.4	29.2	-	97.6
Molluscs	1,219	6,209	2,621	1,008	3,266	9,056	4,003	-	9,492
Birds:									
Waterfowl (# * kg each)	1,006	1,059	2,290	419	1,518	3,630	1,772	-	3,900
Seabirds (# * kg each)	284	300	664	110	436	1,061	511	-	1,141
Waders (# * kg each)	1	2	5	1	2	5	2	-	5
Shorebirds (# * kg each)	1	3	7	1	3	7	3	-	7
Raptors (# * kg each)	0	0	0	0	0	1	0	-	1
Other wildlife:									
Sea otters, other mammals	-	-	-	-	-	-	-	-	-
Pinnipeds	33	34	64	19	45	96	51	1	102
Cetaceans	-	-	-	-	-	-	-	-	-
Totals:									
Subtotal fish and invertebrates	1,337	15,651	2,768	1,039	5,703	20,549	7,886	-	21,499
Subtotal birds	1,292	1,365	2,966	531	1,960	4,703	2,289	-	5,053
Subtotal other wildlife	33	34	64	19	45	96	51	1	102
Total all species	2,662	17,051	5,798	1,589	7,708	25,348	10,226	1	26,654

Table XVI.H-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	5	29	11	3	14	46	18	0	48
Saltmarsh Area (acres)	13	72	28	6	34	114	46	0	120
Saltmarsh Cost (millions of 2004$)	2.5	13.5	5.3	1.2	6.4	21.3	8.6	0.02	22.5
Eelgrass Area (m2)	3	18	7	2	9	29	12	0	30
Eelgrass Area (acres)	8	45	18	4	21	71	29	0	75
Eelgrass Cost (millions of 2004$)	1.0	5.4	2.1	0.5	2.5	8.5	3.4	0.01	8.9

Table XVI.H-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:									
Small pelagic fish	862.3	197.8	126.0	-	822.8	2,626.7	998.7	-	2,763.7
Large pelagic fish	4,688.6	1,377.0	1,019.0	169.7	4,491.8	13,482.9	5,345.0	-	14,196.8
Demersal fish	155.7	21.5	7.0	-	147.7	512.1	185.8	-	536.6
Decapods	44.0	7.6	3.6	-	41.8	140.7	51.9	-	147.6
Molluscs	5,351	3,229	3,164	1,094	4,678	11,512	5,305	-	12,104
Birds:									
Waterfowl (# * kg each)	1,480	1,202	2,224	436	1,533	3,326	1,699	-	3,650
Seabirds (# * kg each)	424	342	645	115	440	971	489	-	1,067
Waders (# * kg each)	1	2	5	1	2	5	2	-	5
Shorebirds (# * kg each)	1	3	7	1	3	7	3	-	7
Raptors (# * kg each)	0	0	0	0	0	0	0	-	1
Other wildlife:									
Sea otters, other mammals	-	-	-	-	-	-	-	-	-
Pinnipeds	44	38	62	20	46	88	50	3	96
Cetaceans	-	-	-	-	-	-	-	-	-
Totals:									
Subtotal fish and invertebrates	11,102	4,833	4,319	1,264	10,182	28,275	11,887	-	29,749
Subtotal birds	1,907	1,550	2,880	553	1,979	4,309	2,194	-	4,729
Subtotal other wildlife	44	38	62	20	46	88	50	3	96
Total all species	13,053	6,421	7,262	1,837	12,207	32,672	14,131	3	34,574

Table XVI.H-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	22.0	10.4	13.8	3.1	21.5	57.7	24.9	0.2	61.4
Saltmarsh Area (acres)	54.3	25.7	34.2	7.5	53.2	142.7	61.6	0.5	151.8
Saltmarsh Cost (millions of 2004$)	10.2	4.8	6.4	1.4	10.0	26.7	11.5	0.09	28.4
Eelgrass Area (m2)	13.7	6.5	8.6	1.9	13.5	36.1	15.6	0.1	38.4
Eelgrass Area (acres)	33.9	16.0	21.3	4.7	33.2	89.1	38.5	0.3	94.8
Eelgrass Cost (millions of 2004$)	4.0	1.9	2.5	0.6	4.0	10.6	4.6	0.04	11.3

XVI.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table XVI.I-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	23.638	25.539	22.689	21.738	23.638	25.538	23.716	20.490	26.942
% Removed by 24 hours	9.2	18.5	3.1	3.6	13.8	23.1	13.7	-	27.6
Compensation (millions $)	58.6	56.9	60.0	57.2	55.6	53.6	55.9	47.7	64.1

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Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	21.738	23.638	22.689	21.738	23.639	25.538	23.744	20.539	26.949
% Removed by 24 hours	20.8	6.2	3.1	3.5	13.8	23.1	0.0	0.0	0.0
Compensation (millions $)	47.0	60.6	60.0	57.2	55.6	53.6	64.8	56.1	73.6

Phase 1: Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XVII: Results of Alternative Response Scenarios for San Juan Islands – Alaskan North Slope Crude

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XVII.A. INTRODUCTION

The results of the alternate response scenarios for the San Juan Islands – Alaskan North Slope Crude are contained in this volume. There were two main stochastic scenarios for this location, oil type and spill volume:

1. Mechanical removal under Washington state Caps standards
2. Mechanical removal under Washington state Caps standards plus dispersant application

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps). The geographic data, current data, and model inputs are the same for each of the alternate response scenarios as was described in Volume XV for the main stochastic scenarios. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup. The figures and tables in this volume summarize the model results for the alternate response scenarios, as well as corresponding 3 runs (of the same start date and time) from the main response scenario.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs (termed the base case runs). The 100 main stochastic scenario runs of the base case scenario were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shoreline cleanup costs are presented. Because each impact index is not necessarily correlated with shoreline cleanup cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th, and 95th percentile runs for shoreline cleanup costs using the base case stochastic scenario were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. Note that in Section II.2, the individual runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs (and their dates and times) varied from one stochastic scenario to the next, and for the alternate scenarios other than the base case, they are not the same runs as those reported in this volume. Thus, in this volume, the alternate response scenarios are labeled with "-base". This indicates the base case 5th, 50th, and 95th percentile runs for shoreline costs were rerun with the same start date and time but with the alternate response. (For scenarios other than the base case, the 5th, 50th, and 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this volume.)

In this volume (Section B), the results for the 5th, 50th, and 95th percentile runs based on shoreline oiling costs (using the base case scenario for sorting) are shown, as plots of the following measures of exposure:

- Water surface exposure to floating hydrocarbons (g/m^2)
- Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill

These figures are followed by additional sections with tables of the wildlife, fish and invertebrate impacts and the NRDA costs (damages).

XVII.B. EXPOSURE FOR INDIVIDUAL MODEL RUNS

XVII.B.1. No Removal, Scenario SI-Crud-N

The response for this scenario includes the use of protection booms only, and no mechanical removal using the three runs as identified as 5th, 50th and 95th percentile in the base case.

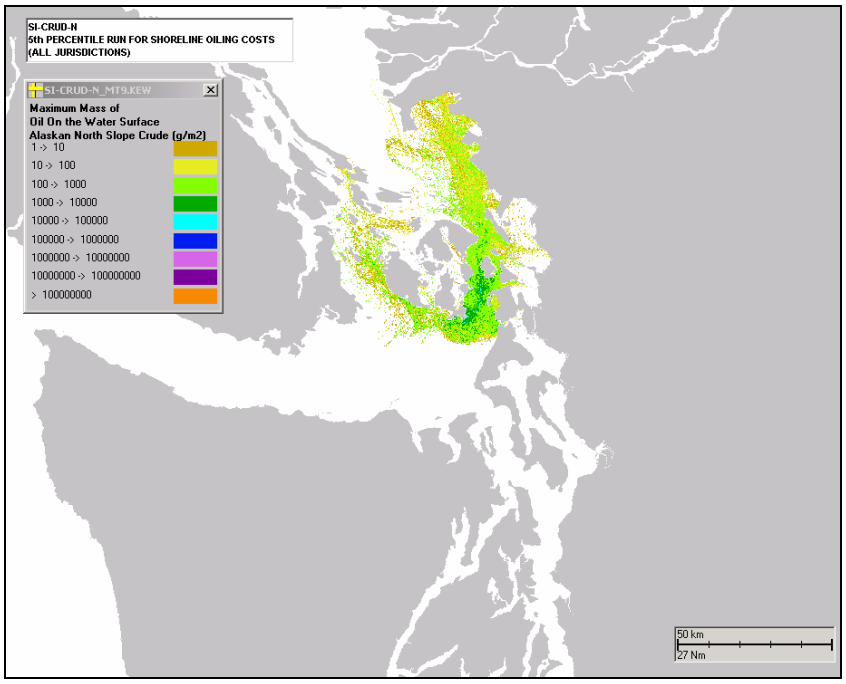


Figure XVII.B.1-1. San Juan Islands, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

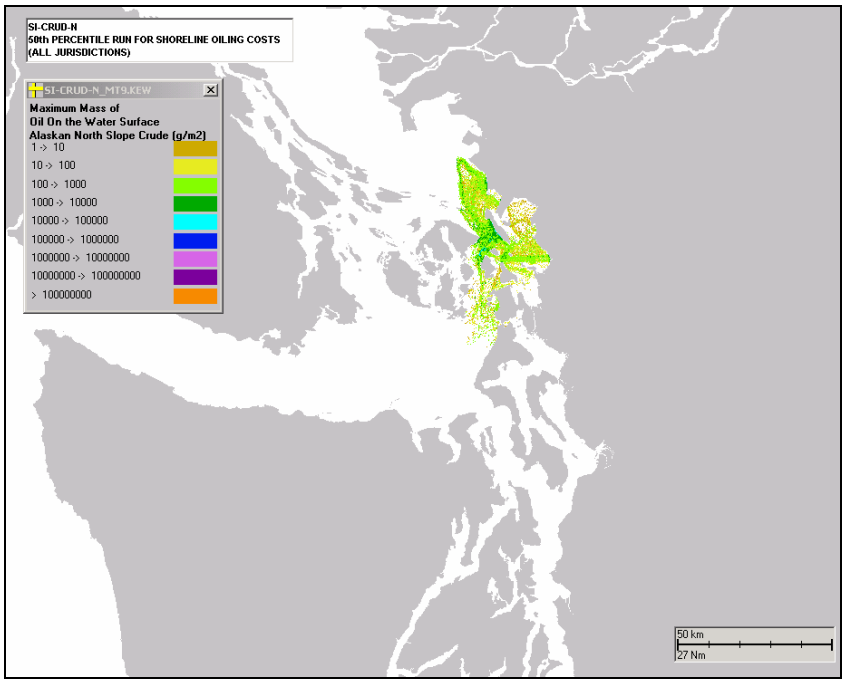


Figure XVII.B.1-2. San Juan Islands, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

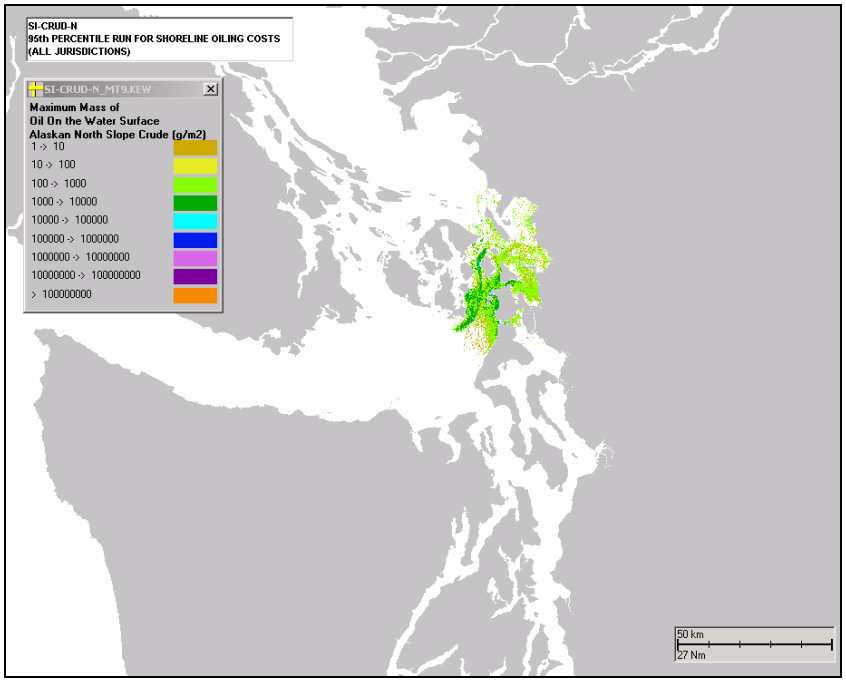


Figure XVII.B.1-3. San Juan Islands, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

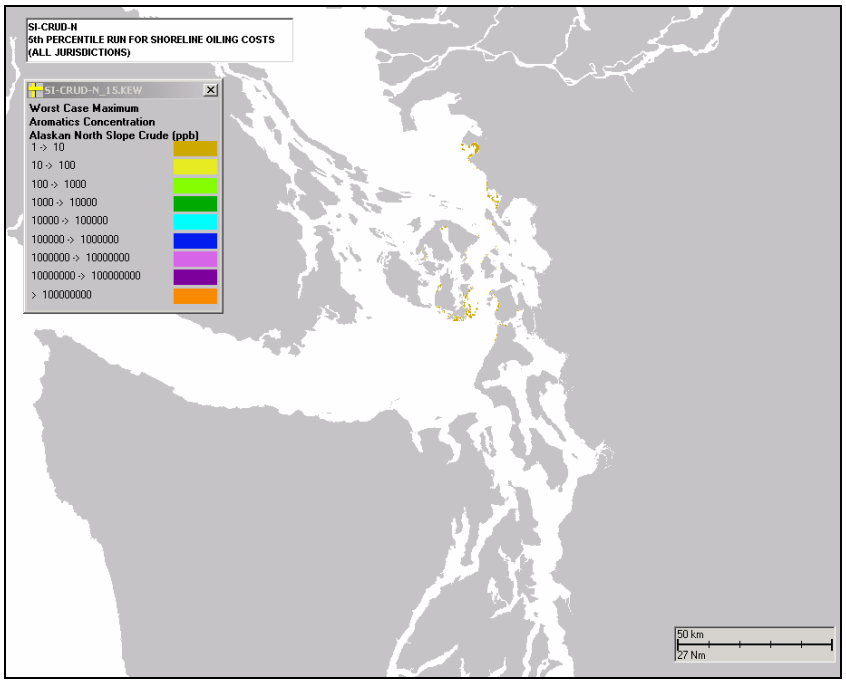


Figure XVII.B.1-4. San Juan Islands, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

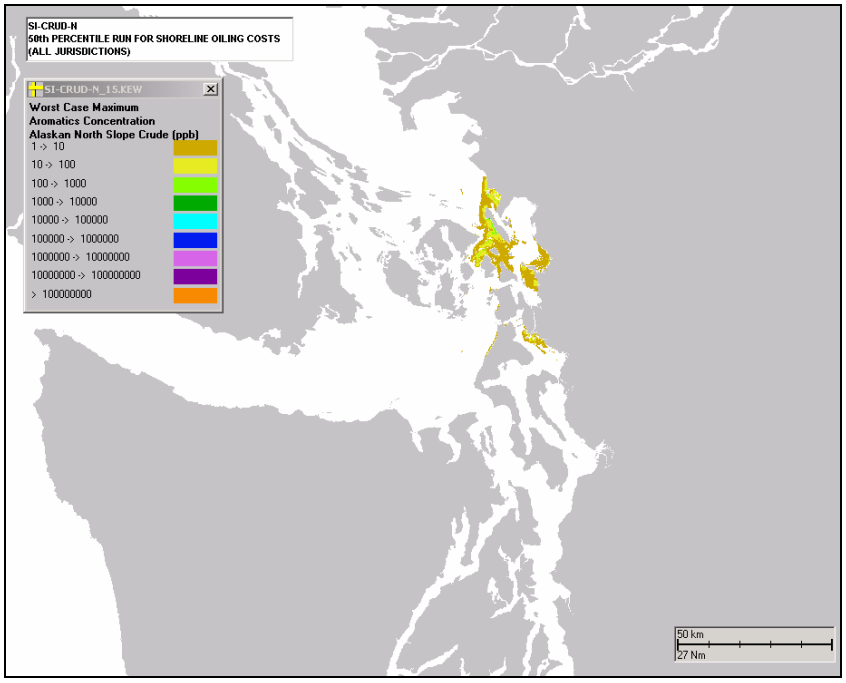


Figure XVII.B.1-5. San Juan Islands, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

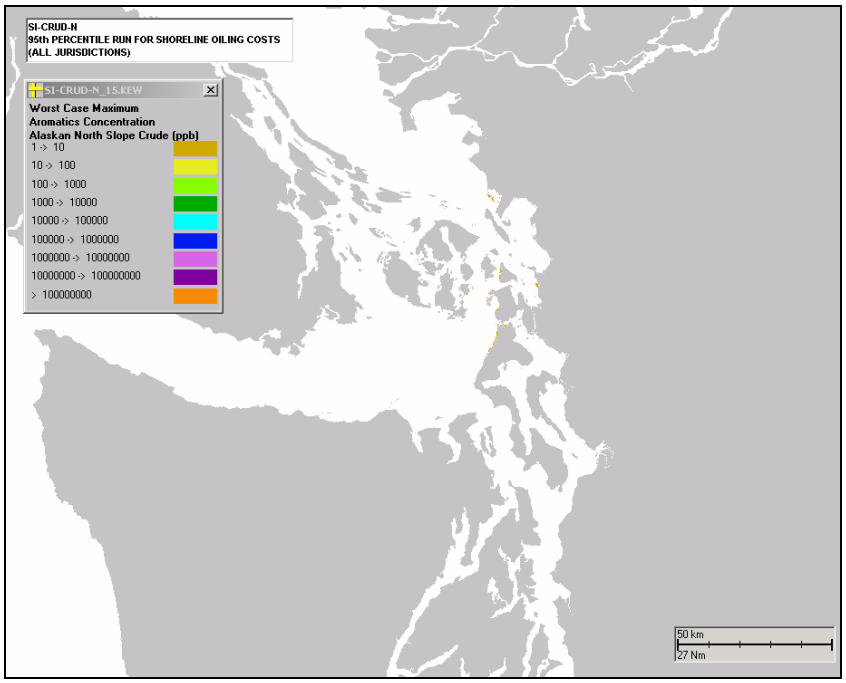


Figure XVII.B.1-6. San Juan Islands, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XVII.B.2. State Mechanical Removal, Scenario SI-Crud-R-ST

The response for this scenario includes the use of mechanical removal based on state standards and protection booming. These results as the same as those shown in Volume XVI, Section XVI.E. This scenario was used to identify the 5th, 50th and 95th percentile based on total shoreline cost, referred to as the "base case".

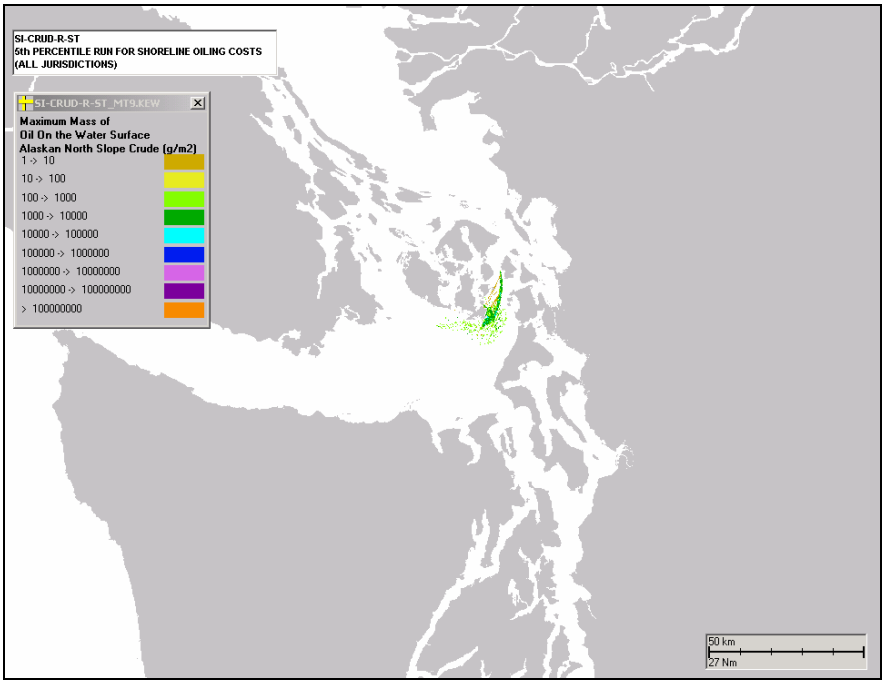


Figure XVII.B.2-1. San Juan Islands, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

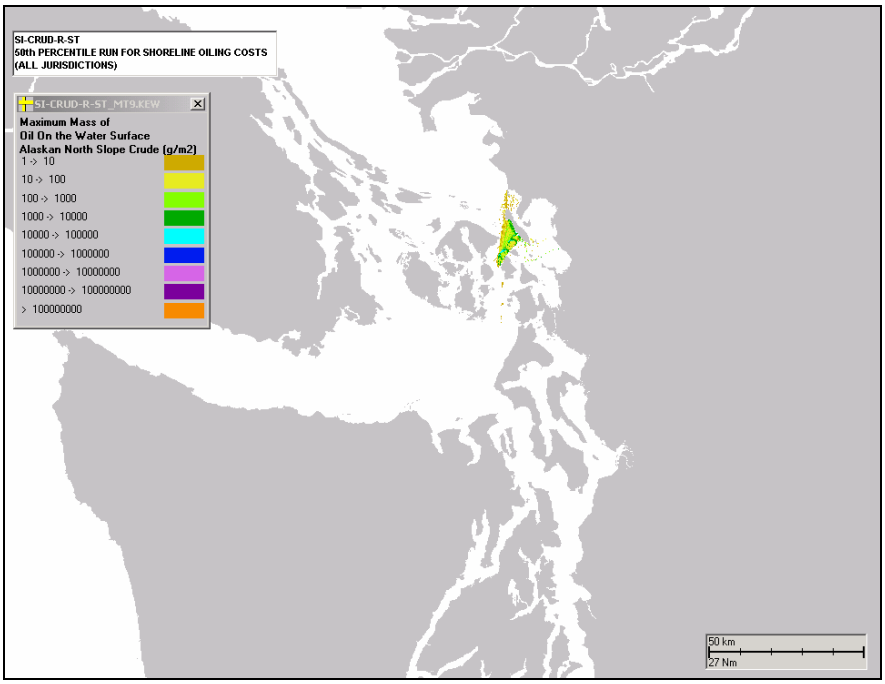


Figure XVII. B.2-2. San Juan Islands, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

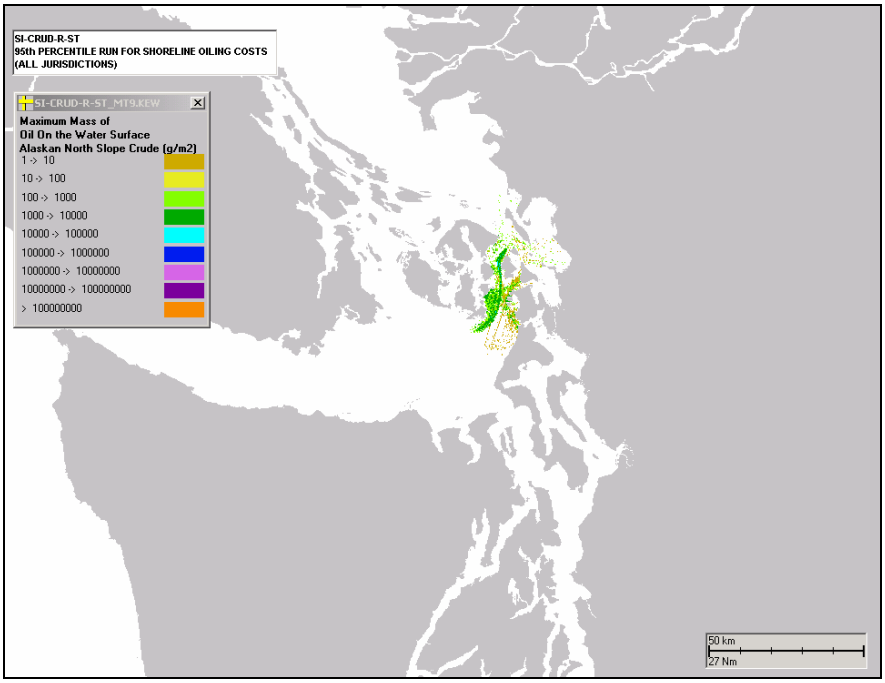


Figure XVII. B.2-3. San Juan Islands, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

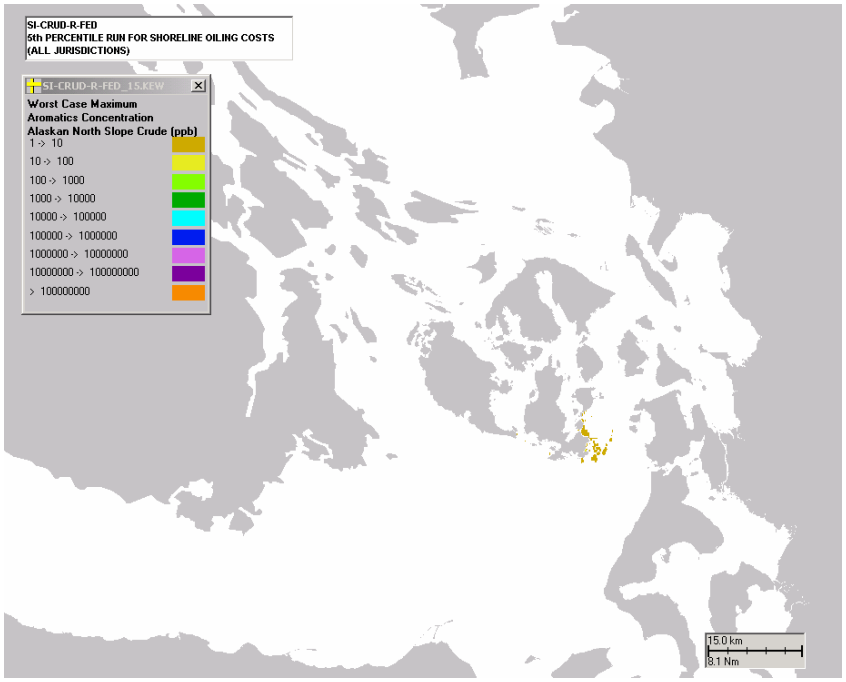


Figure XVII. B.2-4. San Juan Islands, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

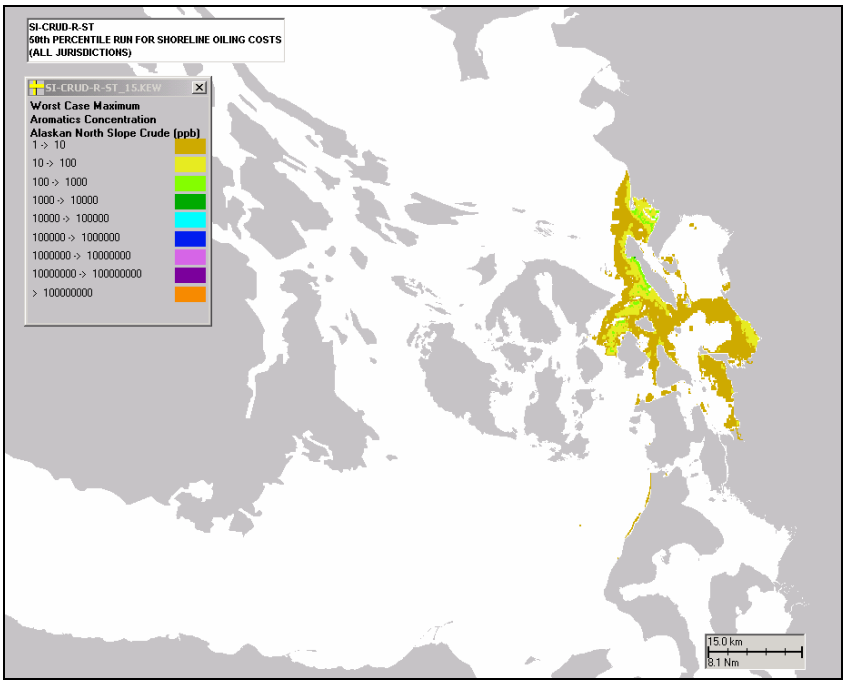


Figure XVII. B.2-5. San Juan Islands, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

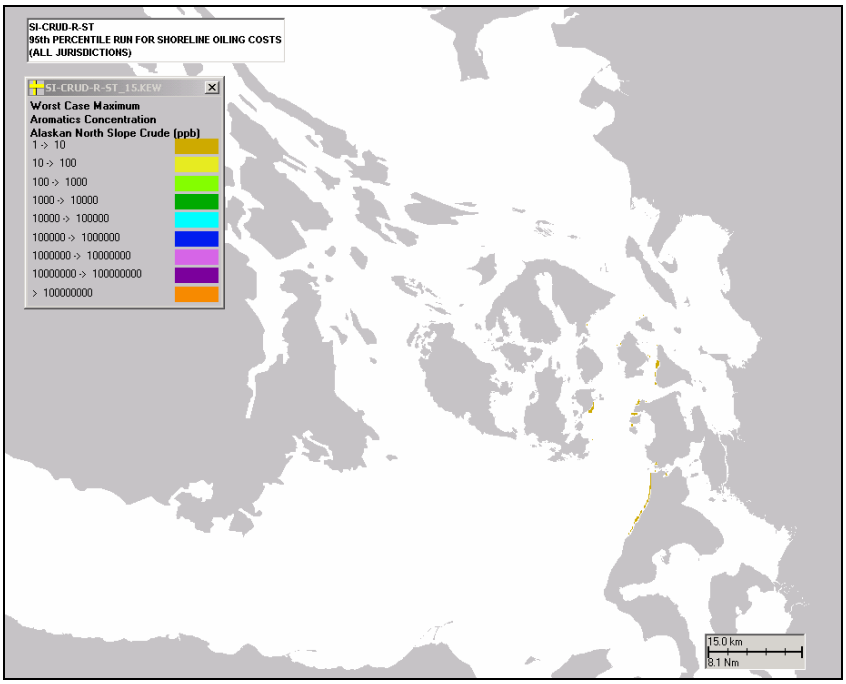


Figure XVII. B.2-6. San Juan Islands, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XVII.B.3. Federal Mechanical Removal, Scenario SI-Crud-R-Fed

The response for this scenario includes the use of mechanical removal based on federal standards and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case.

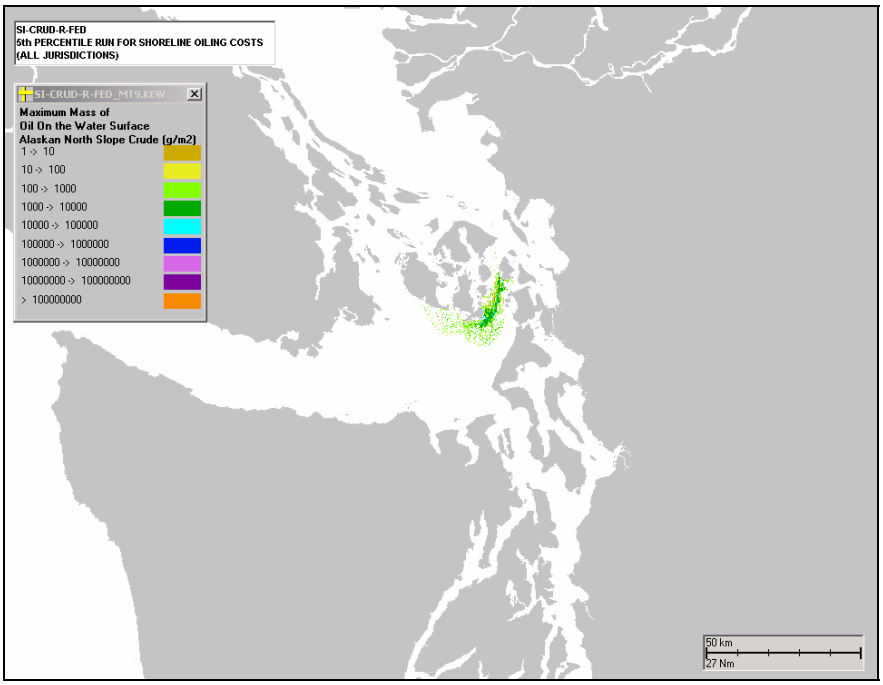


Figure XVII.B.3-1. San Juan Islands, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

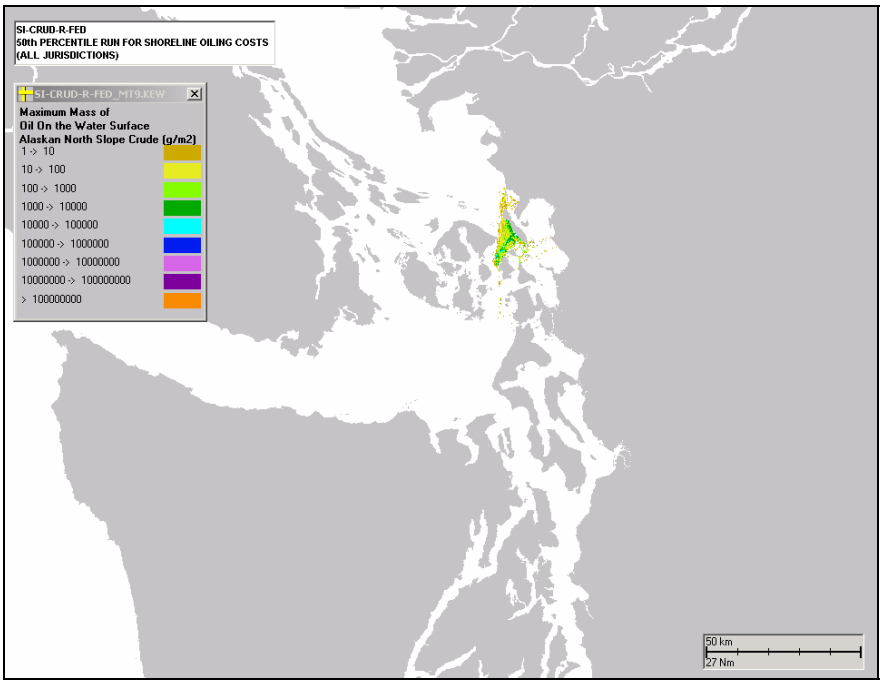


Figure XVII. B.3-2. San Juan Islands, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

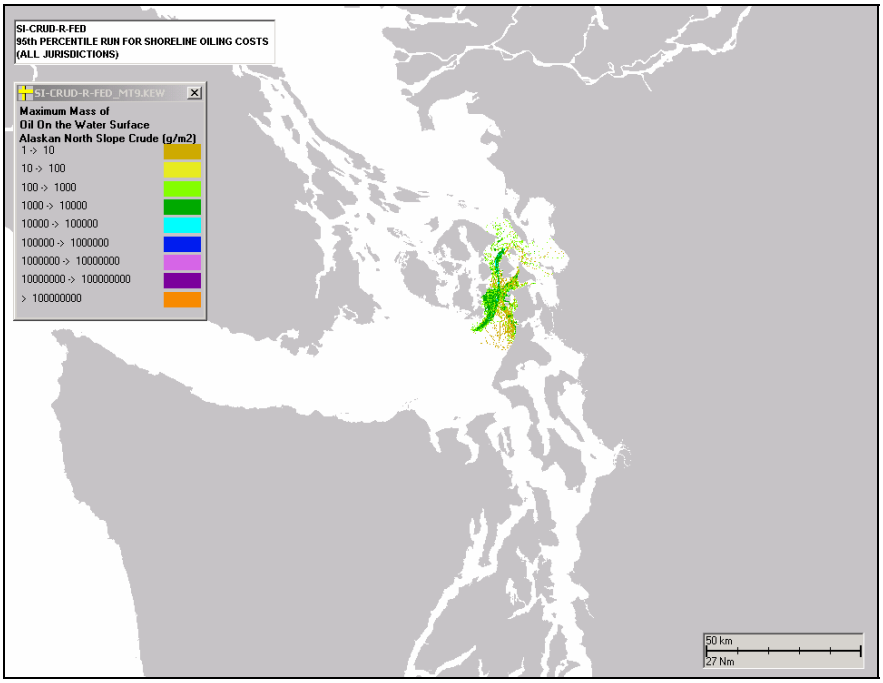


Figure XVII. B.3-3. San Juan Islands, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

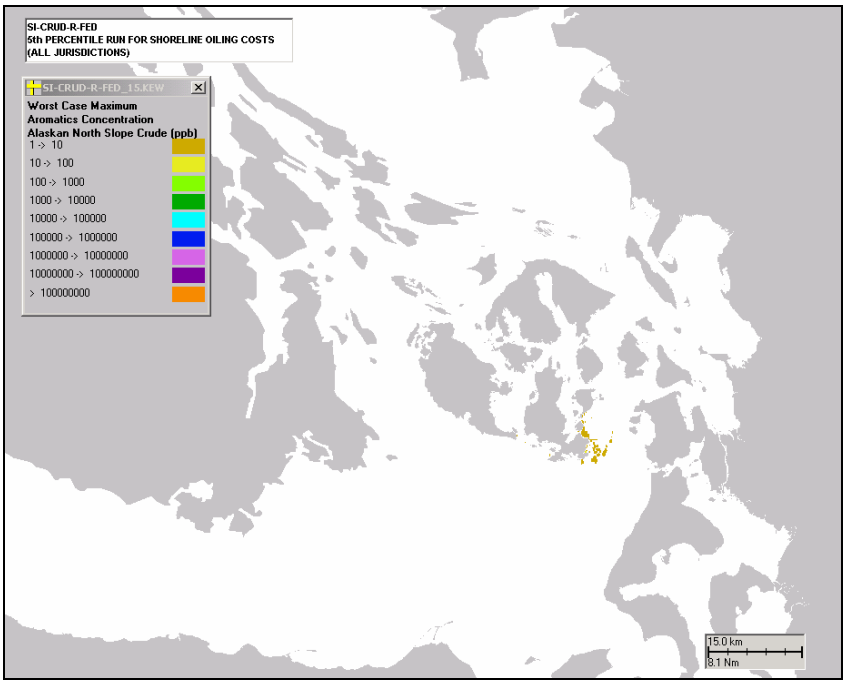


Figure XVII.B.3-4. San Juan Islands, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

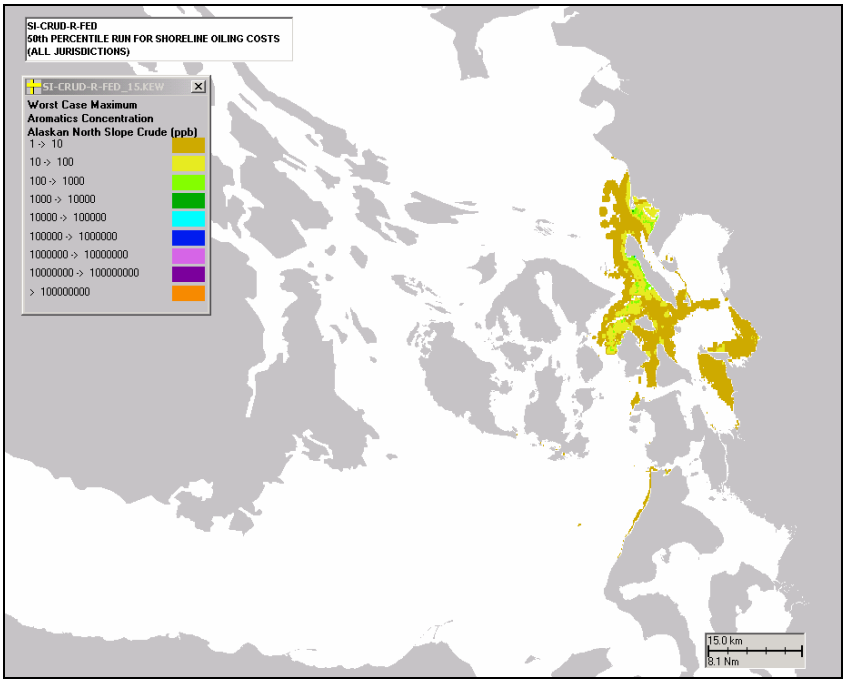


Figure XVII.B.3-5. San Juan Islands, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

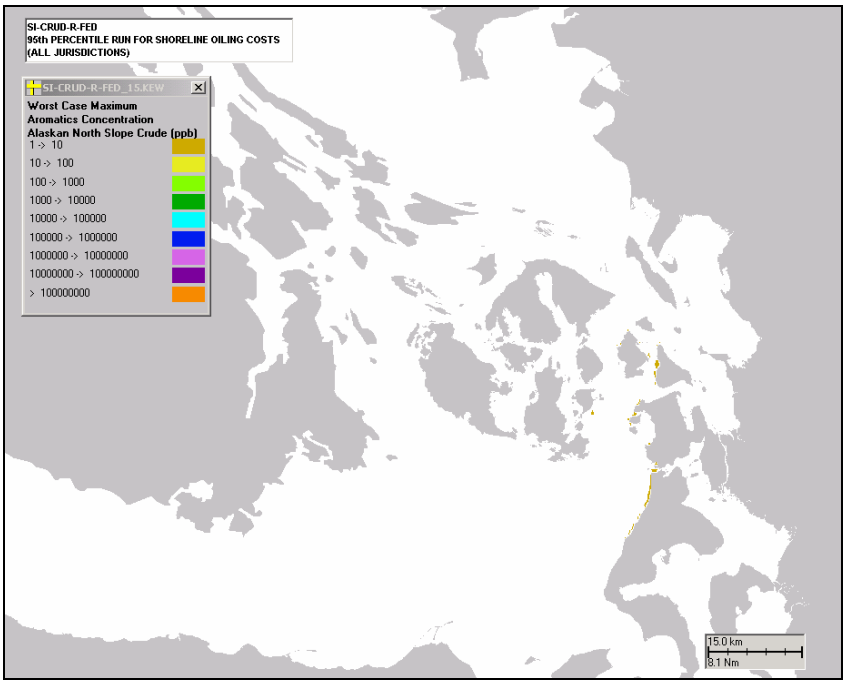


Figure XVII.B.3-6. San Juan Islands, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XVII.B.4. 3rd Alternative Mechanical Removal, Scenario SI-Crud-R-3

The response for this scenario includes the use of mechanical removal based on the 3rd alternative standards and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case.

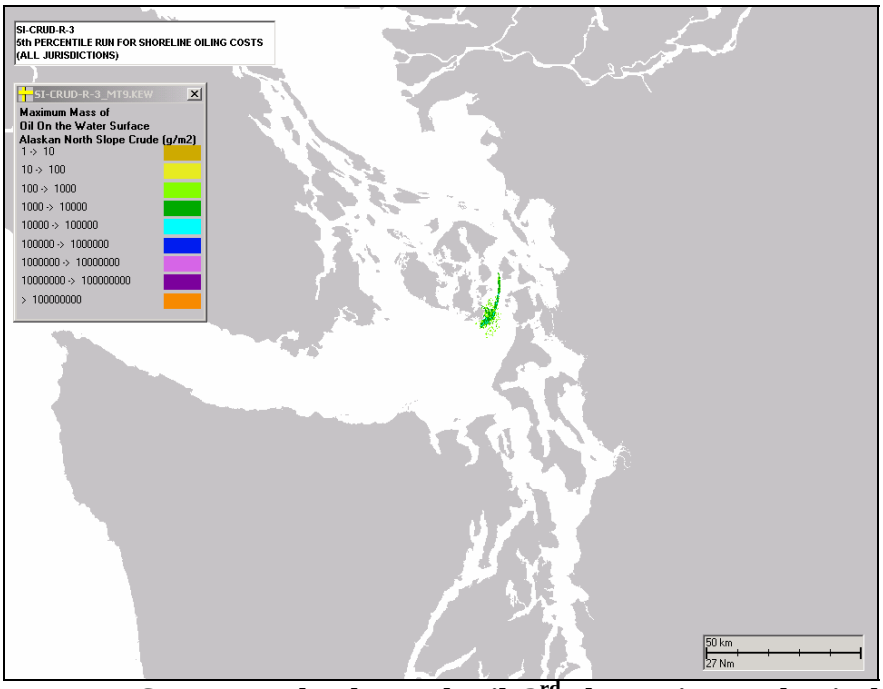


Figure XVII.B.4-1. San Juan Islands, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

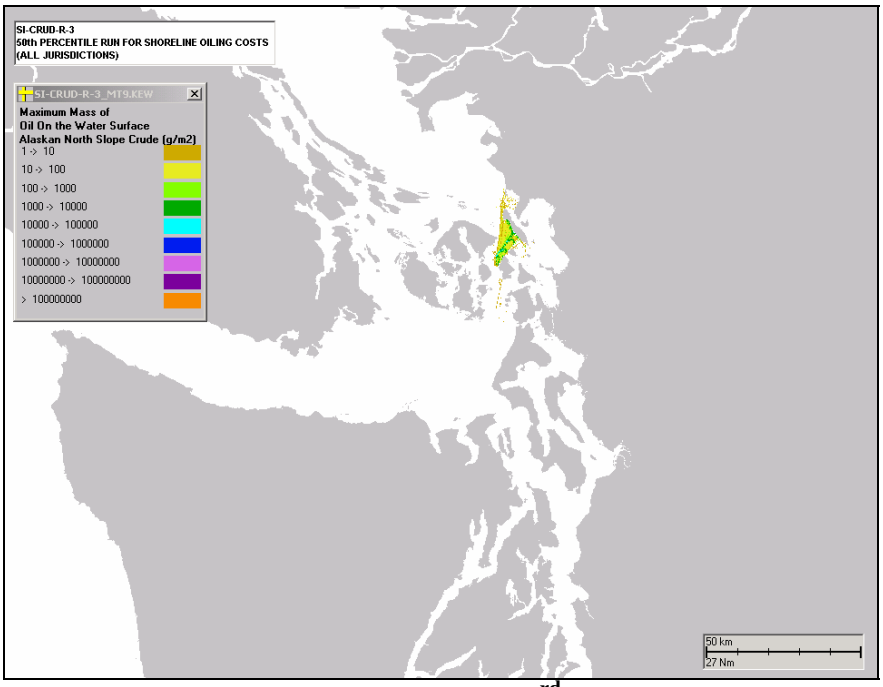


Figure XVII.B.4-2. San Juan Islands, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

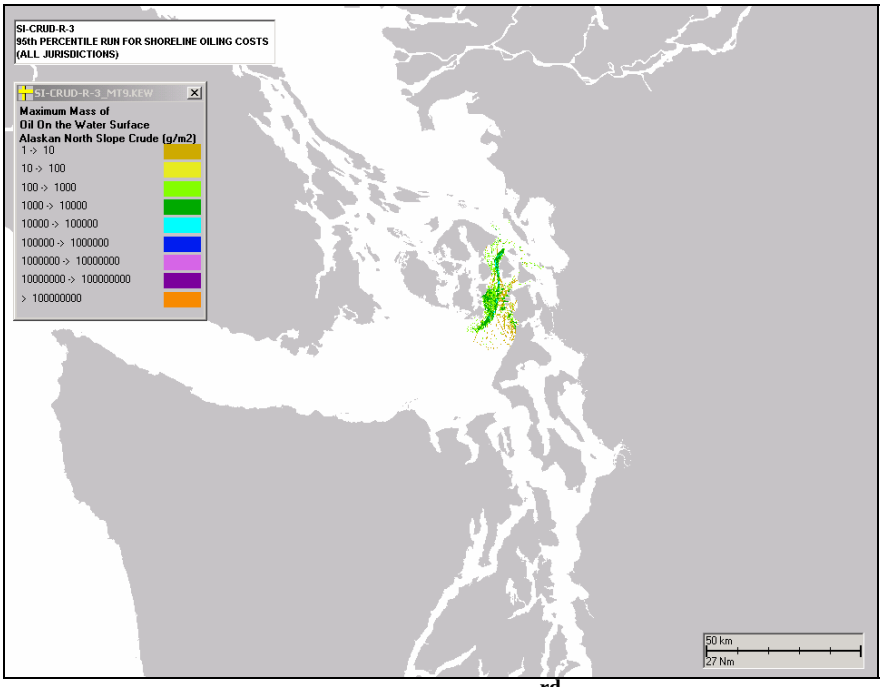


Figure XVII.B.4-3. San Juan Islands, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

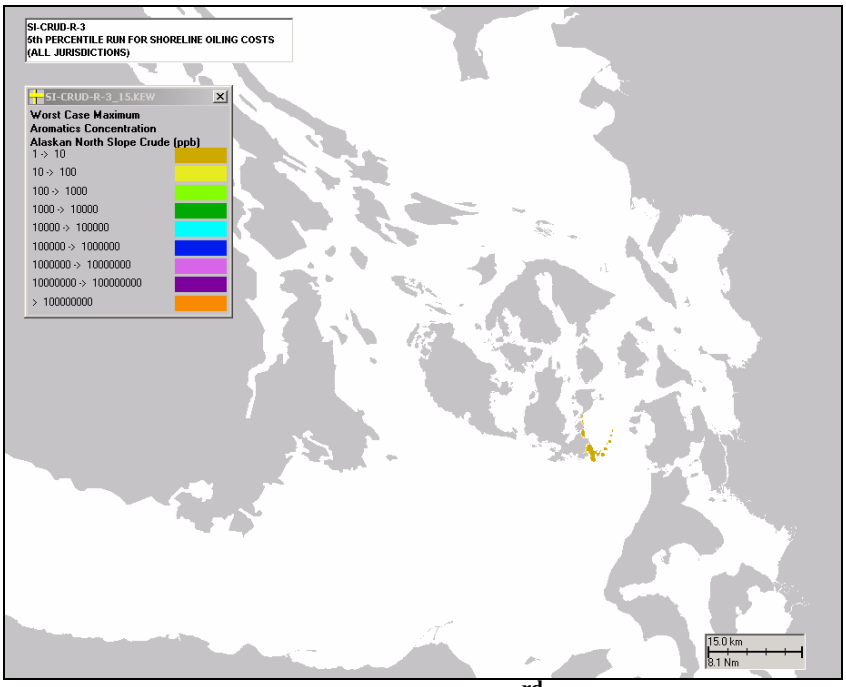


Figure XVII.B.4-4. San Juan Islands, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

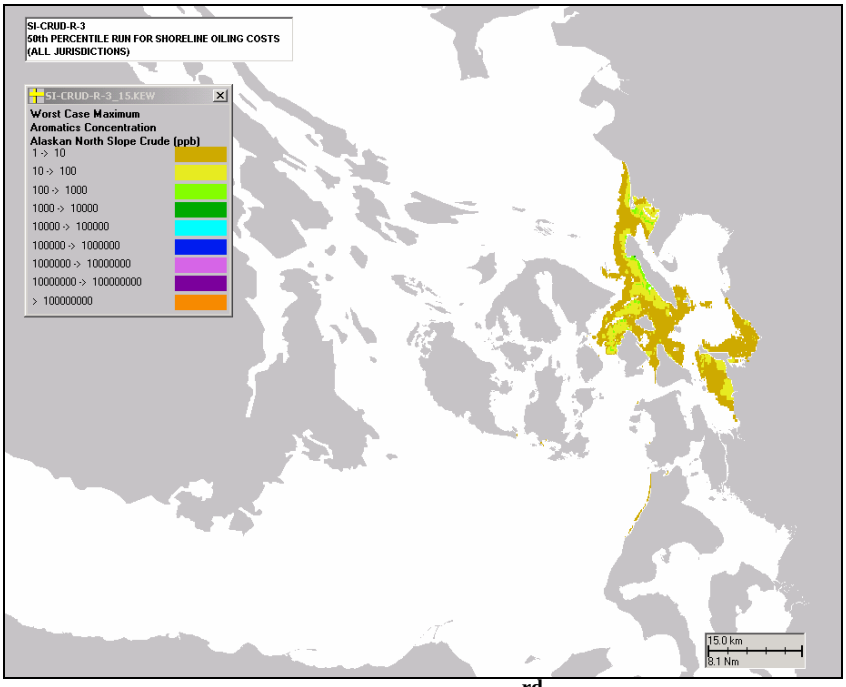


Figure XVII.B.4-5. San Juan Islands, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

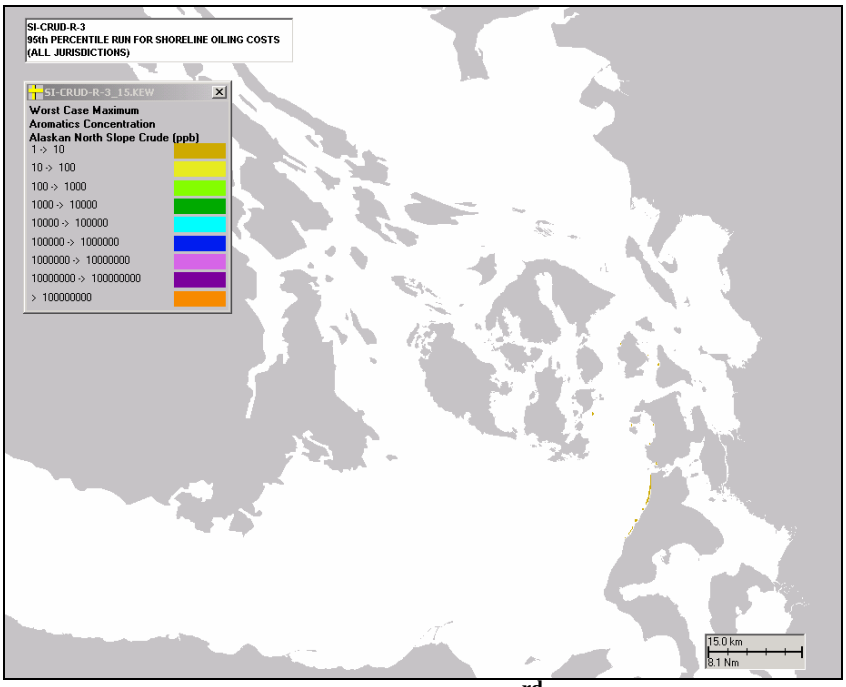


Figure XVII.B.4-6. San Juan Islands, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XVII.B.5. State Mechanical Removal and dispersant, Scenario SI-Crud-C-ST

The response for this scenario includes the use of mechanical removal based on state standards, dispersant and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case where no dispersant was applied.

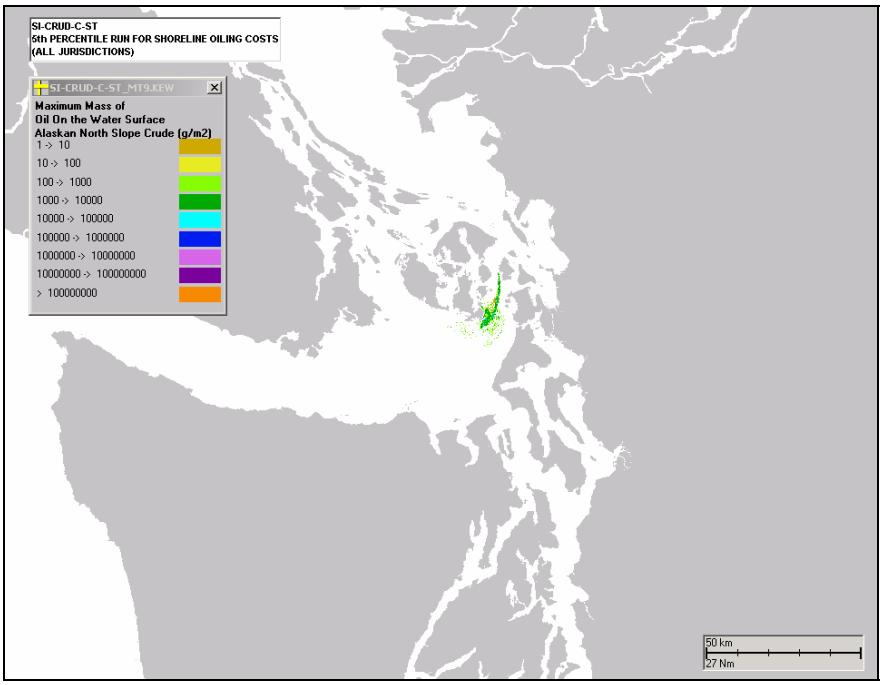


Figure XVII.B.5-1. San Juan Islands, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

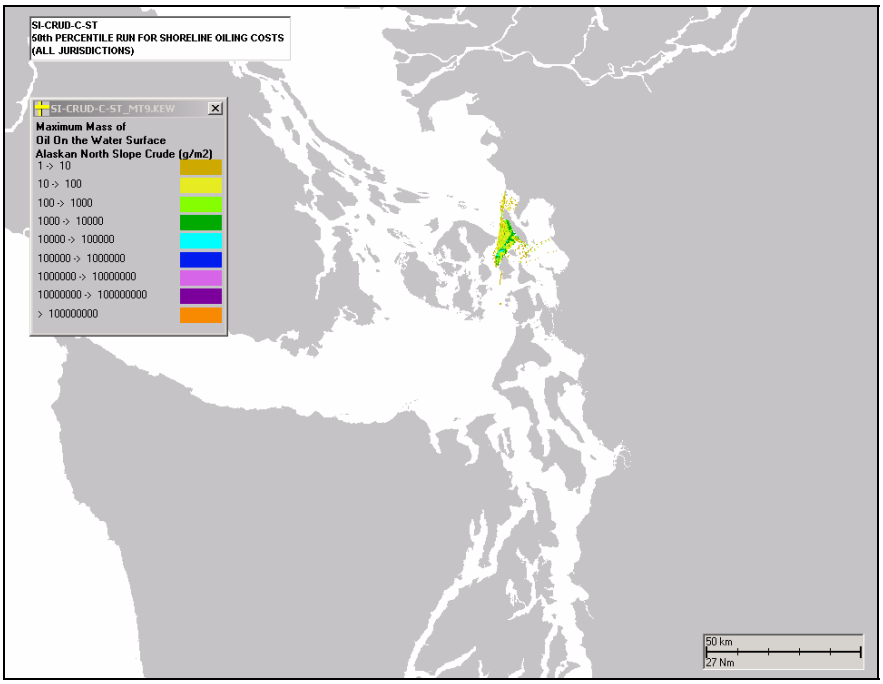


Figure XVII.B.5-2. San Juan Islands, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

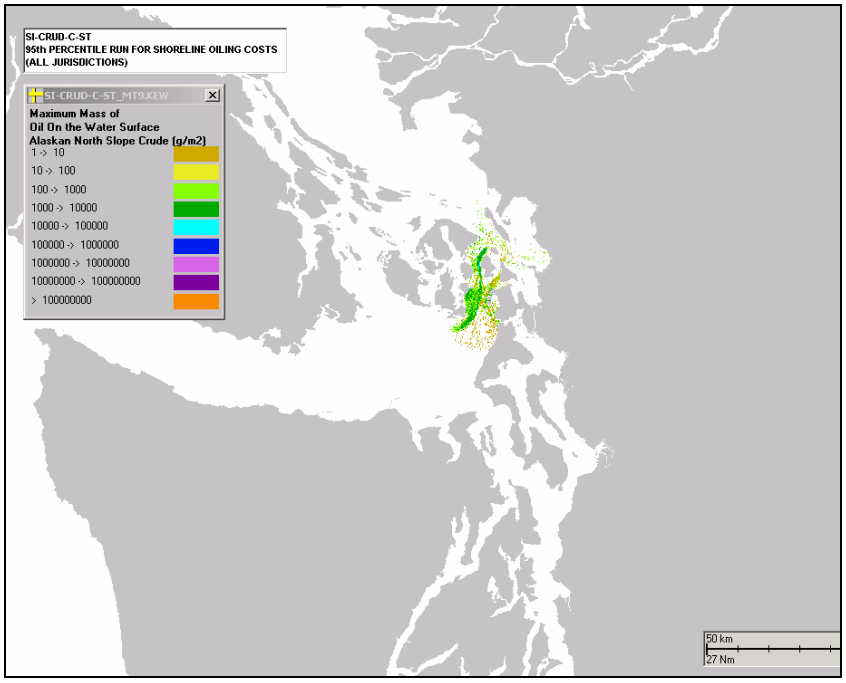


Figure XVII.B.5-3. San Juan Islands, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

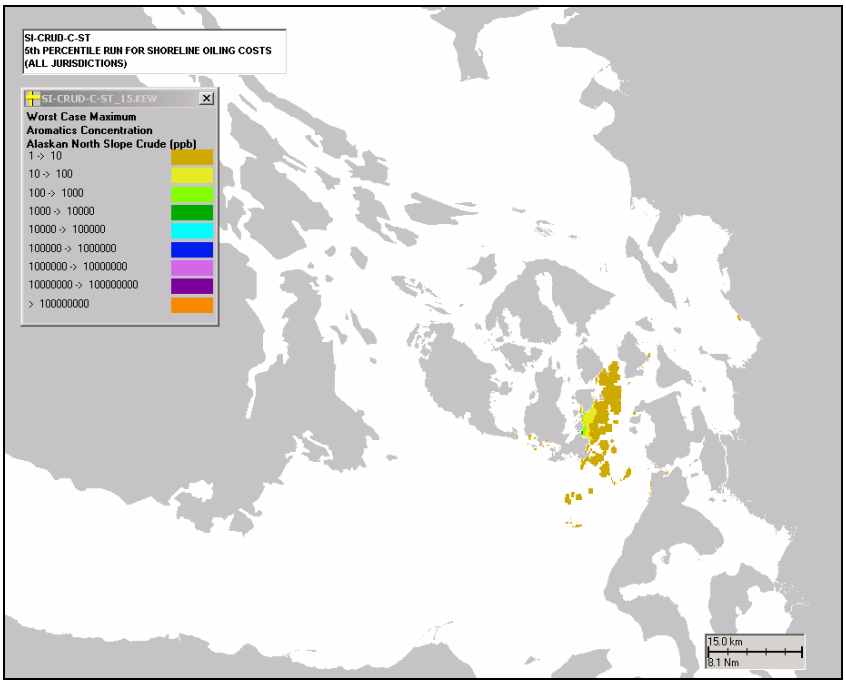


Figure XVII.B.5-4. San Juan Islands, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

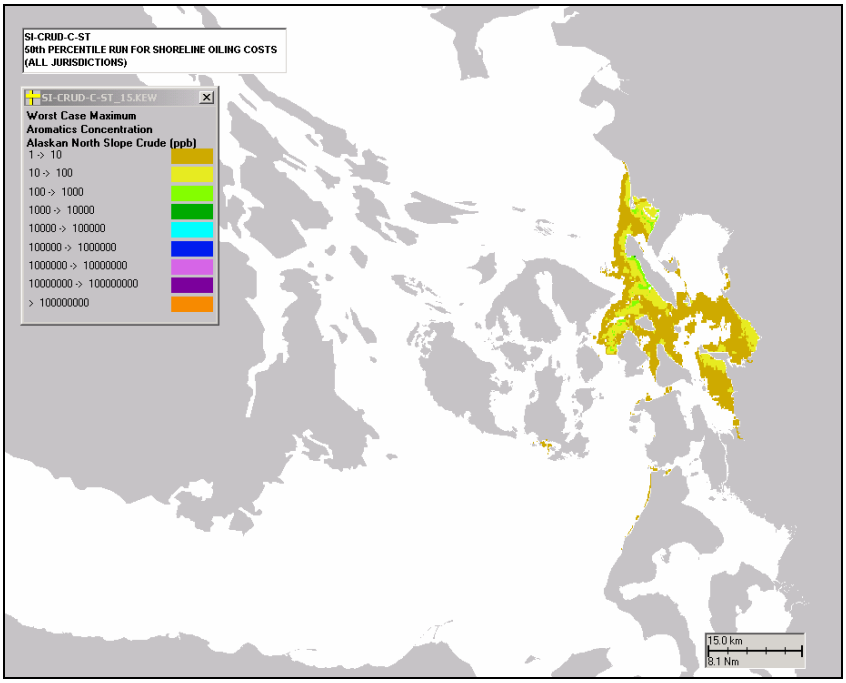


Figure XVII.B.5-5. San Juan Islands, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

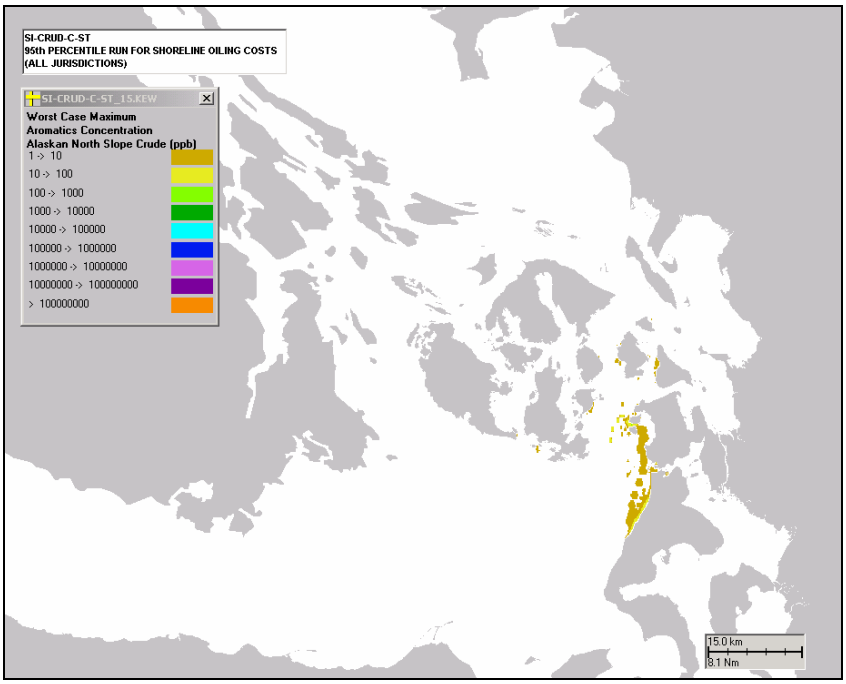


Figure XVII.B.5-6. San Juan Islands, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XVII.B.6. Federal Mechanical Removal and dispersant, Scenario SI-Crud-C-Fed

The response for this scenario includes the use of mechanical removal based on federal standards, dispersant and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case where no dispersant was applied.

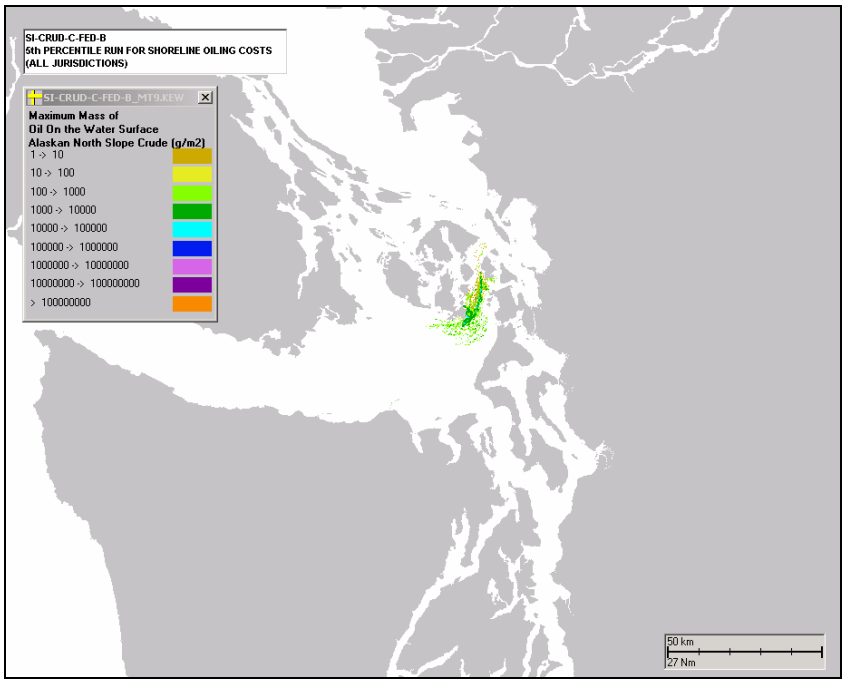


Figure XVII.B.6-1. San Juan Islands, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

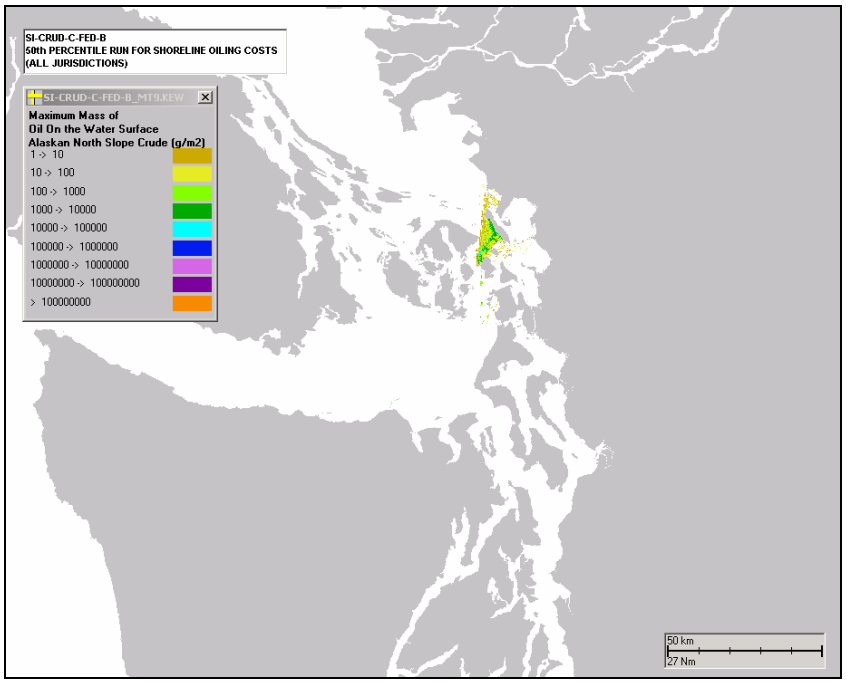


Figure XVII.B.6-2. San Juan Islands, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

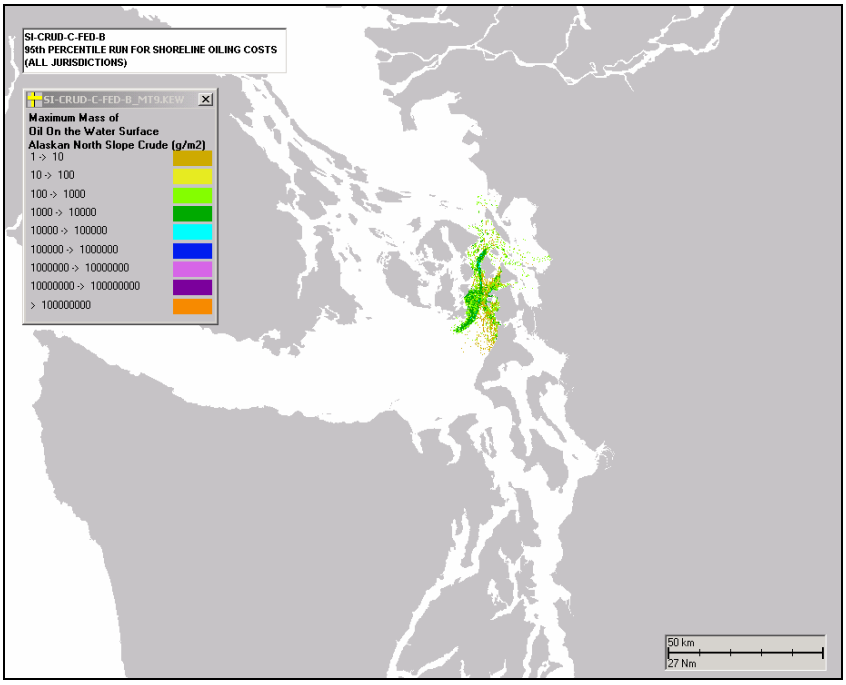


Figure XVII.B.6-3. San Juan Islands, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

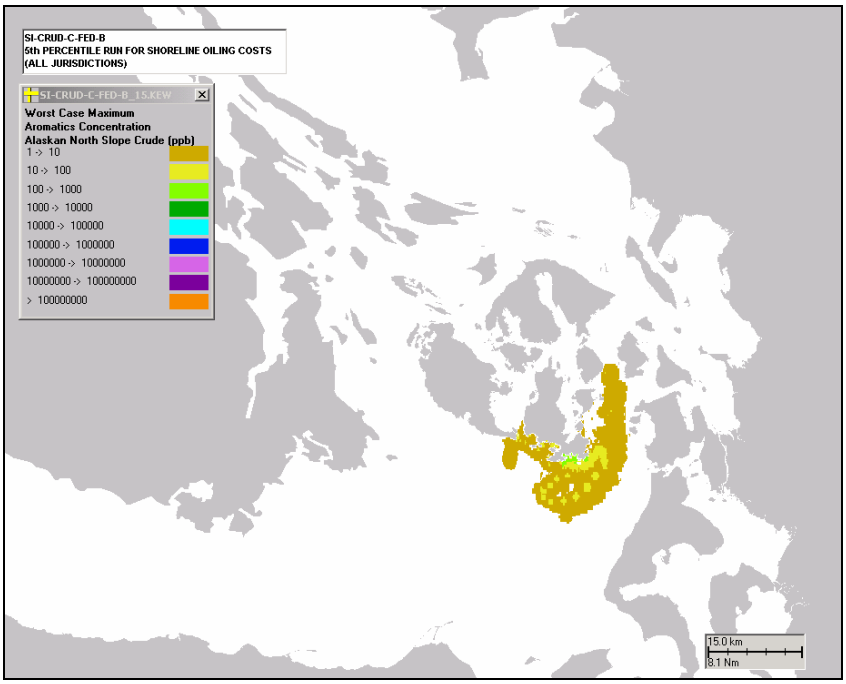


Figure XVII.B.6-4. San Juan Islands, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

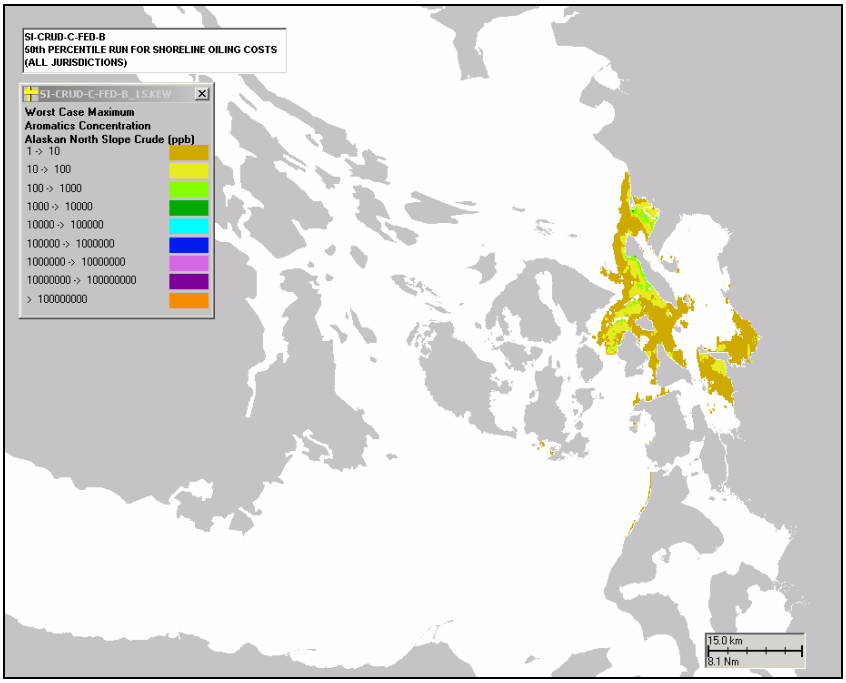


Figure XVII.B.6-5. San Juan Islands, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

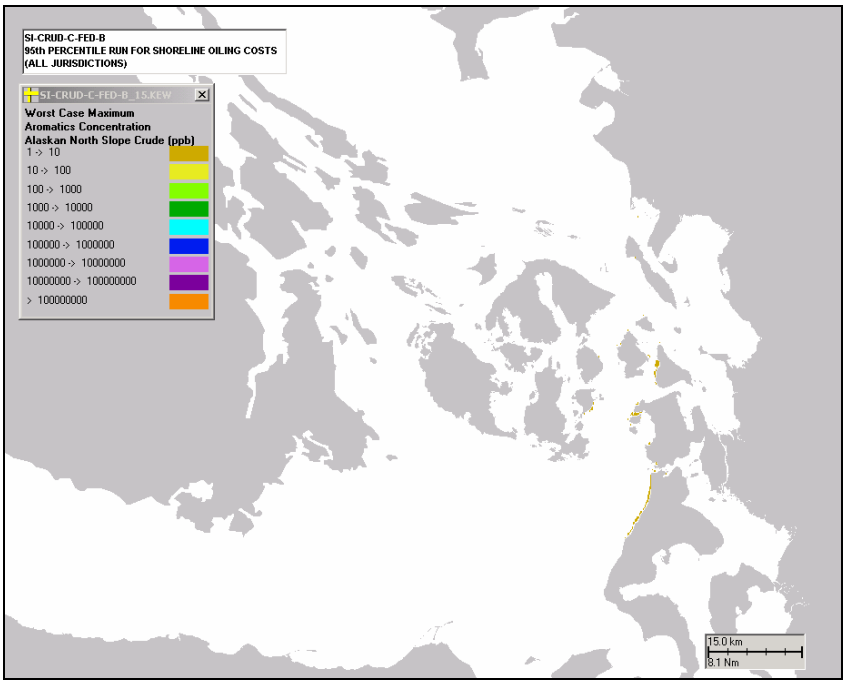


Figure XVII.B.6-6. San Juan Islands, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XVII.B.7. 3rd Alternative Mechanical Removal and dispersant, Scenario SI-Crud-C-3

The response for this scenario includes the use of mechanical removal based on the 3rd alternative standards, dispersant and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case where no dispersant was applied.

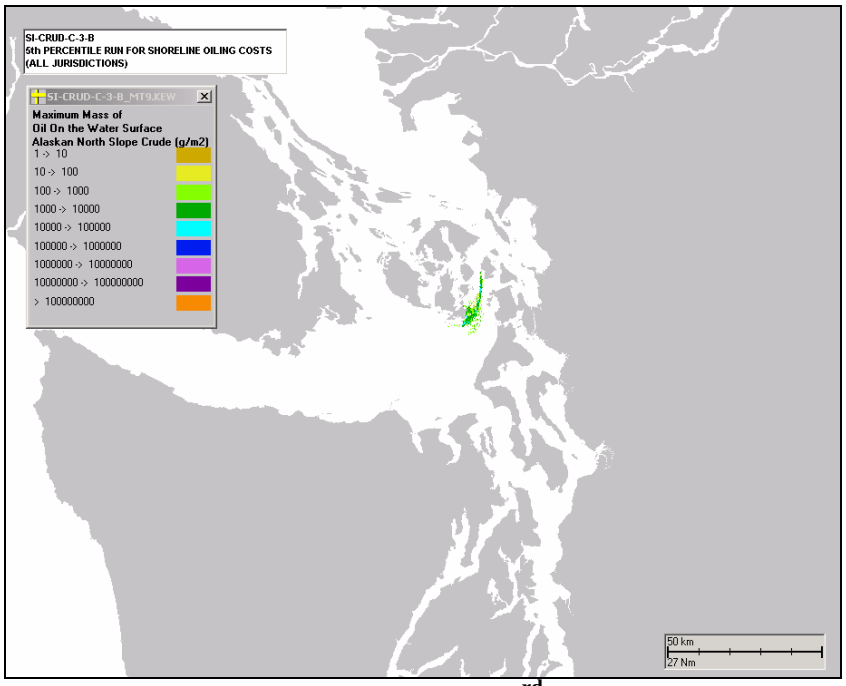


Figure XVII.B.7-1. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

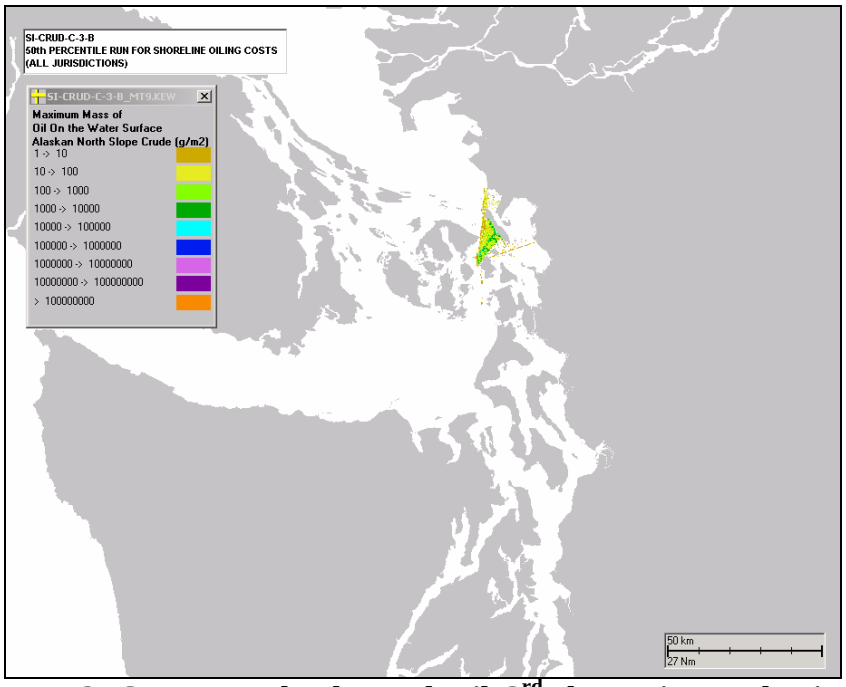


Figure XVII.B.7-2. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

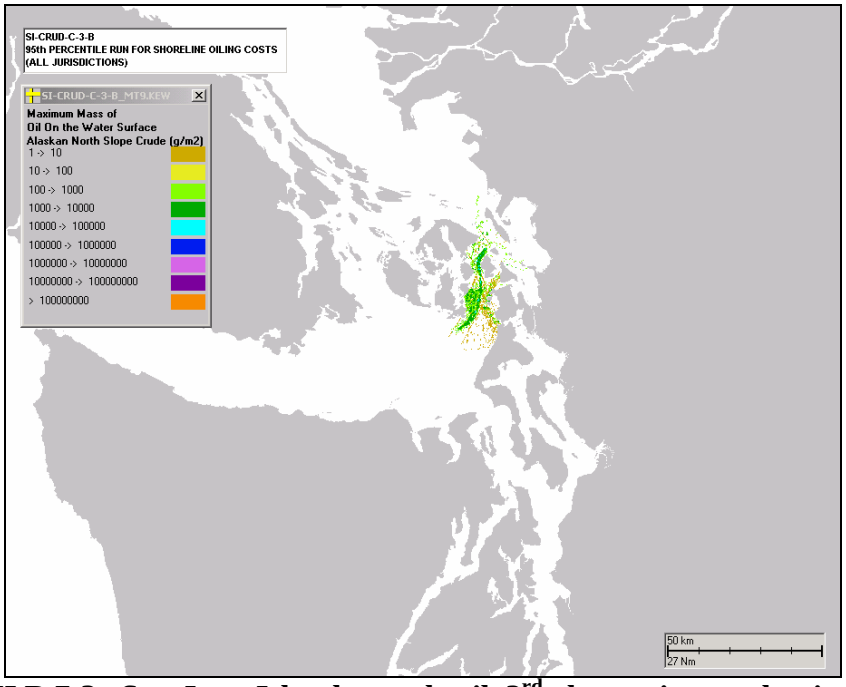


Figure XVII.B.7-3. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

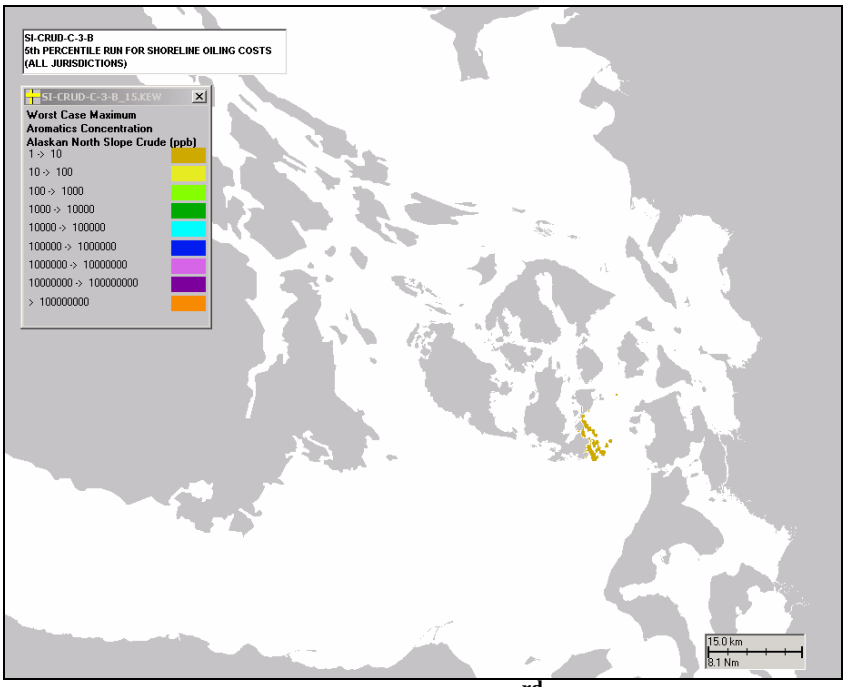


Figure XVII.B.7-4. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

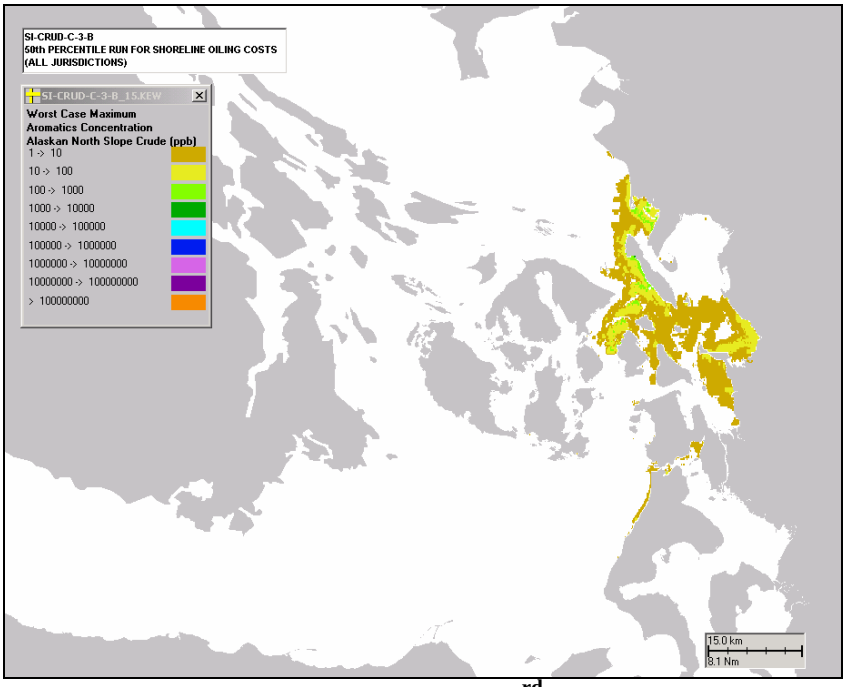


Figure XVII.B.7-5. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

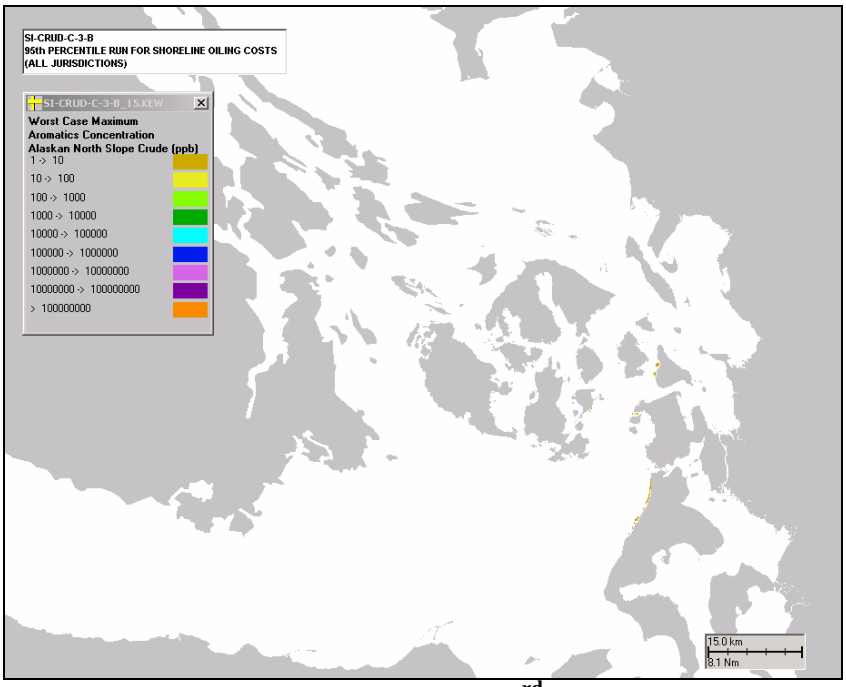


Figure XVII.B.7-6. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XVII.B.8. Oil Fate Over Time

The figures in this section summarize the fate of the oil over time for alternate response scenarios of the 5th, 50th and 95th percentile runs. Figures XVII.B.8-1 to XVII.B.8-21 list the mass balance of oil as a function of time. The oil on the water surface is floating oil (thick, sheen or tar balls) within the model grid. Oil in the water column is either entrained oil droplets or dissolved. The percent removed is by mechanical removal during the response to the spill. Figures XVII.B.8-22 to XVII.B.8-39 summarize the results, showing comparisons of the alternative responses for each of the individual runs.

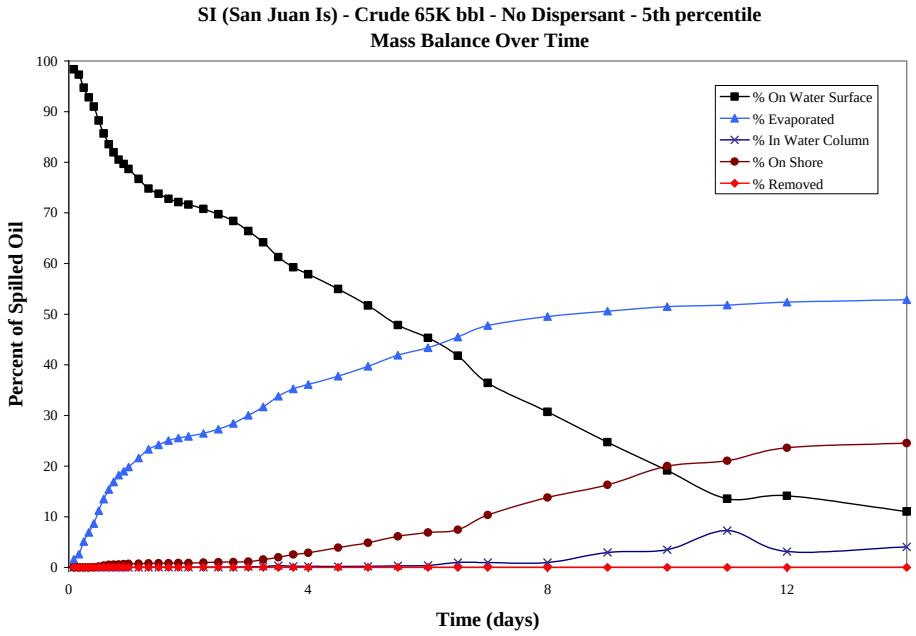


Figure XVII.B.8-1 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

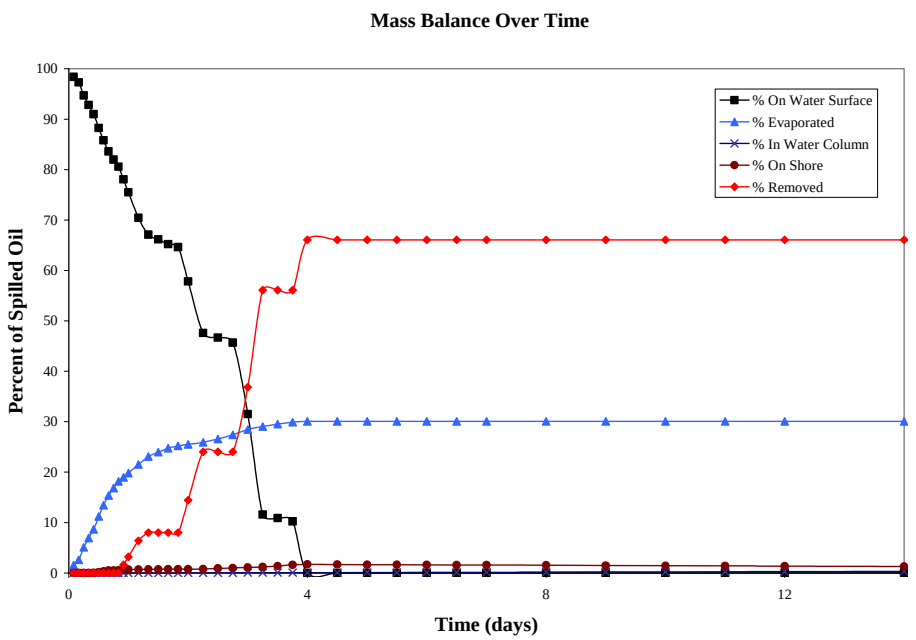


Figure XVII.B.8-2 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

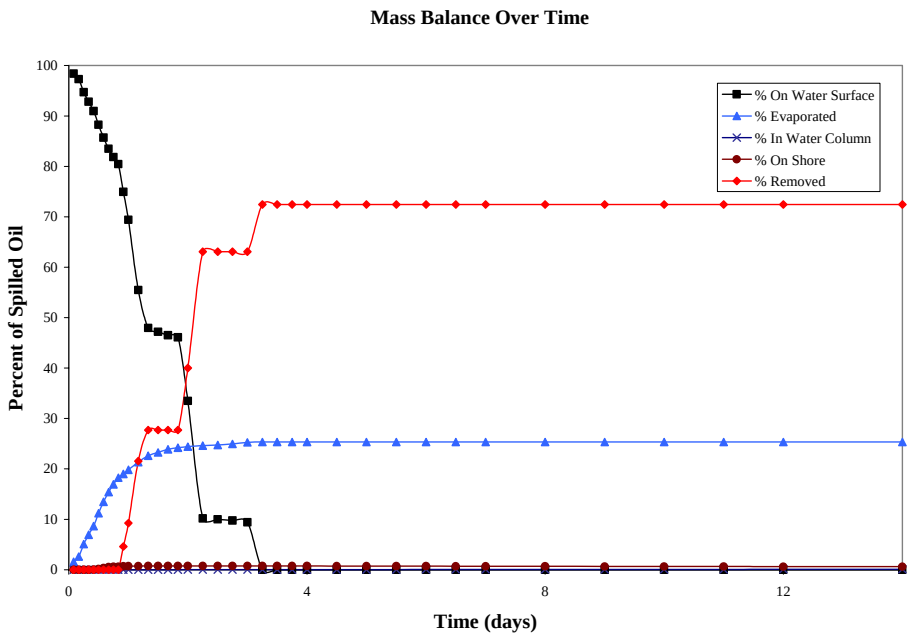


Figure XVII.B.8-3 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

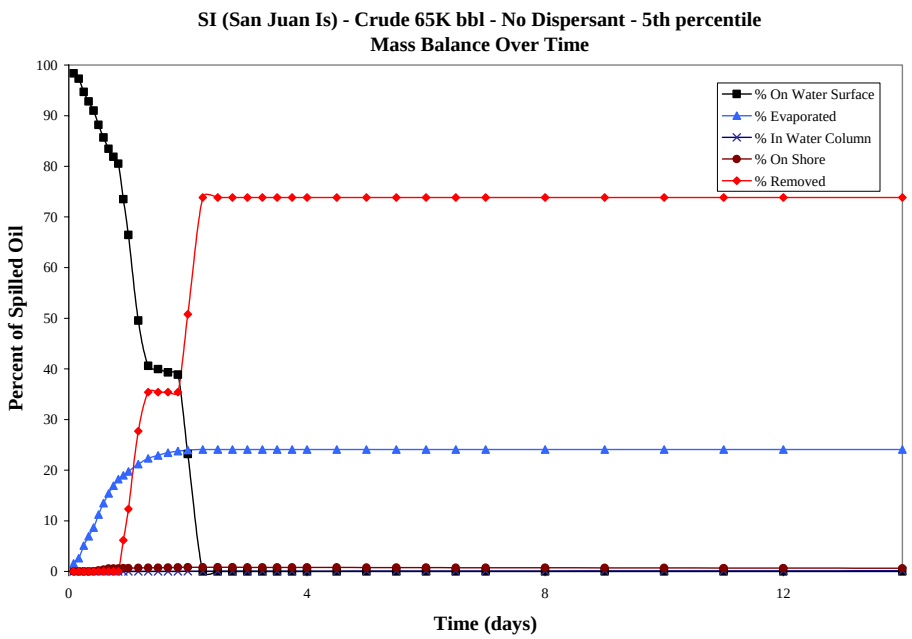


Figure XVII.B.8-4 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

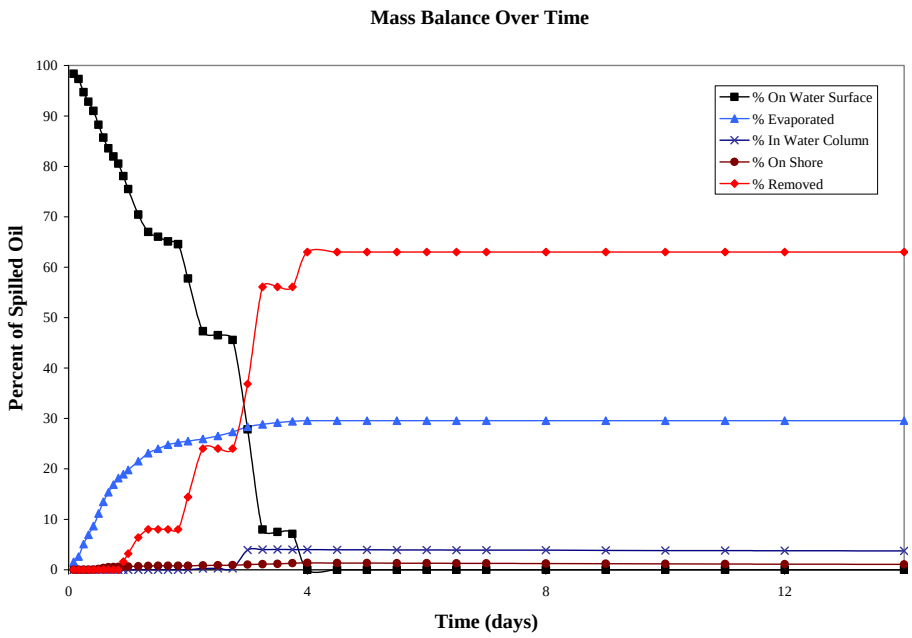


Figure XVII.B.8-5 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

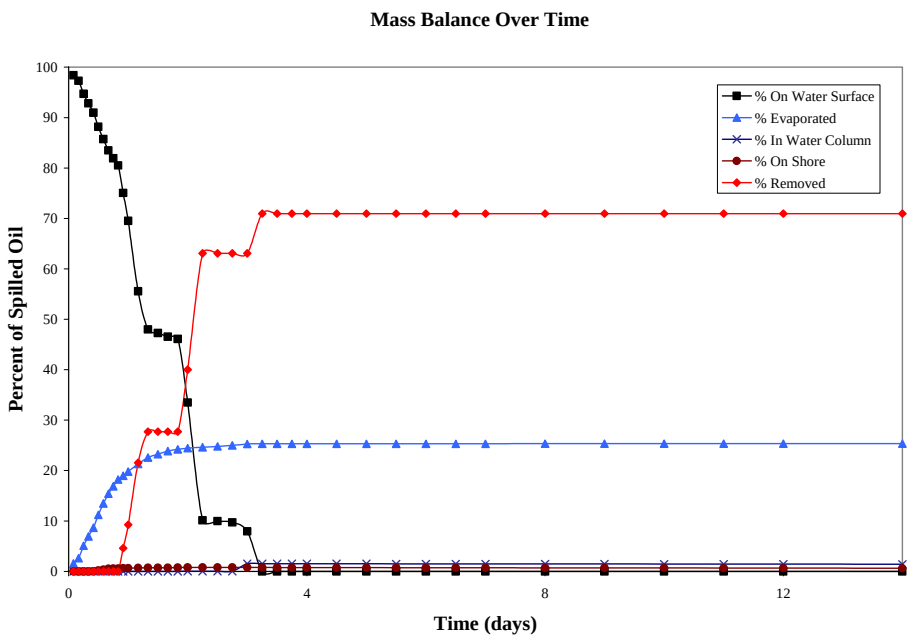


Figure XVII.B.8-6 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

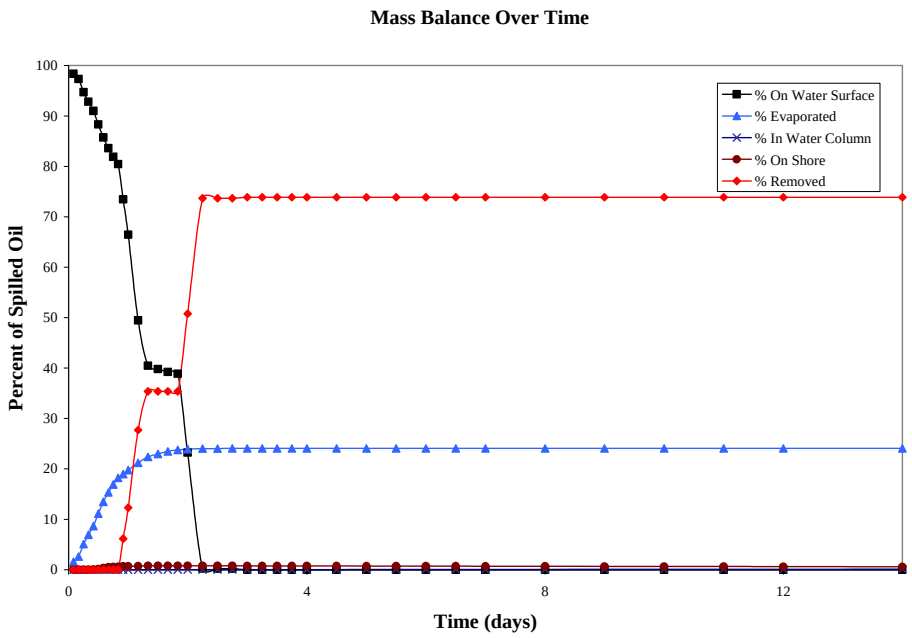


Figure XVII.B.8-7 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

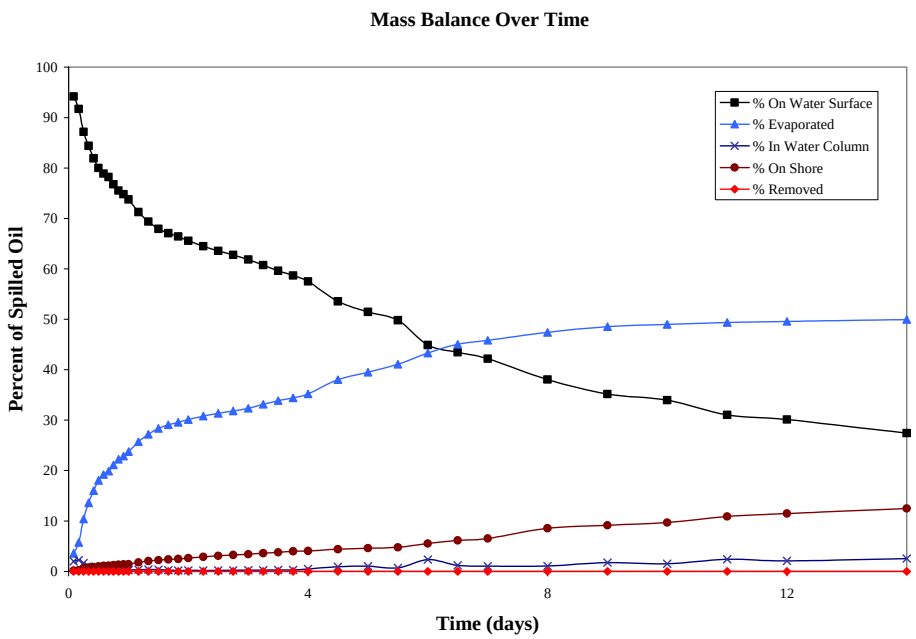


Figure XVII.B.8-8 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

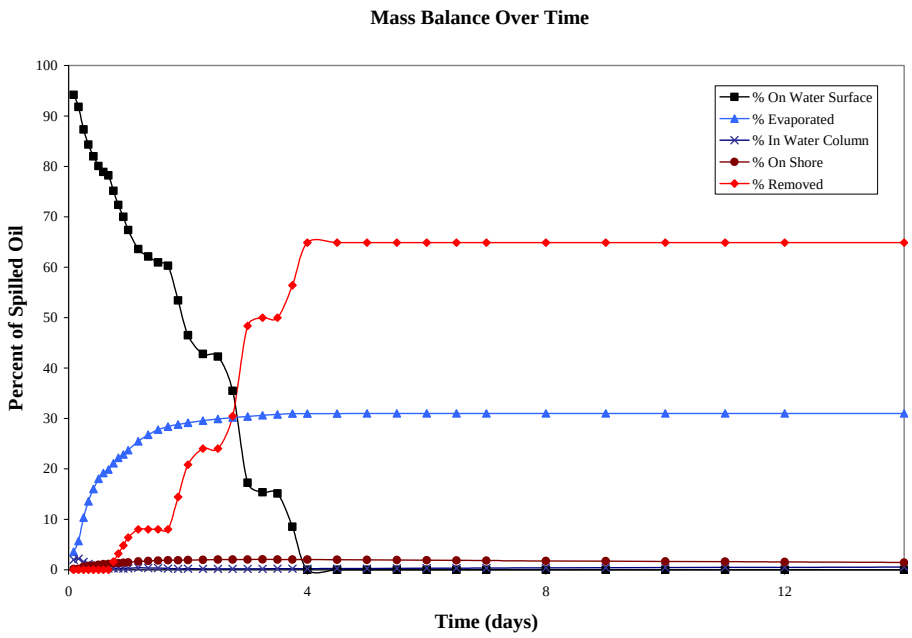


Figure XVII.B.8-9 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

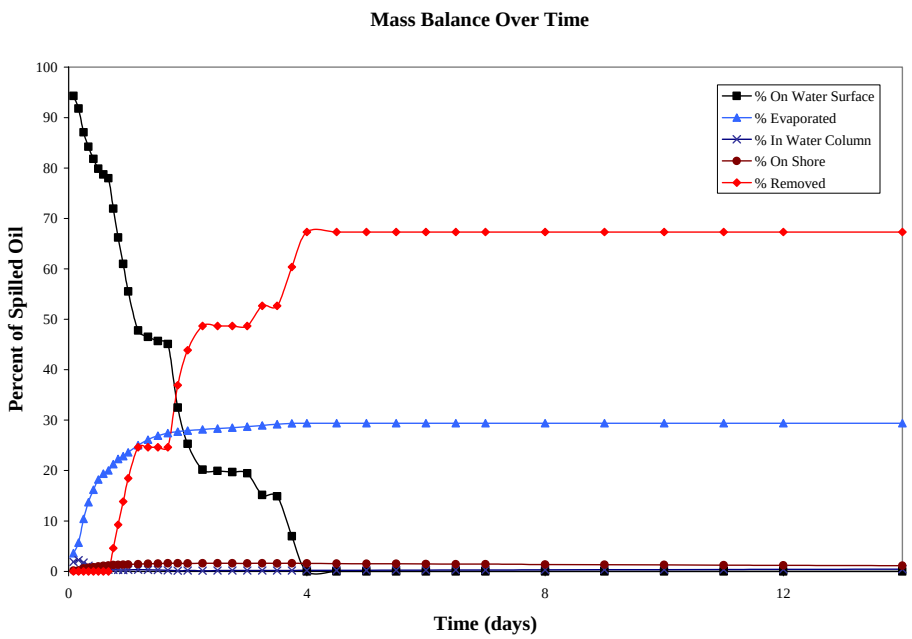


Figure XVII.B.8-10 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

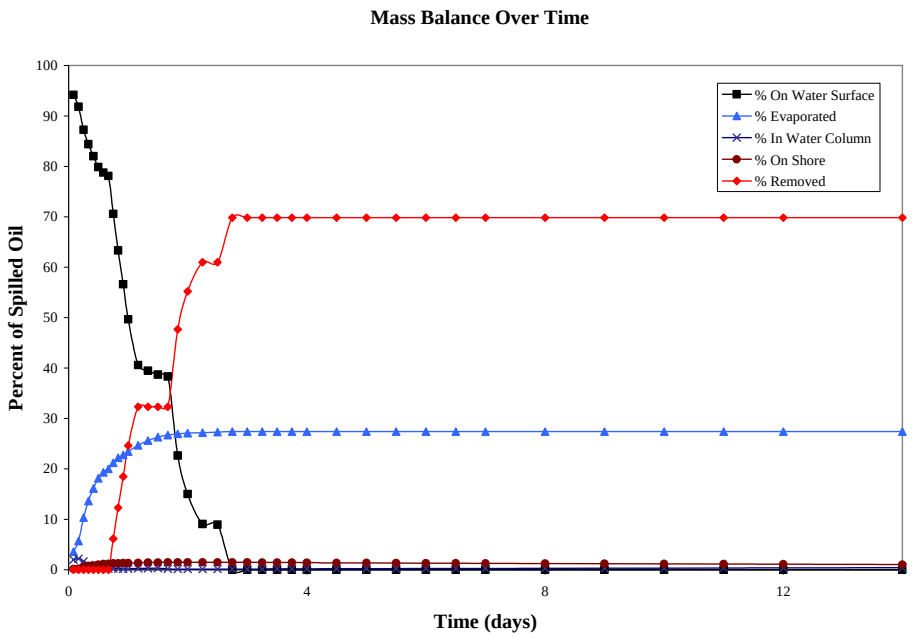


Figure XVII.B.8-11 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

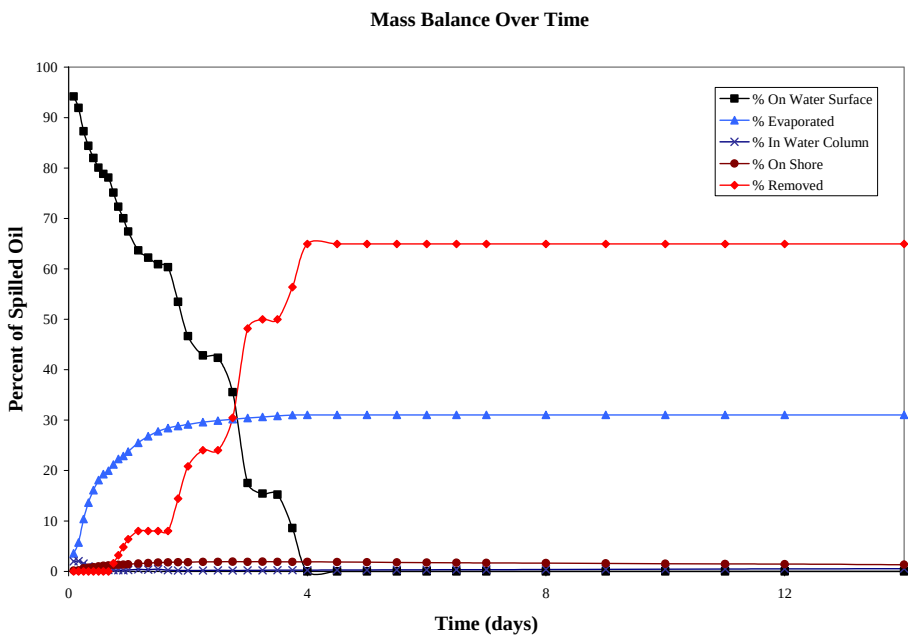


Figure XVII.B.8-12 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

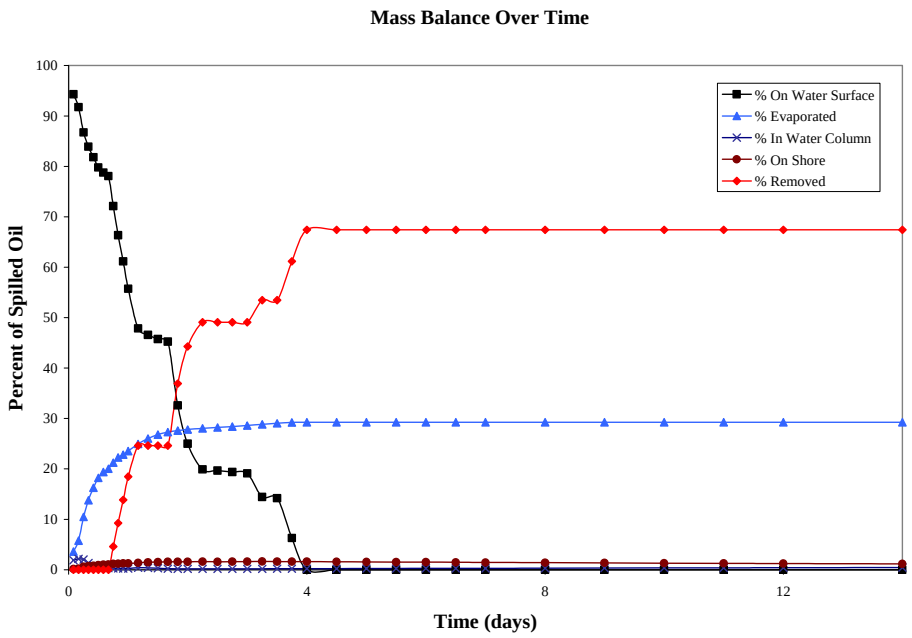


Figure XVII.B.8-13 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

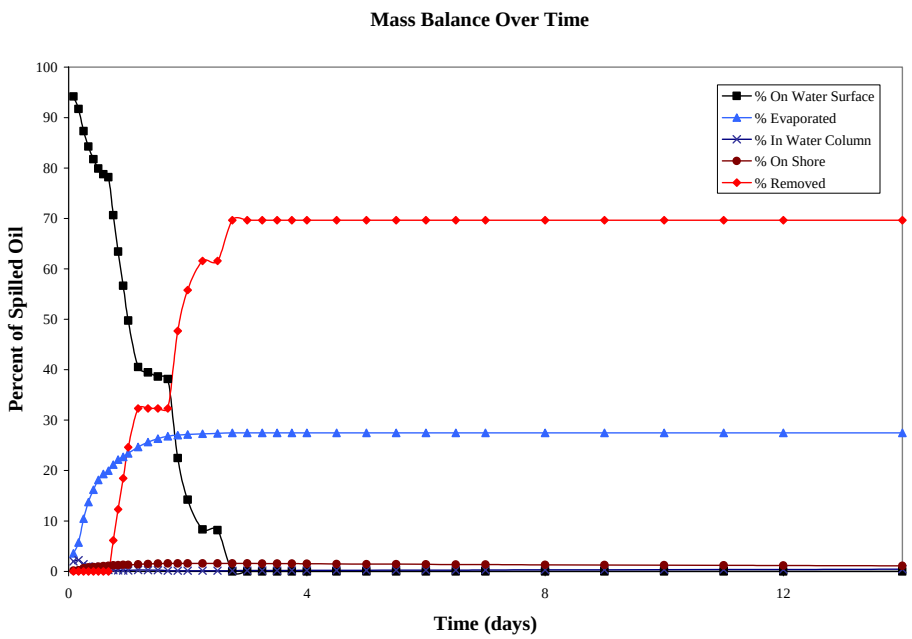


Figure XVII.B.8-14 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

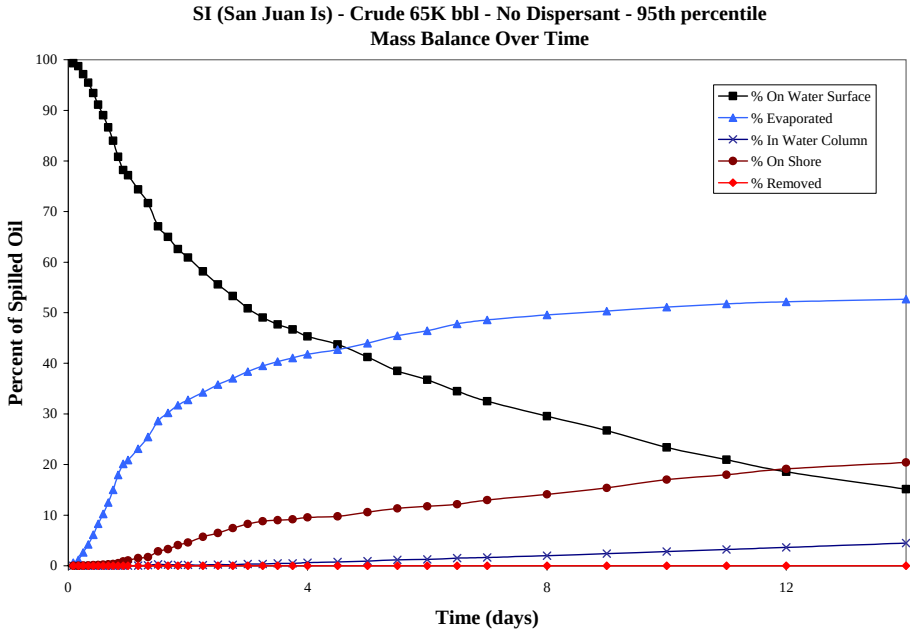


Figure XVII.B.8-15 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

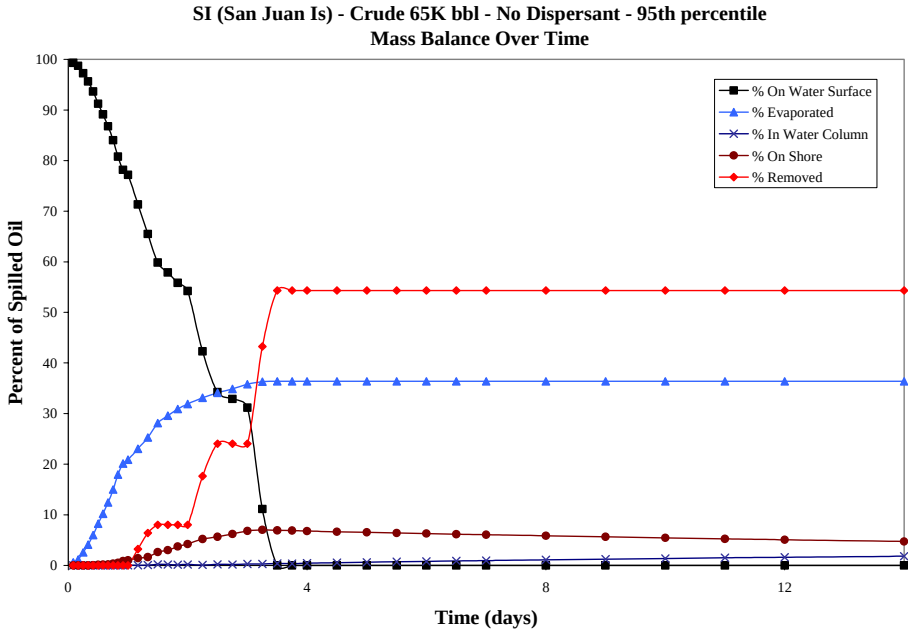


Figure XVII.B.8-16 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

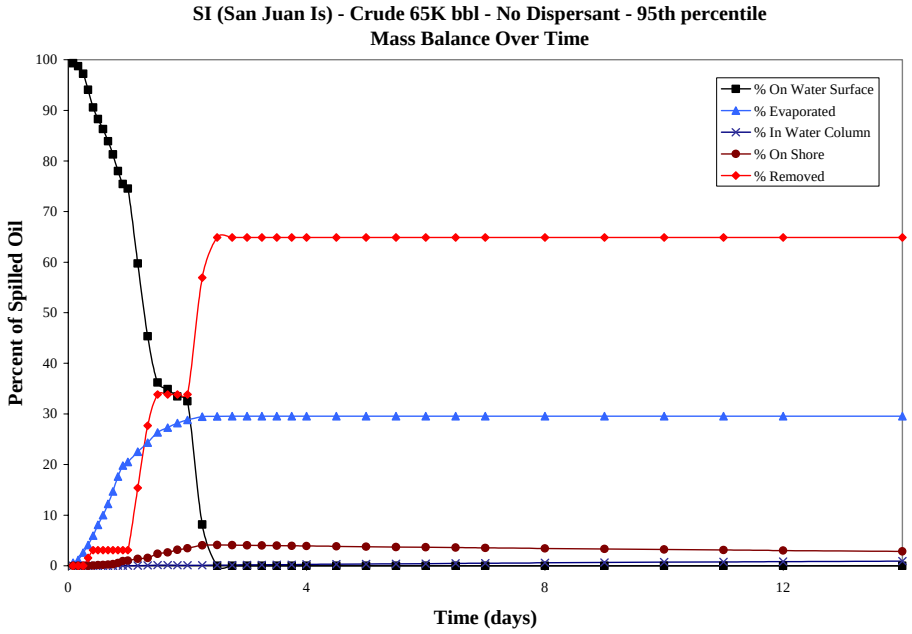


Figure XVII.B.8-17 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

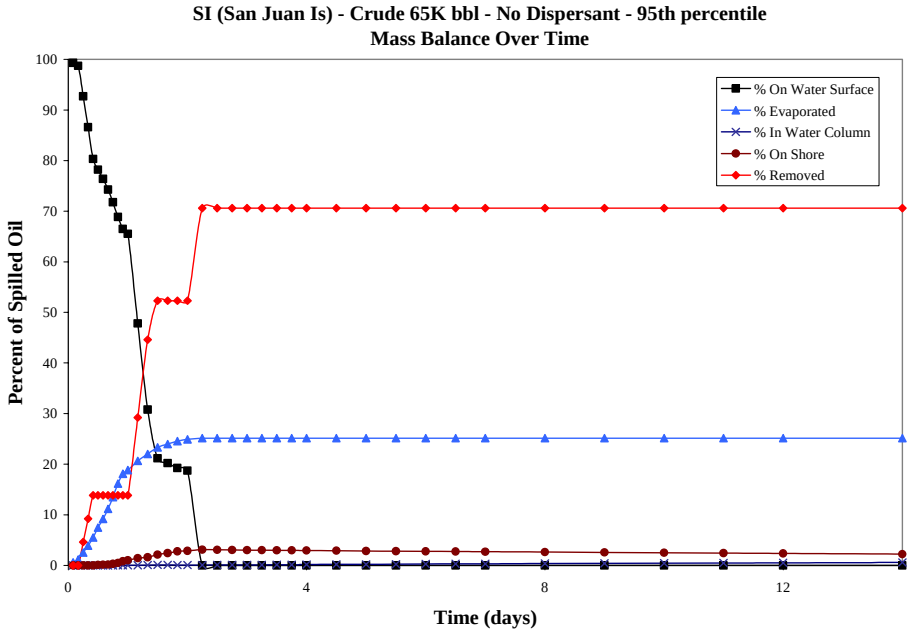


Figure XVII.B.8-18 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

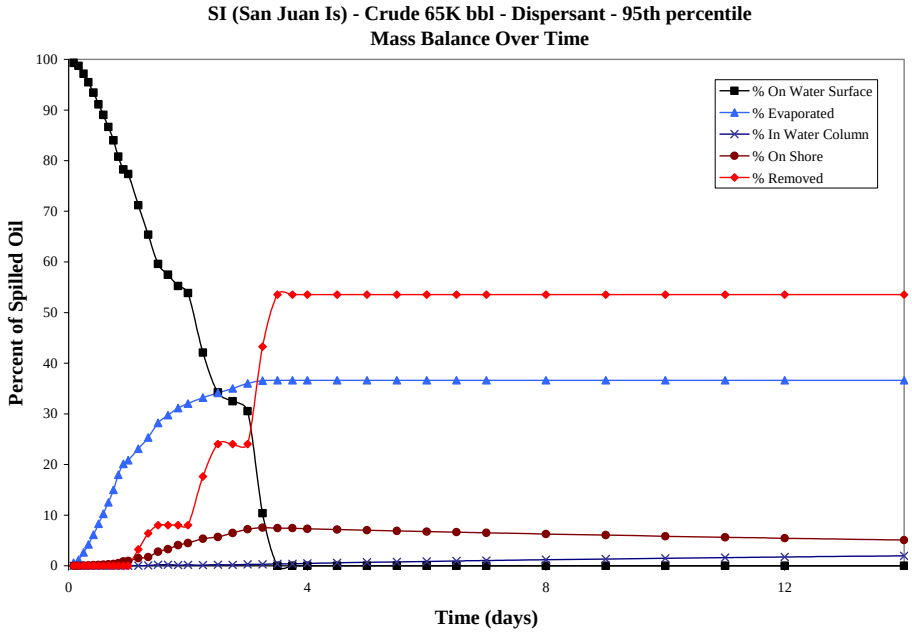


Figure XVII.B.8-19 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

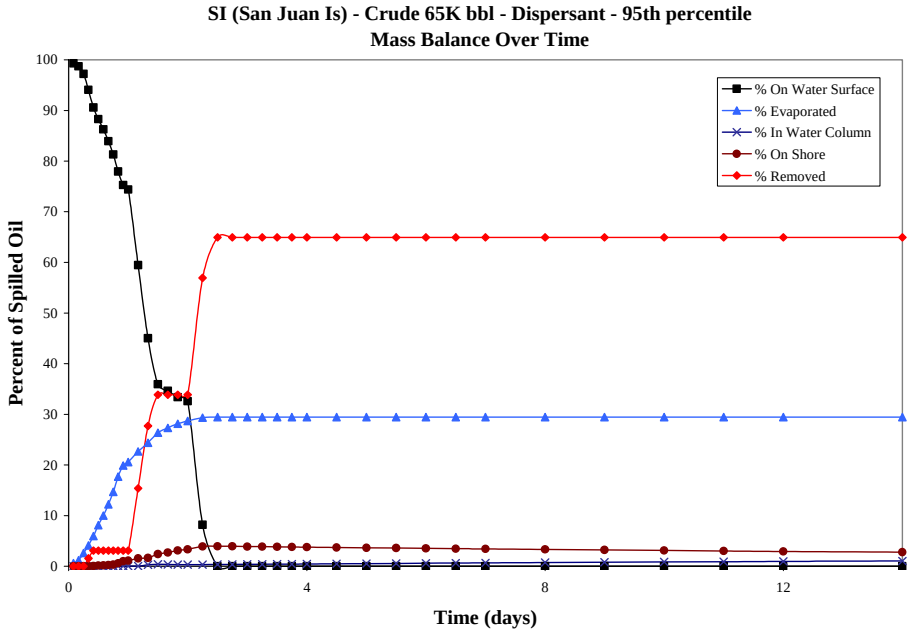


Figure XVII.B.8-20 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

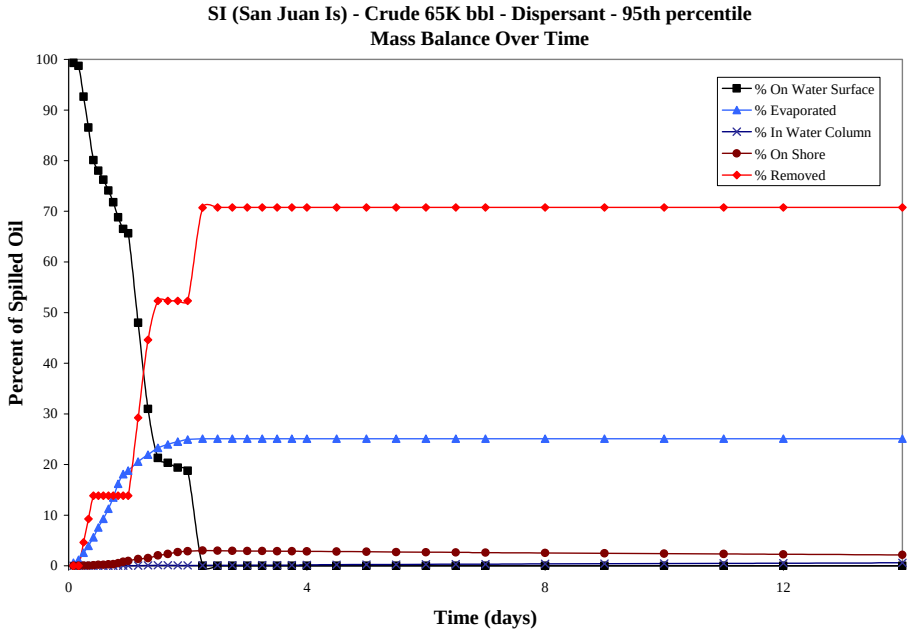
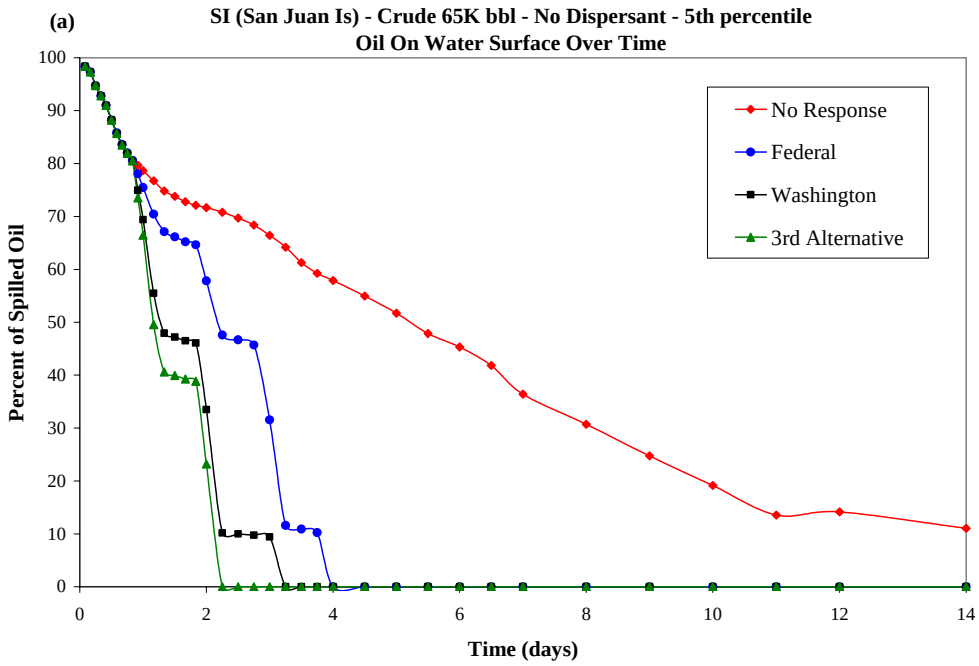


Figure XVII.B.8-21 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).



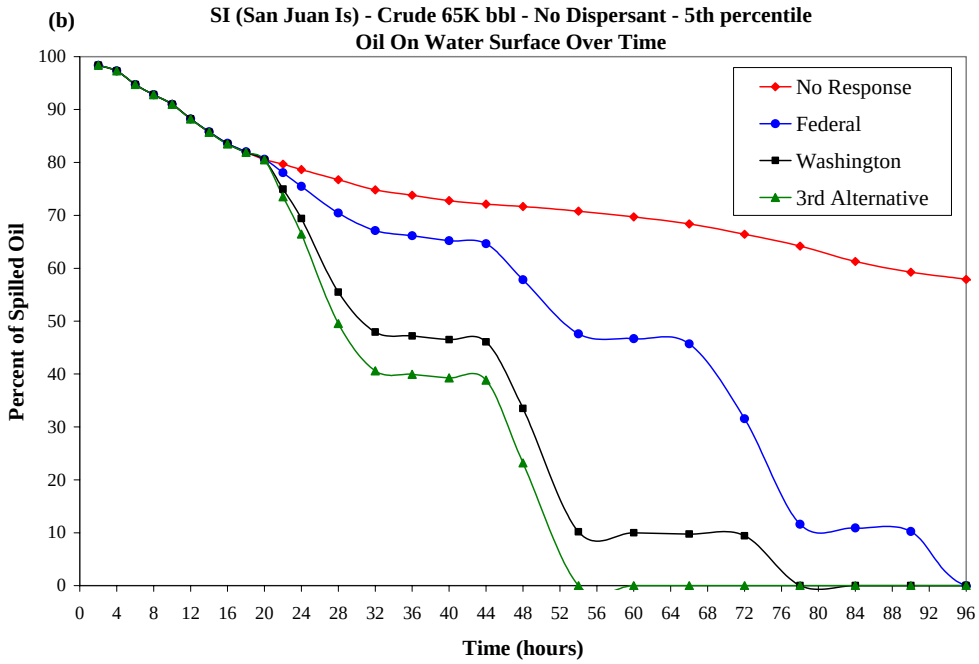
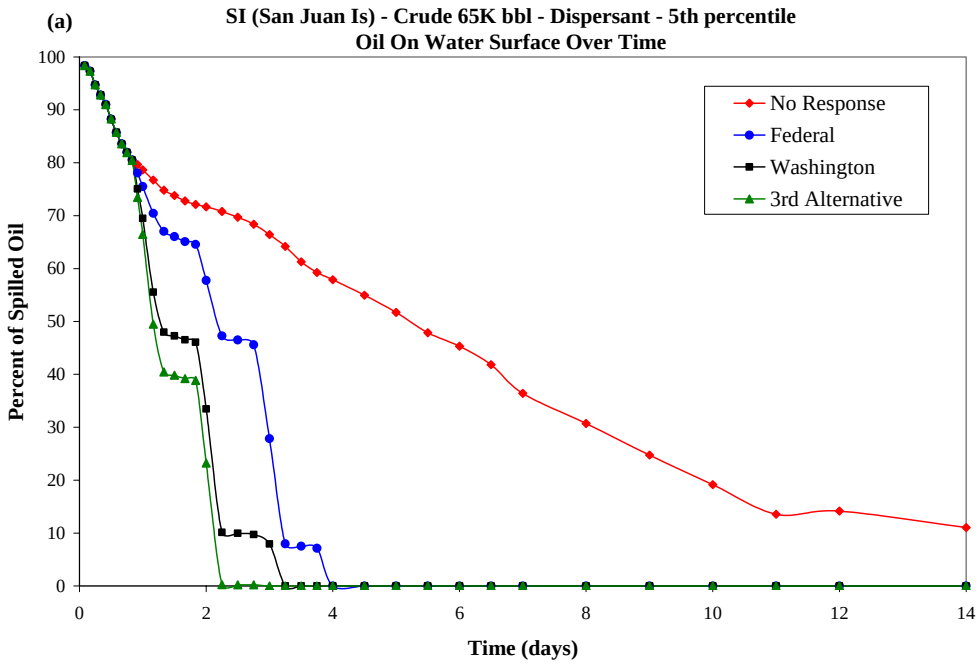


Figure XVII.B.8-22 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



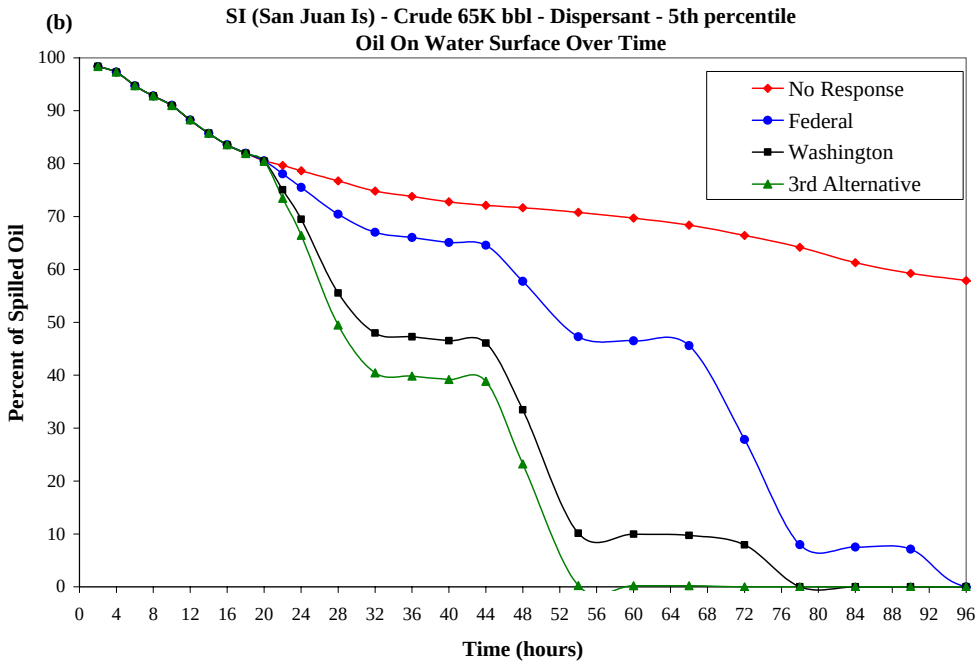
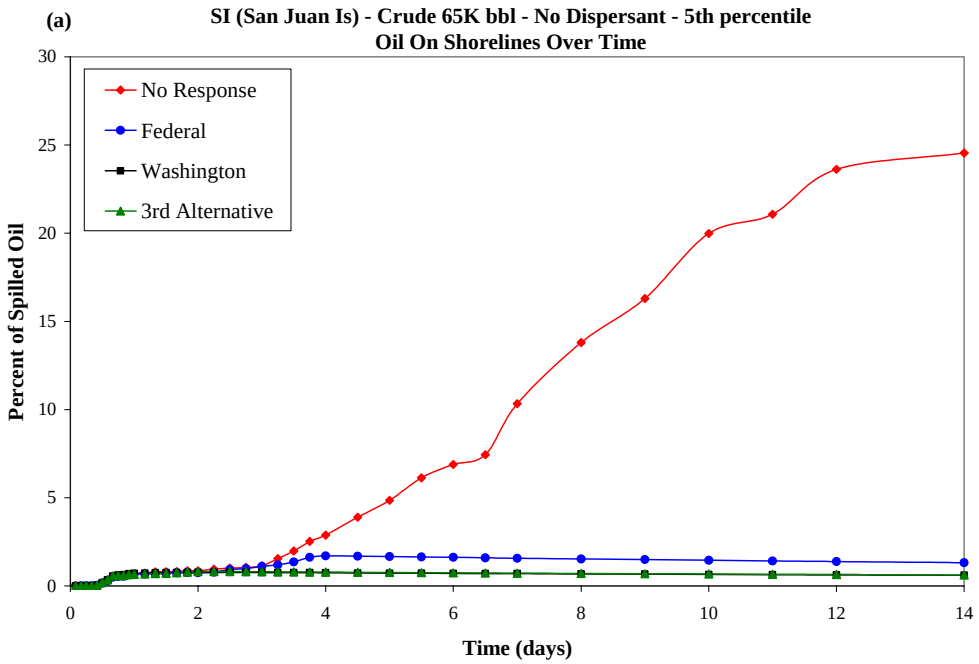


Figure XVII.B.8-23 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



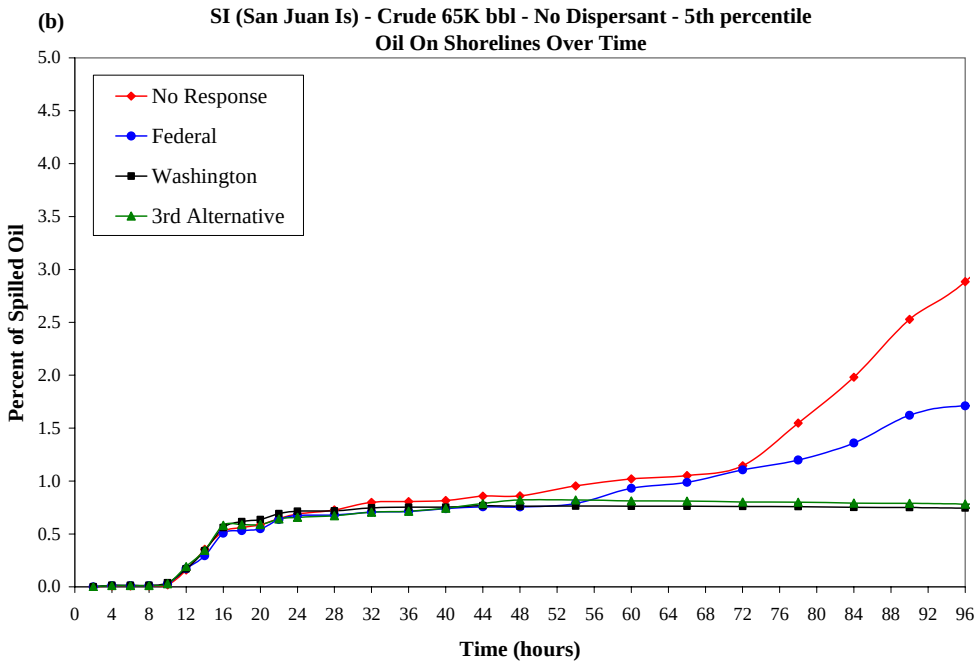
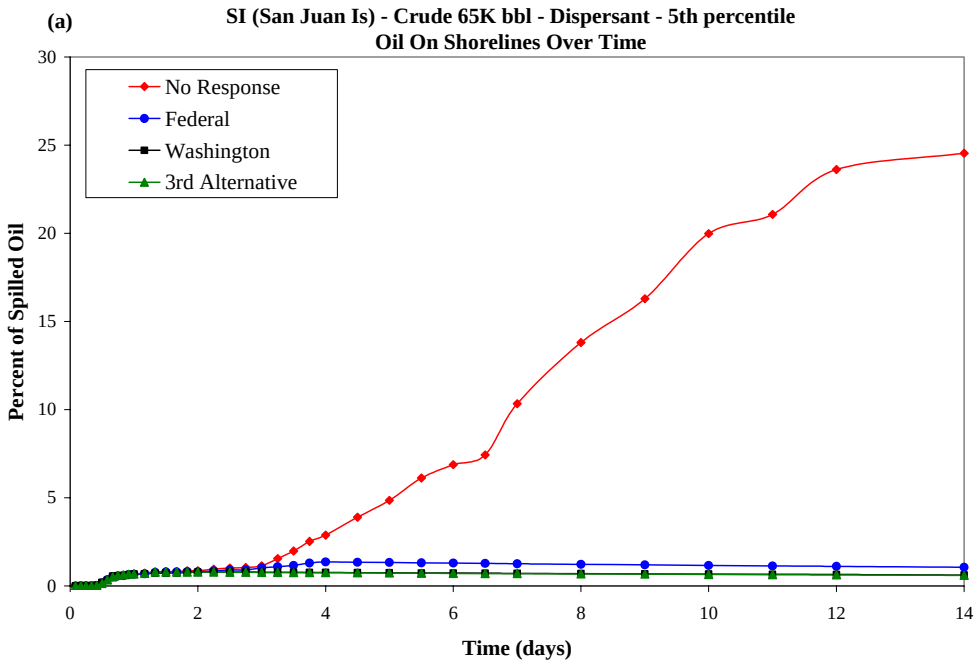


Figure XVII.B.8-24 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



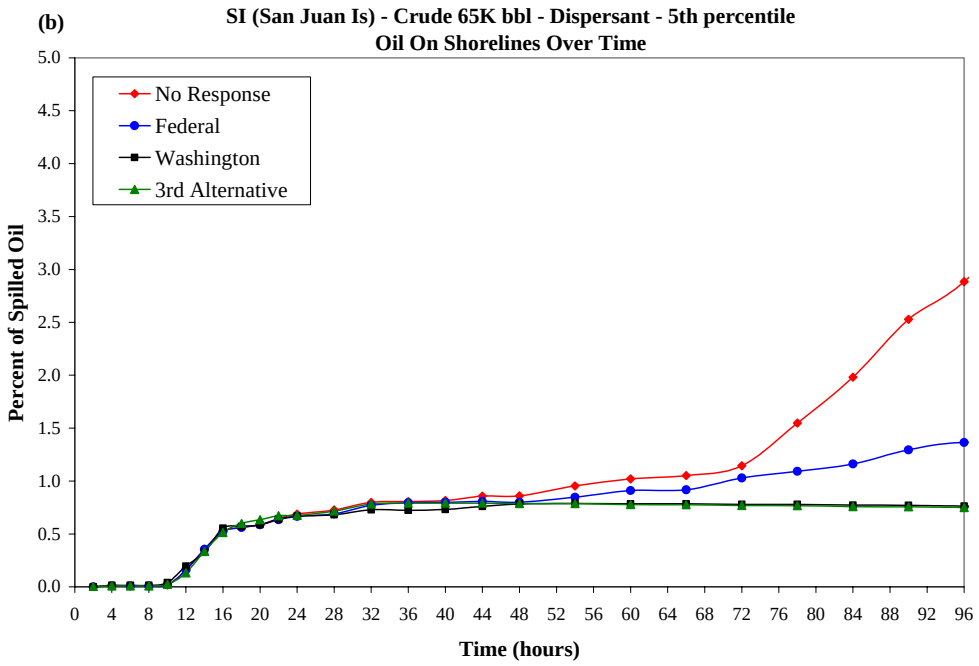
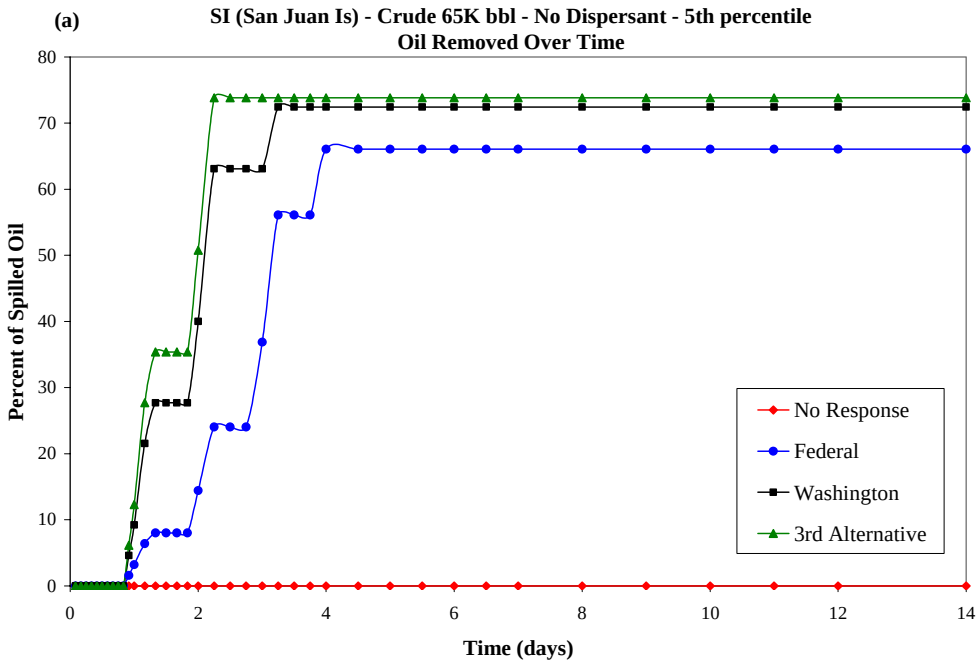


Figure XVII.B.8-25 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



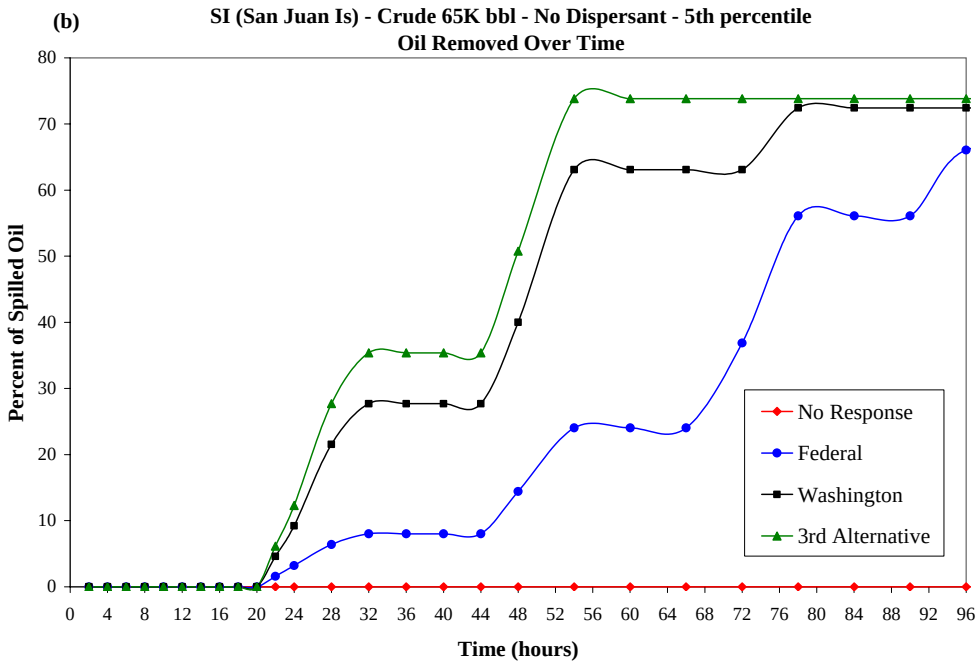
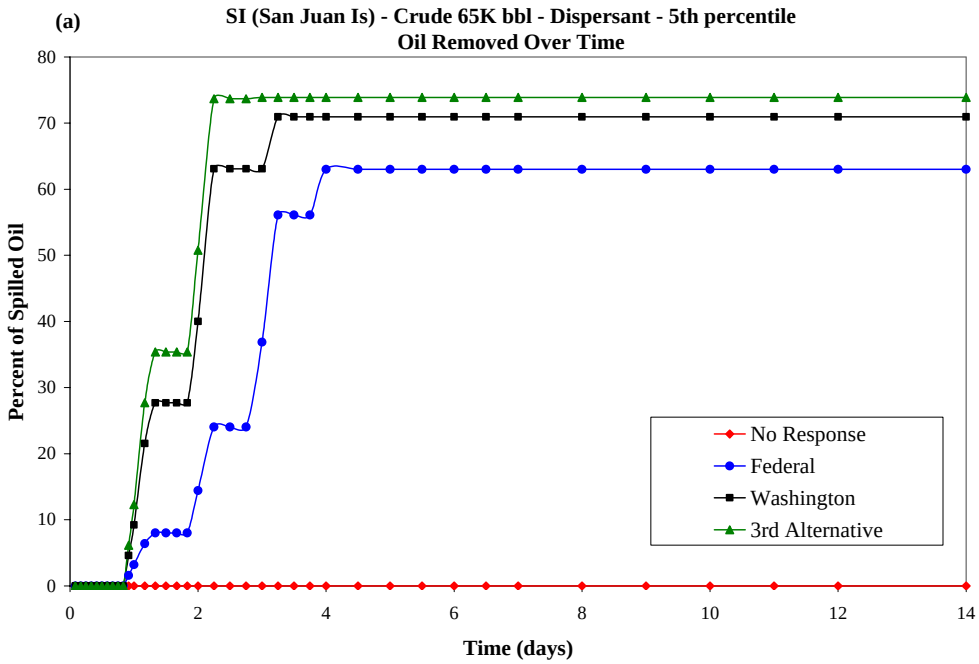


Figure XVII.B.8-26 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



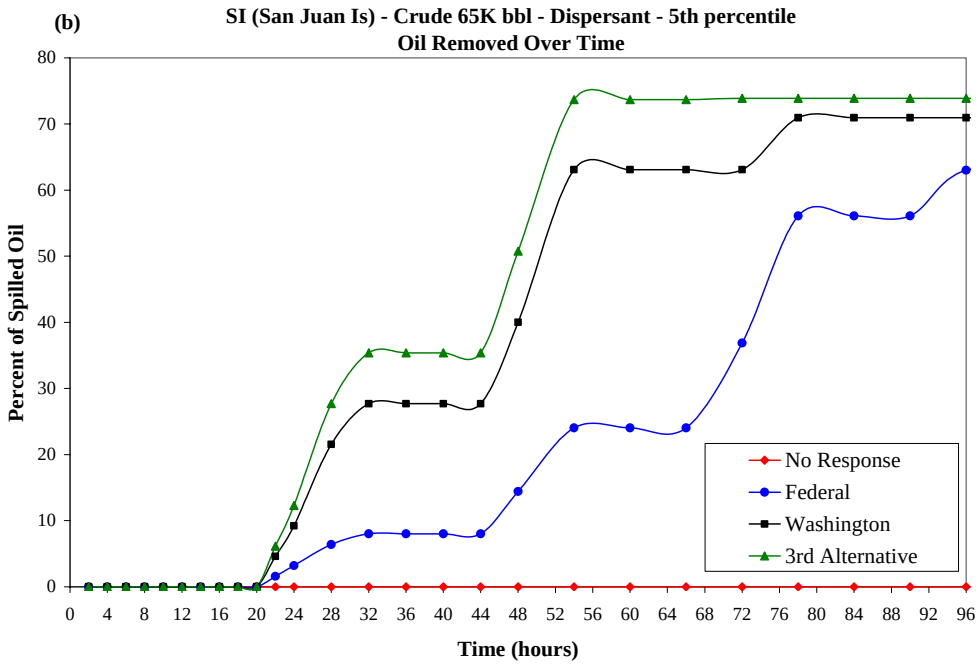
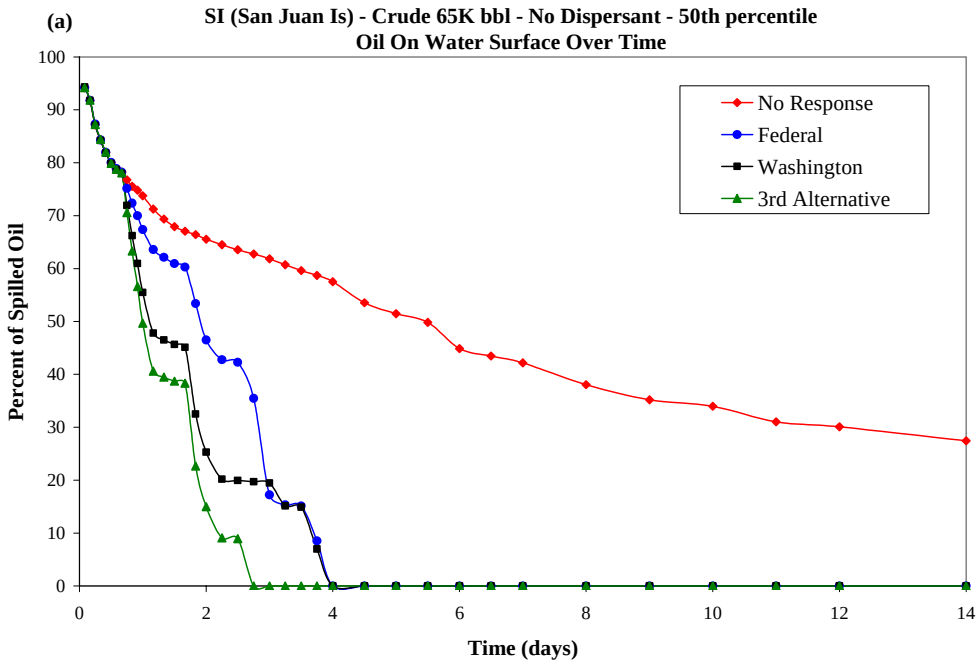


Figure XVII.B.8-27 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



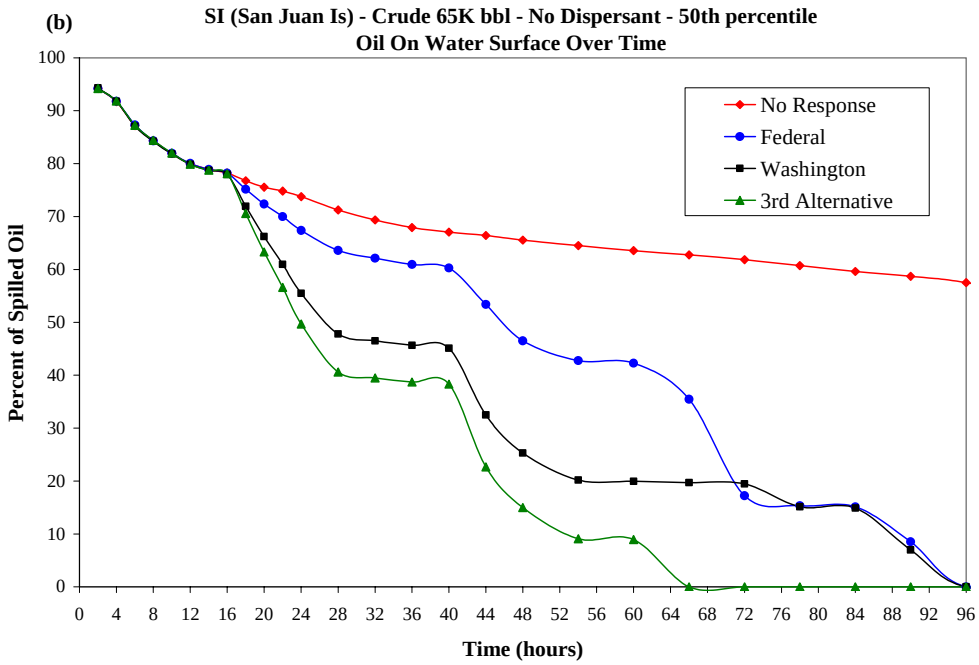
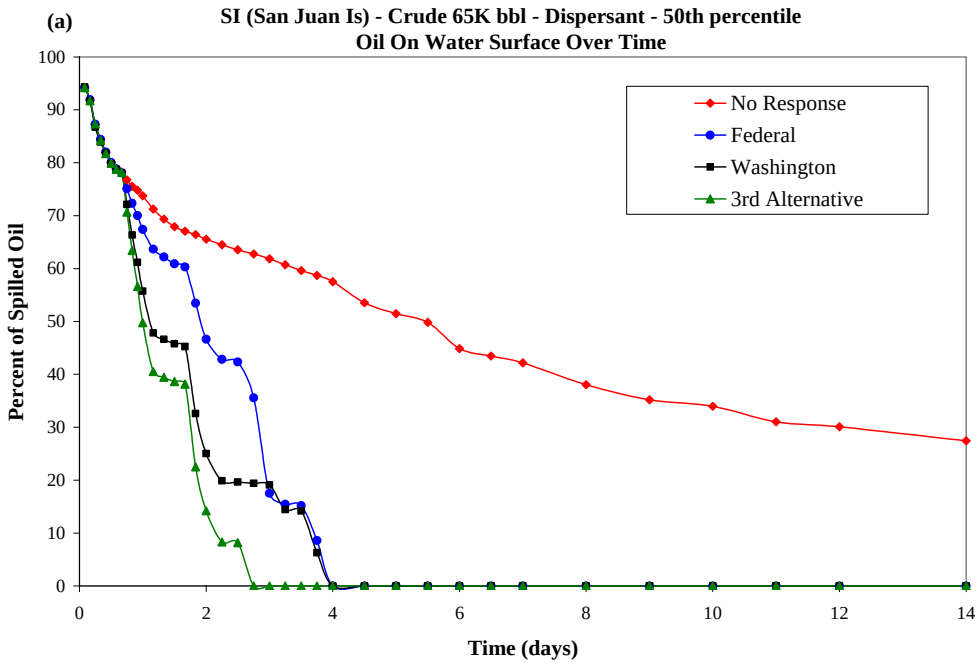


Figure XVII.B.8-28 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



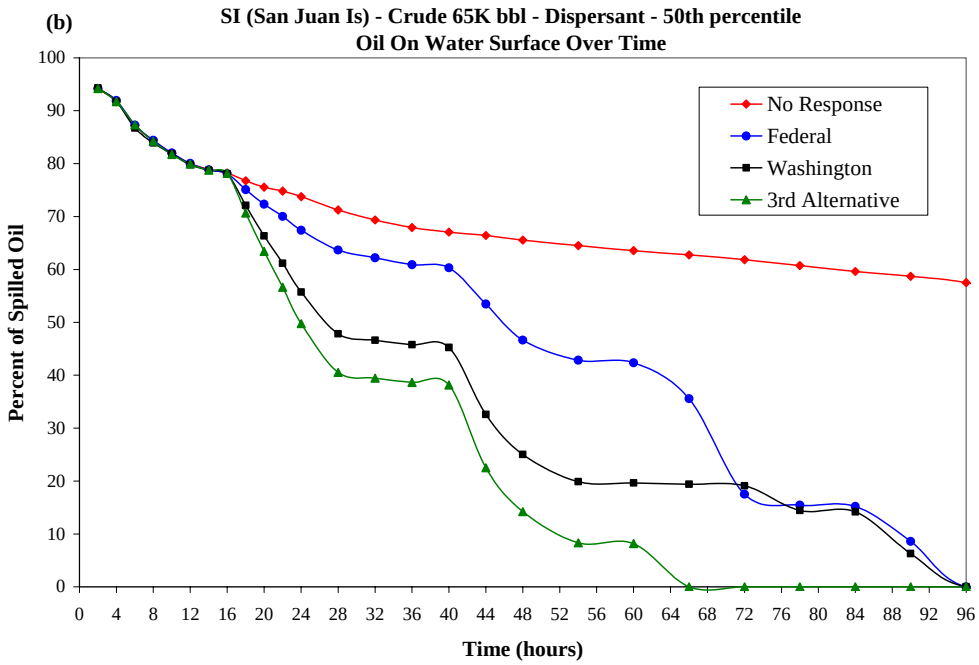
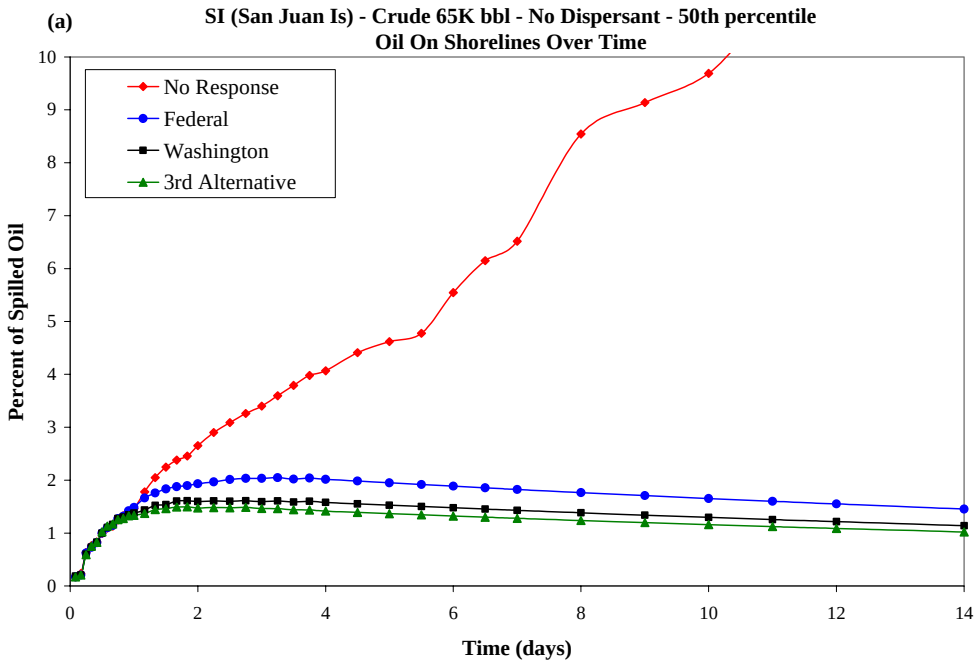


Figure XVII.B.8-29 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



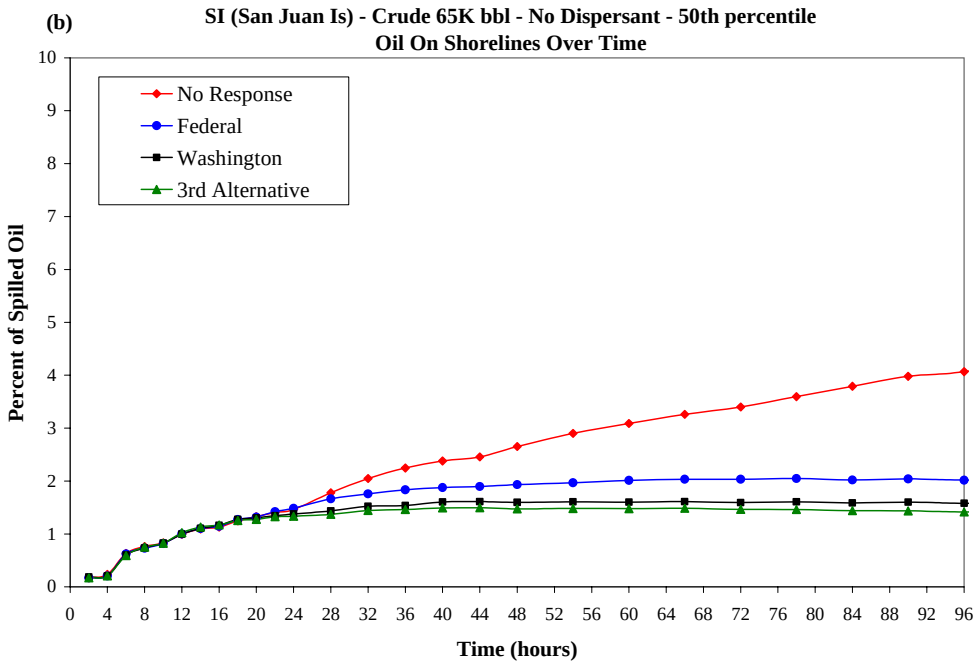
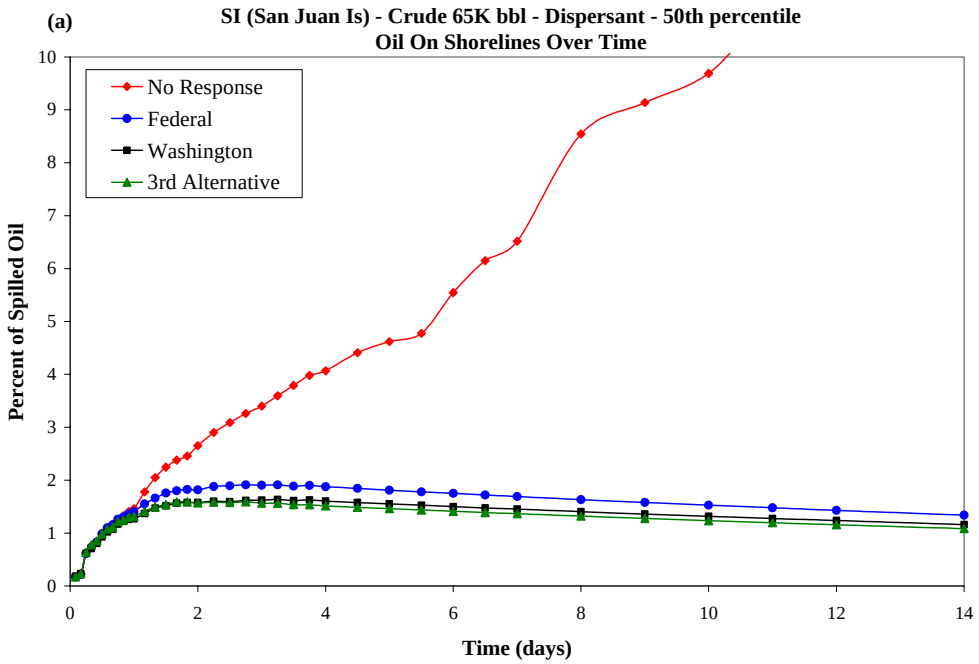


Figure XVII.B.8-30 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



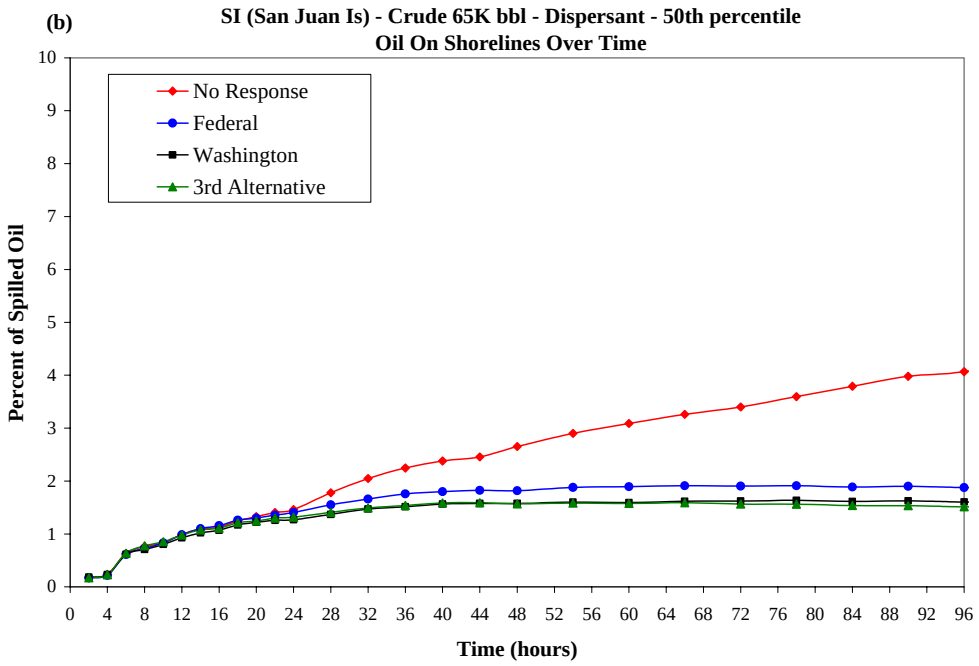
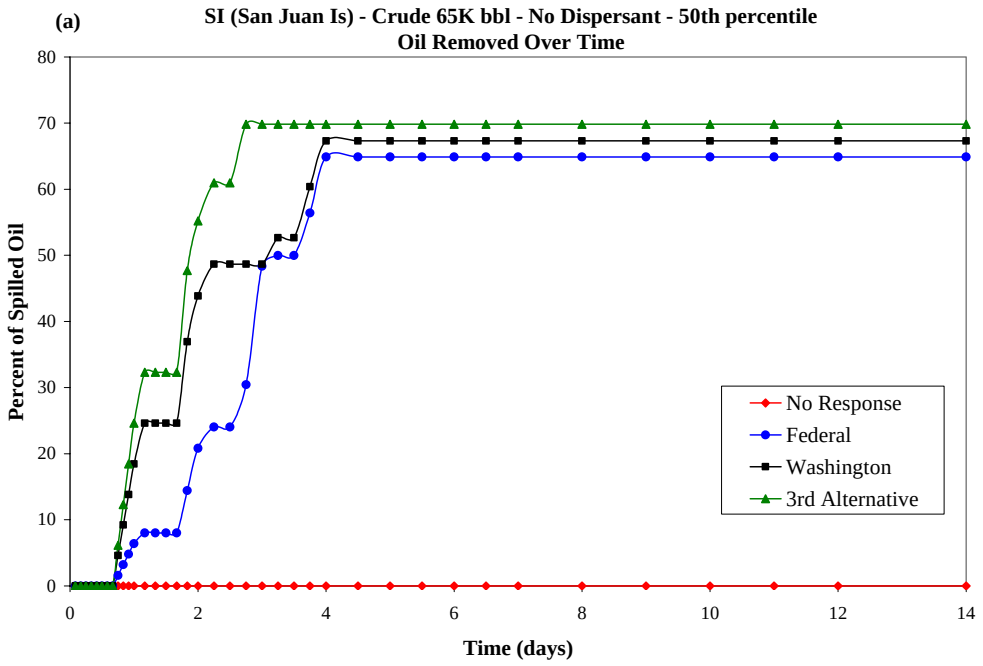


Figure XVII.B.8-31 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



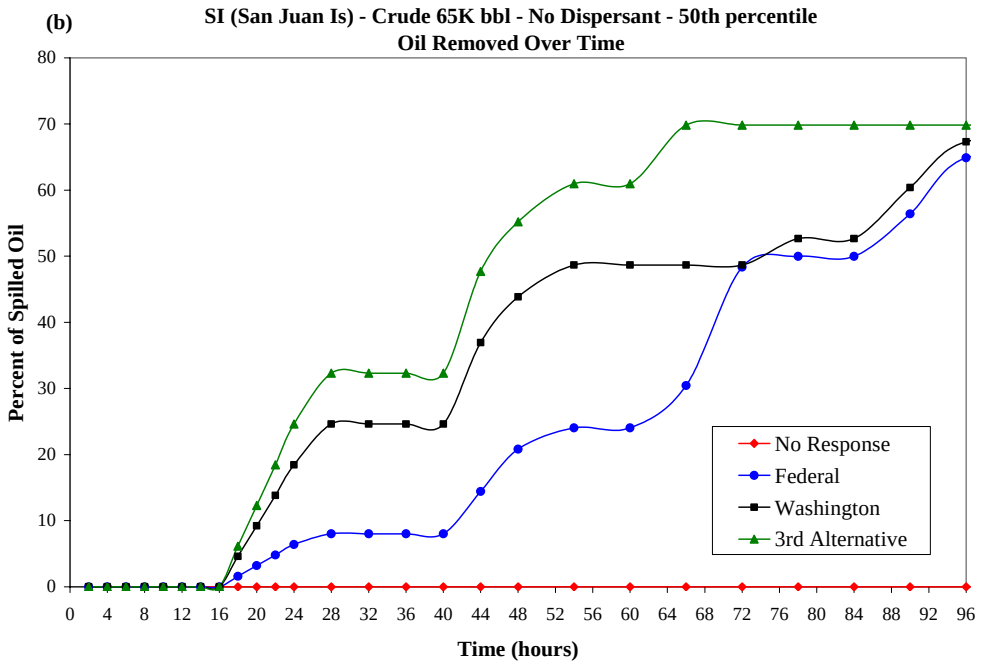
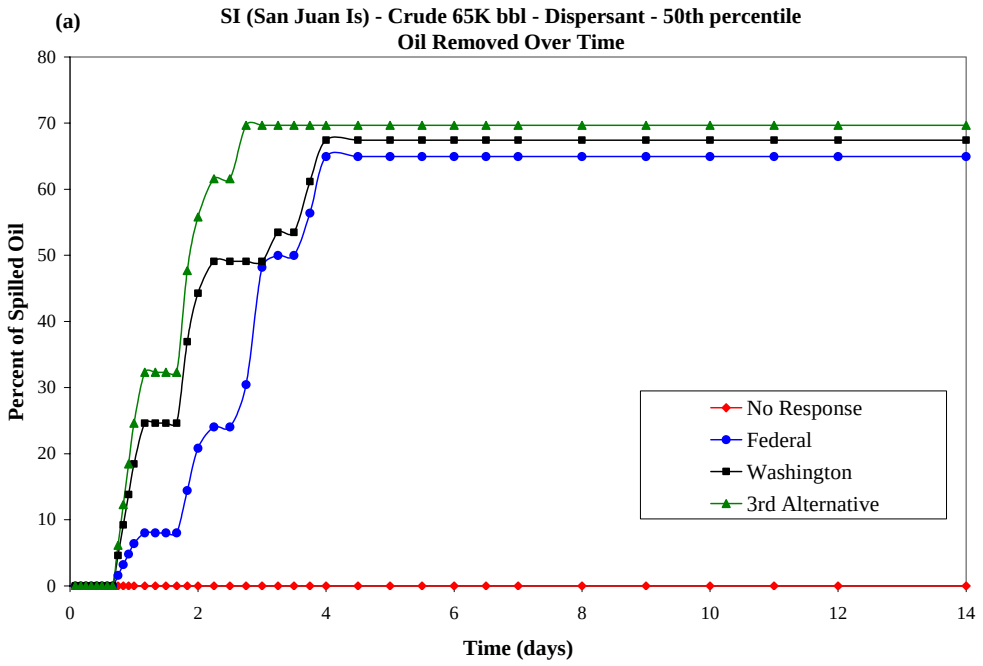


Figure XVII.B.8-32 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



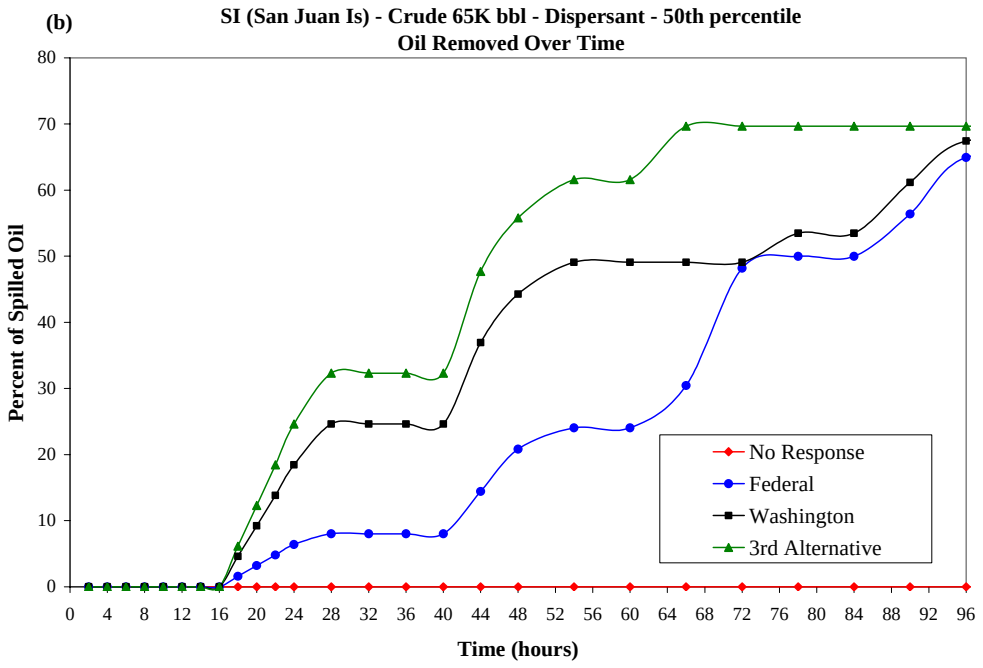
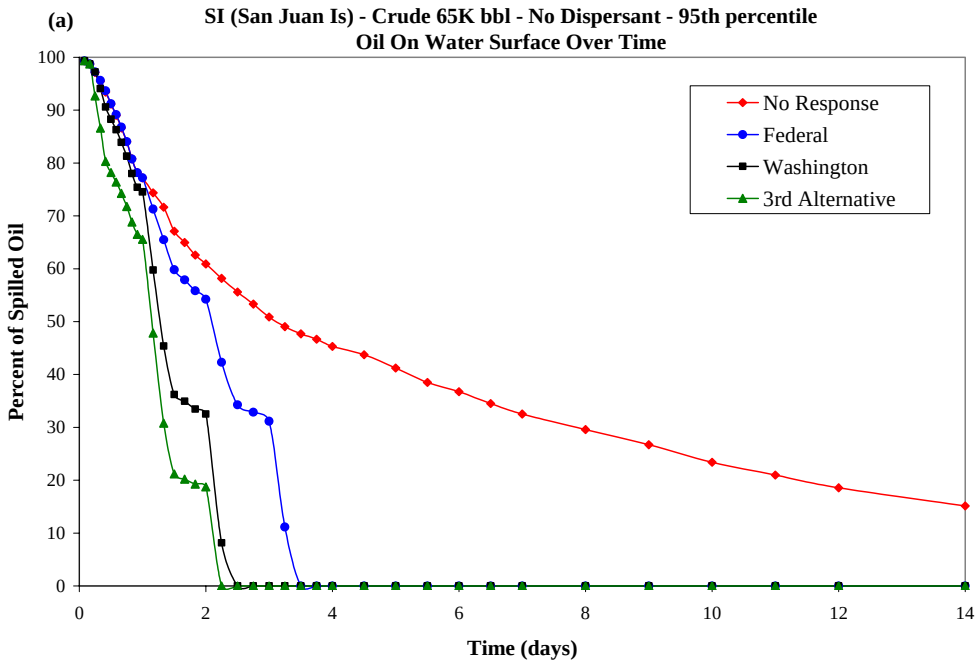


Figure XVII.B.8-33 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



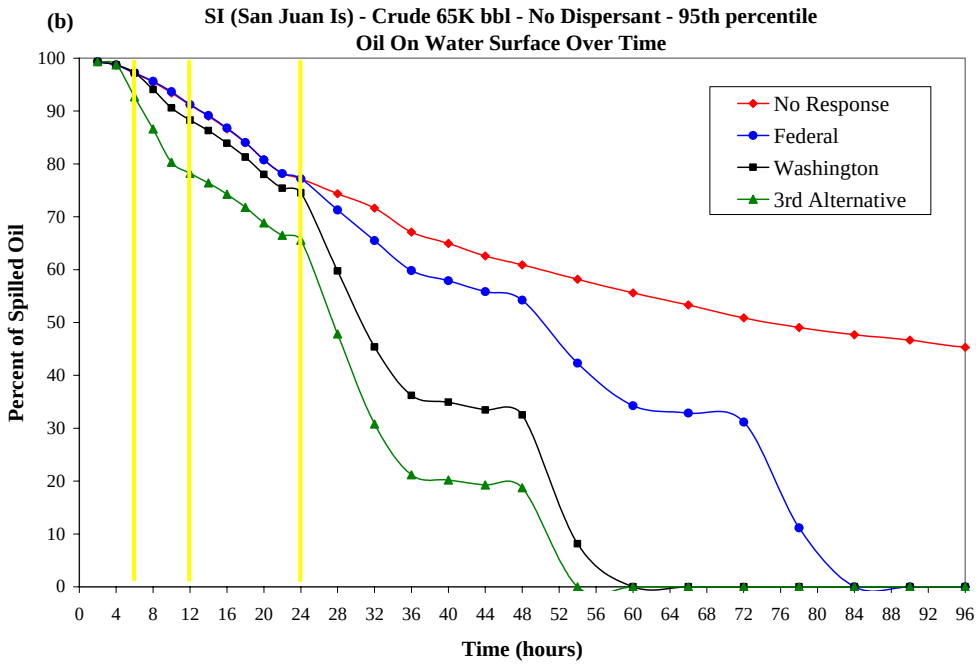
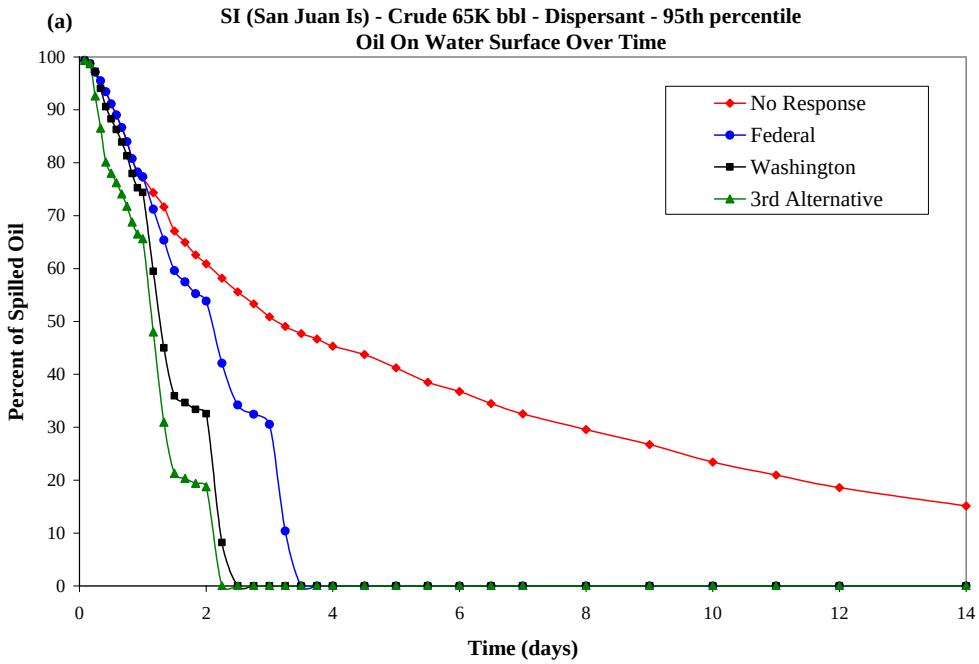


Figure XVII.B.8-34 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



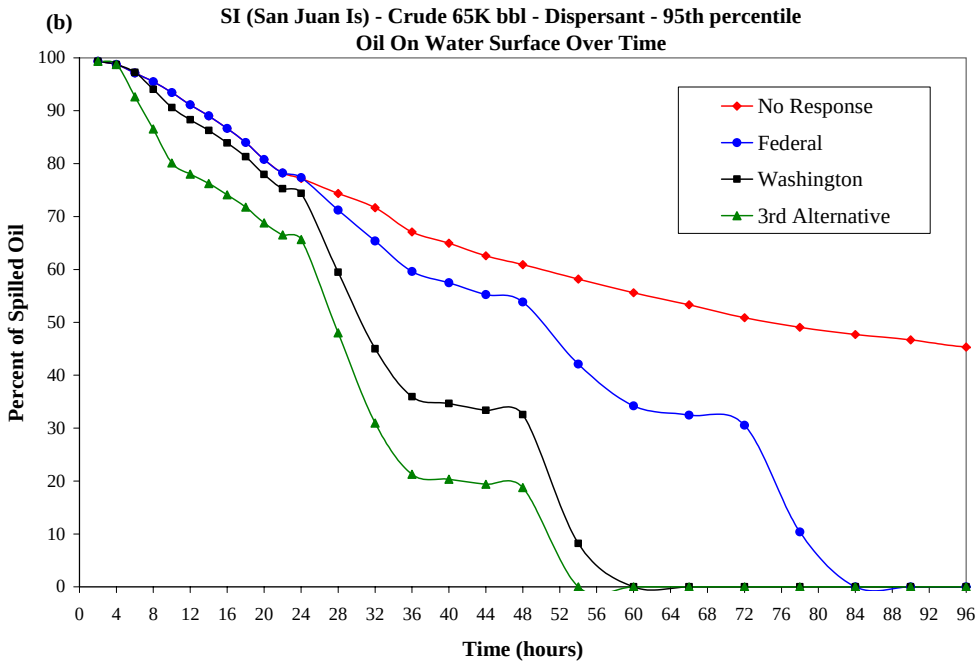
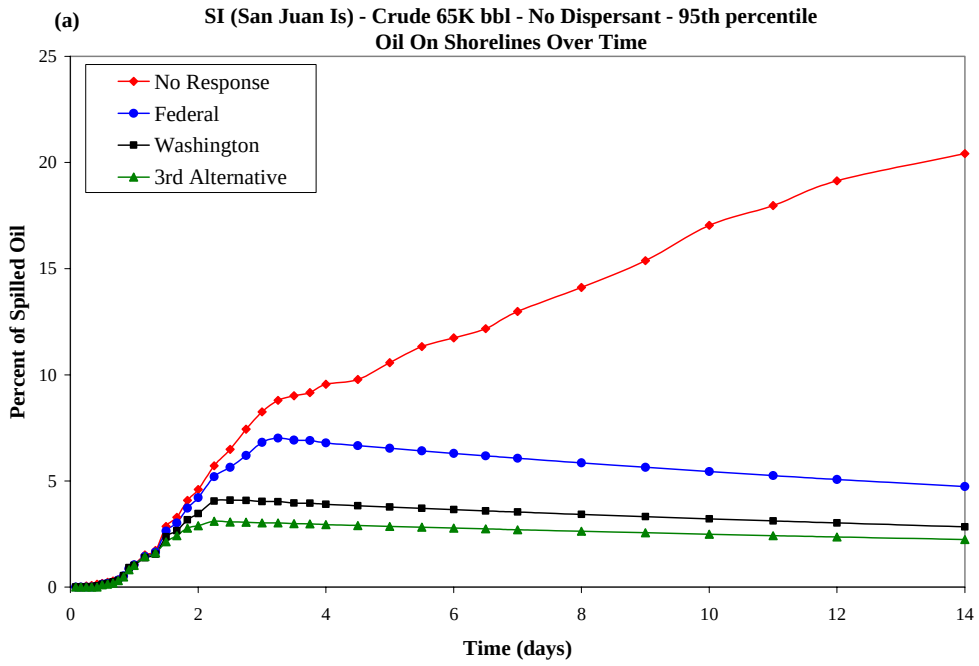


Figure XVII.B.8-35 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



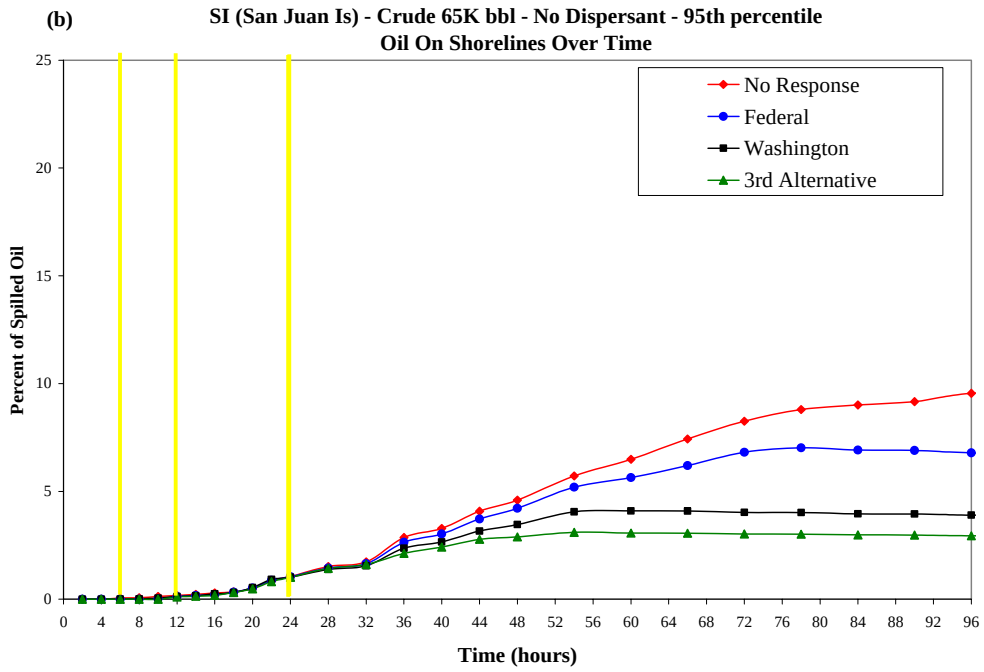
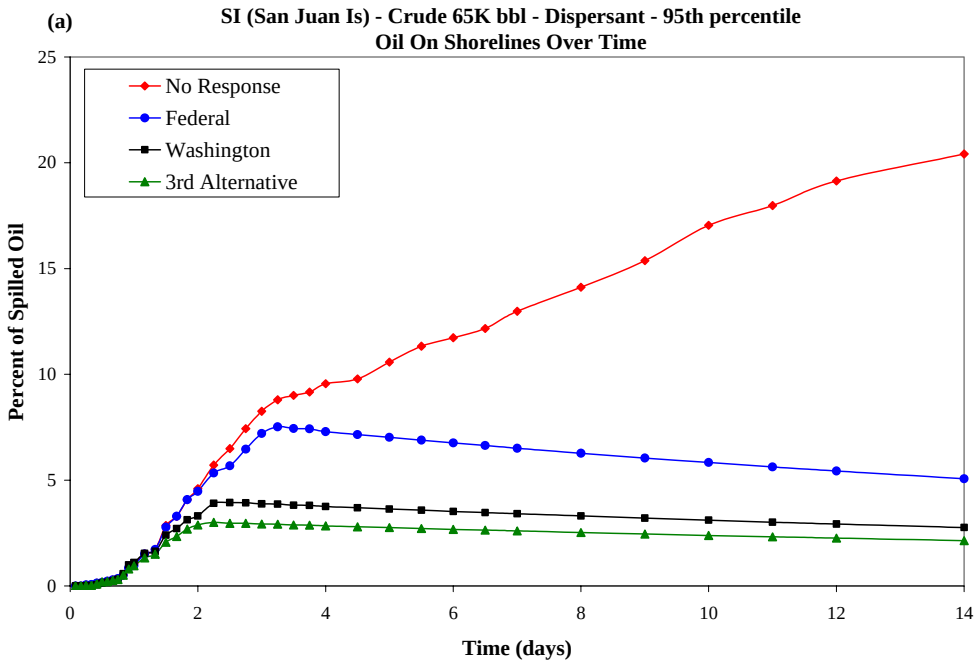


Figure XVII.B.8-36 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



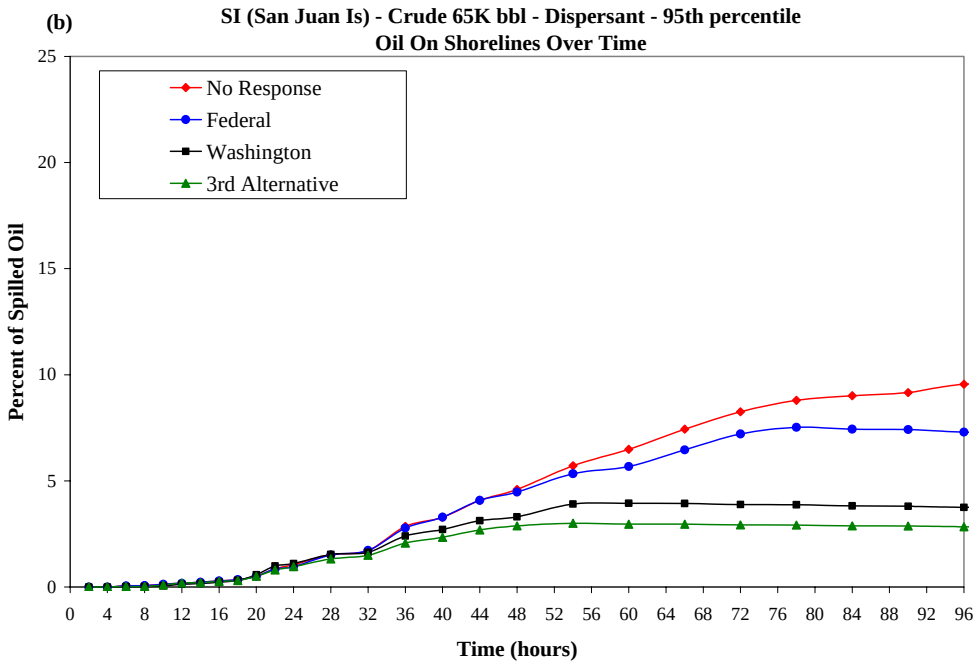
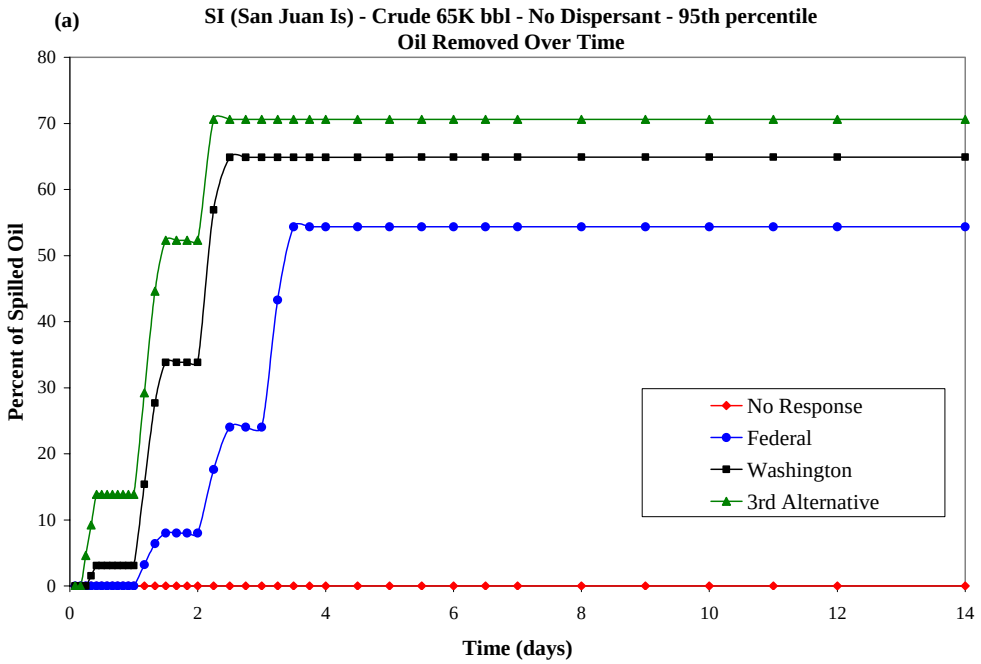


Figure XVII.B.8-37 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



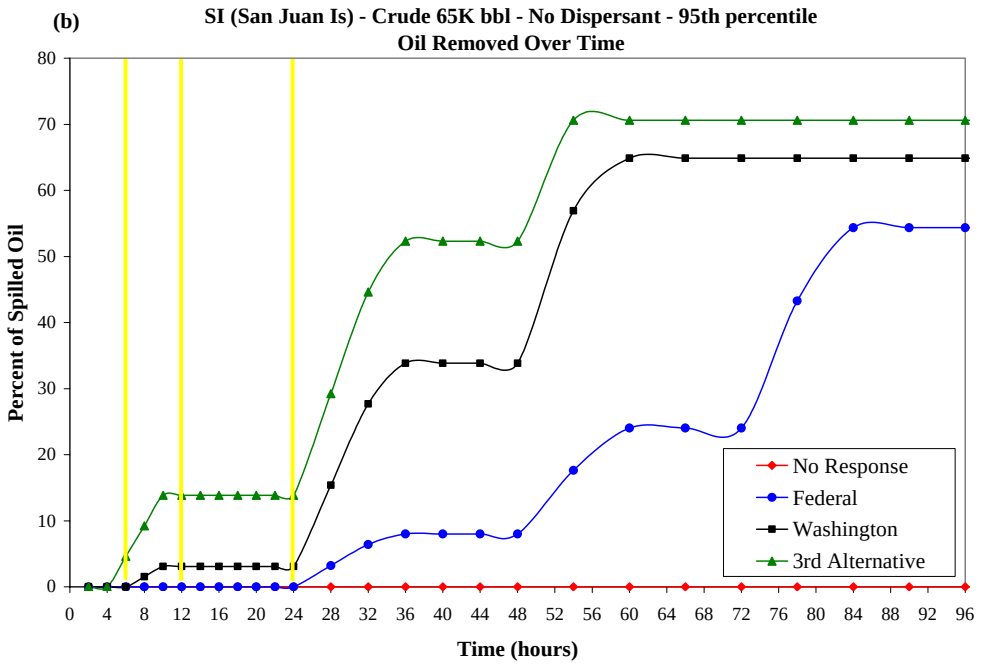
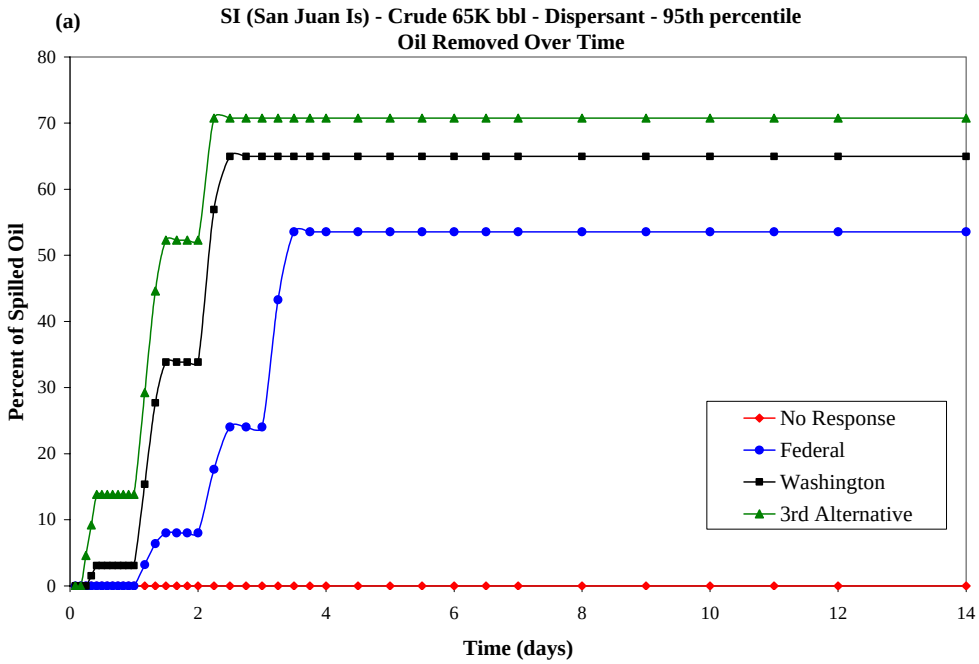


Figure XVII.B.8-38 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run. Part b is a subset of Part a.



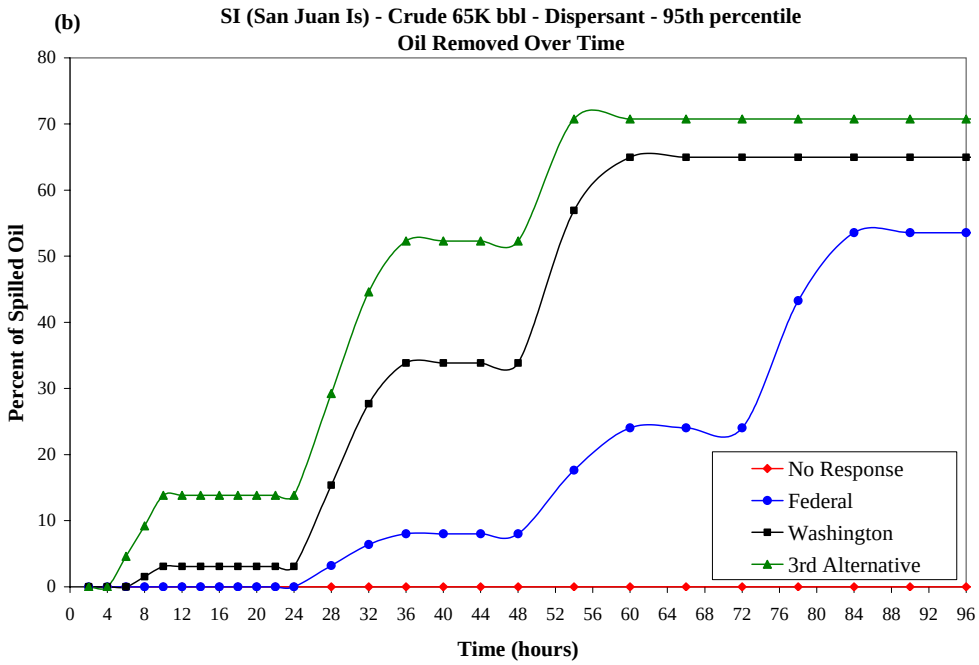


Figure XVII.B.8-39 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run. Part b is a subset of Part a.

XVII.C. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the appropriate seasonal abundance for each of the 5th, 50th and 95th percentile run dates. Impacts are proportional to pre-spill abundance. Thus, for the runs the results were corrected to use the annual mean abundance. Thus, all results are based on annual mean abundance. Note that the statistical data in the shaded cells are based only on 3 runs and so are highly uncertain.

Table IXVII.C-1 San Juan Islands, no removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	49,889	4,212	22	1,409	0	-	4	-	55,536	55,532	4
50th Percentile Run (based on shore cost)	20,702	1,742	10	642	0	-	2	-	23,098	23,097	2
95th Percentile Run (based on shore cost)	16,972	1,426	13	829	2	-	1	-	19,244	19,243	1
Mean	29,188	2,460	15	960	1	-	2	-	32,626	32,624	2
Std Dev (SD)	18,024	1,525	6	400	1	-	1	-	19,934	19,932	1
Mean - 2SD	-	-	3	161	-	-	-	-	-	-	-
Mean + 2SD	65,236	5,511	28	1,759	3	-	5	-	72,493	72,489	5

Table IXVII.C-2 San Juan Islands, WA state mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	2,515	203	1	34	0	-	0	-	2,752	2,752	0
50th Percentile Run (based on shore cost)	2,649	214	2	106	0	-	0	-	2,971	2,971	0
95th Percentile Run (based on shore cost)	5,724	474	4	234	0	-	0	-	6,437	6,437	0
Mean	4,430	365	2	107	0	-	0	-	4,904	4,904	0.38
Std Dev (SD)	2,660	225	1	63	0	-	0	-	2,911	2,911	0.19
Mean - 2SD	-	-	-	-	-	-	0	-	-	-	0.01
Mean + 2SD	9,749	815	4	234	0	-	1	-	10,726	10,725	0.75

Table IXVII.C-3 San Juan Islands, federal mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	4,148	341	1	87	0	-	0	-	4,579	4,578	0
50th Percentile Run (based on shore cost)	3,055	249	2	139	0	-	0	-	3,446	3,445	0
95th Percentile Run (based on shore cost)	6,660	554	5	329	0	-	1	-	7,548	7,548	1
Mean	4,621	381	3	185	0	-	0	-	5,191	5,190	0
Std Dev (SD)	1,848	156	2	127	0	-	0	-	2,119	2,119	0
Mean - 2SD	925	68	-	-	0	-	0	-	953	953	0
Mean + 2SD	8,317	694	7	440	0	-	1	-	9,429	9,428	1

Table IXVII.C-4 San Juan Islands, 3rd alternative mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	1,768	140	1	34	0	-	0	-	1,943	1,942	0
50th Percentile Run (based on shore cost)	2,595	210	2	101	0	-	0	-	2,907	2,907	0
95th Percentile Run (based on shore cost)	4,667	385	3	188	0	-	0	-	5,243	5,242	0
Mean	3,010	245	2	108	0	-	0	-	3,364	3,364	0
Std Dev (SD)	1,493	126	1	77	0	-	0	-	1,697	1,697	0
Mean - 2SD	23	-	-	-	0	-	0	-	-	-	0
Mean + 2SD	5,996	497	4	261	0	-	0	-	6,758	6,757	0

Table IXVII.C-5 San Juan Islands, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	2,058	164	1	33	0	-	0	-	2,256	2,255	0
50th Percentile Run (based on shore cost)	2,979	242	2	110	0	-	0	-	3,333	3,332	0
95th Percentile Run (based on shore cost)	5,559	461	4	230	0	-	0	-	6,254	6,253	0
Mean	3,532	289	2	124	0	-	0	-	3,947	3,947	0
Std Dev (SD)	1,815	154	2	99	0	-	0	-	2,069	2,069	0
Mean - 2SD	-	-	-	-	0	-	0	-	-	-	0
Mean + 2SD	7,162	596	5	323	0	-	1	-	8,085	8,084	1

Table IXVII.C-6 San Juan Islands, federal mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	3,741	307	1	76	0	-	0	-	4,125	4,125	0
50th Percentile Run (based on shore cost)	2,888	234	2	120	0	-	0	-	3,244	3,244	0
95th Percentile Run (based on shore cost)	7,408	617	5	328	0	-	1	-	8,358	8,358	1
Mean	4,679	386	3	175	0	-	0	-	5,243	5,242	0
Std Dev (SD)	2,402	203	2	134	0	-	0	-	2,734	2,734	0
Mean - 2SD	-	-	-	-	0	-	0	-	-	-	0
Mean + 2SD	9,482	792	7	443	0	-	1	-	10,711	10,710	1

Table IXVII.C-7 San Juan Islands, 3rd alternative mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	1,683	132	0	29	0	-	0	-	1,845	1,845	0
50th Percentile Run (based on shore cost)	2,666	216	2	108	0	-	0	-	2,991	2,991	0
95th Percentile Run (based on shore cost)	4,722	390	3	186	0	-	0	-	5,301	5,301	0
Mean	3,024	246	2	108	0	-	0	-	3,379	3,379	0
Std Dev (SD)	1,551	131	1	79	0	-	0	-	1,761	1,760	0
Mean - 2SD	-	-	-	-	0	-	0	-	-	-	0
Mean + 2SD	6,126	508	4	265	0	-	0	-	6,900	6,900	0

XVII.D. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates were calculated using the seasonal abundance for each of the spill dates included in the 3 runs. Note that the statistical data in the shaded cells are based only on 3 runs and so are highly uncertain.

Table XVII.D-1. San Juan Islands, no removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	110.9	943.7	4.0	2.8	1481.1	19,976	22,518
50th Percentile Run (shore cost)	1436.0	7548.3	271.6	75.4	5587.6	8,273	23,192
95th Percentile Run (shore cost)	0.0	289.1	0.0	0.0	1074.1	12,992	14,355
Mean	515.7	2927.0	91.9	26.1	2714.3	13,747	20,022
Std Dev (SD)	799.0	4015.5	155.7	42.8	2496.7	5,888	13,397
Mean - 2SD	0.0	0.0	0.0	0.0	0.0	1,972	1,972
Mean + 2SD	2113.7	10958.1	403.2	111.6	7707.7	25,523	46,817

Table XVII.D-2. San Juan Islands, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	-	117.6	-	-	967.5	252	1,337
50th Percentile Run (shore cost)	1,453.8	7,636.9	275.2	76.4	5,642.7	566	15,651
95th Percentile Run (shore cost)	-	146.8	-	-	985.7	1,636	2,768
Mean	572.7	3,176.9	103.5	29.2	2,869.6	1,134	7,886
Std Dev (SD)	641.8	3,262.3	124.1	34.2	2,028.3	716	6,807
Mean - 2SD	-	-	-	-	-	-	-
Mean + 2SD	1,856.3	9,701.4	351.8	97.6	6,926.3	2,566	21,499

Table XVII.D-3. San Juan Islands, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	0.0	209.0	0.0	0.0	1024.3	472	1,705
50th Percentile Run (shore cost)	1455.3	7644.3	275.5	76.5	5647.3	1,132	16,231
95th Percentile Run (shore cost)	0.0	144.9	0.0	0.0	984.5	3,397	4,527
Mean	485.1	2666.1	91.8	25.5	2552.0	1,667	7,488
Std Dev (SD)	840.2	4311.4	159.1	44.2	2680.6	1,534	9,570
Mean - 2SD	0.0	0.0	0.0	0.0	0.0	-	-
Mean + 2SD	2165.5	11288.8	409.9	113.8	7913.3	4,736	26,627

Table XVII.D-4. San Juan Islands, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	0.0	156.2	0.0	0.0	991.5	315	1,462
50th Percentile Run (shore cost)	1310.9	6924.8	246.3	68.6	5200.0	786	14,537
95th Percentile Run (shore cost)	0.0	77.1	0.0	0.0	942.3	1,132	2,152
Mean	437.0	2386.1	82.1	22.9	2377.9	744	6,050
Std Dev (SD)	756.9	3930.9	142.2	39.6	2444.1	411	7,724
Mean - 2SD	0.0	0.0	0.0	0.0	0.0	-	-
Mean + 2SD	1950.7	10247.8	366.6	102.0	7266.1	1,566	21,499

Table XVII.D-5. San Juan Islands, WA state mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	313.1	1951.5	44.8	13.9	2107.8	252	4,683
50th Percentile Run (shore cost)	1524.9	7991.0	289.5	80.3	5862.8	786	16,535
95th Percentile Run (shore cost)	126.0	1019.0	7.0	3.6	1528.0	1,636	4,319
Mean	654.7	3653.8	113.8	32.6	3166.2	891	8,512
Std Dev (SD)	759.4	3784.9	153.4	41.6	2353.3	698	7,791
Mean - 2SD	0.0	0.0	0.0	0.0	0.0	-	-
Mean + 2SD	2173.4	11223.6	420.5	115.8	7872.8	2,287	24,094

Table XVII.D-6. San Juan Islands, federal mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	1075.7	5752.2	198.8	55.7	4470.9	503	12,057
50th Percentile Run (shore cost)	1277.3	6757.3	239.5	66.7	5095.8	944	14,380
95th Percentile Run (shore cost)	0.0	163.8	0.0	0.0	996.2	3,209	4,369
Mean	784.3	4224.4	146.1	40.8	3521.0	1,552	10,269
Std Dev (SD)	686.7	3552.4	128.2	35.8	2208.7	1,452	8,063
Mean - 2SD	0.0	0.0	0.0	0.0	0.0	-	-
Mean + 2SD	2157.7	11329.1	402.5	112.3	7938.4	4,455	26,395

Table XVII.D-7. San Juan Islands, 3rd alternative mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	0.0	276.8	0.0	0.0	1066.5	346	1,689
50th Percentile Run (shore cost)	1605.8	8394.3	305.9	84.7	6113.6	786	17,291
95th Percentile Run (shore cost)	0.0	86.5	0.0	0.0	948.2	1,070	2,104
Mean	535.3	2919.2	102.0	28.2	2709.4	734	7,028
Std Dev (SD)	927.1	4742.5	176.6	48.9	2948.7	365	9,208
Mean - 2SD	0.0	0.0	0.0	0.0	0.0	5	5
Mean + 2SD	2389.5	12404.2	455.2	126.1	8606.8	1,463	25,445

XVII.E. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All weights are as wet weight; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

NRDA costs were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because impacts are not necessarily correlated with shore cost, the results for NRDA costs may not be in increasing order from 5th to 95th percentile run by shore cost.

Table XVII.E-1. San Juan Islands, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	110.9	1,436.0	-	515.7	-	2,113.7
Large pelagic fish	943.7	7,548.3	289.1	2,927.0	-	10,958.1
Demersal fish	4.0	271.6	-	91.9	-	403.2
Decapods	2.8	75.4	-	26.1	-	111.6
Molluscs	21,457	13,861	14,066	16,461	1,972	33,230
Birds:						
Waterfowl (# * kg each)	19,956	15,734	6,789	14,159	713	27,605
Seabirds (# * kg each)	5,897	1,272	1,997	3,055	-	8,030
Waders (# * kg each)	29	13	17	20	3	36
Shorebirds (# * kg each)	42	19	25	29	5	53
Raptors (# * kg each)	2	1	10	4	-	14
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	484	206	171	287	-	630
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	22,518	23,192	14,355	20,022	1,972	46,817
Subtotal birds	25,926	17,039	8,838	17,267	722	35,739
Subtotal other wildlife	484	206	171	287	-	630
Total all species	48,928	40,437	23,363	37,576	2,693	83,185

Table XVII.E-2. San Juan Islands, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	94	64	33	64	1	157
Saltmarsh Area (acres)	233	158	82	158	3	389
Saltmarsh Cost (millions of 2004$)	43.7	29.6	15.4	29.6	0.5	72.9
Eelgrass Area (m2)	59	40	21	40	1	98
Eelgrass Area (acres)	146	99	51	99	2	243
Eelgrass Cost (millions of 2004$)	17.4	11.8	6.1	11.8	0.2	29.0

Table XVII.E-3. San Juan Islands, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	1,453.8	-	572.7	-	1,856.3
Large pelagic fish	117.6	7,636.9	146.8	3,176.9	-	9,701.4
Demersal fish	-	275.2	-	103.5	-	351.8
Decapods	-	76.4	-	29.2	-	97.6
Molluscs	1,219	6,209	2,621	4,003	-	9,492
Birds:						
Waterfowl (# * kg each)	1,006	1,059	2,290	1,772	-	3,900
Seabirds (# * kg each)	284	300	664	511	-	1,141
Waders (# * kg each)	1	2	5	2	-	5
Shorebirds (# * kg each)	1	3	7	3	-	7
Raptors (# * kg each)	0	0	0	0	-	1
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	33	34	64	51	1	102
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	1,337	15,651	2,768	7,886	-	21,499
Subtotal birds	1,292	1,365	2,966	2,289	-	5,053
Subtotal other wildlife	33	34	64	51	1	102
Total all species	2,662	17,051	5,798	10,226	1	26,654

Table XVII.E-4. San Juan Islands, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	5	29	11	18	0	48
Saltmarsh Area (acres)	13	72	28	46	0	120
Saltmarsh Cost (millions of 2004$)	2.5	13.5	5.3	8.6	0.02	22.5
Eelgrass Area (m2)	3	18	7	12	0	30
Eelgrass Area (acres)	8	45	18	29	0	75
Eelgrass Cost (millions of 2004$)	1.0	5.4	2.1	3.4	0.01	8.9

Table XVII.E-5. San Juan Islands, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	1,455.3	-	485.1	-	2,165.5
Large pelagic fish	209.0	7,644.3	144.9	2,666.1	-	11,288.8
Demersal fish	-	275.5	-	91.8	-	409.9
Decapods	-	76.5	-	25.5	-	113.8
Molluscs	1,496	6,780	4,382	4,219	-	12,649
Birds:						
Waterfowl (# * kg each)	1,659	2,322	2,664	2,215	1,194	3,236
Seabirds (# * kg each)	478	181	775	478	-	1,072
Waders (# * kg each)	2	3	7	4	-	9
Shorebirds (# * kg each)	3	4	10	6	-	13
Raptors (# * kg each)	0	0	0	0	0	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	49	38	73	53	18	88
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	1,705	16,231	4,527	7,488	-	26,627
Subtotal birds	2,142	2,511	3,456	2,703	1,194	4,331
Subtotal other wildlife	49	38	73	53	18	88
Total all species	3,895	18,780	8,055	10,244	1,212	31,046

Table XVII.E-6. San Juan Islands, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	9	30	13	17	3	52
Saltmarsh Area (acres)	21	75	33	43	6	128
Saltmarsh Cost (millions of 2004$)	4.0	14.1	6.2	8.1	1.2	23.9
Eelgrass Area (m2)	5	19	8	11	2	32
Eelgrass Area (acres)	13	47	21	27	4	80
Eelgrass Cost (millions of 2004$)	1.6	5.6	2.4	3.2	0.5	9.5

Table XVII.E-7. San Juan Islands, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	1,310.9	-	437.0	-	1,950.7
Large pelagic fish	156.2	6,924.8	77.1	2,386.1	-	10,247.8
Demersal fish	-	246.3	-	82.1	-	366.6
Decapods	-	68.6	-	22.9	-	102.0
Molluscs	1,306	5,986	2,075	3,122	-	8,832
Birds:						
Waterfowl (# * kg each)	707	1,972	1,867	1,515	112	2,919
Seabirds (# * kg each)	196	153	539	296	-	719
Waders (# * kg each)	1	2	4	2	-	5
Shorebirds (# * kg each)	1	3	6	3	-	8
Raptors (# * kg each)	0	0	0	0	0	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	26	34	54	38	9	66
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	1,462	14,537	2,152	6,050	-	21,499
Subtotal birds	905	2,130	2,415	1,817	112	3,651
Subtotal other wildlife	26	34	54	38	9	66
Total all species	2,393	16,701	4,621	7,905	121	25,216

Table XVII.E-8. San Juan Islands, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	4	27	9	14	1	44
Saltmarsh Area (acres)	10	67	23	34	2	109
Saltmarsh Cost (millions of 2004$)	2.0	12.6	4.3	6.3	0.3	20.5
Eelgrass Area (m2)	3	17	6	8	0	28
Eelgrass Area (acres)	7	42	14	21	1	68
Eelgrass Cost (millions of 2004$)	0.8	5.0	1.7	2.5	0.1	8.1

Table XVII.E-9. San Juan Islands, WA state mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	313.1	1,524.9	126.0	654.7	-	2,173.4
Large pelagic fish	1,951.5	7,991.0	1,019.0	3,653.8	-	11,223.6
Demersal fish	44.8	289.5	7.0	113.8	-	420.5
Decapods	13.9	80.3	3.6	32.6	-	115.8
Molluscs	2,359	6,649	3,164	4,057	-	10,160
Birds:						
Waterfowl (# * kg each)	823	2,264	2,224	1,770	129	3,411
Seabirds (# * kg each)	230	177	645	350	-	863
Waders (# * kg each)	1	2	5	3	-	7
Shorebirds (# * kg each)	1	3	7	4	-	10
Raptors (# * kg each)	0	0	0	0	0	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	29	38	62	43	8	77
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	4,683	16,535	4,319	8,512	-	24,094
Subtotal birds	1,055	2,447	2,880	2,127	130	4,291
Subtotal other wildlife	29	38	62	43	8	77
Total all species	5,767	19,019	7,262	10,683	138	28,462

Table XVII.E-10. San Juan Islands, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	10	31	14	18	1	49
Saltmarsh Area (acres)	26	77	34	46	2	122
Saltmarsh Cost (millions of 2004$)	4.8	14.5	6.4	8.6	0.3	22.9
Eelgrass Area (m2)	6	20	9	12	0	31
Eelgrass Area (acres)	16	48	21	29	1	76
Eelgrass Cost (millions of 2004$)	1.9	5.8	2.5	3.4	0.1	9.1

Table XVII.E-11. San Juan Islands, federal mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	1,075.7	1,277.3	-	784.3	-	2,157.7
Large pelagic fish	5,752.2	6,757.3	163.8	4,224.4	-	11,329.1
Demersal fish	198.8	239.5	-	146.1	-	402.5
Decapods	55.7	66.7	-	40.8	-	112.3
Molluscs	4,974	6,039	4,205	5,073	-	12,394
Birds:						
Waterfowl (# * kg each)	1,496	2,195	2,963	2,218	751	3,686
Seabirds (# * kg each)	429	171	864	488	-	1,188
Waders (# * kg each)	2	2	7	4	-	9
Shorebirds (# * kg each)	2	4	10	5	-	13
Raptors (# * kg each)	0	0	0	0	0	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	45	37	80	54	8	99
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	12,057	14,380	4,369	10,269	-	26,395
Subtotal birds	1,930	2,372	3,844	2,715	751	4,897
Subtotal other wildlife	45	37	80	54	8	99
Total all species	14,031	16,789	8,292	13,038	759	31,391

Table XVII.E-12. San Juan Islands, federal mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	25	27	15	22	1	54
Saltmarsh Area (acres)	62	67	36	55	3	133
Saltmarsh Cost (millions of 2004$)	11.7	12.6	6.8	10.4	0.6	24.9
Eelgrass Area (m2)	16	17	9	14	1	34
Eelgrass Area (acres)	39	42	23	35	2	83
Eelgrass Cost (millions of 2004$)	4.7	5.0	2.7	4.1	0.3	9.9

Table XVII.E-13. San Juan Islands, 3rd alternative mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	1,605.8	-	535.3	-	2,389.5
Large pelagic fish	276.8	8,394.3	86.5	2,919.2	-	12,404.2
Demersal fish	-	305.9	-	102.0	-	455.2
Decapods	-	84.7	-	28.2	-	126.1
Molluscs	1,413	6,900	2,018	3,443	5	10,070
Birds:						
Waterfowl (# * kg each)	673	2,026	1,889	1,529	40	3,019
Seabirds (# * kg each)	185	157	546	296	-	729
Waders (# * kg each)	1	2	4	2	-	5
Shorebirds (# * kg each)	1	3	6	3	-	8
Raptors (# * kg each)	0	0	0	0	0	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	25	35	54	38	8	67
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	1,689	17,291	2,104	7,028	5	25,445
Subtotal birds	860	2,189	2,444	1,831	40	3,761
Subtotal other wildlife	25	35	54	38	8	67
Total all species	2,575	19,514	4,603	8,897	54	29,274

Table XVII.E-14. San Juan Islands, 3rd alternative mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	4	32	9	15	1	51
Saltmarsh Area (acres)	11	79	23	38	1	126
Saltmarsh Cost (millions of 2004$)	2.1	14.8	4.3	7.1	0.3	23.7
Eelgrass Area (m2)	3	20	6	10	0	32
Eelgrass Area (acres)	7	49	14	24	1	79
Eelgrass Cost (millions of 2004$)	0.8	5.9	1.7	2.8	0.1	9.4

XVII.F. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

The Washington Compensation Schedule was applied to the model results for the hypothetical spills simulated. The methods are described in Section 6.2 of Volume I. Note that the Compensation Schedule is designed to be a simplified procedure for small spills. Thus, for spills the size of those considered here, the OPA procedures using restoration costs (listed in section XVII.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table XVII.F-1. San Juan Islands, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	25.540	25.543	22.714	24.599	21.334	27.864
% Removed by 24 hours	-	-	-	-	-	-
Compensation (millions $)	69.7	69.7	62.0	67.2	58.2	76.1

Table XVII.F-2. San Juan Islands, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	23.638	25.539	22.689	23.716	20.490	26.942
% Removed by 24 hours	9.2	18.5	3.1	13.7	-	27.6
Compensation (millions $)	58.6	56.9	60.0	55.9	47.7	64.1

Table XVII.F-3. San Juan Islands, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	23.638	25.539	22.689	23.955	21.053	26.857
% Removed by 24 hours	3.2	6.4	0.0	3.2	-	9.6
Compensation (millions $)	62.5	65.3	61.9	63.3	55.6	71.0

Table XVII.F-4. San Juan Islands, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	23.638	25.538	22.689	23.955	21.053	26.857
% Removed by 24 hours	12.3	24.6	13.8	16.9	3.5	30.3
Compensation (millions $)	56.6	52.6	53.4	54.3	46.9	61.7

Table XVII.F-5. San Juan Islands, WA state mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	23.638	25.539	22.689	23.744	20.539	26.949
% Removed by 24 hours	9.2	18.5	3.1	13.7	-0.3	27.6
Compensation (millions $)	58.6	56.8	60.0	56.0	47.8	64.1

Table XVII.F-6. San Juan Islands, federal mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	23.638	25.538	22.689	23.955	21.054	26.857
% Removed by 24 hours	3.2	6.4	-	3.2	-	9.6
Compensation (millions $)	62.5	65.3	61.9	63.3	55.6	71.0

Table XVII.F-7. San Juan Islands, 3rd alternative mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	23.638	25.538	22.689	23.955	21.053	26.857
% Removed by 24 hours	12.3	24.6	13.8	16.9	3.5	30.3
Compensation (millions $)	56.6	52.6	53.4	54.3	46.9	61.7

Draft Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XVIII: Model Inputs for Inner Straits/Puget Sound – Alaskan North Slope Crude

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XVIII.A. INTRODUCTION

This appendix contains model input data (in maps, figures and tables) for the modeled locations and the sources for that information. The approach and sources applicable to all modeled locations are described in Volume I, Section 3 of this technical report. Specifics to this model location are below. Thus, the reader should refer to Volume I, Section 3 for background and the context within which these data are used.

XVIII.B. GEOGRAPHICAL DATA

Geographic data for the modeled location are presented in this section. The sources for these data are described in Volume I, Section 3. Maps are also presented below showing areas where mechanical removal, dispersant application (as applicable), and in situ burning (ISB, as applicable) were assumed to occur in the model simulations. The assumptions for the response scenarios are in Volume I, Section 3.

XVIII.B.1. Maps of the Vicinity of the Modeled Spill Locations

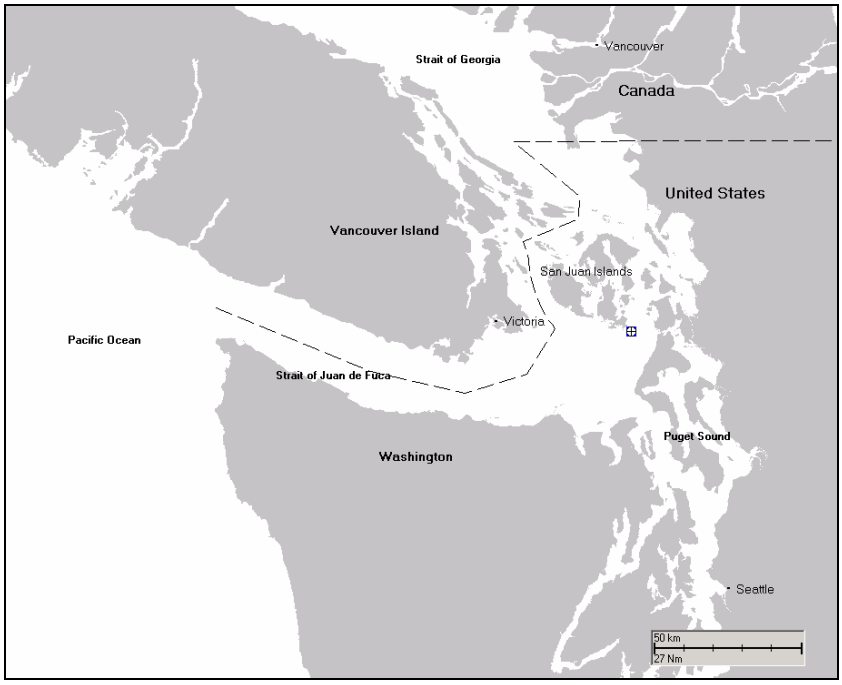

Figure XVIII.B.1-1 Map of the vicinity of the potential spill locations.

XVIII.B.2. Gridded Habitat Mapping

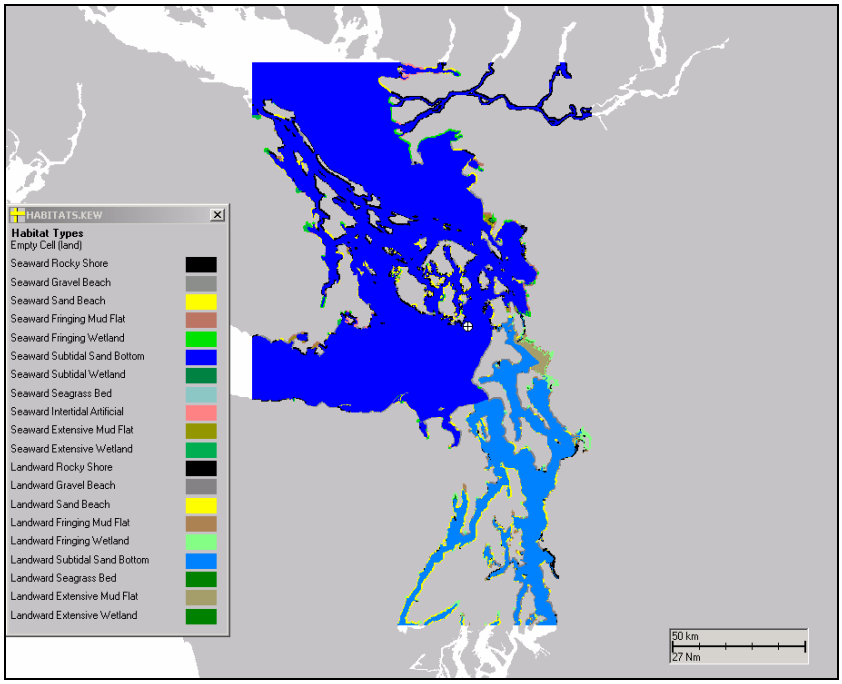

Figure XVIII.B.2-1 Habitat grid used for modeling the potential spills.

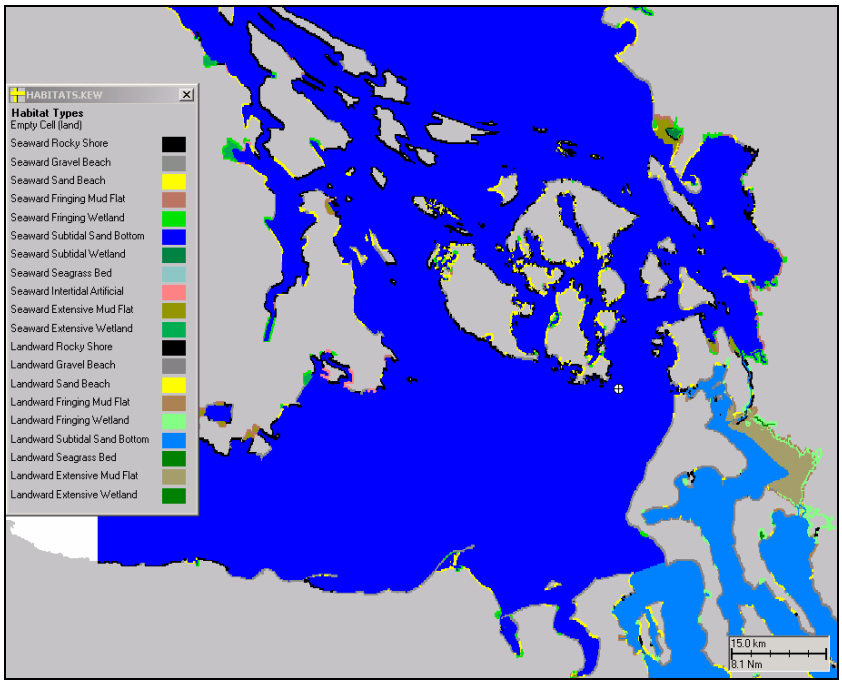

Figure XVIII.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XVIII.B-3. Gridded Depth Data

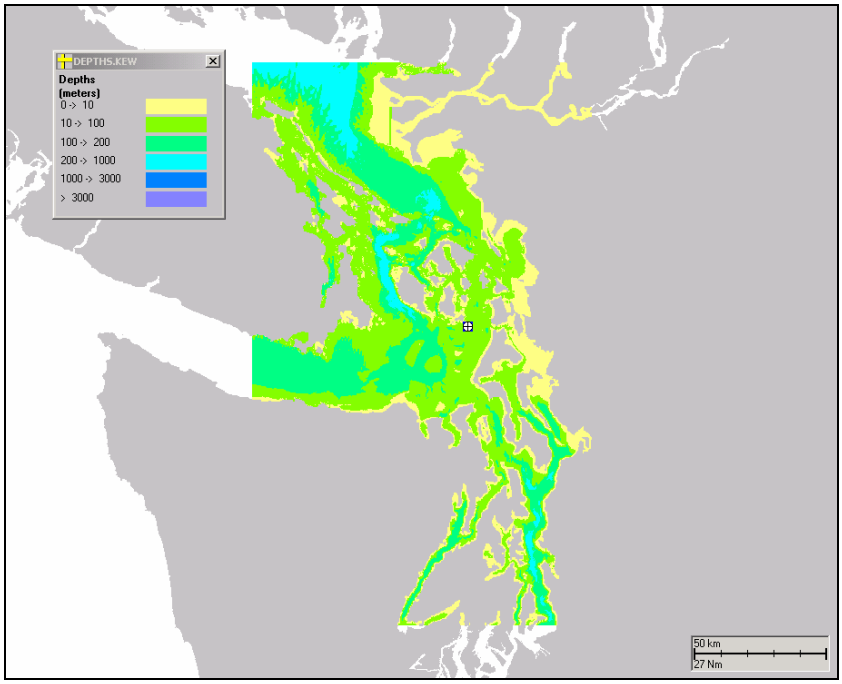

Figure XVIII.B.3-1 Depth grid used for modeling the potential spills.

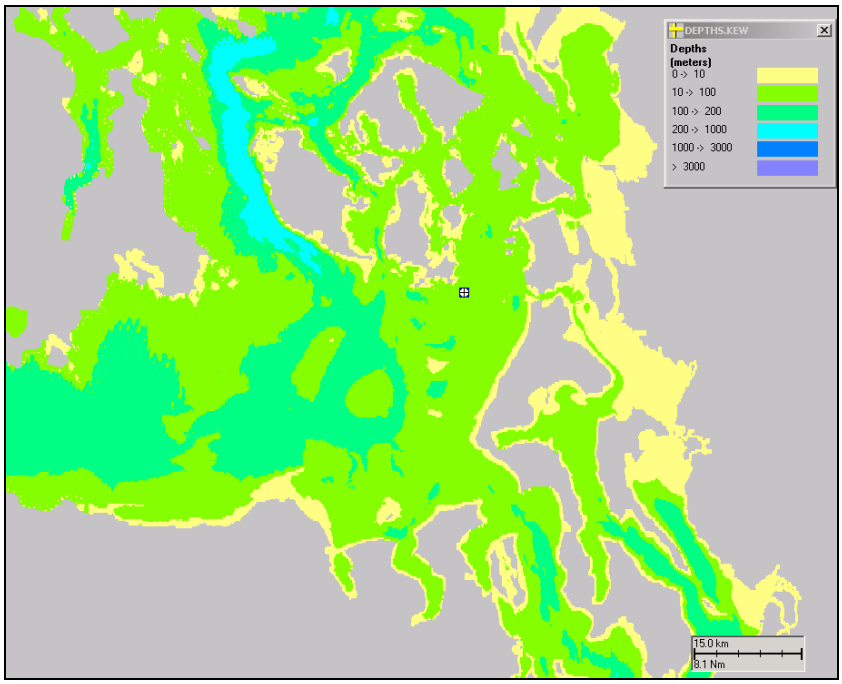

Figure XVIII.B.3-2 Depth grid used for modeling the potential spills (closer view).

XVIII.B-4. Areas Where Response Actions Assumed

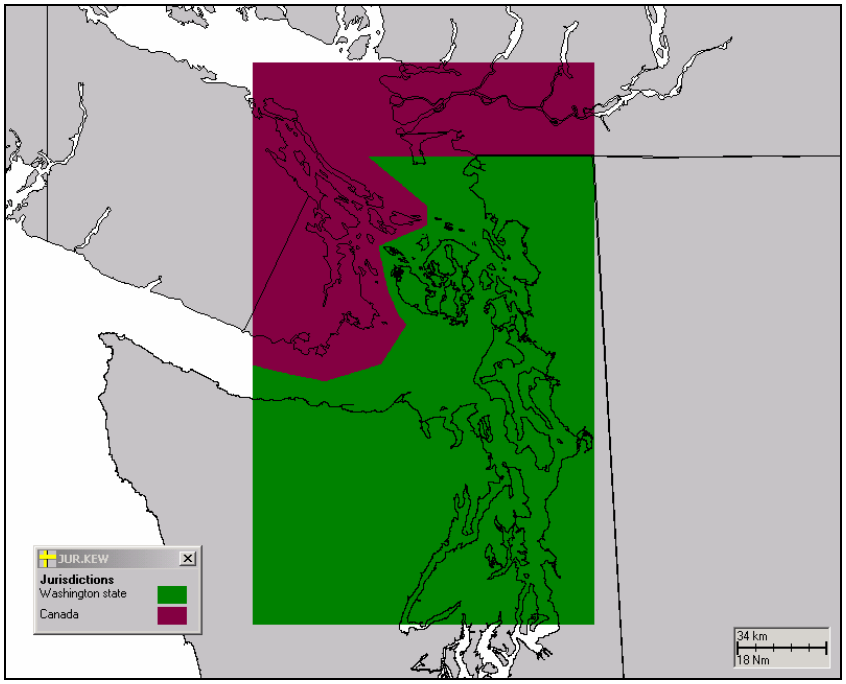

Figure XVIII.B.4-1 Jurisdictions in the area of the potential spills.

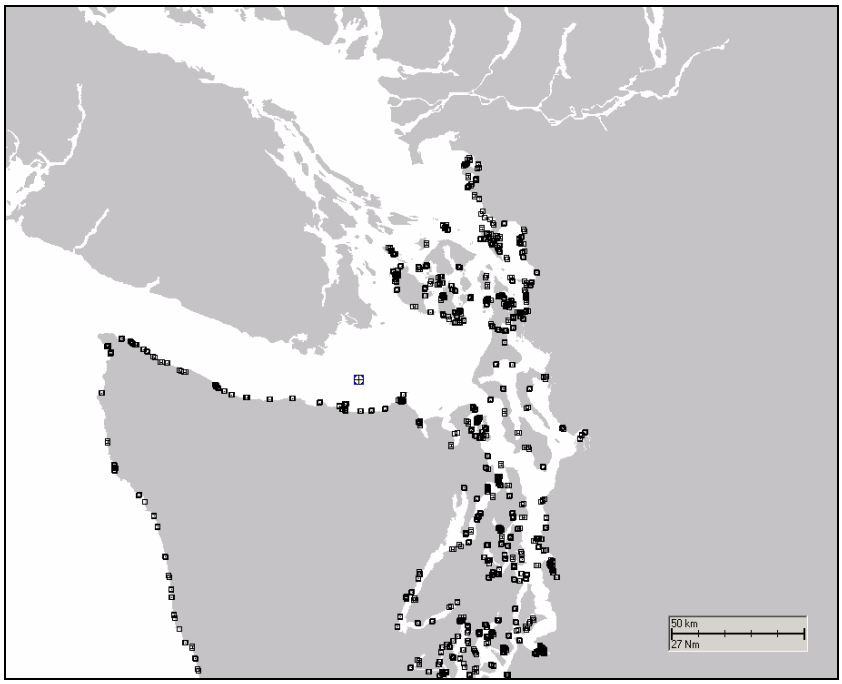

Figure XVIII.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

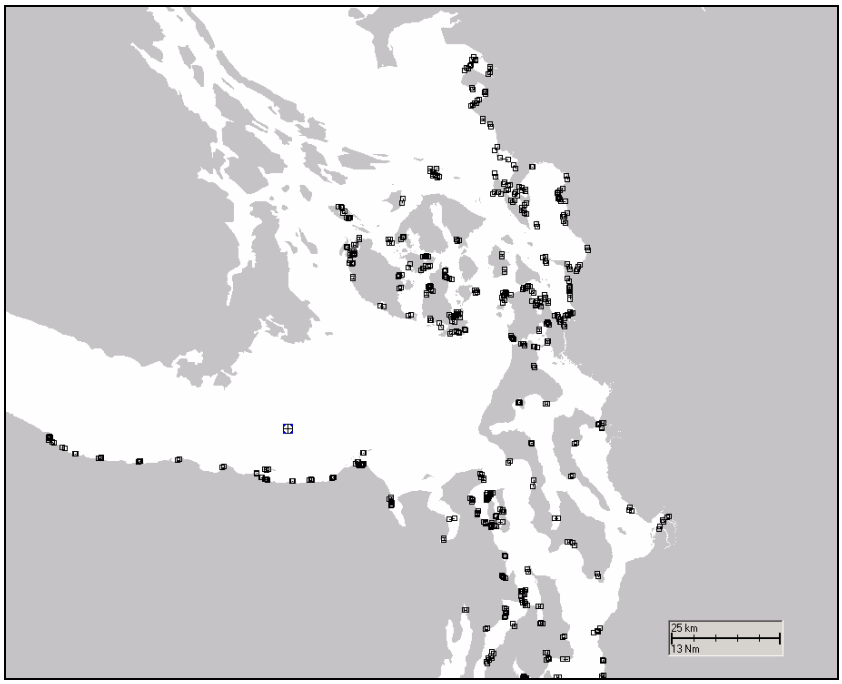

Figure XVIII.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

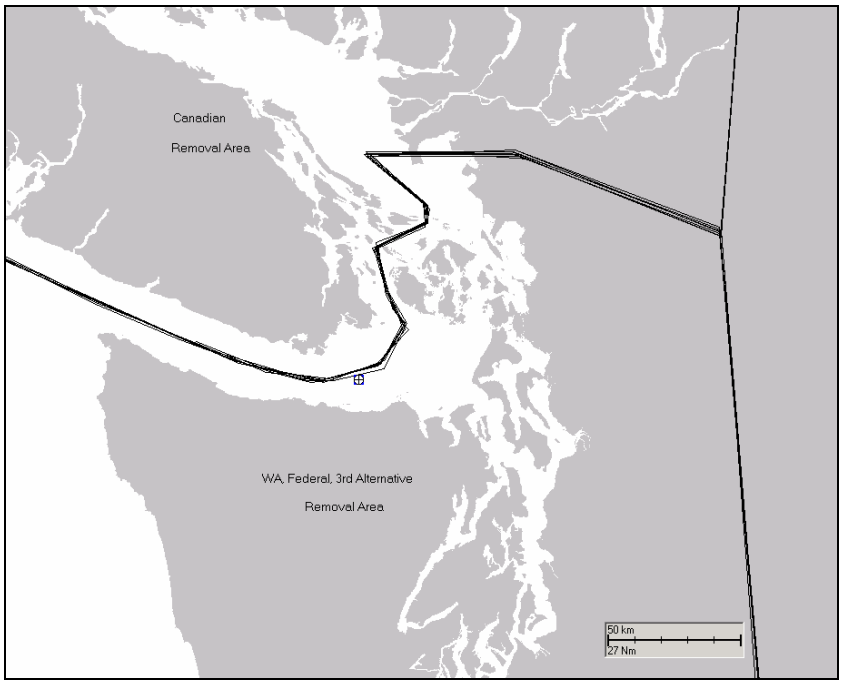

Figure XVIII.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

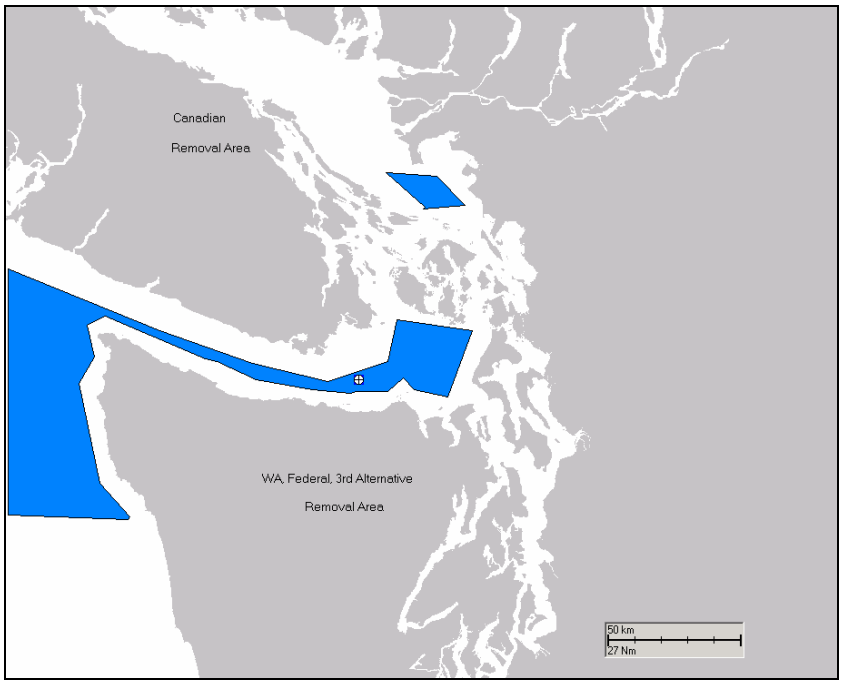

Figure XVIII.B.4-5 Areas where dispersant application was assumed to occur in modeling the potential spills.

XVIII.C. CURRENT DATA

XVIII.C.1. Basis of Current Data

Currents were based on hydrodynamic model data from D.O. Hodgins (1998; Seaconsult Marine Research Ltd, 8805 Osler Street, Vancouver V6P 4G1, Canada), who simulated currents in the Strait of Georgia. The surface currents from Hodgins' three-dimensional model outputs were formatted for use in SIMAP. The tidal forcing functions applied were the 9 harmonic constituents (M_2, S_2, N_2, K_2, MF, Q_1, K_1, O_1 and P_1).

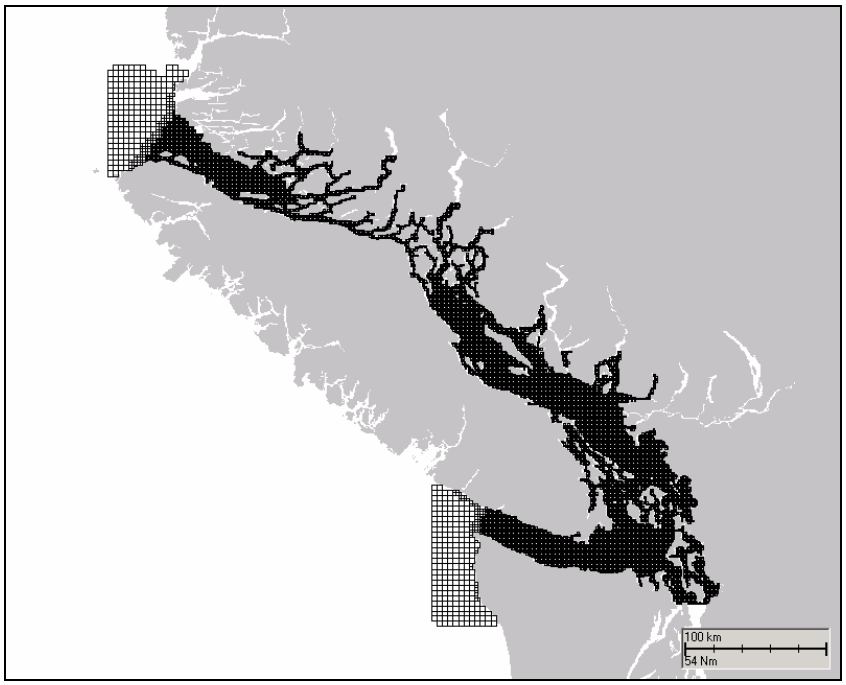

Figure XVIII.C.1-1 Grid used for the hydrodynamic model-generated current data.

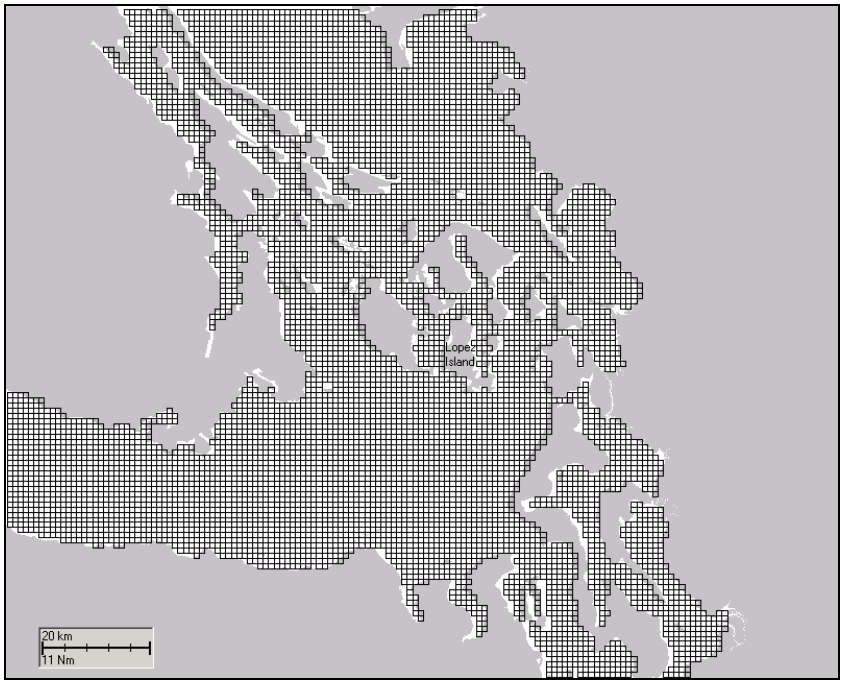

Figure XVIII.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island).

XVIII.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations

The figures below show the maximum flood and ebb of the M_2 and K_1 component. Note that 0.5 m/sec = 1 knot.

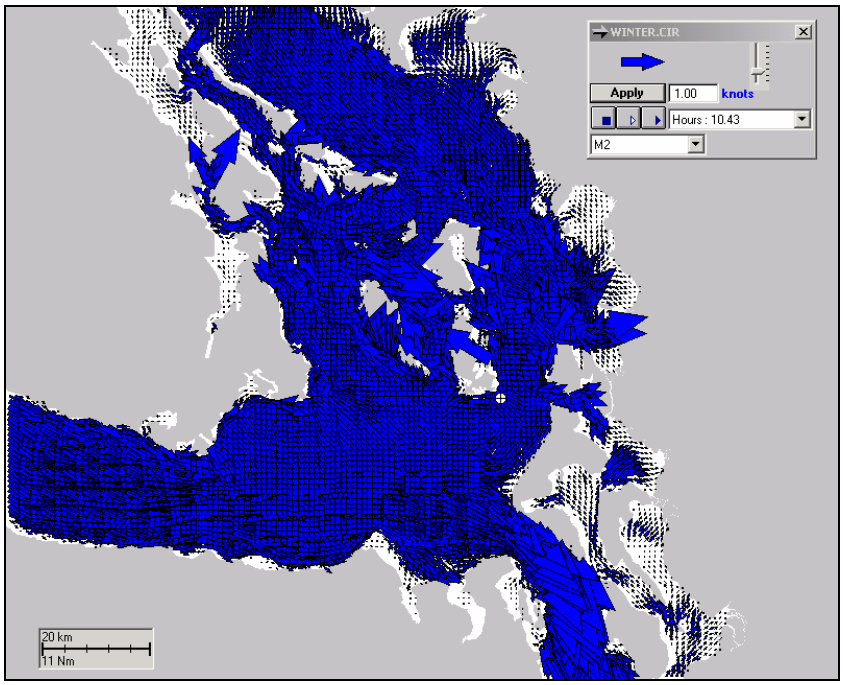

Figure XVIII.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Lopez Island.

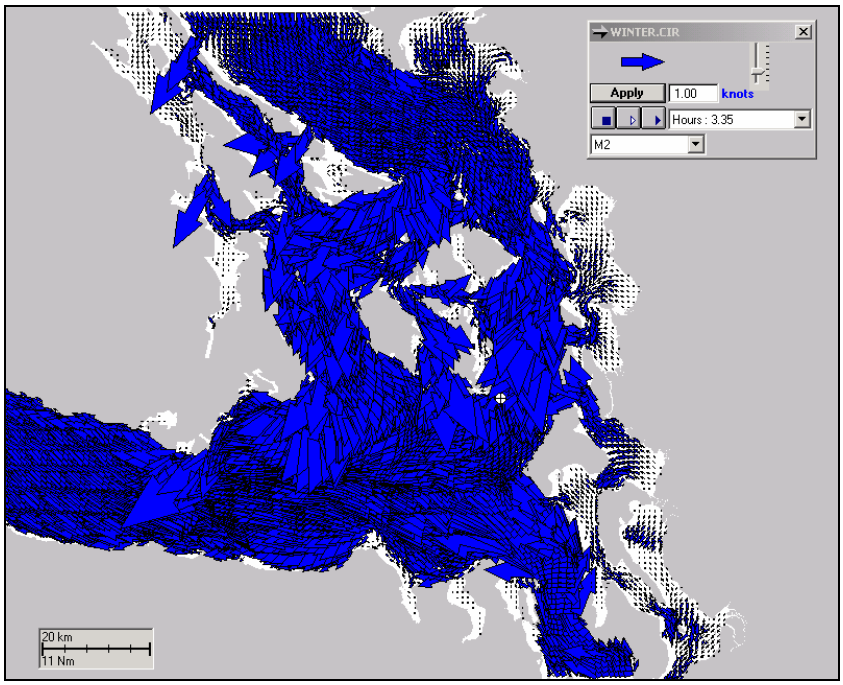

Figure XVIII.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Lopez Island.

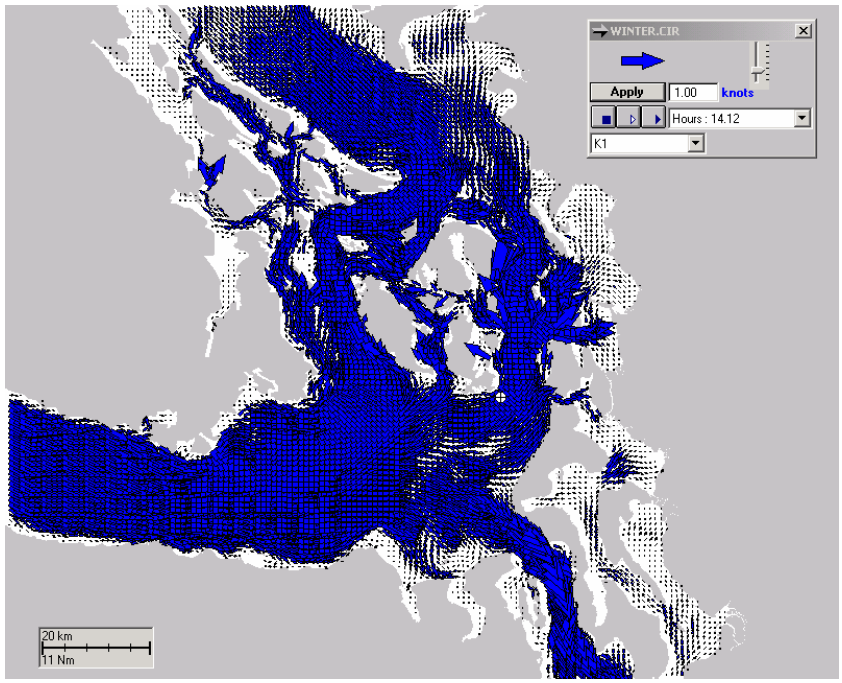

Figure XVIII.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Lopez Island.

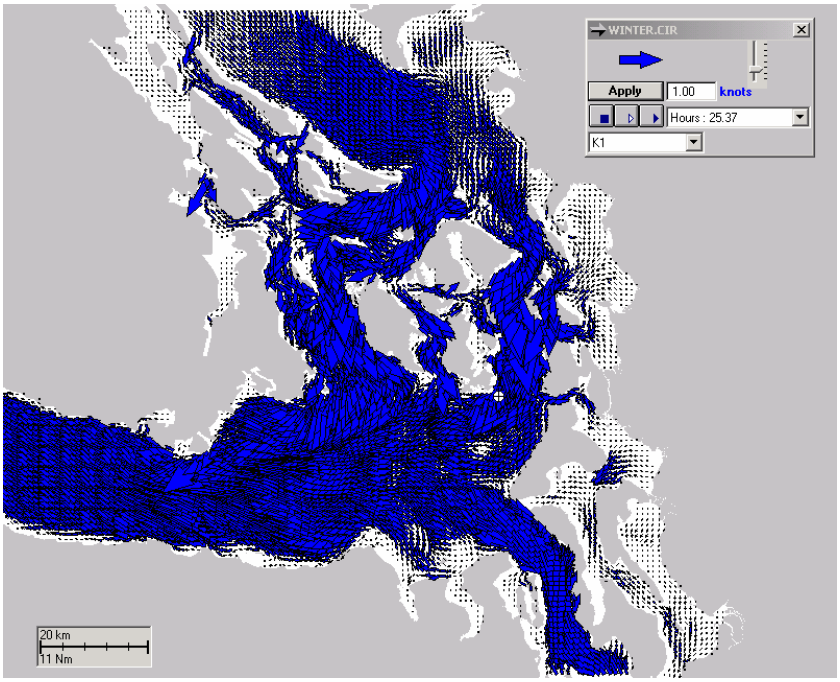

Figure XVIII.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Lopez Island.

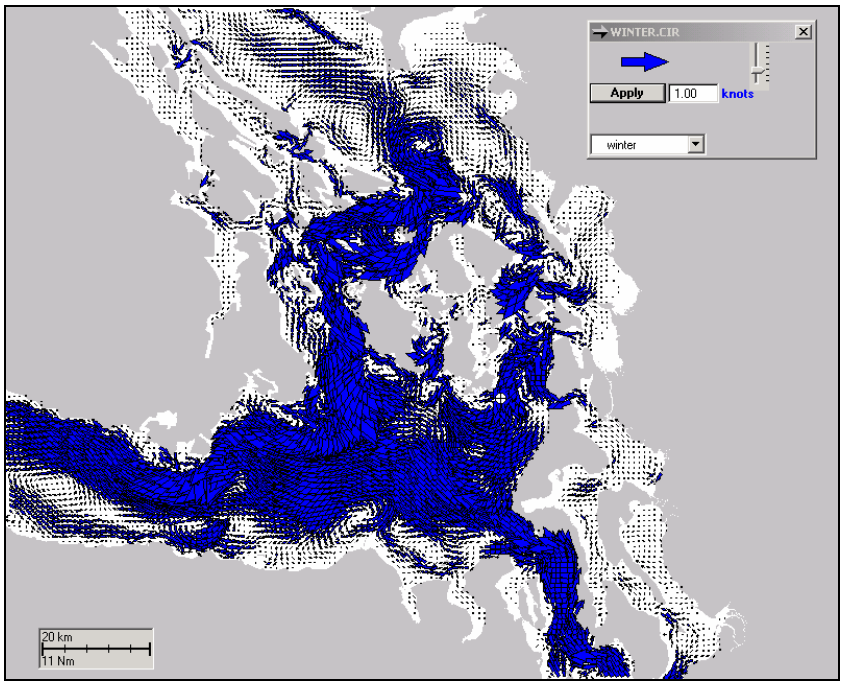

Figure XVIII.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction.

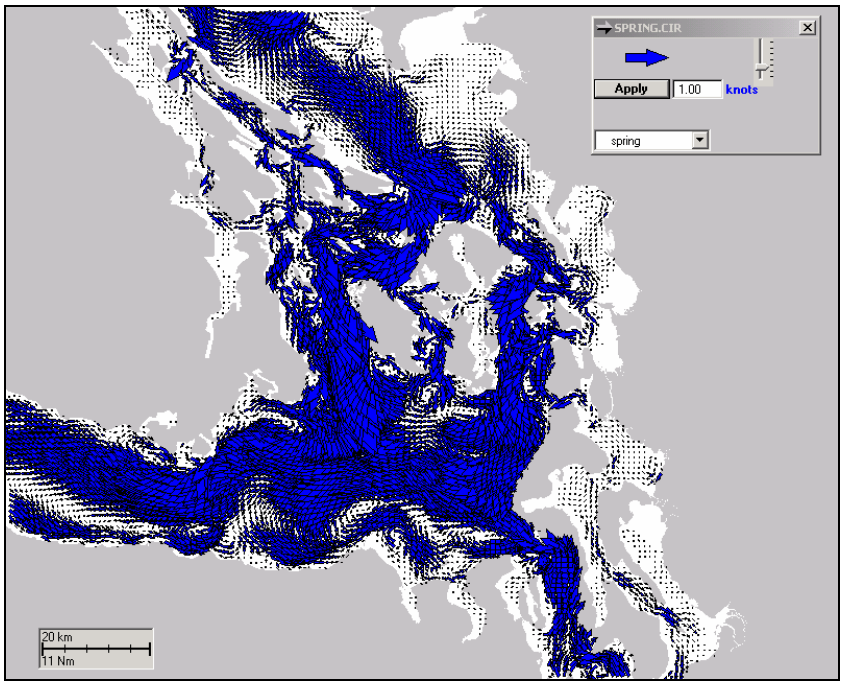

Figure XVIII.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction.

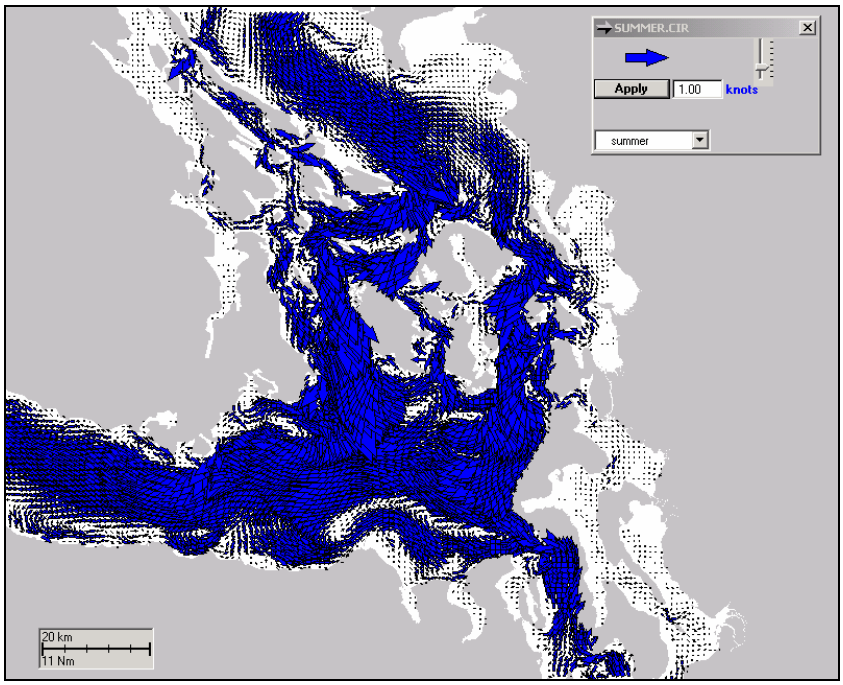

Figure XVIII.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.

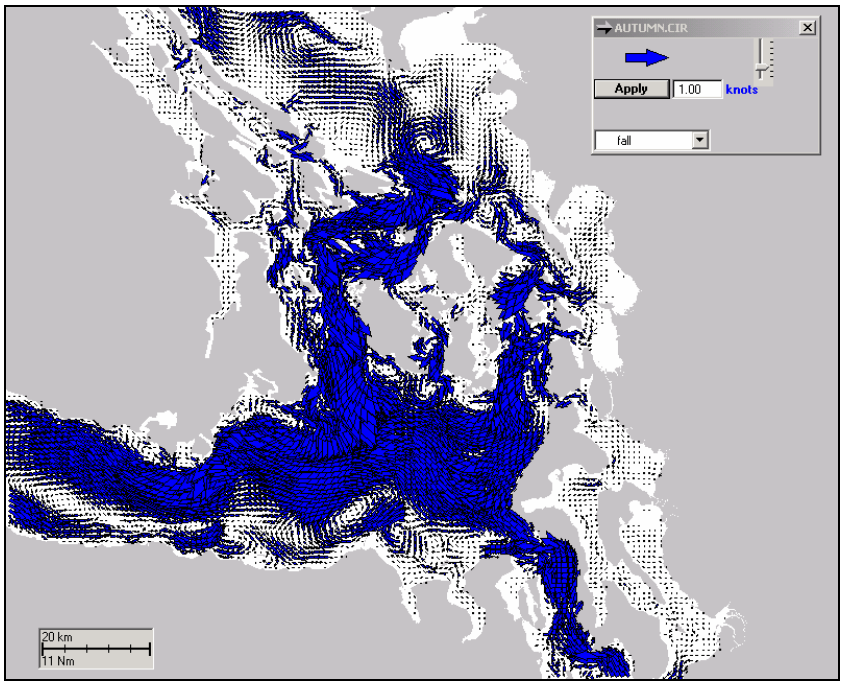

Figure XVIII.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction.

XVIII.D: OIL PROPERTIES

Table XVIII.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.8761	Wang et al. (1999)
Viscosity @ 25 deg. C (cp)	16	Wang et al. (1999)
Surface Tension (dyne/cm)	27	Wang et al. (1999)
Pour Point (deg. C)	-54	Wang et al. (1999)
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.030662	Wang et al. (1999)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.010372	A.D. Little (1996)
Fraction 2-ring aromatics (included in PAHs above)	0.00375	A.D. Little (1996)
Fraction 3-ring aromatics (included in PAHs above)	0.006622	A.D. Little (1996)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.189338	Wang et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.13325	Wang et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.200378	Wang et al. (1999)[1]
Minimum Oil Thickness (m)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	70	Wang et al. (1999)[2]; NOAA (2000)[2]
Mousse Water Content as Spilled (%)	0	-
Water content of fuel (not in mousse, %)	0	-
Degradation Rate (/day), Surface & Shore	0.01	National Research Council (1985)
Degradation Rate (/day), Hydrocarbons in Water	0.01	National Research Council (1985)
Degradation Rate (/day), Oil in Sediment	0.001	Haines and Atlas (1982)
Degradation Rate (/day), Aromatics in Water	0.01	French et al. (1996b)
Degradation Rate (/day), Aromatics in Sediment	0.001	French et al. (1996b)

[1] – Wang et al. (1999) provided total hydrocarbon data. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.
[2] – Mid-value used.

Table XVIII.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil.

Aromatic	Log(K_{ow})*	Concentration (mg/kg)
benzene	2.13	0.0
Toluene	2.69	0.0
Ethylbenzene	3.13	0.0
o-Xylene	3.15	0.0
p-Xylene	3.18	0.0
m-Xylene	3.2	0.0
Xylenes	3.18	0.0
styrene	3.05	0.0
methylstyrenes	3.35	0.0
1,2,3-Trimethylbenzene	3.55	0.0
1,2,4-Trimethylbenzene	3.6	0.0
1,3,4-Trimethylbenzene	3.6	0.0
1,3,5-Trimethylbenzene	3.58	0.0
Trimethylbenzenes	3.58	0.0
n-propylbenzene	3.69	0.0
iso-propylbenzene	3.63	0.0
ethyl-methylbenzenes	3.63	0.0
iso-propyl-4-methylbenzene	4.10	0.0
butylbenzenes	4.12	0.0
tetramethylbenzenes	4.01	0.0
tetralin	3.83	0.0
diphenylmethane	4.14	0.0
naphthalene	3.37	650
C1-naphthalenes	3.87	1,300
C2-naphthalenes	4.37	1,800
C3-naphthalenes	5.00	1,400
C4-naphthalenes	5.55	850
biphenyls	3.9	180
acenaphthylene	4.07	0.0
acenaphthene	3.92	0.0
dibenzofuran	4.31	0.0
Fluorene	4.18	82
C1-fluorenes	4.97	220
C2-fluorenes	5.20	260
C3-fluorenes	5.50	280

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

Table XVIII.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	200
C1-dibenzothiophene	4.86	360
C2-dibenzothiophene	5.50	540
C3-dibenzothiophene	5.73	460
phenanthrene	4.57	230
anthracene	4.54	0.0
C1-phenanthrenes/anthracenes	5.14	430
C2-phenanthrenes/anthracenes	5.25	490
C3-phenanthrenes/anthracenes	6.00	380
C4-phenanthrenes/anthracenes	6.51	260
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total log(K_{ow})$\leq$5.6	-	9,272

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

XVIII.E: INPUTS TO THE SIMAP PHYSICAL FATES MODEL

This section summarizes the model input data for the scenarios run and the sources for that information. The approach and sources applicable to all modeled locations are described in Volume I, Section 3 of this technical report. Specifics to this model location are below. Thus, the reader should refer to Volume I, Section 3 for background and the context within which these data are used.

The model grid and cell size were set to provide the maximum resolution (minimum cell size) possible within the memory constraints of the model, while also providing sufficient geographic coverage to encompass the maximum extent of oiling possible for the scenario. Test runs (randomizing weather conditions) were made to estimate the maximum extent of surface oiling and the grid size was set to cover that area.

Table XVIII.E-1. Inputs to the Fates Model for Stochastic Scenarios

Name	Description	Units	Source(s) of Information	Value(s)
Spill Site	Location of the spill site	-	Washington DOE	Port Angeles to the south end of Lopez Island
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure XVIII.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure XVIII.E-1)
Depth of release	Depth below the water surface of the release or 0 for surface release	m	Washington DOE	0 m
Start time and date	Randomized over selected months of the year	Date, hr,min	(randomized)	Jan-Dec
Spill duration	Hours over which the release occurs	Hours	(assumed)	4 hours
Total spill amount	Total volume (or weight) released (maximum if range)	bbl	Washington DOE	65,000 bbl
Model time step	Time step used for model calculations	Hours	-	0.25
Model duration	Length of each model simulation	Days	-	14 days

Table XVIII.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	320
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table XVIII.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Salinity	Surface water salinity	ppt	French et al. (1996b) province 51	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XVIII.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XVIII.E-4)
Air Temperature	Air water temperature at water surface	Degrees C	(assume = water temperature)	(= water temperature)
Fetch	Fetch = distance to land to N, S, E, W (if landfall not in model domain)	km	Chart	(calculated from model grid)
Wind drift speed	Speed oil moves down wind relative to wind	% of wind speed	Youssef (1993); Youssef and Spaulding (1993)	(model calculated)
Wind drift angle	Angle to right of wind (in northern hemisphere) that oil drifts	Deg. to right of down wind	Youssef (1993); Youssef and Spaulding (1993, 1994)	(model calculated)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y	m^2/sec	French et al. (1996, 1999a) based on Okubo (1971)	1 m^2/sec (estuaries and low energy coastal areas)
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z	m^2/sec	French et al. (1996, 1999) based on Okubo (1971)	0.0001 m^2/sec
Suspended sediment concentration	Average suspended sediment concentration during spill period	mg/l	French et al. (1996b)	10 mg/l
Suspended sediment settling rate	Net settling rate for suspended sediments	m/day	French et al. (1996b)	1 m/day

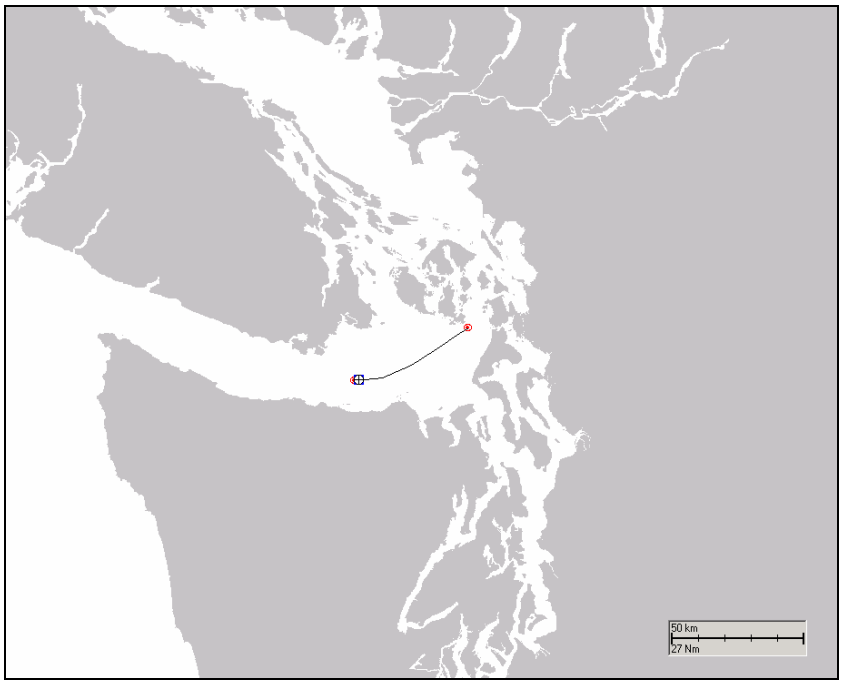

Figure XVIII.E-1 Varied range of spill site, from Port Angeles to the south end of Lopez Island.

Table XVIII.E-2. Time, date and location inputs for each of the 100 stochastic runs.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	2002	10	25	3	48.39042	122.8312
2	1995	3	22	3	48.23953	123.2197
3	2003	8	29	0	48.22791	123.3447
4	1992	8	3	1	48.36469	122.8905
5	2000	3	7	14	48.34583	122.9342
6	1999	1	6	20	48.39021	122.8316
7	1994	10	28	23	48.30183	123.0384
8	1997	5	3	20	48.26513	123.1382
9	2002	10	17	11	48.23462	123.2353
10	1997	3	21	16	48.23345	123.2412
11	1992	8	30	20	48.27802	123.0972
12	1998	1	2	2	48.23148	123.2781
13	2002	6	16	6	48.23197	123.2688
14	1994	8	16	12	48.27356	123.1114
15	2002	5	26	22	48.23882	123.222
16	1999	5	6	14	48.23256	123.2578
17	2000	10	17	4	48.26393	123.142
18	1993	11	18	20	48.28375	123.0815
19	1999	4	7	19	48.36864	122.8814
20	1998	5	11	14	48.40054	122.8091
21	1993	1	23	6	48.28177	123.0862
22	2002	5	13	16	48.37005	122.8782
23	2002	8	8	2	48.32549	122.982
24	2001	10	15	20	48.39827	122.814
25	2002	12	4	11	48.25053	123.1847
26	1995	8	9	18	48.33159	122.9675
27	1994	10	22	12	48.35171	122.9206
28	2001	4	4	22	48.38735	122.8382
29	1996	12	2	18	48.30677	123.0266
30	1997	3	6	21	48.25225	123.1792
31	1993	10	22	10	48.2569	123.1644
32	2000	8	25	9	48.36485	122.8902
33	2002	3	31	20	48.23097	123.2875
34	1994	9	23	2	48.23108	123.2855
35	1998	2	18	23	48.25852	123.1593
36	2000	8	20	8	48.2575	123.1625
37	1995	10	10	0	48.26175	123.149
38	2000	6	6	8	48.36328	122.8938
39	1996	12	25	12	48.23279	123.2535
40	2000	11	24	18	48.3622	122.8963
41	2000	2	10	13	48.35432	122.9145
42	1995	3	23	3	48.30373	123.0339
43	1997	4	17	10	48.36821	122.8824
44	2001	10	19	17	48.31875	122.9981
45	2003	7	22	21	48.26908	123.1256
46	1999	12	12	11	48.36829	122.8822
47	2002	11	25	10	48.22741	123.3541
48	1998	3	13	0	48.40209	122.8057
49	2000	2	12	23	48.27632	123.1026
50	2003	8	25	23	48.23245	123.2599

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
51	2000	6	9	8	48.3436	122.9393
52	1996	12	1	2	48.23176	123.2728
53	1998	10	27	0	48.34365	122.9392
54	1995	10	21	6	48.37258	122.8723
55	1994	1	11	14	48.33887	122.9503
56	2002	12	9	13	48.3485	122.928
57	1995	1	25	5	48.23084	123.29
58	1993	12	2	7	48.39193	122.8279
59	1999	5	16	7	48.33482	122.9598
60	2000	5	8	7	48.28493	123.0787
61	2003	1	26	14	48.23136	123.2802
62	1994	12	20	5	48.25049	123.1848
63	1994	3	13	7	48.30201	123.038
64	1993	7	28	6	48.23173	123.2733
65	1998	7	30	23	48.40232	122.8052
66	1993	12	23	13	48.22925	123.3197
67	1994	8	27	11	48.35711	122.9081
68	2002	7	25	23	48.33389	122.962
69	1998	12	31	20	48.3637	122.8928
70	1997	4	29	22	48.3544	122.9143
71	1997	5	9	9	48.23022	123.3016
72	1999	4	19	7	48.25042	123.185
73	1998	3	2	1	48.38813	122.8364
74	2000	7	22	8	48.39139	122.829
75	1992	8	9	22	48.27543	123.1054
76	1994	3	12	19	48.27413	123.1095
77	1996	5	16	3	48.33954	122.9487
78	2002	10	31	19	48.37515	122.8664
79	2001	5	6	8	48.37009	122.8781
80	1998	12	26	20	48.34862	122.9277
81	1996	2	21	3	48.35574	122.9112
82	2000	4	11	16	48.37618	122.864
83	2003	4	18	21	48.40431	122.8009
84	2001	5	5	15	48.29715	123.0496
85	2003	2	24	5	48.23153	123.2771
86	1993	4	16	16	48.23114	123.2843
87	2002	2	25	3	48.40993	122.7886
88	1993	8	12	20	48.35202	122.9198
89	1999	10	10	10	48.23228	123.263
90	1994	11	18	14	48.35768	122.9068
91	2002	4	9	12	48.2747	123.1077
92	2001	6	6	18	48.33813	122.952
93	1994	5	15	12	48.25329	123.1759
94	2002	1	7	16	48.27835	123.0961
95	1993	11	16	1	48.35554	122.9117
96	1996	2	2	15	48.25293	123.177
97	2002	2	20	22	48.23096	123.2876
98	1992	7	24	15	48.39771	122.8152
99	1999	9	30	12	48.3089	123.0216
100	2003	2	1	18	48.40118	122.8077

Table XVIII.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	SI_HABS2.HAB
Grid W edge	123° 57.76'W
Grid S edge	47° 22.01' N
Cell size (^{o}longitude)	0.12^o W
Cell size (^{o}latitude)	0.12^o N
Cell size (m) west-east	150.14
Cell size (m) south-north	221.67
# cells west-east	890
# cells south-north	978
Water cell area (m^2)	33,279.9
Shore cell length (m)	182.43
Shore cell width – Rocky shore (m)	1.0
Shore cell width – Artificial shore (m)	1.0
Shore cell width – Gravel beach (m)	1.0
Shore cell width – Sand beach (m)	1.0
Shore cell width – Mud flat (m)	1.0
Shore cell width – Wetlands (fringing,m)	1.0

Table XVIII.E-4. Water temperature by month of the year (from French et al., 1996b).

Month	**Surface Water Temperature (^{o}C)**	**Bottom Water Temperature (^{o}C)**	**Pycnocline Depth (m)**
January	10	8	20
February	10	8	20
March	10	8	20
April	11	8	20
May	12	8	20
June	14	8	20
July	14	7	10
August	14	7	10
September	14	7	10
October	13	7	20
November	12	7	20
December	10	7	20

Table XVIII.E-5. Wind data sources and records used.

File Name	Location	Latitude Longitude	Dates	Data Source
SISW1_1992_2003_ LST.WNE	Station SISW1 - Smith Island, WA	48.32 ºN 122.84 ºW	1991-2003	National Data Buoy Center

The SISW1_1992_2003_LST.WNE wind data were downloaded from one buoy Station SISW1 - Smith Island, WA. Figure XVIII.E-2 displays where the buoy is located along with surrounding buoys. SISW1_1992_2003_LST.WNE data start on 31 December 1991 and end on 31 December 2003.

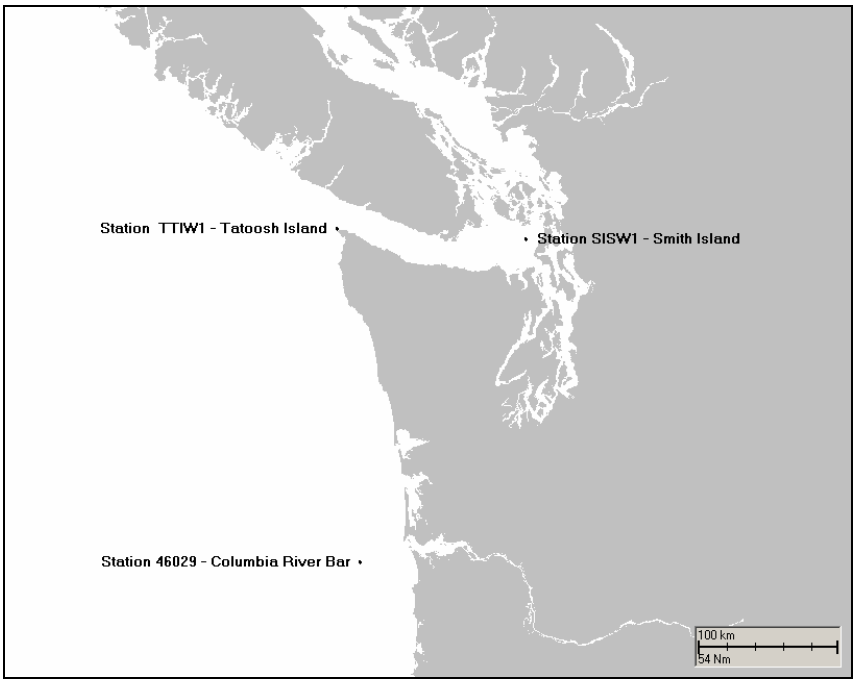

Figure XVIII.E-2 Wind Station Locations.

Draft Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XIX: Stochastic Model Results for Inner Straits/Puget Sound – Alaskan North Slope Crude

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XIX.A. INTRODUCTION

The results of the main stochastic scenarios for the Inner Straits/Puget Sound – Alaskan North Slope Crude are contained in this volume. There were two main stochastic scenarios:

1. Mechanical removal under Washington state Caps standards
2. Mechanical removal under Washington state Caps standards plus dispersant application

XIX.B. MAPS OF EXPOSURE PROBABILITY, TIME FIRST EXPOSED, AND MAXIMUM POSSIBLE CONTAMINATION

The results of multiple model runs are evaluated to develop the following statistics, for each cell in the model grid ("location") and for each exposure index. Maps of the results summarizing all 100 runs of a scenario are contained in this section.

- Probability of exposure greater than the minimum threshold (probability that the minimum threshold thickness or concentration will be exceeded at each location at any time following the spill). For surface oil, the model records if any oil of greater than that thickness passes through the grid cell, regardless of the aerial coverage of the oil. For concentrations, the average concentration in the grid cell is used to determine if the threshold is exceeded.
- Time (hours) to first exceedance of the minimum threshold at each location (i.e., in teach cell).
- Worst-case maximum exposure (thickness, volume or concentration) at any time after the spill, at a given location (peak exposure at each location delineated by the grid cells). The amounts are averaged over the area of the model grid cell. The worst-case maximum amount is for all possible releases (i.e., maximum peak exposure for all the model runs). This is calculated in two steps: (1) For each individual run (for each spill date run), the maximum amount over all time after the spill is saved for each location (cell) in the model grid. (2) The runs are evaluated to determine the highest amount possible at each location. Note that these *worst-case maximum* amounts are not additive over all locations. These represent maximum possible amounts of oil that could ever reach each site (grid cell), considered individually, and based on the model runs performed. Thus, "worst-case" represents the highest exposure of the most adverse of the runs performed.

Exposure indices and minimum thresholds (i.e., those less than values that might have an impact on any resource) used in the modeling were:

- Surface slick or floating oil: $\geq$ 0.01 g/m^2 (average thickness $\geq$ 0.01 micron)
- Shoreline: average mass loading over the shore segment (length of one grid cell, calculated as the cell diagonal length, times the typical width for the habitat type) $\geq$ 0.01 g/m^2

- Dissolved aromatics: average over the water cell $\geq$ 1 ppb (1 mg/m^3)
- Subsurface oil (entrained in water): average over the water cell $\geq$ 10 ppb (10 mg/m^3)
- Sediment total hydrocarbons: average over the cell $\geq$ 0.0001 g/ m^2
- Sediment dissolved aromatic concentrations: average over the cell $\geq$ 0.0001 g/ m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10 cm, the assumed bioturbation zone)

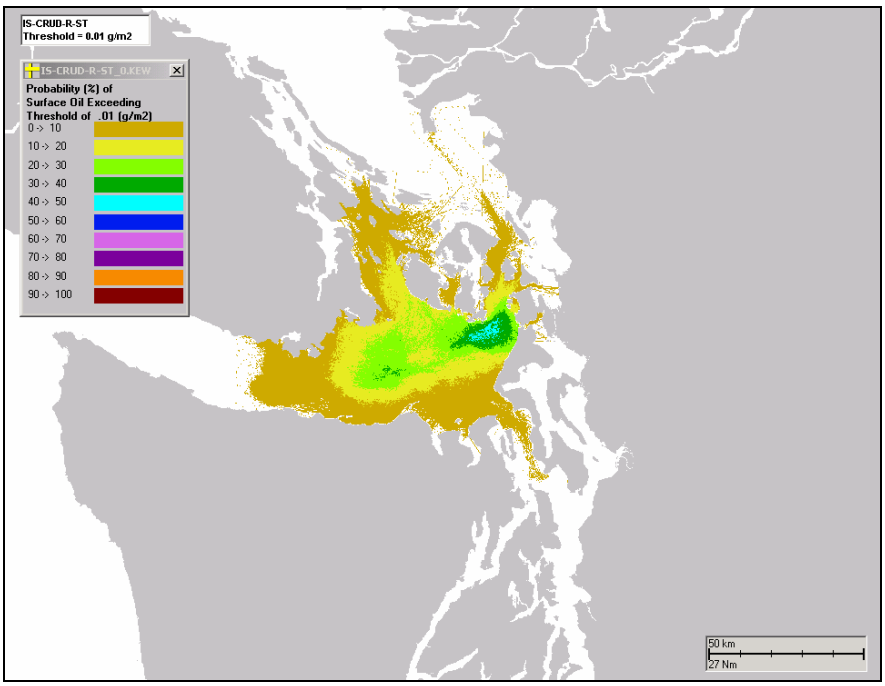

Figure XIX.B-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

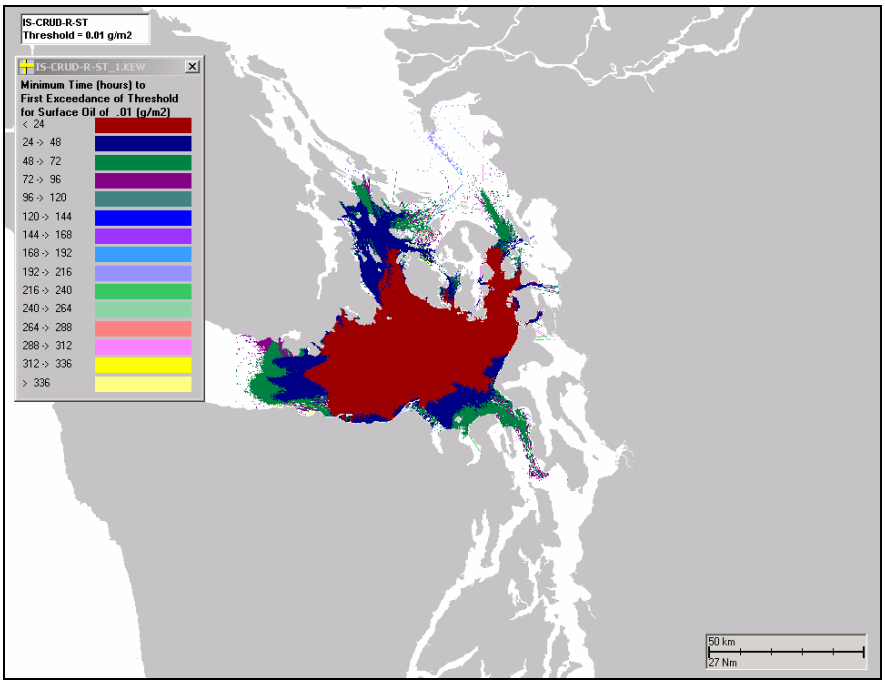

Figure XIX.B-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

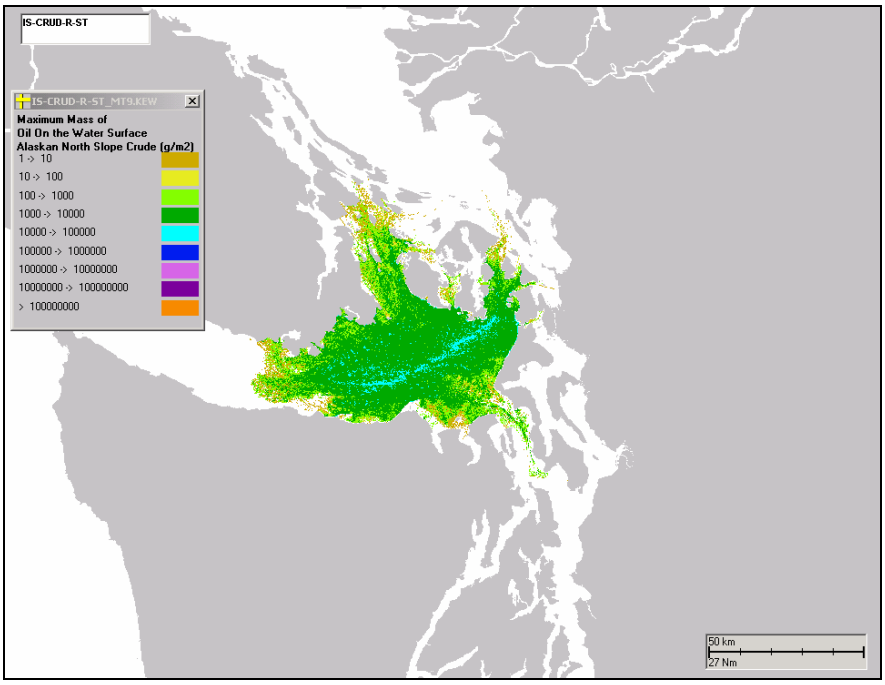

Figure XIX.B-3. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

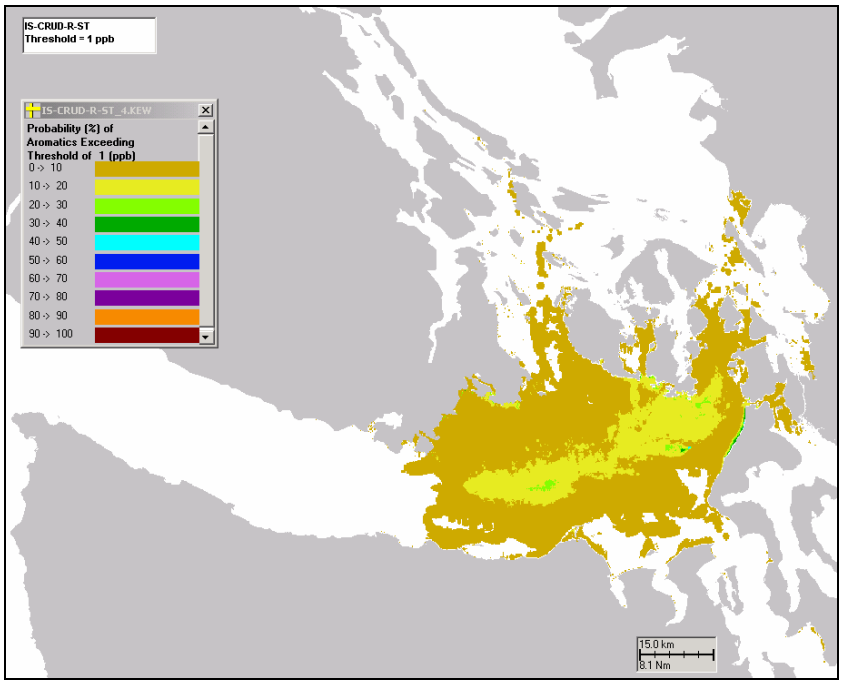

Figure XIX.B-4. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

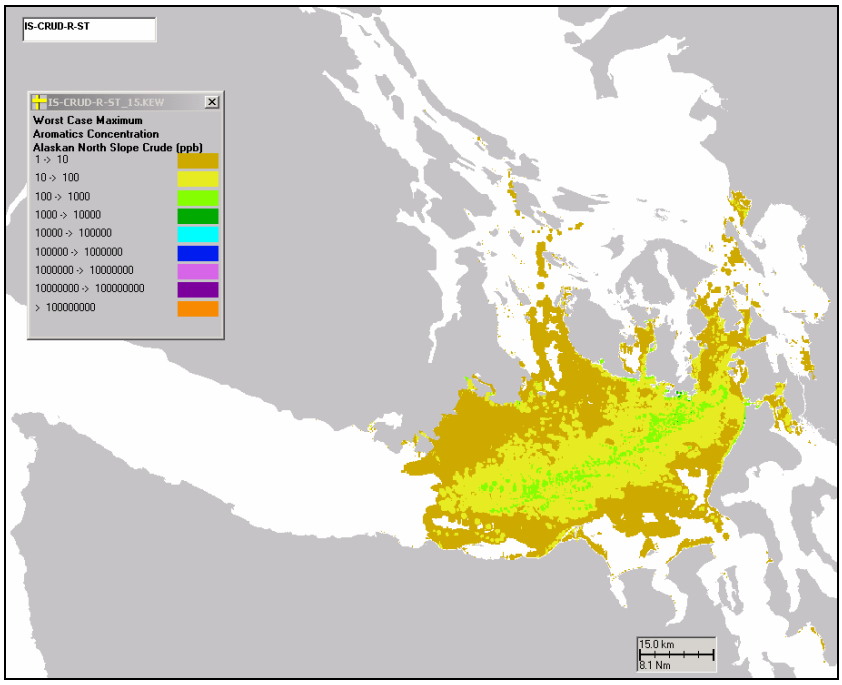

Figure XIX.B-5. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

Sediment exposure to total hydrocarbons does not exceed 0.01g/m^2

Figure XIX.B-6. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Sediment exposure to total hydrocarbons (g/m^2) under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

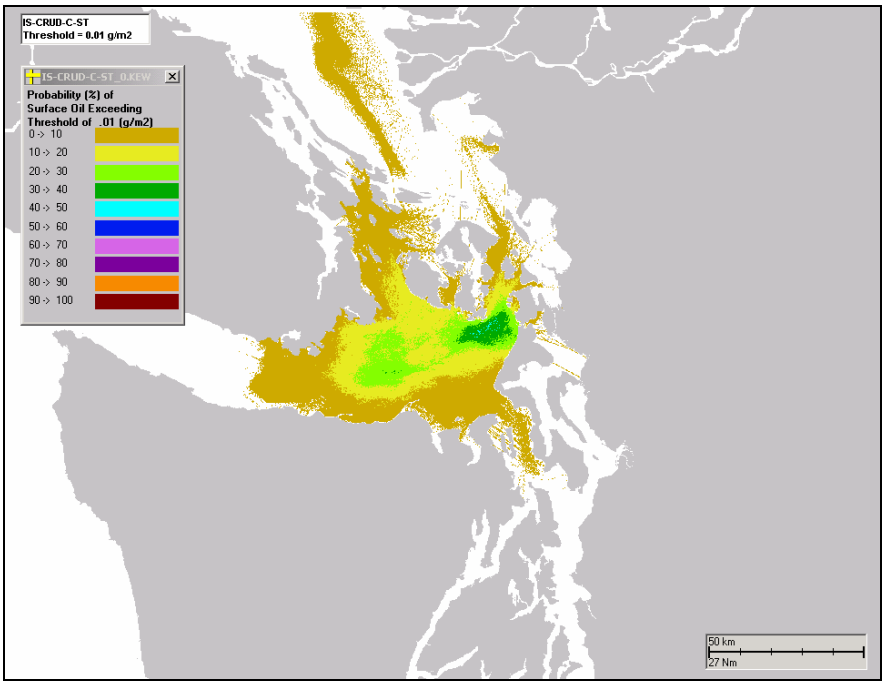

Figure XIX.B-7. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

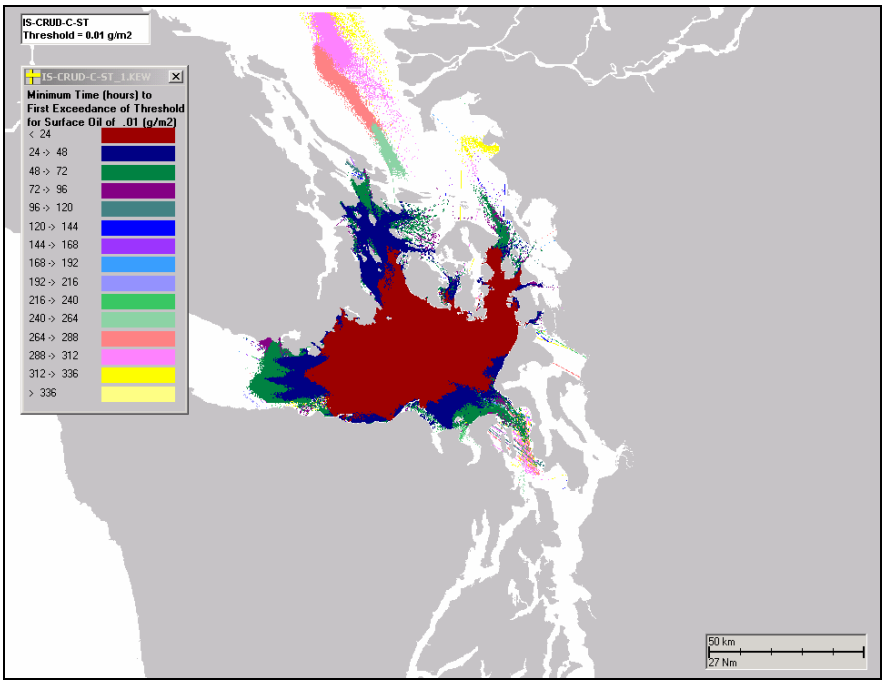

Figure XIX.B-8. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

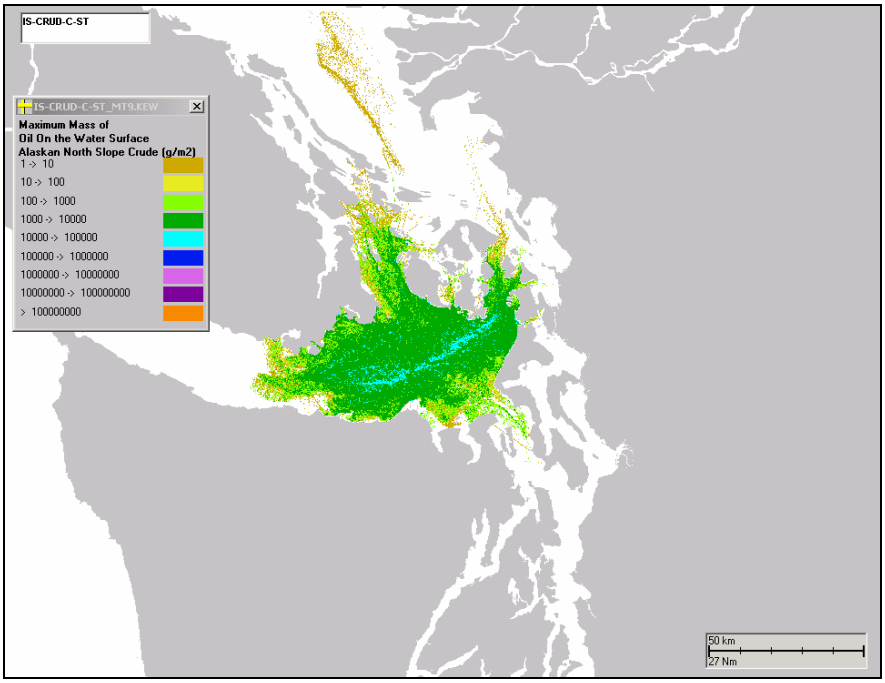

Figure XIX.B-9. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

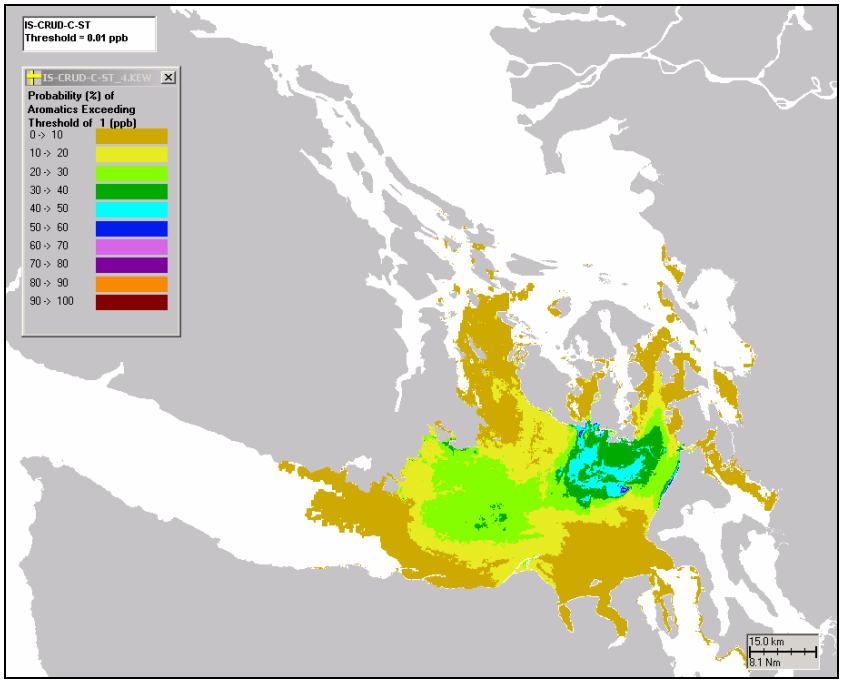

Figure XIX.B-10. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

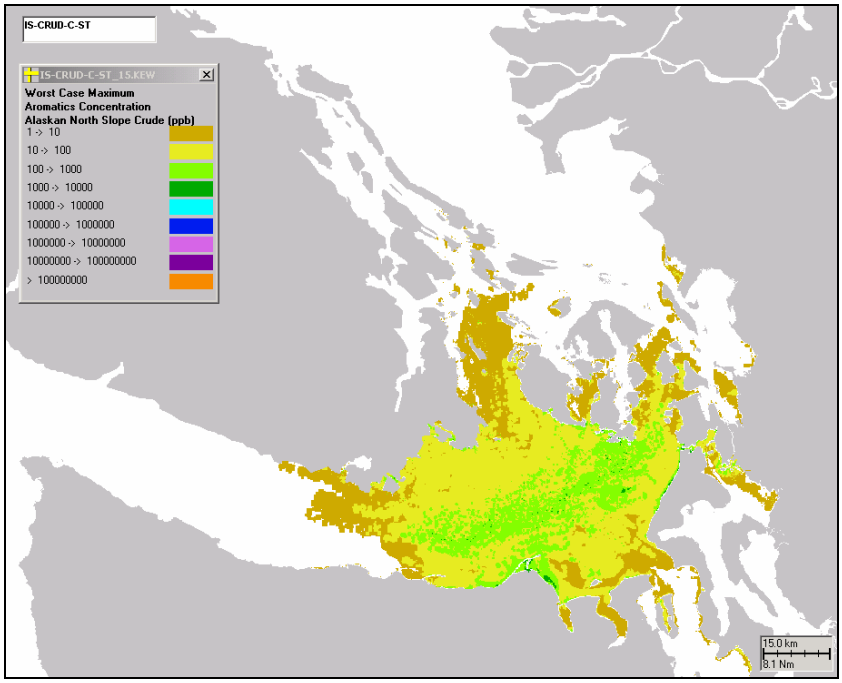

Figure XIX.B-11. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

Sediment exposure to total hydrocarbons does not exceed0.01 g/m^2

Figure XIX.B-12. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Sediment exposure to total hydrocarbons (g/m^2) under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

XIX.C. RANK ORDER DISTRIBUTIONS FOR ALL MODEL RUNS

In this section, the following impact indices are plotted as rank order distributions:

- Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 (which is sheen) times duration of exposure (in m^2-hrs)
- Shoreline area (m^2) exposed to hydrocarbons of various threshold thicknesses (>0.01, 1, 10, 100, and 1000 g/m^2)
- Water volume exposed to > 1 ppb (>1 mg/m^3) of dissolved aromatic concentration at some time after the spill
- Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill
- Percent of spilled hydrocarbon mass eventually going ashore
- Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats)
- Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill, and
- Percent of spilled hydrocarbon mass removed mechanically an by in situ burning (ISB, if applicable).

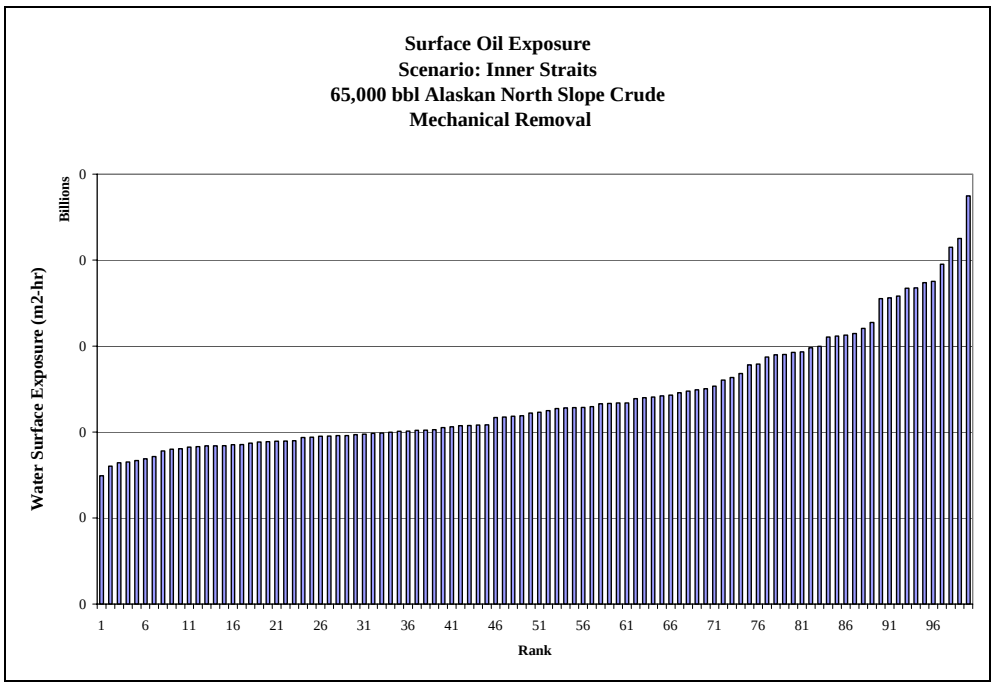

Figure XIX.C-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

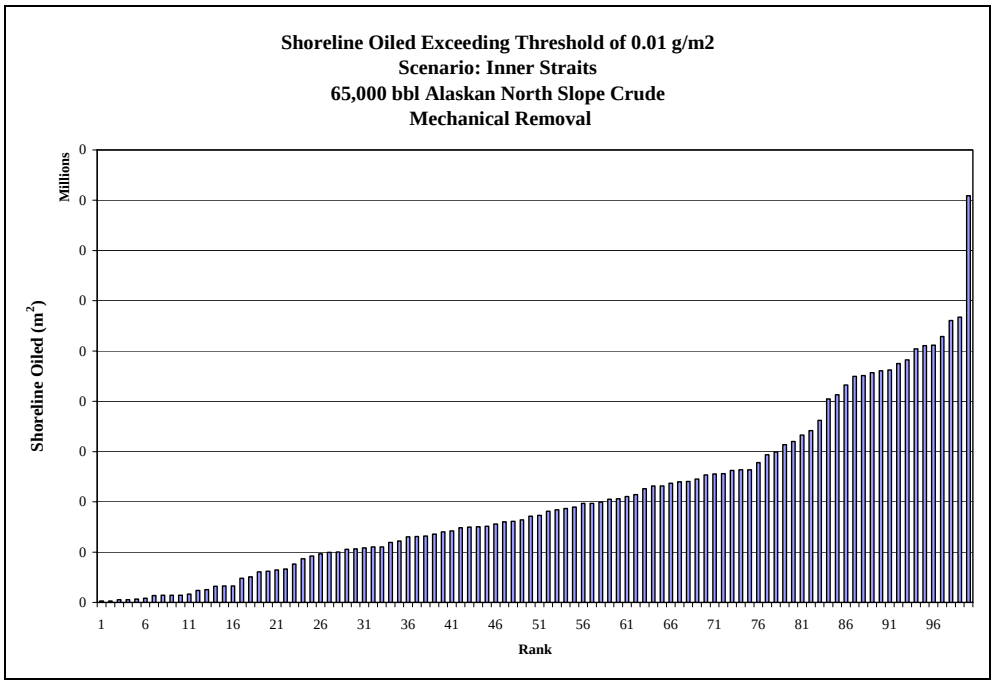

Figure XIX.C-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

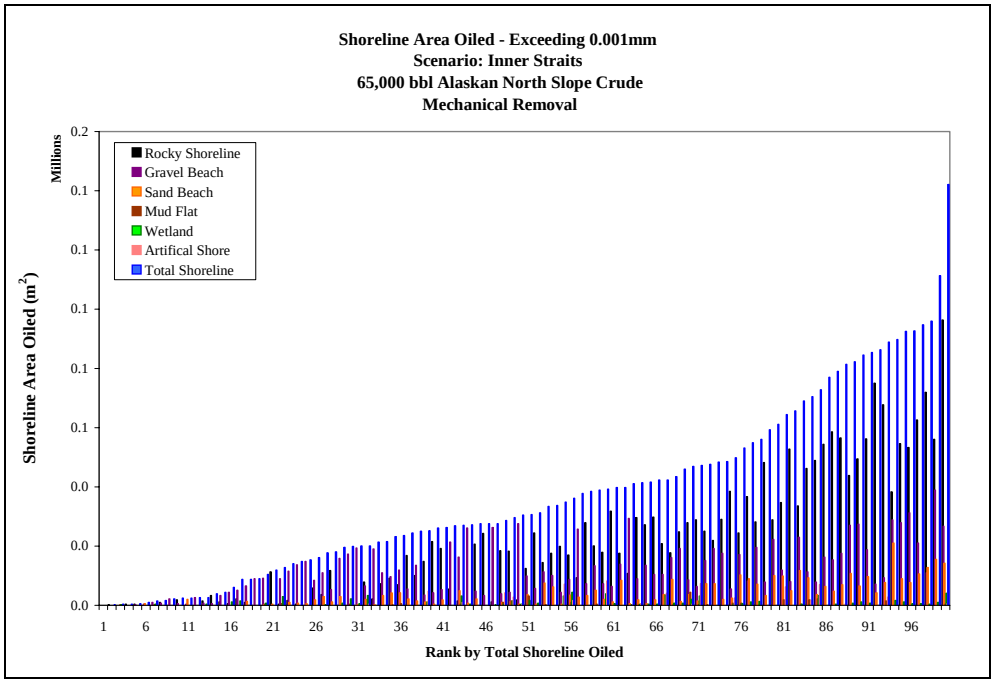

Figure XIX.C-3. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

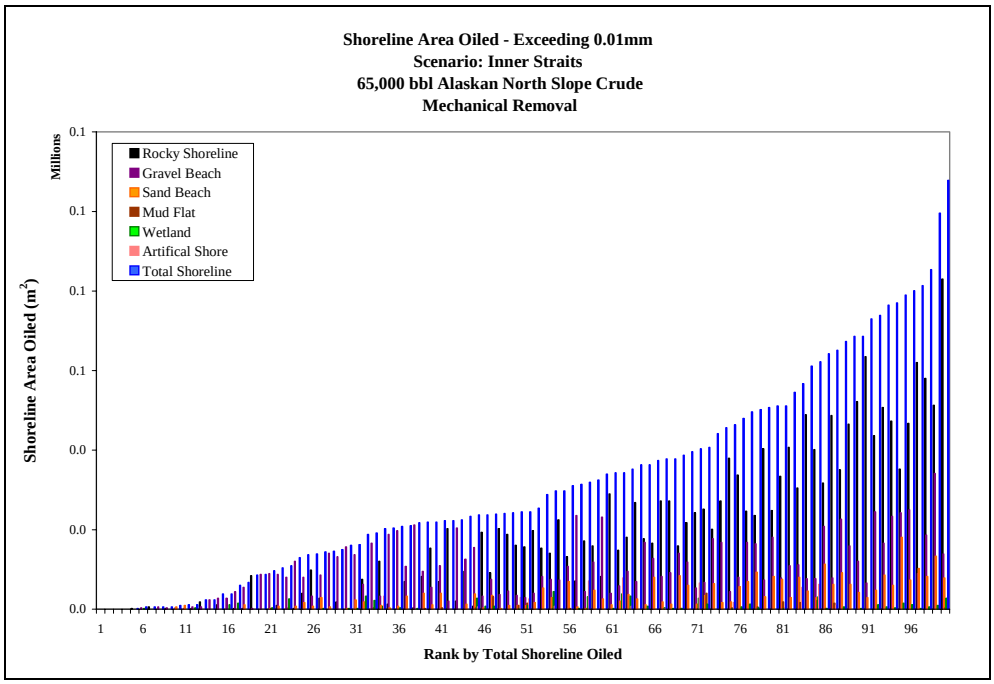

Figure XIX.C-4. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

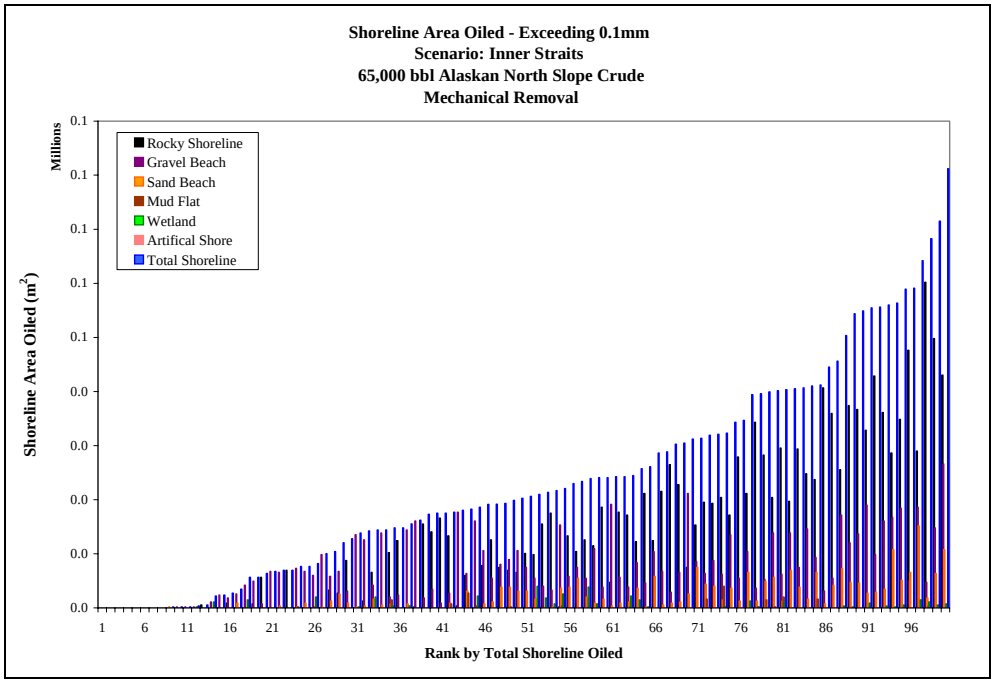

Figure XIX.C-5. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

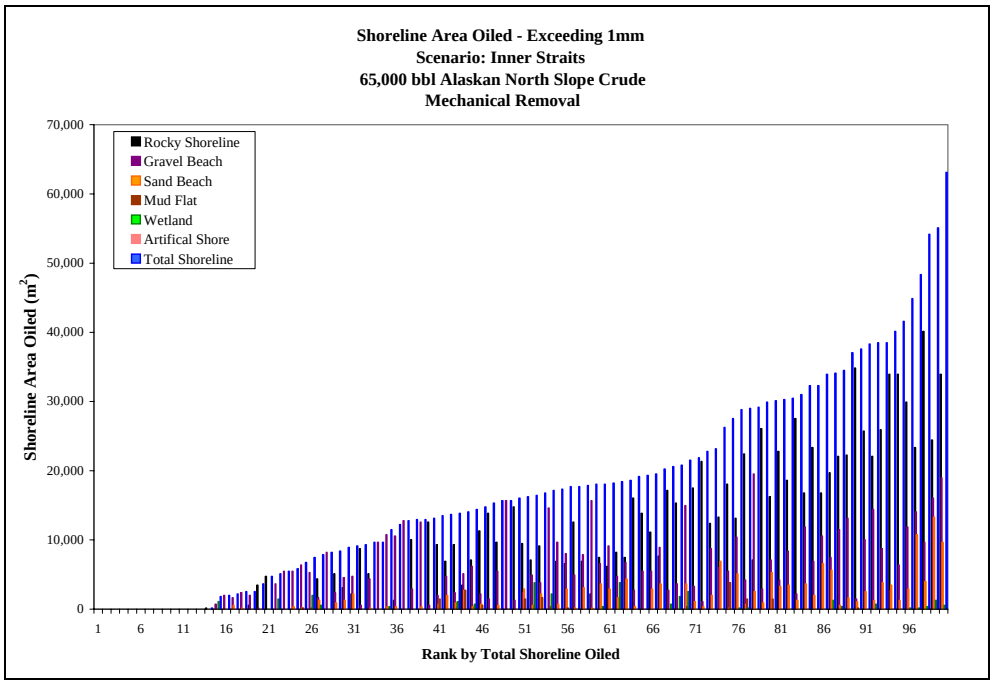

Figure XIX.C-6. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

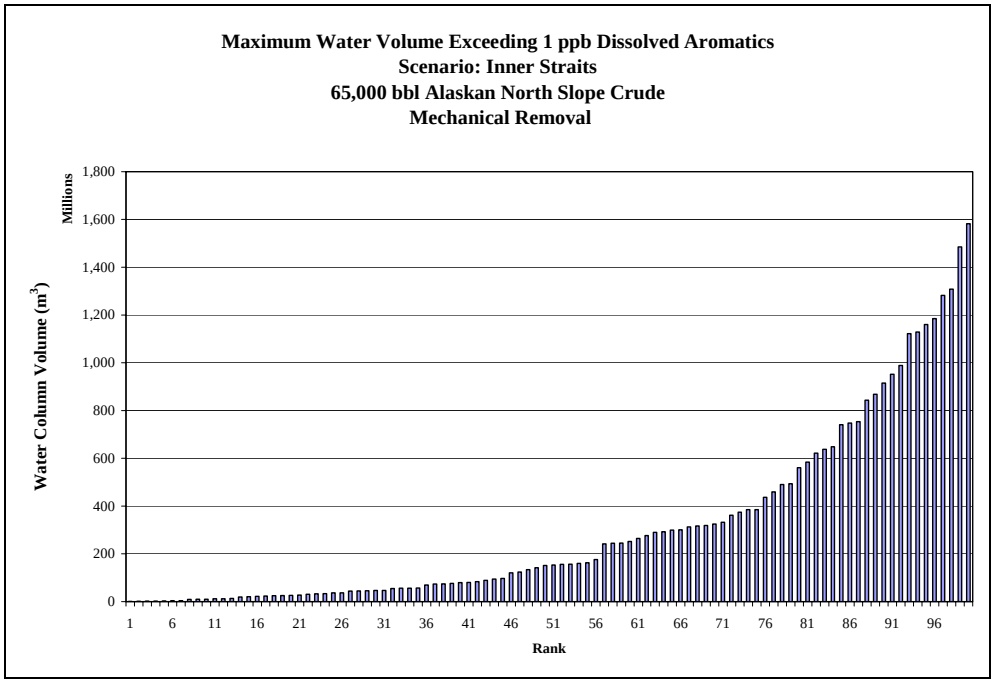

Figure XIX.C-7. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

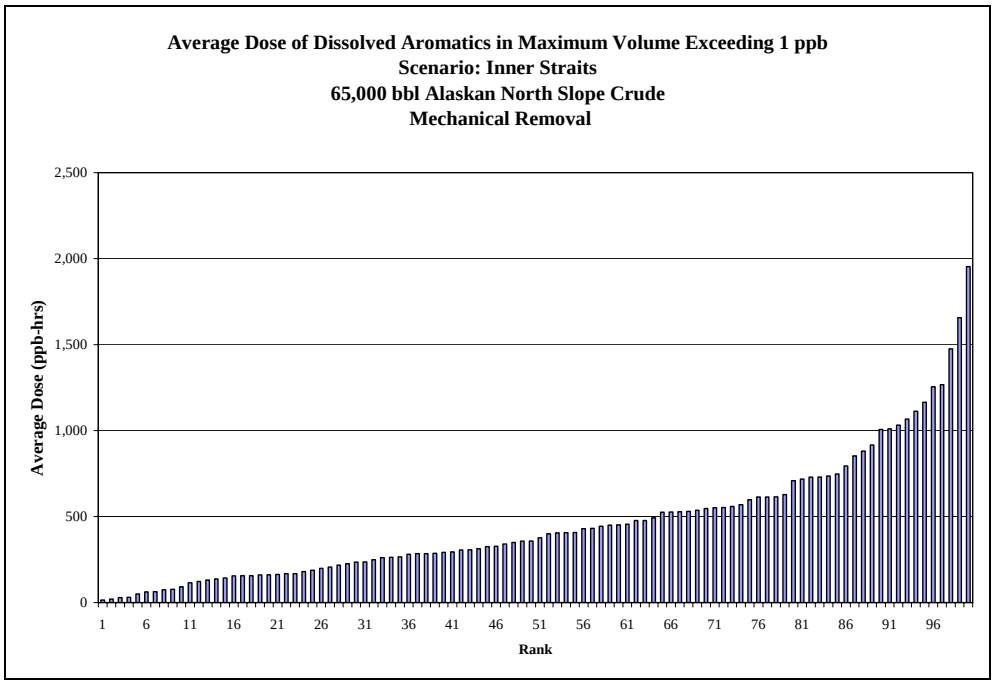

Figure XIX.C-8. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

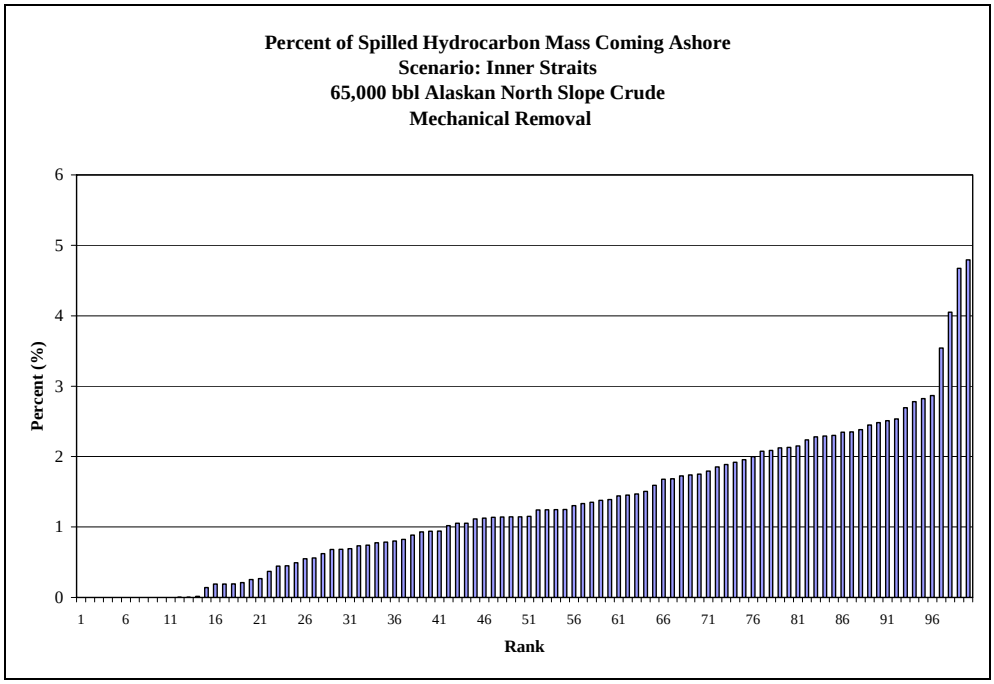

Figure XIX.C-9. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

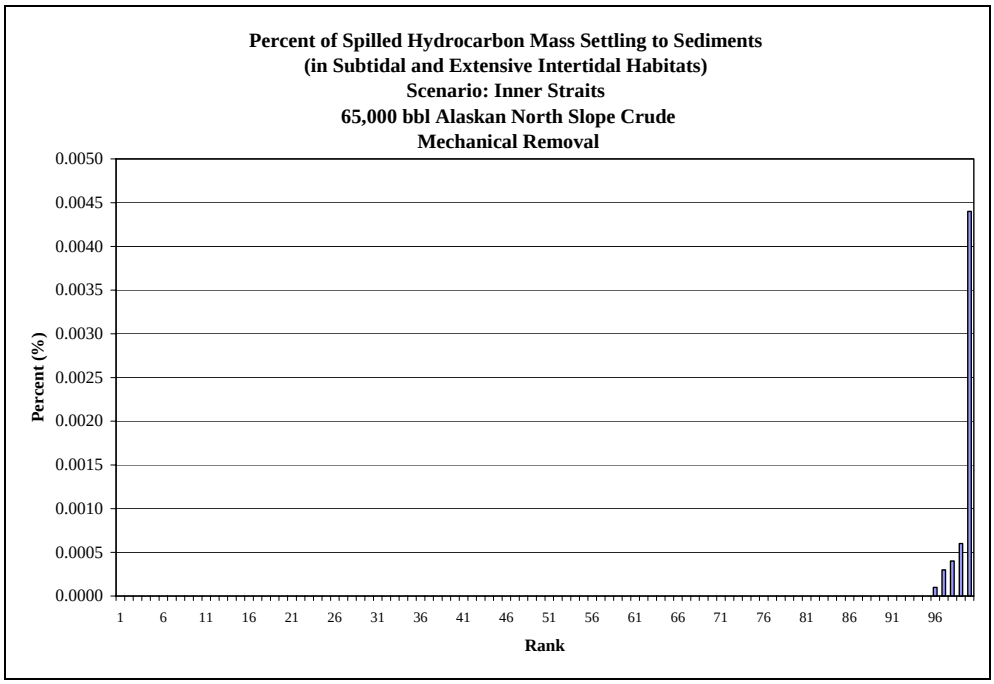

Figure XIX.C-10. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

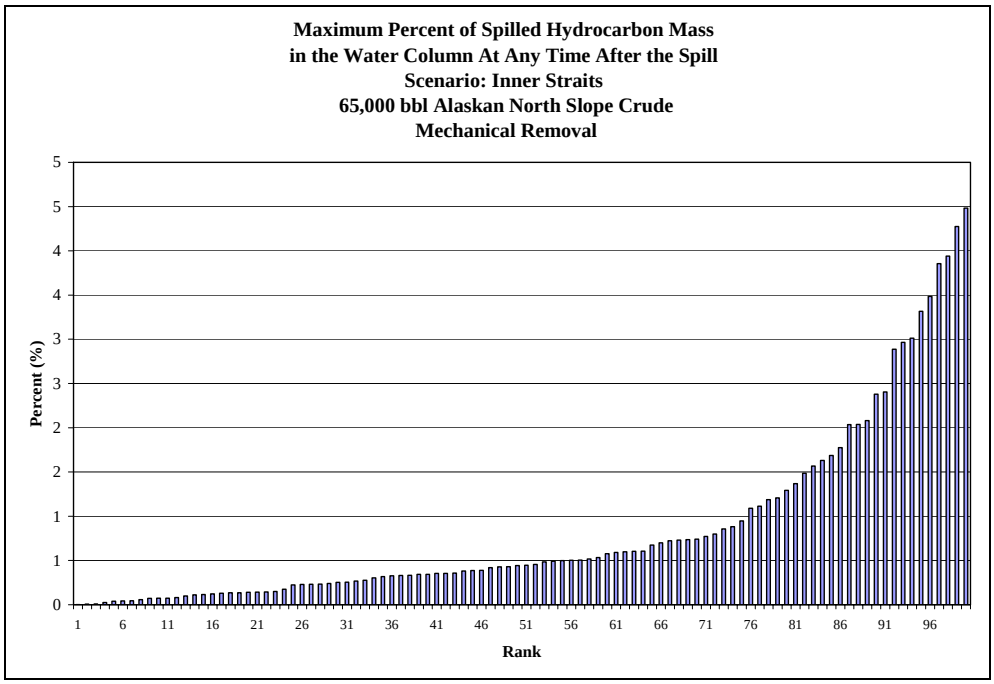

Figure XIX.C-11. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

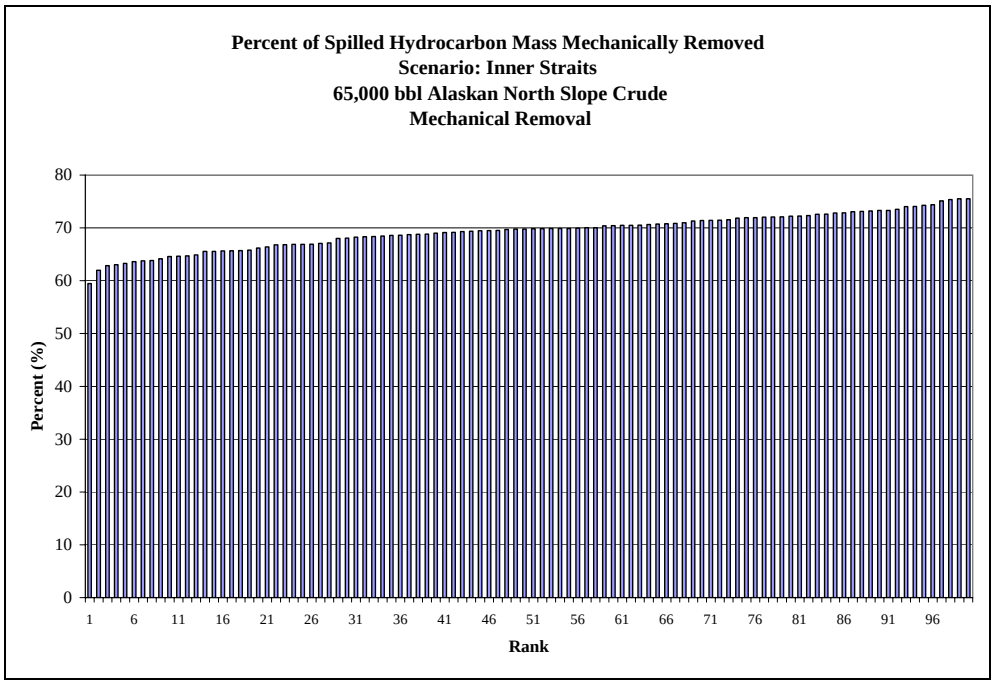

Figure XIX.C-12. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass mechanically removed.

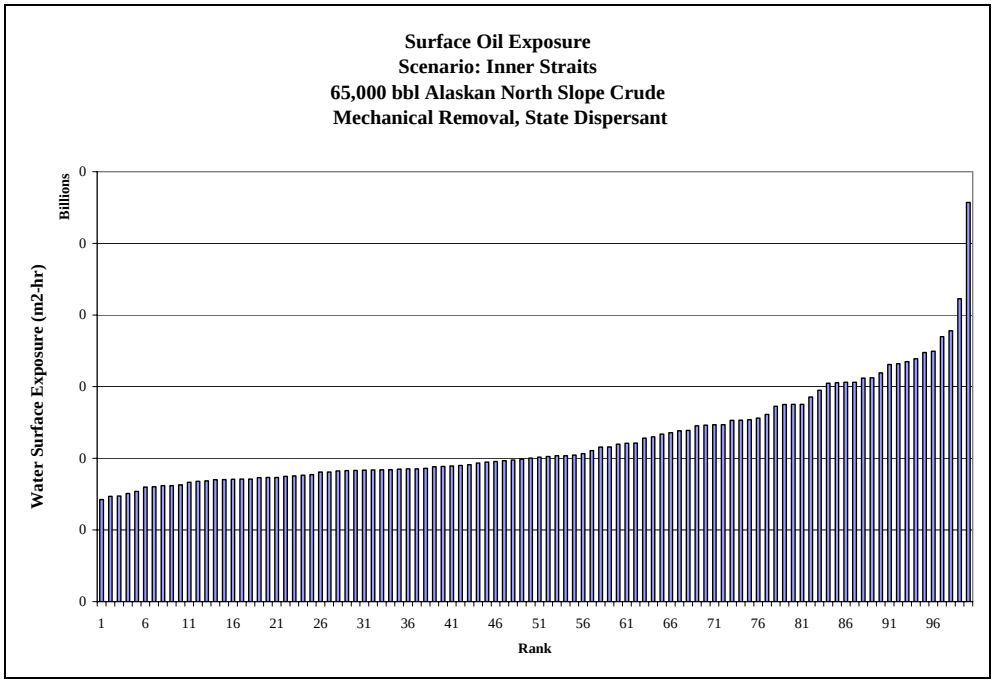

Figure XIX.C-13. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

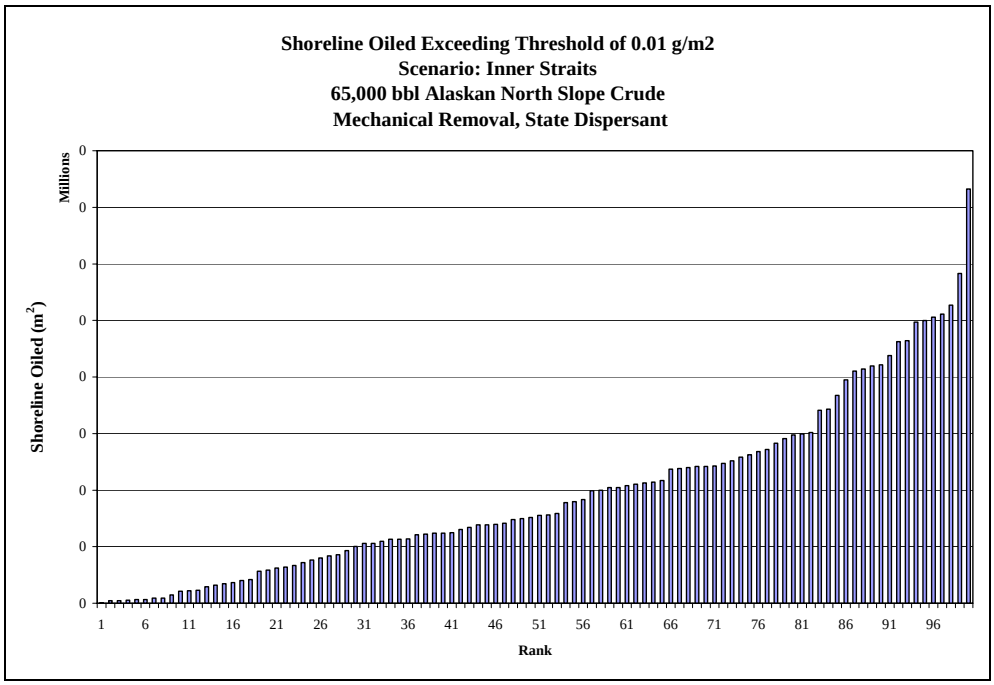

Figure XIX.C-14. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

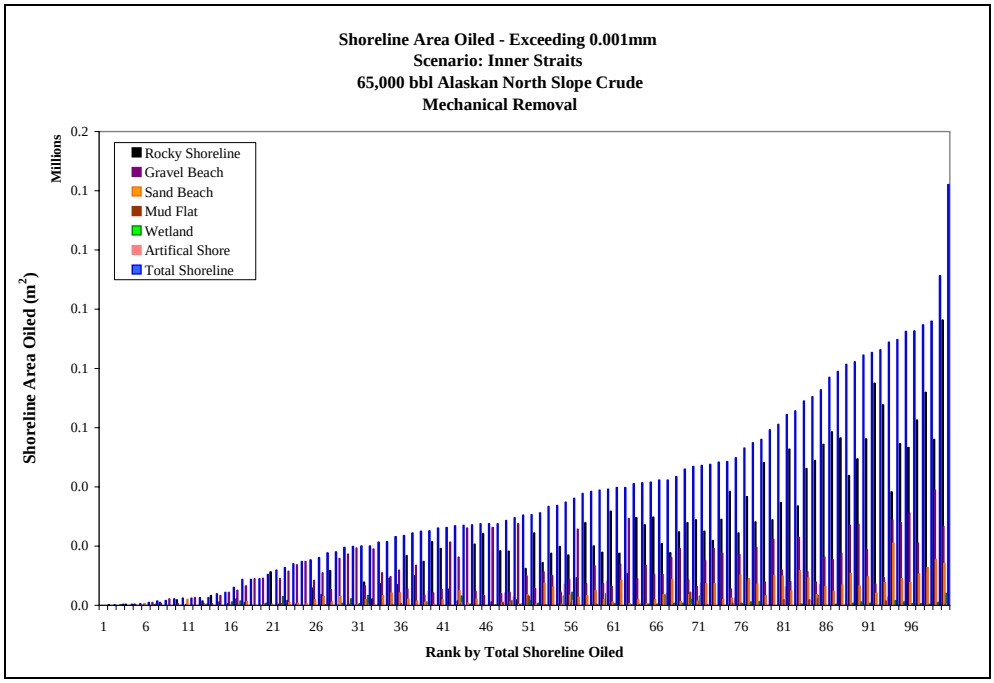

Figure XIX.C-15. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

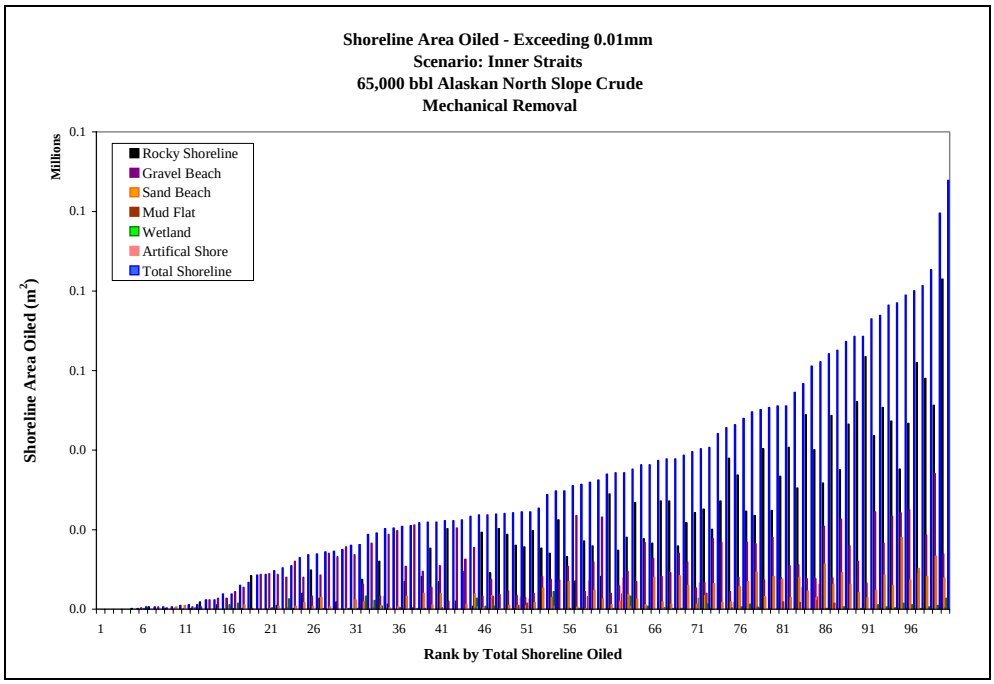

Figure XIX.C-16. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

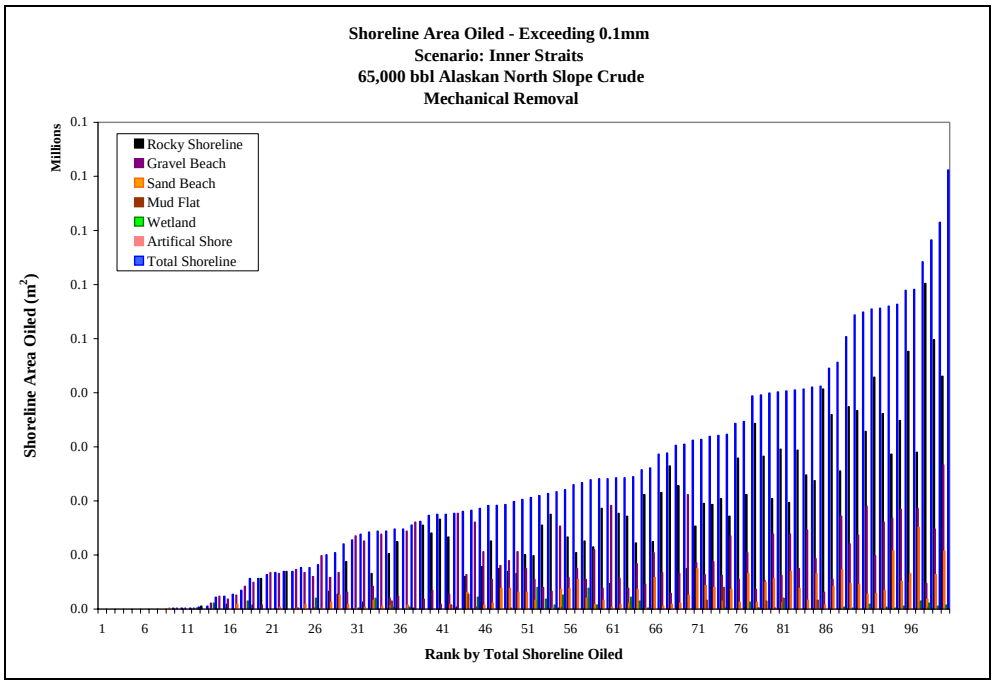

Figure XIX.C-17. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

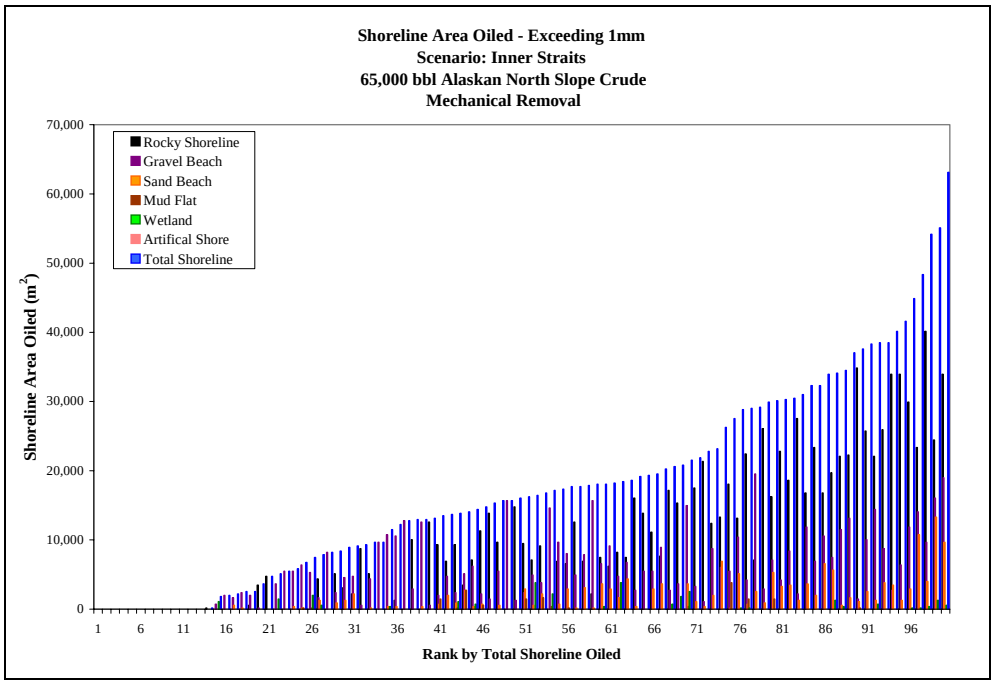

Figure XIX.C-18. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

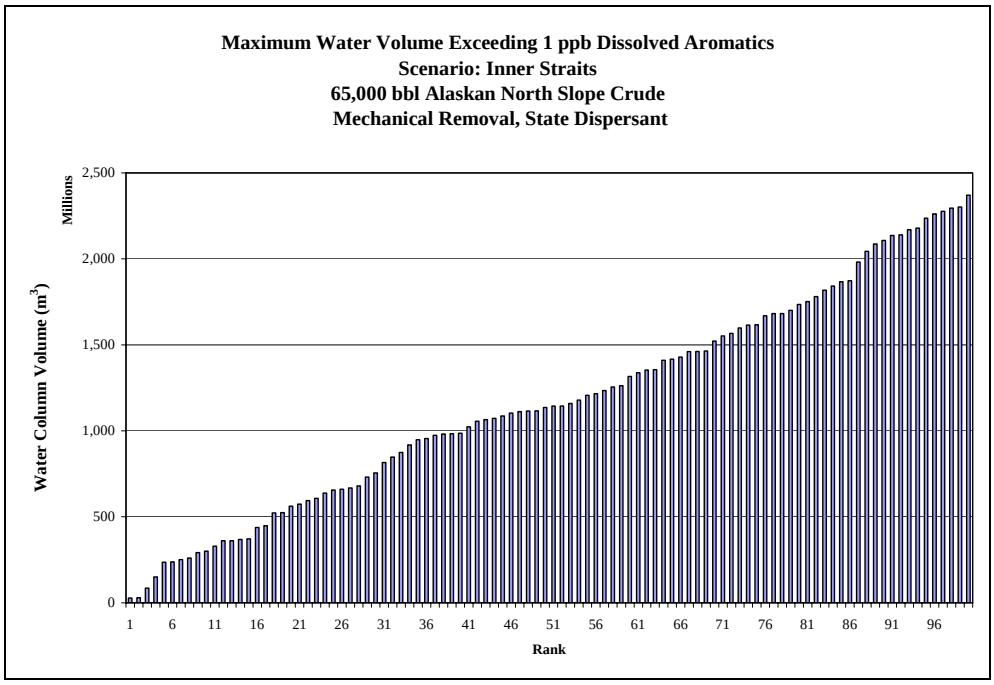

Figure XIX.C-19. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

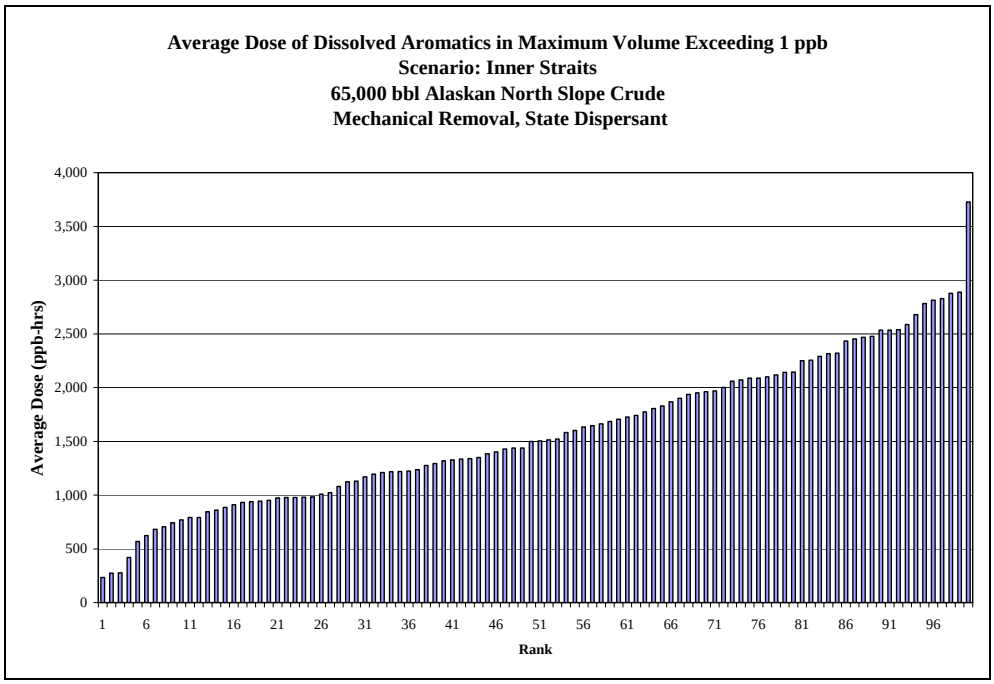

Figure XIX.C-20. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

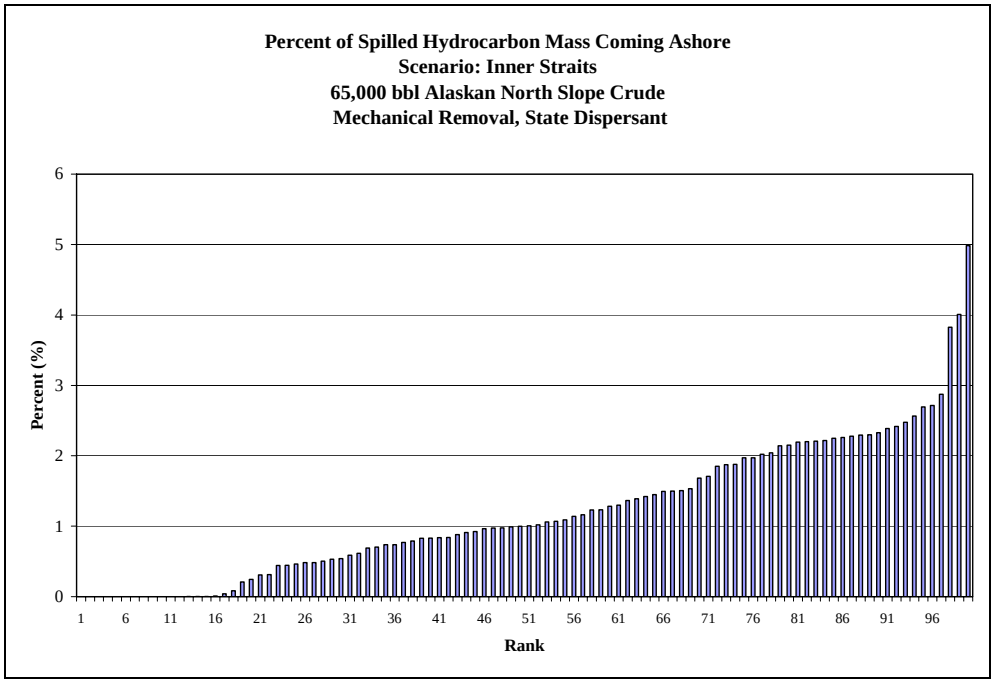

Figure XIX.C-21. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

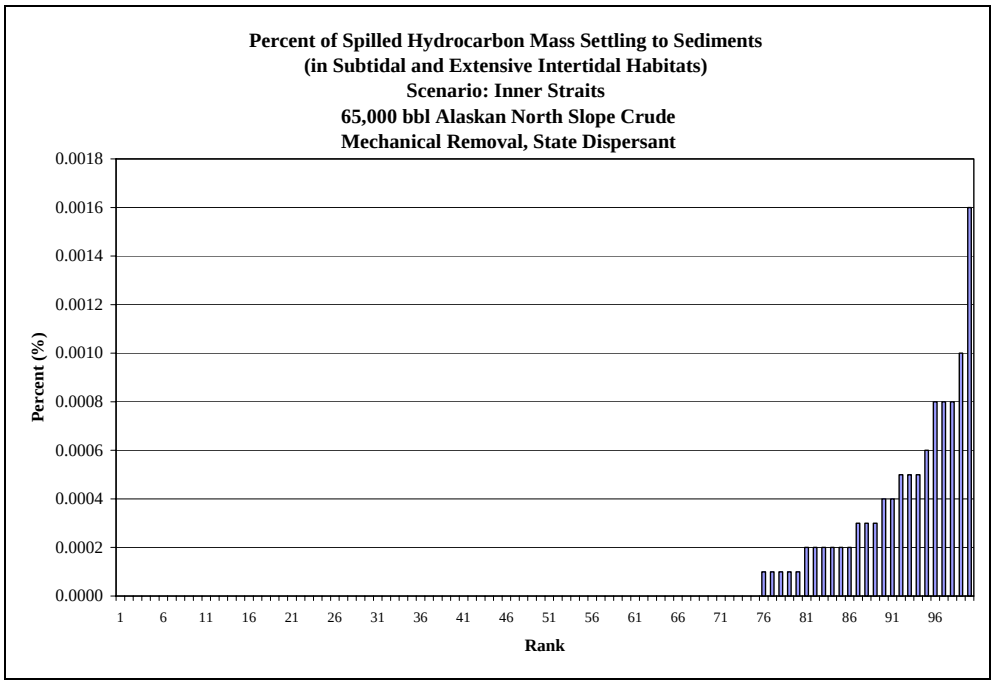

Figure XIX.C-22. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

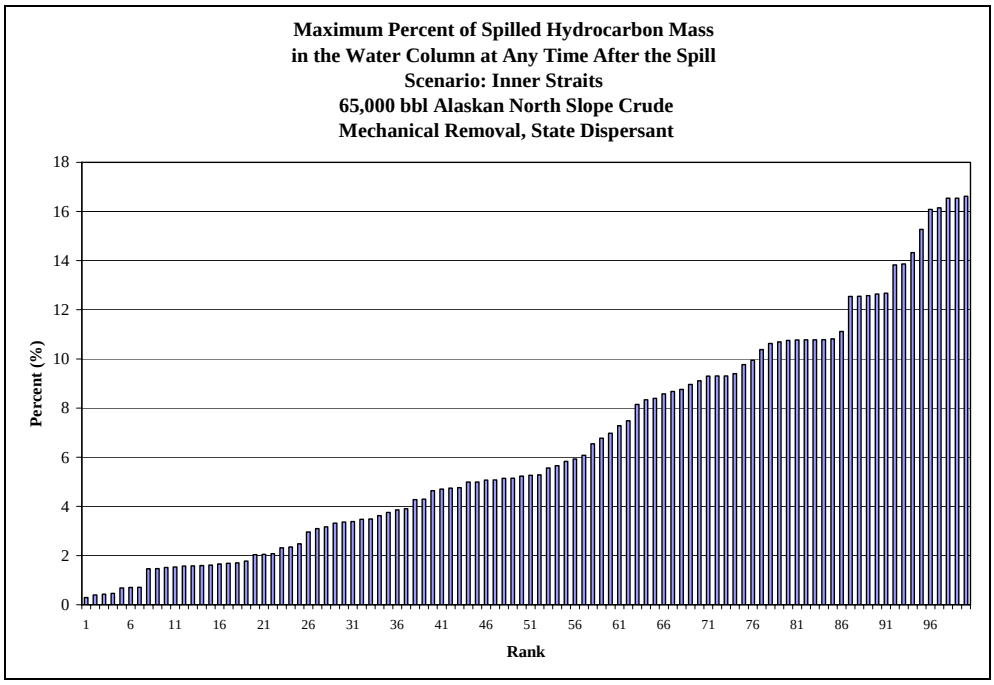

Figure XIX.C-23. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

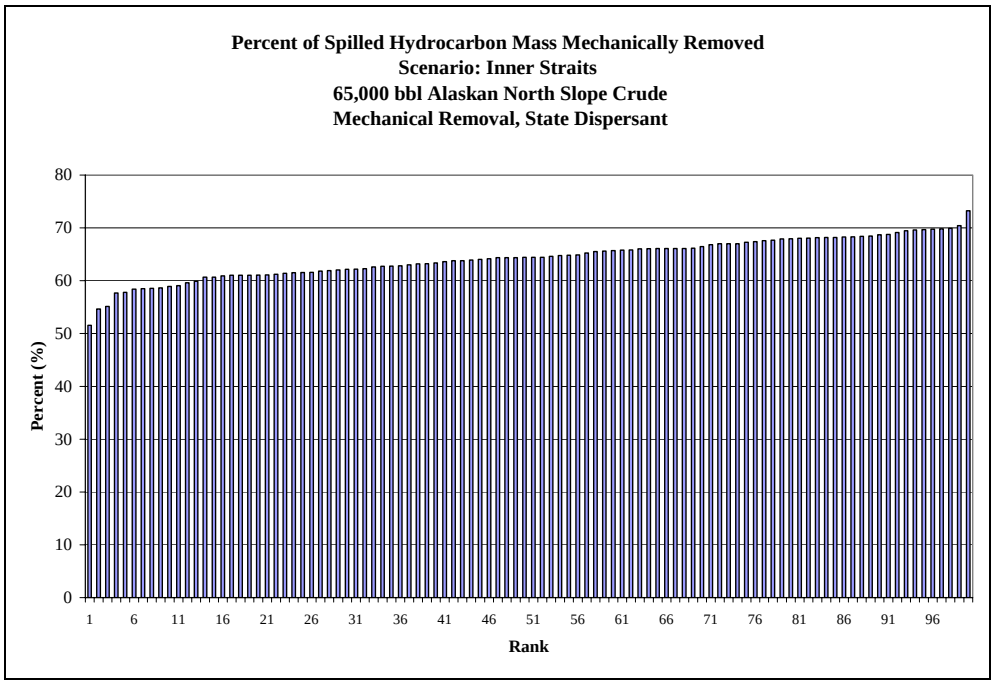

Figure XIX.C-24. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass mechanically removed.

XIX.D. SHORELINE AREAS EXPOSED BY SHORE TYPE

The tables in this section list the areas of shoreline oiled by shore type for the main stochastic scenarios. The 50th and 95th percentile results are sorted by total shoreline oiled at the indicated threshold. Thus, these are not the same runs as those sorted by shoreline cleanup cost (which are reported in Volume II).

Table XIX.D-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	30,648	12,405	9,851	3,649	3,101	1,642	0
95th	92,673	53,269	31,195	7,662	0	547	0
Maximum	142,111	96,323	38,857	20,979	4,378	4,378	8,209
Mean	37,680	20,934	11,613	3,599	244	657	633
Std. Dev.	29,740	21,408	8,702	4,191	659	1,062	1,746
Mean + 2 Std. Dev.	97,160	63,750	29,017	11,981	1,562	2,781	4,125

Table XIX.D-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	24,445	15,689	2,919	912	1,459	912	2,554
95th	80,087	46,702	24,993	7,297	0	1,095	0
Maximum	107815	83005	34114	18060	4013	4378	7844
Mean	32021	18011	9795	2994	206	545	471
Std. Dev.	25220	18550	7337	3514	625	985	1532
Mean + 2 Std. Dev.	82,461	55,111	24,469	10,022	1,456	2,515	3,535

Table XIX.D-3. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	20,615	10,034	7,480	3,101	0	0	0
95th	59,107	47,614	4,926	6,567	0	0	0
Maximum	81,180	60,201	26,634	15,142	4,013	4,013	0
Mean	23,955	13,828	7,421	2,160	179	367	0
Std. Dev.	19,003	14,116	5,923	2,793	596	783	0
Mean + 2 Std. Dev.	61,961	42,060	19,267	7,746	1,371	1,933	0

Table XIX.D-4. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	16,236	9,486	2,372	2,919	1,459	0	0
95th	92,673	29,918	11,858	2,919	0	182	0
Maximum	63,121	40,134	19,520	13,317	3,831	3,831	0
Mean	17,787	10,045	5,705	1,596	162	279	0
Std. Dev.	14,150	10,309	4,892	2,388	564	717	0
Mean + 2 Std. Dev.	46,087	30,663	15,489	6,372	1,290	1,713	0

Table XIX.D-5. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	28,277	17,696	4,743	1,095	1,459	365	2,919
95th	90,119	76,073	7,844	6,020	0	182	0
Maximum	128,611	93,221	37,763	20,614	4,561	4,378	8,939
Mean	35,309	19,381	10,962	3,503	228	613	622
Std. Dev.	28,243	20,182	8,071	4,084	627	984	1,813
Mean + 2 Std. Dev.	91,795	59,745	27,104	11,671	1,482	2,581	4,248

Table XIX.D-6. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	23,533	9,851	9,304	4,378	0	0	0
95th	77,168	45,790	23,168	7,115	0	1,095	0
Maximum	102341	80451	32107	18790	4196	4196	7662
Mean	29787	16575	9187	2899	195	502	429
Std. Dev.	24091	17312	7087	3558	594	928	1510
Mean + 2 Std. Dev.	77,969	51,199	23,361	10,015	1,383	2,358	3,449

Table XIX.D-7. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	19,520	8,939	6,750	3,831	0	0	0
95th	56,553	34,661	16,966	3,831	0	1,095	0
Maximum	71,329	58,012	22,986	16,419	4,013	3,831	0
Mean	22,258	12,704	6,912	2,100	168	374	0
Std. Dev.	17,982	13,131	5,717	2,876	581	810	0
Mean + 2 Std. Dev.	58,222	38,966	18,346	7,852	1,330	1,994	0

Table XIX.D-8. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	14,959	9,121	5,473	365	0	0	0
95th	90,119	14,959	5,290	182	0	0	0
Maximum	55,641	35,209	18,060	13,865	3,649	3,466	0
Mean	16,508	9,346	5,259	1,479	151	272	0
Std. Dev.	13,398	9,747	4,612	2,270	549	707	0
Mean + 2 Std. Dev.	43,304	28,840	14,483	6,019	1,249	1,686	0

XIX.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

In this section, the results for the 5th, 50th, and 95th percentile runs based on shoreline oiling costs (using the base case scenario for sorting) are shown, as plots of the following measures of exposure:

- Water surface exposure to floating hydrocarbons (g/m^2)
- Shoreline exposure to hydrocarbons (g/m^2) (for 95th percentile run only)
- Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill

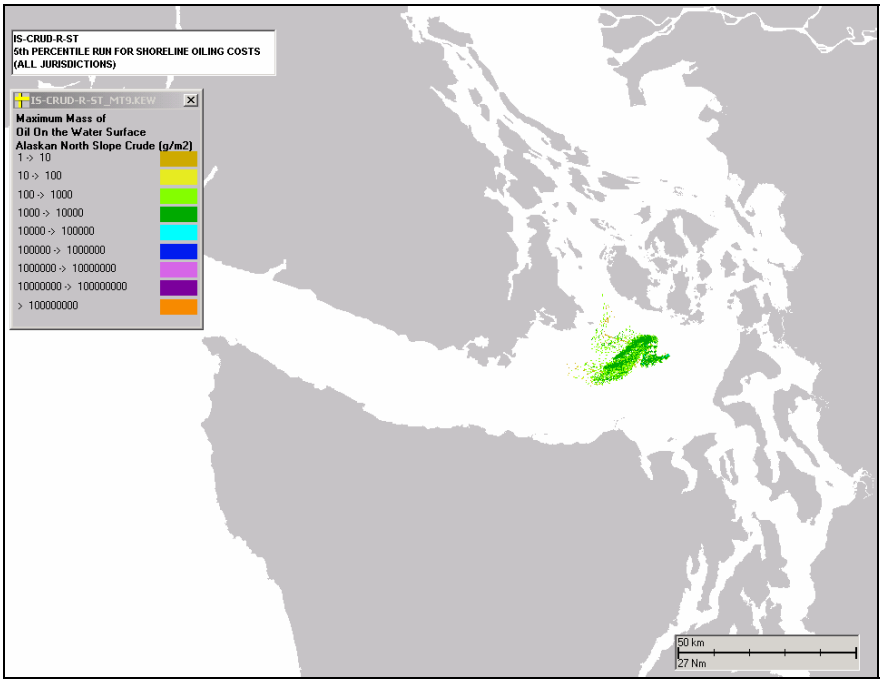

Figure XIX.E-1. Inner Straits/Puget Sound, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

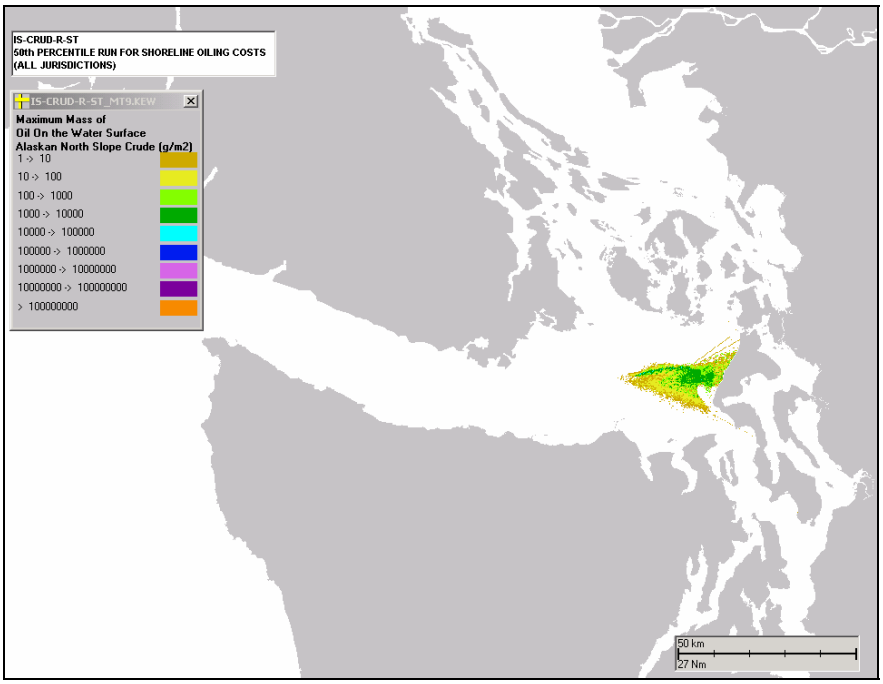

Figure XIX.E-2. Inner Straits/Puget Sound, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

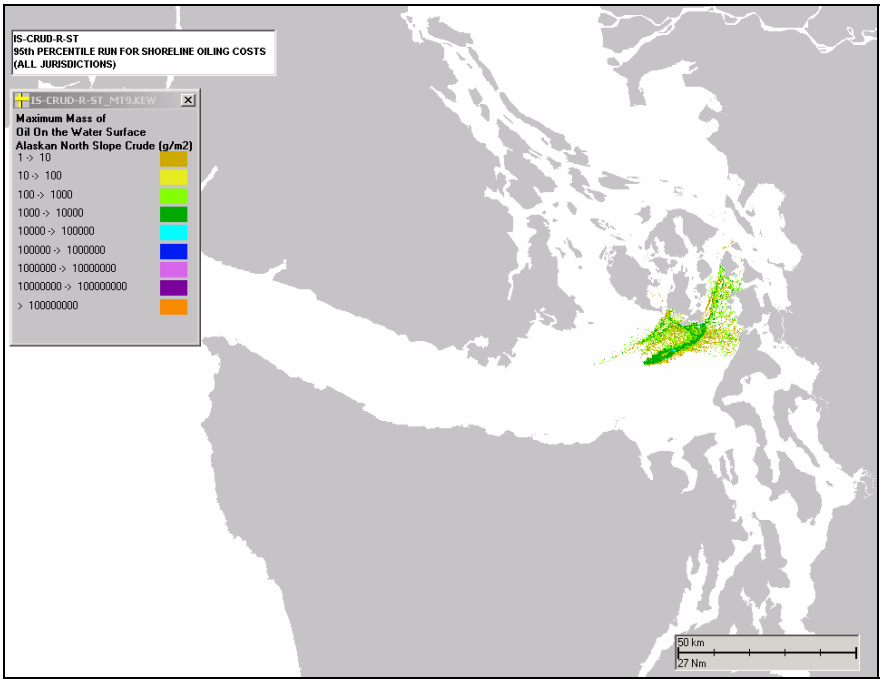

Figure XIX.E-3. Inner Straits/Puget Sound, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

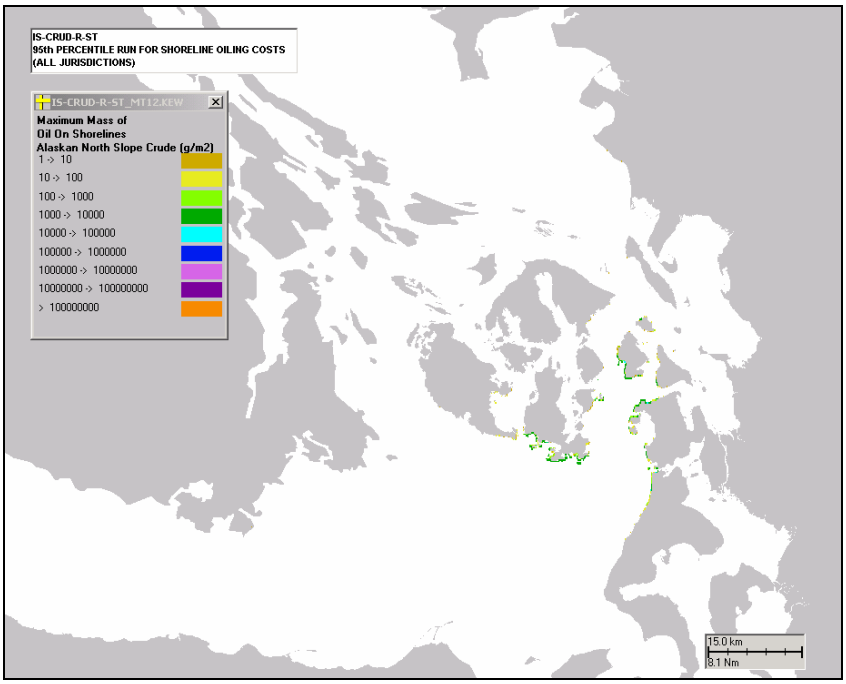

Figure XIX.E-4. Inner Straits/Puget Sound, WA state mechanical removal: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

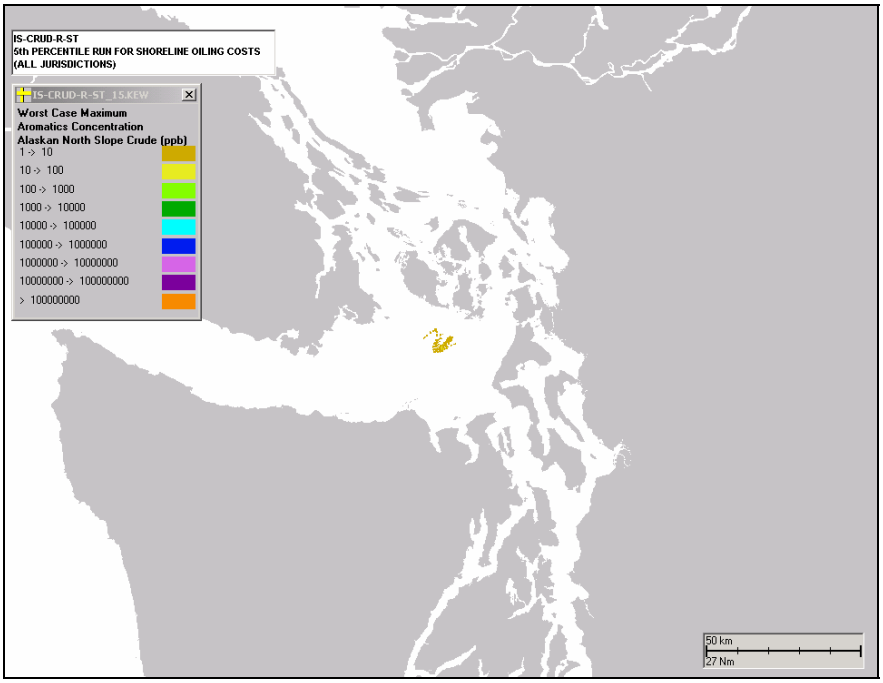

Figure XIX.E-5. Inner Straits/Puget Sound, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

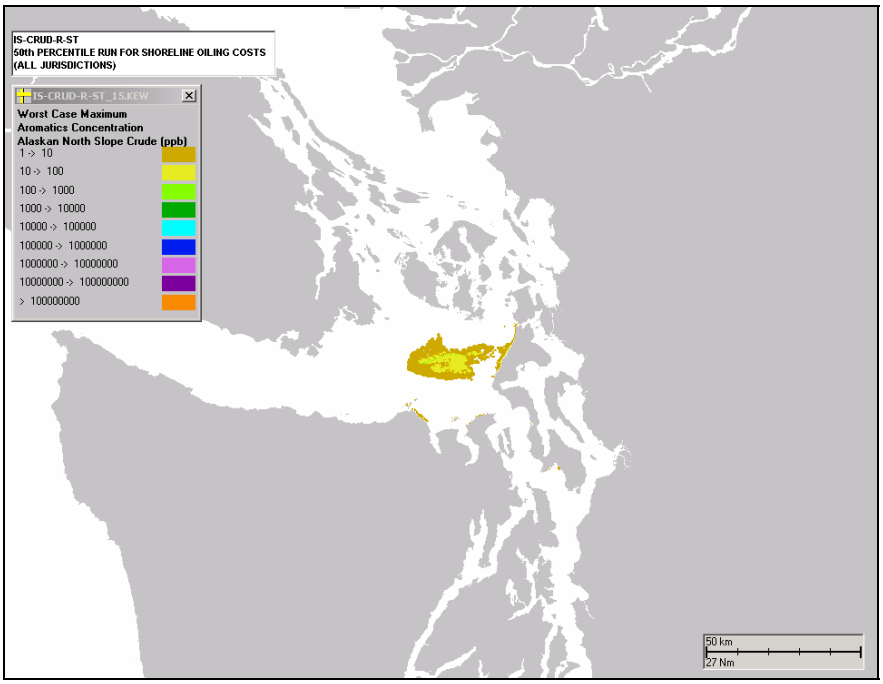

Figure XIX.E-6. Inner Straits/Puget Sound, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

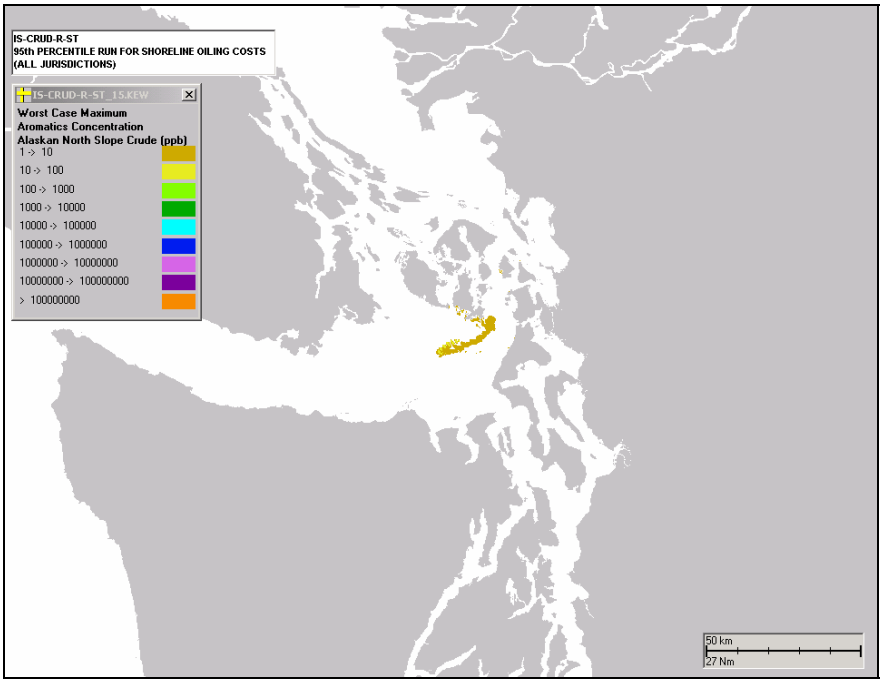

Figure XIX.E-7. Inner Straits/Puget Sound, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

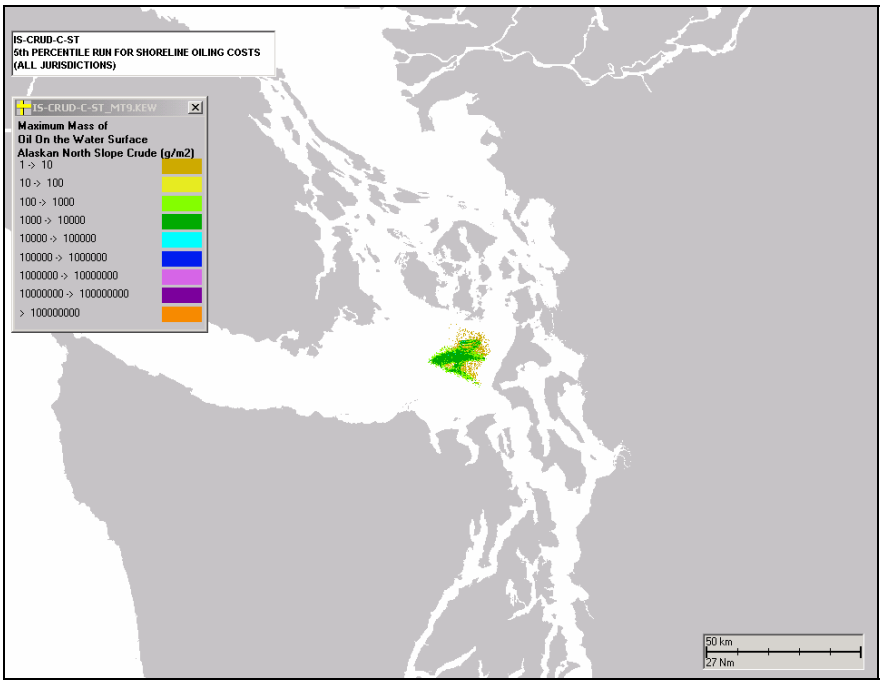

Figure XIX.E-8. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

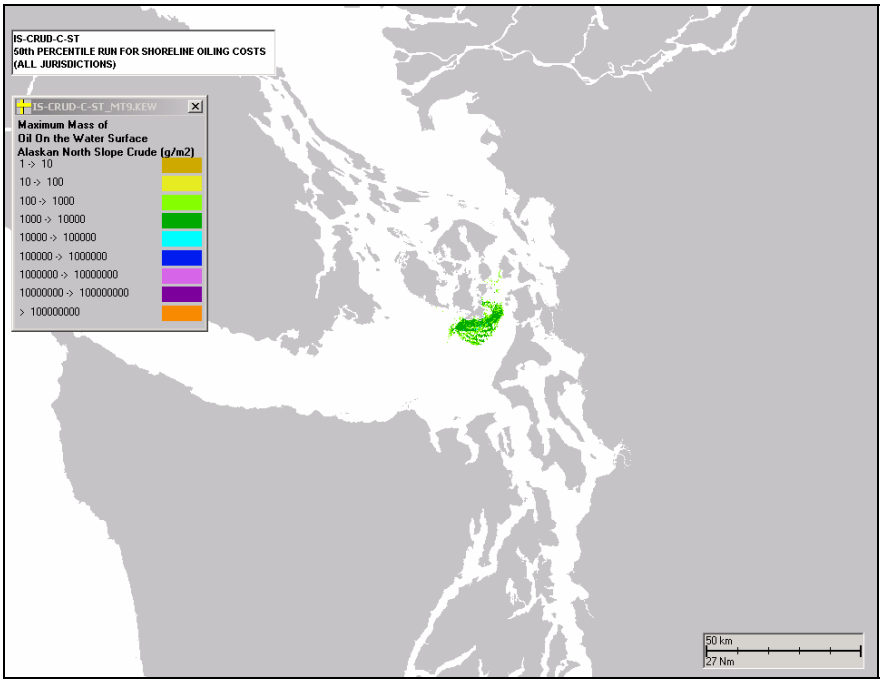

Figure XIX.E-9. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

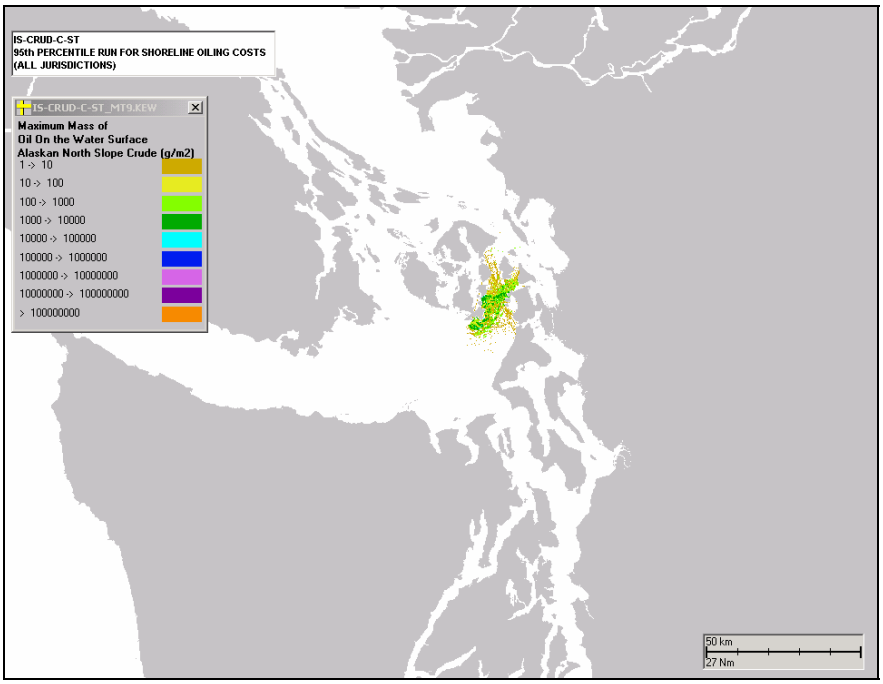

Figure XIX.E-10. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

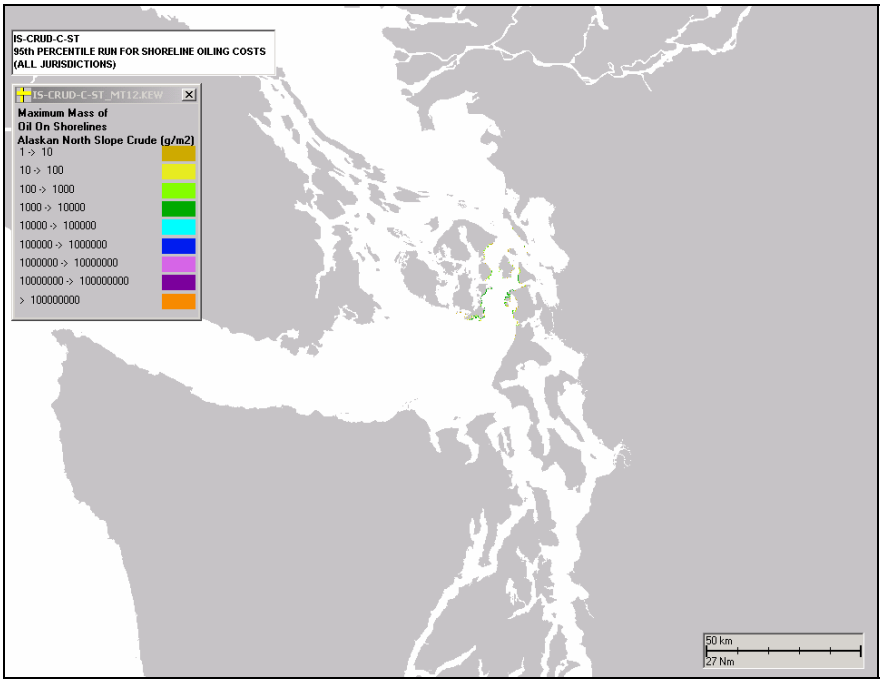

Figure XIX.E-11. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

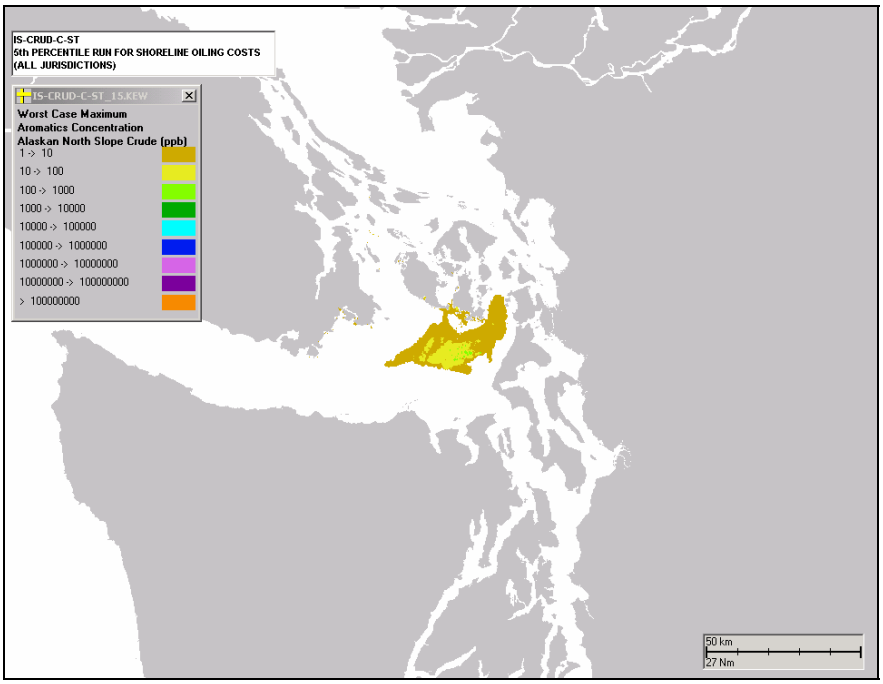

Figure XIX.E-12. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

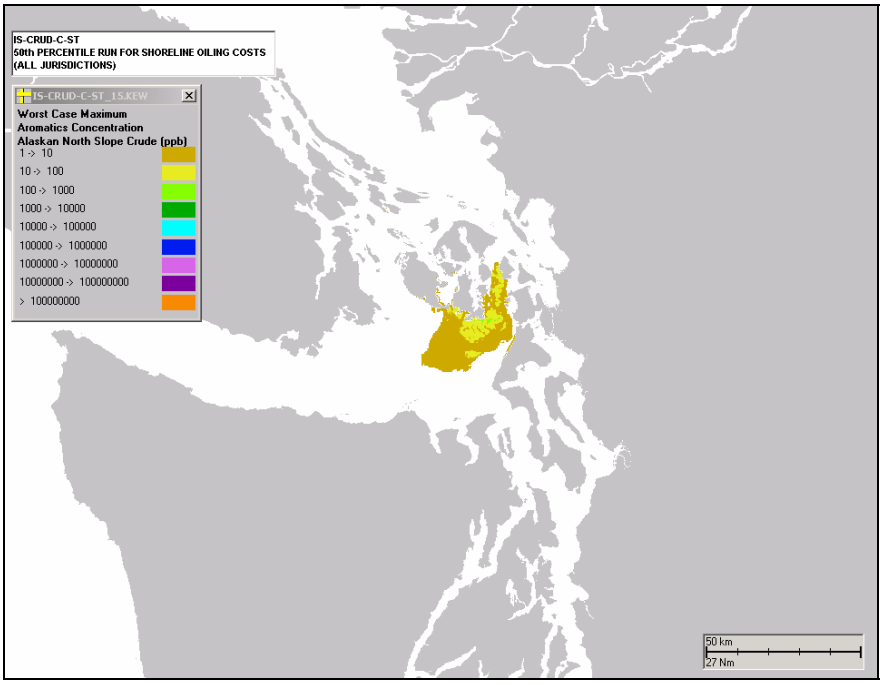

Figure XIX.E-13. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

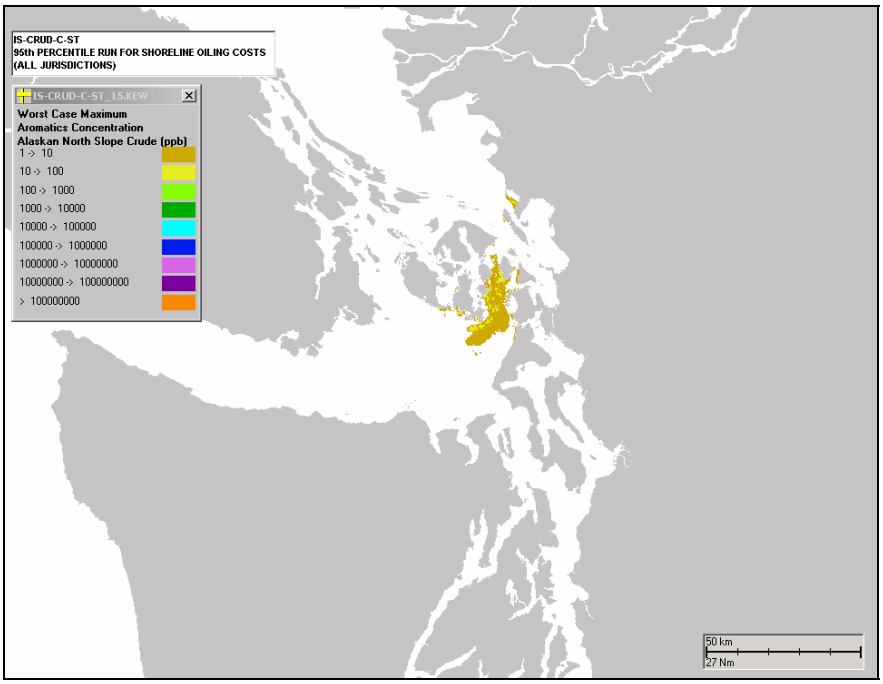

Figure XIX.E-14. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIX.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost.

The wildlife impacts for all 100 runs were estimated from the habitat area occupied by the species group that was oiled, i.e., areas of water swept by oil > 10 g/m^2 and shoreline oiled by >100 g/m^2, using the methods described in Section 2.3 of Volume I. The actual 5th, 50th and 95th percentile results for the 100 estimates of wildlife impact were calculated by sorting only the wildlife group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact indices of a given scenario. Thus, to evaluate the various impact results for different species groups within a single scenario (i.e., different wildlife groups within a single table), the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table XIX.F-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	7,022	1,777	0	1	-	-	1	-	8,801	8,800	1
50th Percentile Run (based on shore cost)	7,637	2,809	0	1	0	-	1	-	10,448	10,447	1
95th Percentile Run (based on shore cost)	7,404	2,418	0	2	0	-	1	-	9,826	9,825	1
5th Percentile	5,975	19	0	1	-	-	0	-	5,996	5,995	0.42
50th Percentile	7,156	2,000	0	1	0	-	1	-	9,158	9,157	0.72
95th Percentile	10,570	7,733	0	3	1	-	2	-	18,307	18,305	1.59
Mean	7,596	2,764	0	2	0	-	1	-	10,364	10,363	0.83
Std Dev (SD)	1,542	2,557	0	4	3	-	0	-	4,099	4,098	0.39
Mean - 2SD	4,512	-	-	-	-	-	0	-	2,166	2,166	0.05
Mean + 2SD	10,679	7,879	0	9	6	-	2	-	18,561	18,559	1.62

Table XIX.F-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	6,593	1,055	0	1	-	-	1	-	7,650	7,649	1
50th Percentile Run (based on shore cost)	6,524	940	0	1	0	-	1	-	7,466	7,465	1
95th Percentile Run (based on shore cost)	6,267	509	0	2	0	-	0	-	6,779	6,779	0
5th Percentile	5,947	-	0	1	-	-	0	-	5,950	5,950	0.41
50th Percentile	6,942	1,642	0	1	0	-	1	-	8,587	8,586	0.67
95th Percentile	10,342	7,350	0	2	1	-	2	-	17,694	17,693	1.54
Mean	7,400	2,441	0	2	0	-	1	-	9,845	9,844	0.78
Std Dev (SD)	1,412	2,335	0	4	2	-	0	-	3,747	3,746	0.36
Mean - 2SD	4,576	-	-	-	-	-	0	-	2,351	2,351	0.06
Mean + 2SD	10,224	7,111	0	10	4	-	2	-	17,338	17,336	1.51

XIX.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because fish and invertebrate impacts are not necessarily correlated with shore cost, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run by shore cost.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the habitat area occupied by the species group that was contaminated using the methods described in Section 2.3 of Volume I. The actual 5th, 50th and 95th percentile results for the 100 estimates of fish and invertebrate impact were calculated by sorting only the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact indices of a given scenario. Thus, to evaluate the various impact results for different species groups within a single scenario (i.e., different fish and invertebrate groups within a single table), the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table XIX.G-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	-	-	-	-	-	-	-
50th Percentile Run (shore cost)	3,243.6	9,657.2	25.0	21.9	8,786.4	-	21,734
95th Percentile Run (shore cost)	-	-	-	-	-	724	724
5th Percentile	-	-	-	-	-	-	-
50th Percentile	-	-	-	-	-	283	283
95th Percentile	5,534.0	16,606.4	42.5	36.4	14,598.2	1,386	38,203
Mean	1,299.4	3,857.9	10.0	8.9	3,559.6	506	9,242
Std Dev (SD)	2,071.6	6,222.8	15.9	13.6	5,446.5	554	14,325
Mean - 2SD	-	-	-	-	-	-	-
Mean + 2SD	5,442.6	16,303.4	41.8	36.0	14,452.6	1,615	37,891

Table XIX.G-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	6,496.3	19,526.2	49.9	42.5	17,040.1	-	43,155
50th Percentile Run (shore cost)	7,194.3	21,644.0	55.2	46.9	18,811.3	189	47,940
95th Percentile Run (shore cost)	1,898.3	5,575.6	14.7	13.4	5,372.8	1,007	13,882
5th Percentile	578.5	1,571.1	4.7	5.0	2,023.7	-	4,183
50th Percentile	5,920.4	17,778.8	45.5	38.9	15,578.7	299	39,661
95th Percentile	14,414.1	43,549.3	110.3	92.7	37,131.4	1,513	96,811
Mean	6,322.6	19,006.6	48.5	41.4	16,577.2	490	42,487
Std Dev (SD)	3,841.0	11,641.7	29.4	24.4	9,784.0	578	25,899
Mean - 2SD	-	-	-	-	-	-	-
Mean + 2SD	14,004.7	42,289.9	107.2	90.3	36,145.2	1,647	94,284

XIX.H. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All weights are as wet weight; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

NRDA costs were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because impacts are not necessarily correlated with shore cost, the results for NRDA costs may not be in increasing order from 5th to 95th percentile run by shore cost.

The NRDA costs for all 100 runs were estimated from the wildlife, fish and invertebrate impact estimates for each run. The actual 5th, 50th and 95th percentile results for the 100 estimates were calculated by sorting by NRDA cost for the specific group. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

In addition, the same run may not be the 5th, 50th or 95th percentile run for shoreline costs when comparing one response alternative to another at the same location. The response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal or dispersant application is added to the scenario. Comparisons among scenarios should be made using the 5th, 50th or 95th percentile result for the species group (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5th, 50th or 95th *runs based on shore costs*. The results for 5th, 50th or 95th *runs based on shore costs* are for the same runs across all impact groups of a given scenario. Thus, to evaluate the various NRDA cost contributions for different species groups within a single scenario (i.e., different fish and invertebrate groups within a single table), the results for 5th, 50th or 95th *runs based on shore costs* are meaningful.

Table XIX.H-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:									
Small pelagic fish	-	3,243.6	-	-	-	5,534.0	1,299.4	-	5,442.6
Large pelagic fish	-	9,657.2	-	-	-	16,606.4	3,857.9	-	16,303.4
Demersal fish	-	25.0	-	-	-	42.5	10.0	-	41.8
Decapods	-	21.9	-	-	-	36.4	8.9	-	36.0
Molluscs	-	8,786	724	-	283	15,984	4,065	-	16,067
Birds:									
Waterfowl (# * kg each)	5,477	5,957	5,775	4,660	5,581	8,245	5,925	3,519	8,330
Seabirds (# * kg each)	2,239	3,539	3,047	24	2,520	9,744	3,483	-	9,928
Waders (# * kg each)	0	0	0	0	0	0	0	-	0
Shorebirds (# * kg each)	0	0	0	0	0	0	0	-	0
Raptors (# * kg each)	-	0	0	-	0	4	2	-	31
Other wildlife:									
Sea otters, other mammals	-	-	-	-	-	-	-	-	-
Pinnipeds	69	84	79	42	72	159	83	5	162
Cetaceans	-	-	-	-	-	-	-	-	-
Totals:									
Subtotal fish and invertebrates	-	21,734	724	-	283	38,203	9,242	-	37,891
Subtotal birds	7,716	9,496	8,823	4,684	8,102	17,993	9,410	3,519	18,289
Subtotal other wildlife	69	84	79	42	72	159	83	5	162
Total all species	7,785	31,314	9,625	4,726	8,457	56,356	18,735	3,524	56,342

Table XIX.H-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	24	64	30	8	26	131	45	5	132
Saltmarsh Area (acres)	60	159	75	21	65	324	112	11	325
Saltmarsh Cost (millions of 2004$)	11.2	29.7	14.0	3.8	12.2	60.7	21.1	2.1	61.0
Eelgrass Area (m2)	15	40	19	5	16	82	28	3	82
Eelgrass Area (acres)	37	99	47	13	41	202	70	7	203
Eelgrass Cost (millions of 2004$)	4.5	11.8	5.6	1.5	4.9	24.2	8.4	0.8	24.3

Table XIX.H-3. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:									
Small pelagic fish	6,496.3	7,194.3	1,898.3	578.5	5,920.4	14,414.1	6,322.6	-	14,004.7
Large pelagic fish	19,526.2	21,644.0	5,575.6	1,571.1	17,778.8	43,549.3	19,006.6	-	42,289.9
Demersal fish	49.9	55.2	14.7	4.7	45.5	110.3	48.5	-	107.2
Decapods	42.5	46.9	13.4	5.0	38.9	92.7	41.4	-	90.3
Molluscs	17,040	19,000	6,379	2,024	15,878	38,645	17,068	-	37,792
Birds:									
Waterfowl (# * kg each)	5,142	5,089	4,889	4,639	5,415	8,066	5,772	3,569	7,975
Seabirds (# * kg each)	1,330	1,184	642	-	2,069	9,261	3,076	-	8,960
Waders (# * kg each)	0	0	0	0	0	0	0	-	0
Shorebirds (# * kg each)	0	0	0	0	0	0	0	-	0
Raptors (# * kg each)	-	0	0	-	0	6	2	-	19
Other wildlife:									
Sea otters, other mammals	-	-	-	-	-	-	-	-	-
Pinnipeds	58	56	49	41	67	154	78	6	151
Cetaceans	-	-	-	-	-	-	-	-	-
Totals:									
Subtotal fish and invertebrates	43,155	47,940	13,882	4,183	39,661	96,811	42,487	-	94,284
Subtotal birds	6,472	6,273	5,530	4,639	7,484	17,333	8,849	3,569	16,955
Subtotal other wildlife	58	56	49	41	67	154	78	6	151
Total all species	49,685	54,270	19,461	8,863	47,211	114,298	51,415	3,576	111,390

Table XIX.H-4. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	79.4	85.1	30.6	13.1	79.3	212.6	90.4	4.7	206.7
Saltmarsh Area (acres)	196.3	210.3	75.5	32.5	195.9	525.4	223.4	11.6	510.6
Saltmarsh Cost (millions of 2004$)	36.8	39.4	14.2	6.1	36.7	98.4	41.9	2.2	95.7
Eelgrass Area (m2)	49.6	53.2	19.1	8.2	49.5	132.9	56.5	2.9	129.1
Eelgrass Area (acres)	122.7	131.4	47.2	20.3	122.4	328.3	139.6	7.2	319.1
Eelgrass Cost (millions of 2004$)	14.6	15.7	5.6	2.4	14.6	39.2	16.7	0.9	38.1

XIX.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table XIX.I-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	19.852	23.638	20.788	22.688	23.643	22.122	19.447	24.798
% Removed by 24 hours	13.8	16.2	13.3	3.1	11.5	23.1	12.7	-	27.0
Compensation (millions $)	48.9	45.4	56.0	55.0	54.8	49.6	52.7	45.9	59.5

Table XIX.I-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	23.638	22.688	20.788	22.688	23.646	22.115	19.596	24.633
% Removed by 24 hours	11.5	11.5	3.8	3.1	11.5	23.1	12.7	-	26.9
Compensation (millions $)	50.2	57.1	59.6	55.0	54.8	49.7	52.7	46.3	59.1

Phase 1: Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XX: Results of Alternative Response Scenarios for Inner Straits/Puget Sound – Alaskan North Slope Crude

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XX.A. INTRODUCTION

The results of the alternate response scenarios for the Inner Straits/Puget Sound – Alaskan North Slope Crude are contained in this volume. There were two main stochastic scenarios for this location, oil type and spill volume:

1. Mechanical removal under Washington state Caps standards
2. Mechanical removal under Washington state Caps standards plus dispersant application

For each main stochastic case, alternate response scenarios were run, where the mechanical removal was altered to federal standards (US Federal Caps) or to a third removal scheme (3rd Alternative Caps). The geographic data, current data, and model inputs are the same for each of the alternate response scenarios as was described in Volume XVIII for the main stochastic scenarios. For the alternate response scenarios, just 3 representative runs were run with each set of response assumptions: the 5th, 50th and 95th percentile run based on shoreline oiling and area-based costs for cleanup. The figures and tables in this volume summarize the model results for the alternate response scenarios, as well as corresponding 3 runs (of the same start date and time) from the main response scenario.

The main stochastic scenario assuming the Washington state mechanical response standards (and no dispersants or ISB) was used to identify the run dates and times for 5th, 50th and 95th percentile impacts as measured by shoreline costs (termed the base case runs). The 100 main stochastic scenario runs of the base case scenario were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results for the individual 5th, 50th, and 95th percentile runs based on shoreline cleanup costs are presented. Because each impact index is not necessarily correlated with shoreline cleanup cost, the results for the index may not be in increasing order from 5th to 95th percentile run by shore cost. The mean and standard deviation, as well as mean plus or minus two standard deviations, of the 3 results are also listed. However, these statistics assume a normal (Gaussian) distribution based on just 3 data points, and so are highly uncertain and should be used with caution.

In addition, the same runs identified as the 5th, 50th, and 95th percentile runs for shoreline cleanup costs using the base case stochastic scenario were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made. Note that in Section II.2, the individual runs identified as the 5th, 50th, and 95th percentile runs for shoreline costs (and their dates and times) varied from one stochastic scenario to the next, and for the alternate scenarios other than the base case, they are not the same runs as those reported in this volume. Thus, in this volume, the alternate response scenarios are labeled with "-base". This indicates the base case 5th, 50th, and 95th percentile runs for shoreline costs were rerun with the same start date and time but with the alternate response. (For scenarios other than the base case, the 5th, 50th, and 95th percentile runs for shoreline costs listed in the tables in Section II.2 are those sorted within the particular scenario, and they are not the same runs or results as using the base case runs reported in this volume.)

In this volume (Section B), the results for the 5th, 50th, and 95th percentile runs based on shoreline oiling costs (using the base case scenario for sorting) are shown, as plots of the following measures of exposure:

- Water surface exposure to floating hydrocarbons (g/m^2)
- Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill

These figures are followed by additional sections with tables of the wildlife, fish and invertebrate impacts and the NRDA costs (damages).

XX.B. EXPOSURE FOR INDIVIDUAL MODEL RUNS

XX.B.1. No Removal, Scenario IS-Crud-N

The response for this scenario includes the use of protection booms only, and no mechanical removal using the three runs as identified as 5th, 50th and 95th percentile in the base case.

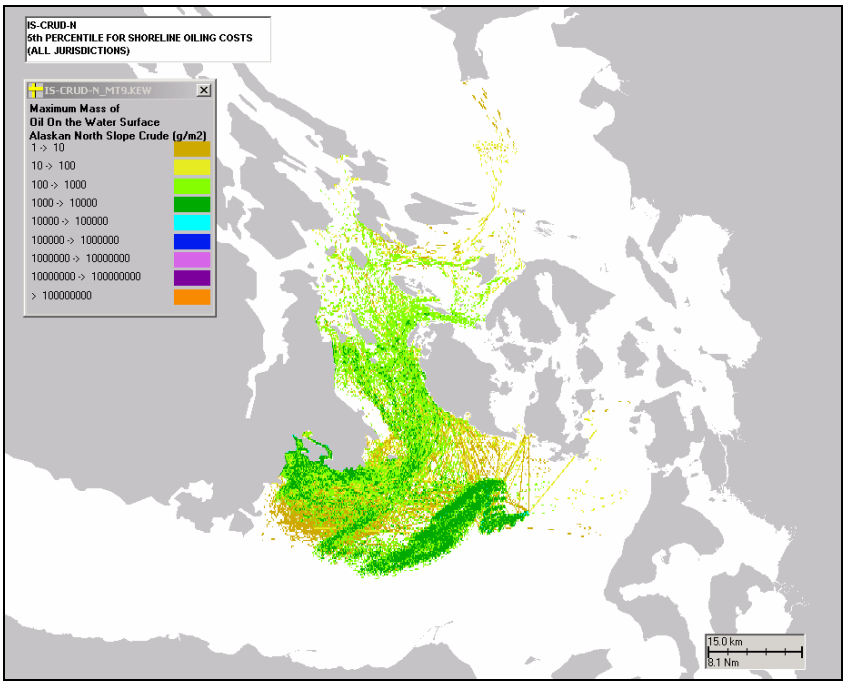


Figure XX.B.1-1. Inner Straits/Puget Sound, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

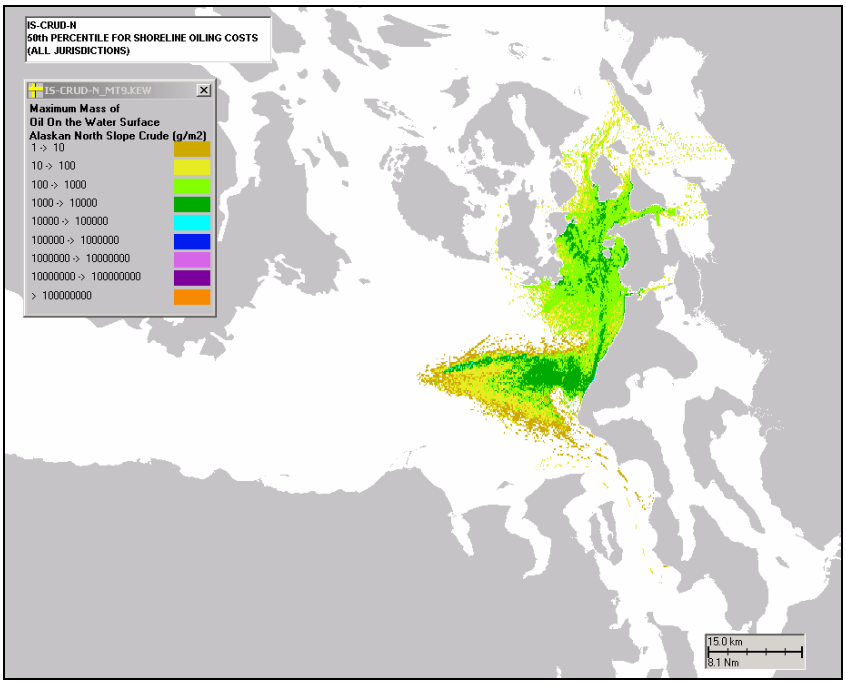


Figure XX.B.1-2. Inner Straits/Puget Sound, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

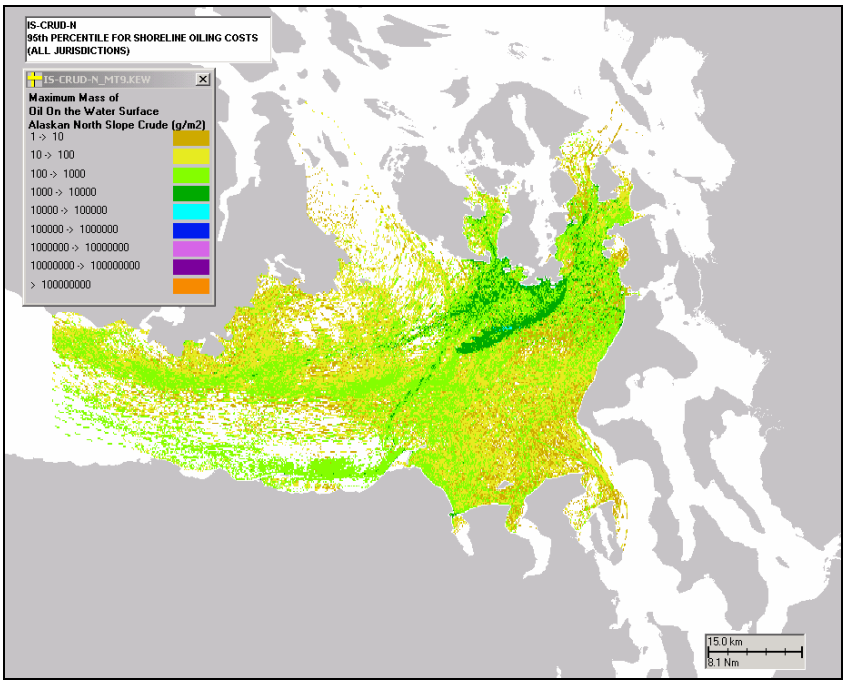


Figure XX.B.1-3. Inner Straits/Puget Sound, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

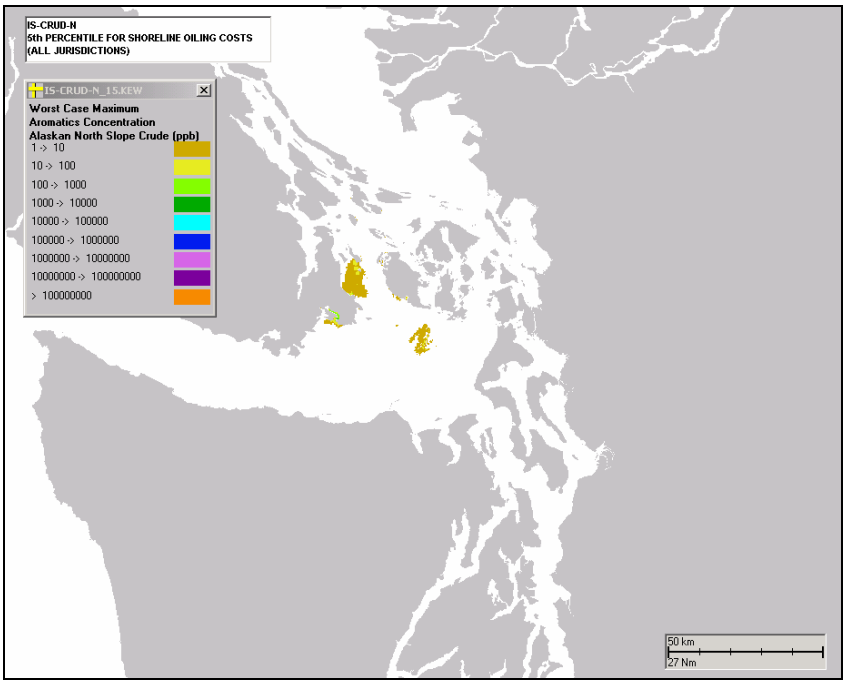


Figure XX.B.1-4. Inner Straits/Puget Sound, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

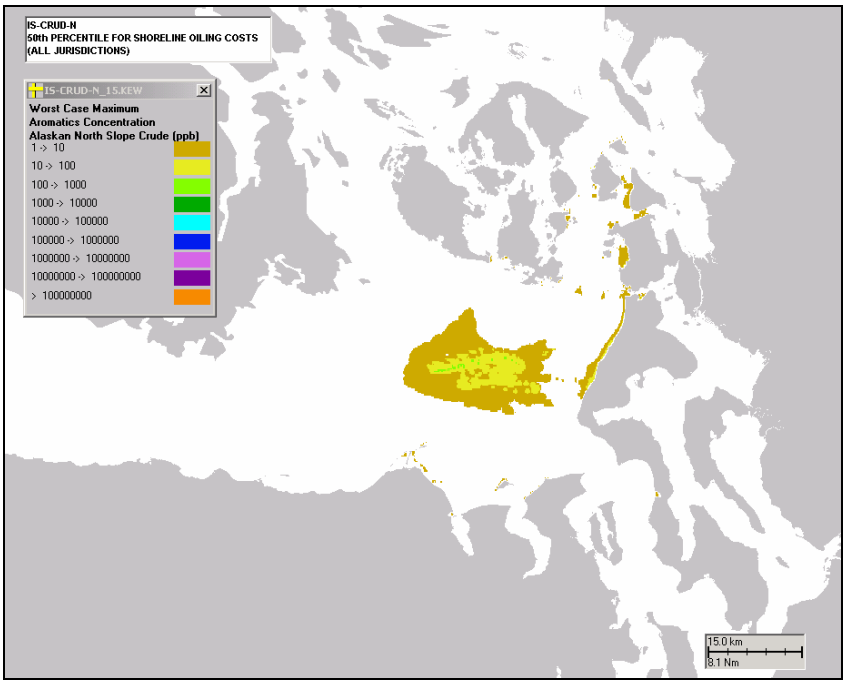


Figure XX.B.1-5. Inner Straits/Puget Sound, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

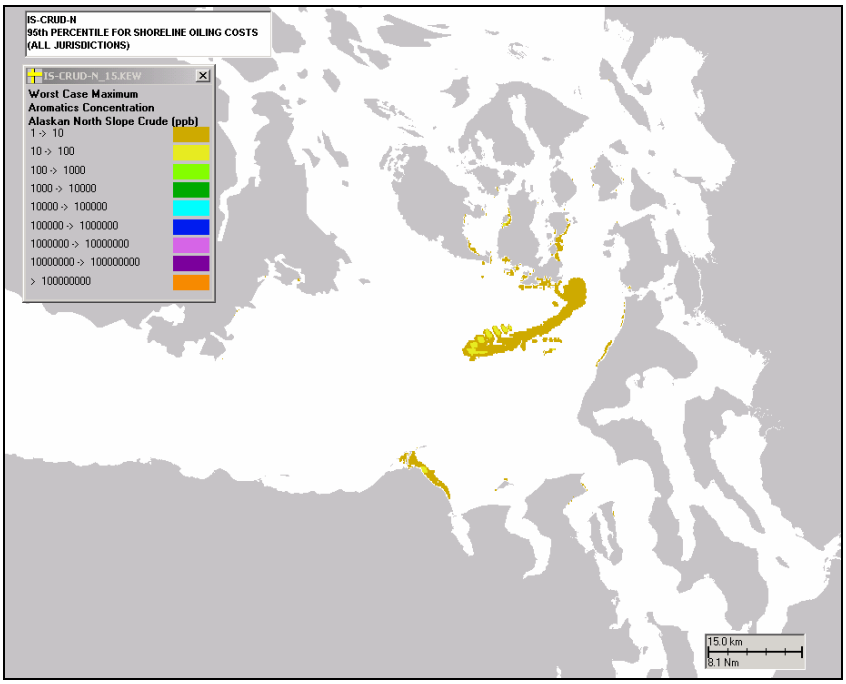


Figure XX.B.1-6. Inner Straits/Puget Sound, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XX.B.2. State Mechanical Removal, Scenario IS-Crud-R-ST

The response for this scenario includes the use of mechanical removal based on state standards and protection booming. These results as the same as those shown in Volume XIX, Section XIX.E. This scenario was used to identify the 5th, 50th and 95th percentile based on total shoreline cost, referred to as the " base case".

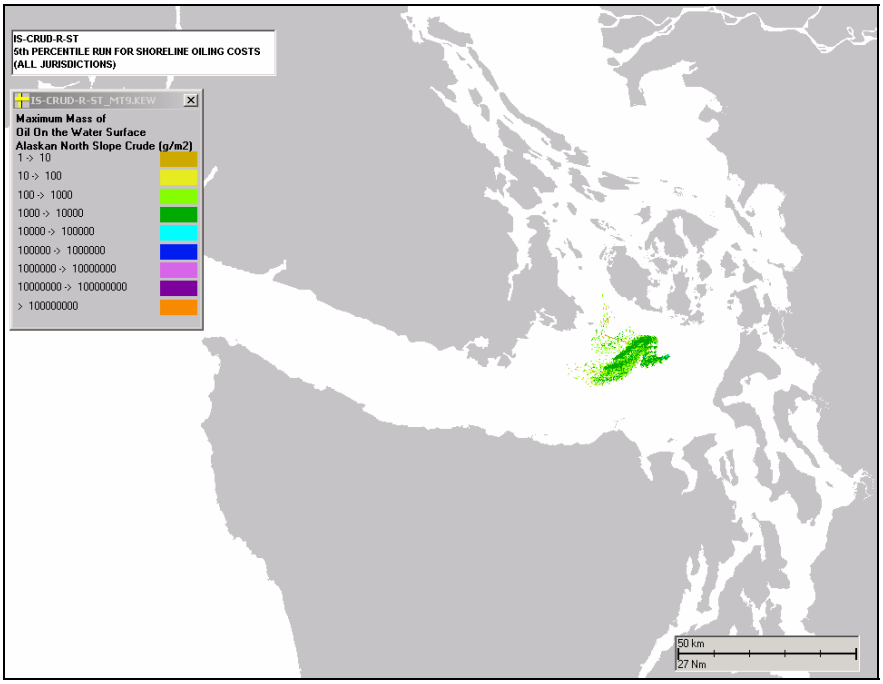


Figure XX.B.2-1. Inner Straits/Puget Sound, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

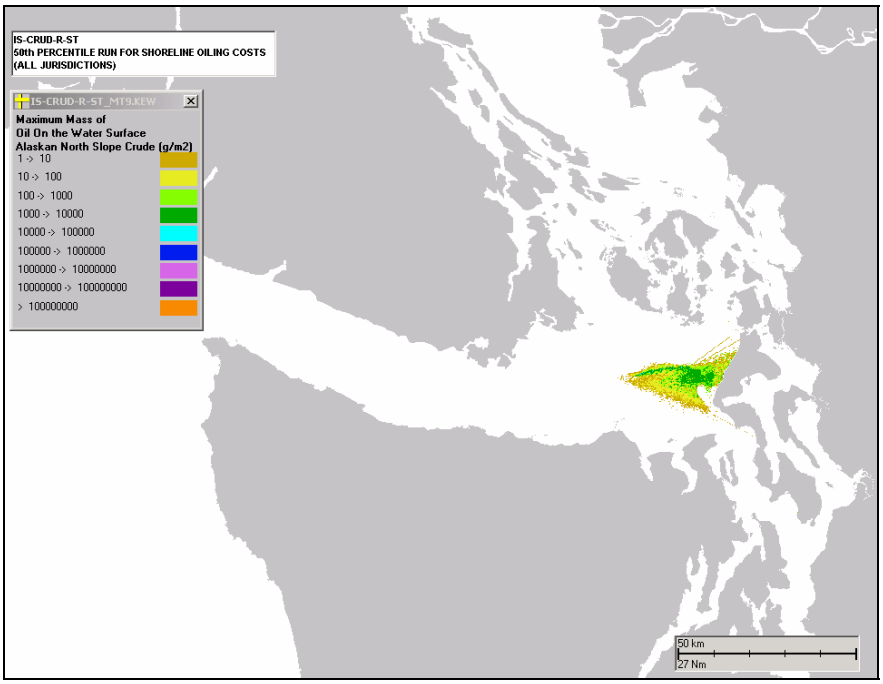


Figure XX. B.2-2. Inner Straits/Puget Sound, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

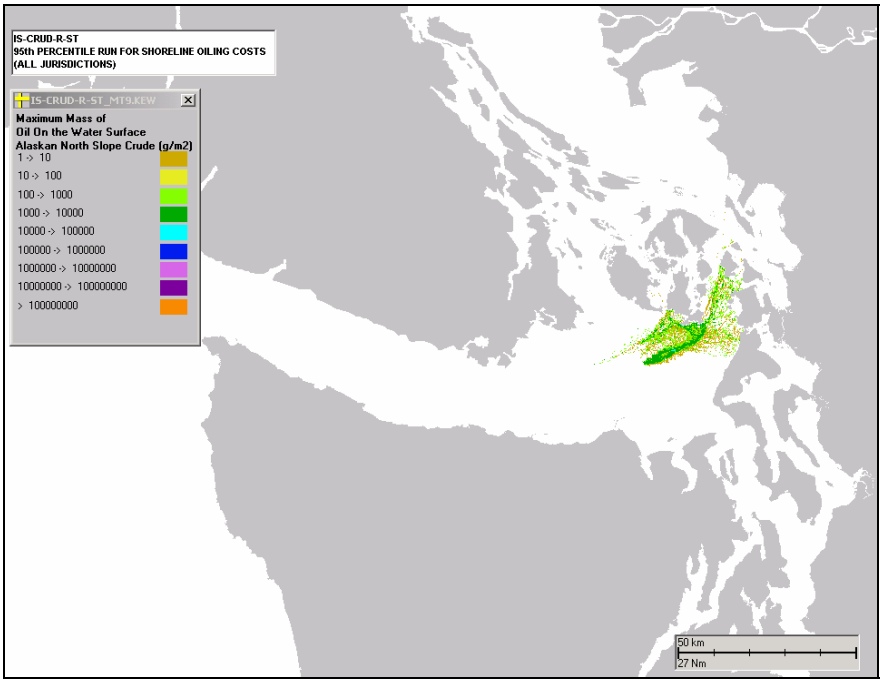


Figure XX. B.2-3. Inner Straits/Puget Sound, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

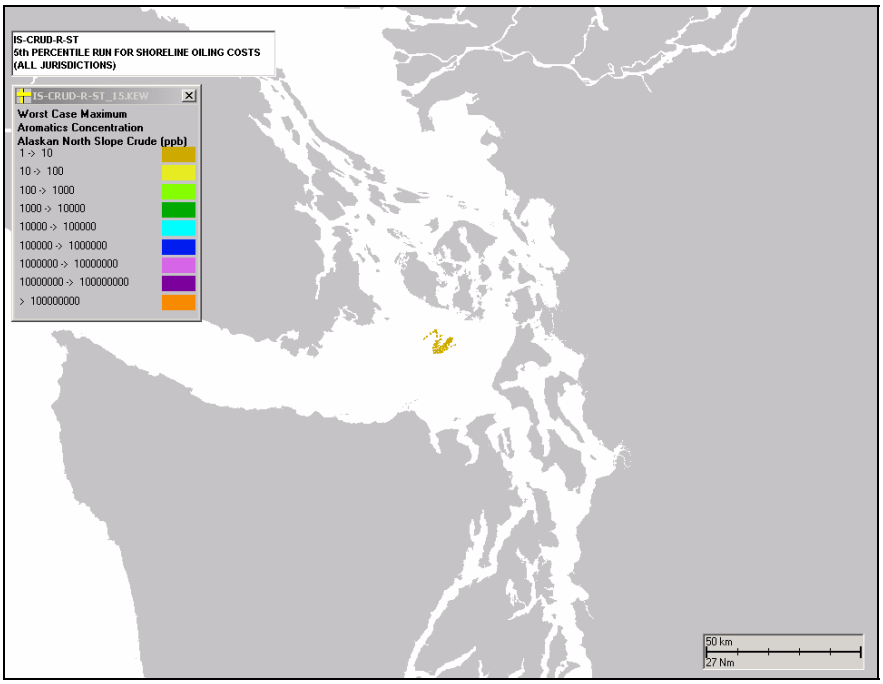


Figure XX. B.2-4. Inner Straits/Puget Sound, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

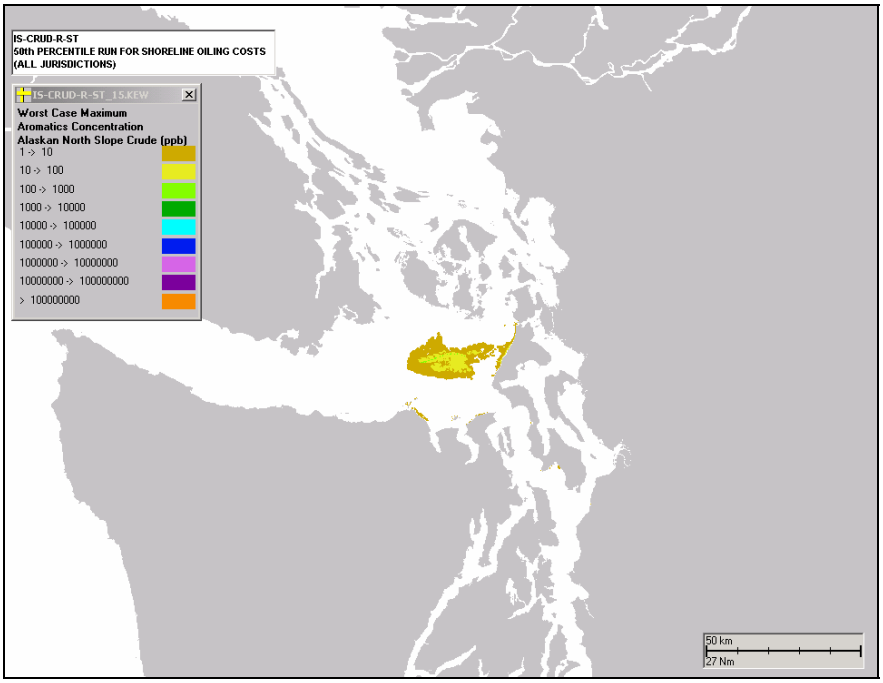


Figure XX. B.2-5. Inner Straits/Puget Sound, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

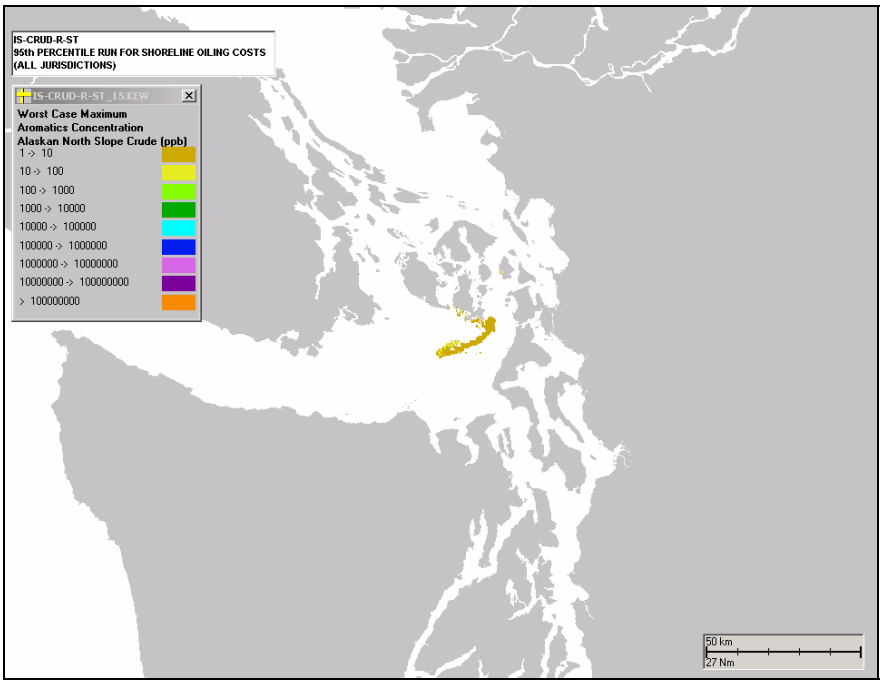


Figure XX. B.2-6. Inner Straits/Puget Sound, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XX.B.3. Federal Mechanical Removal, Scenario IS-Crud-R-Fed

The response for this scenario includes the use of mechanical removal based on federal standards and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case.

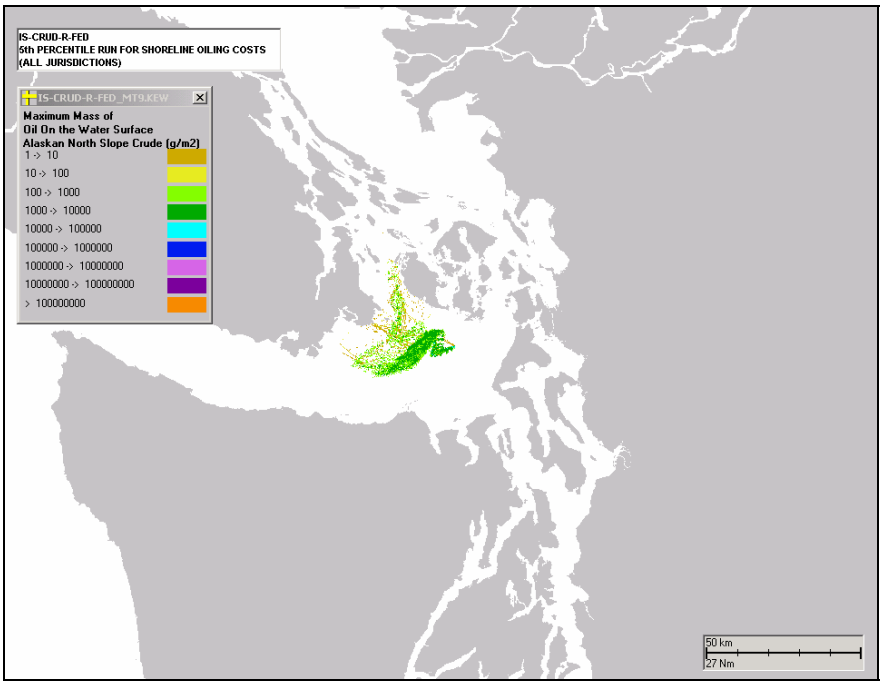


Figure XX.B.3-1. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

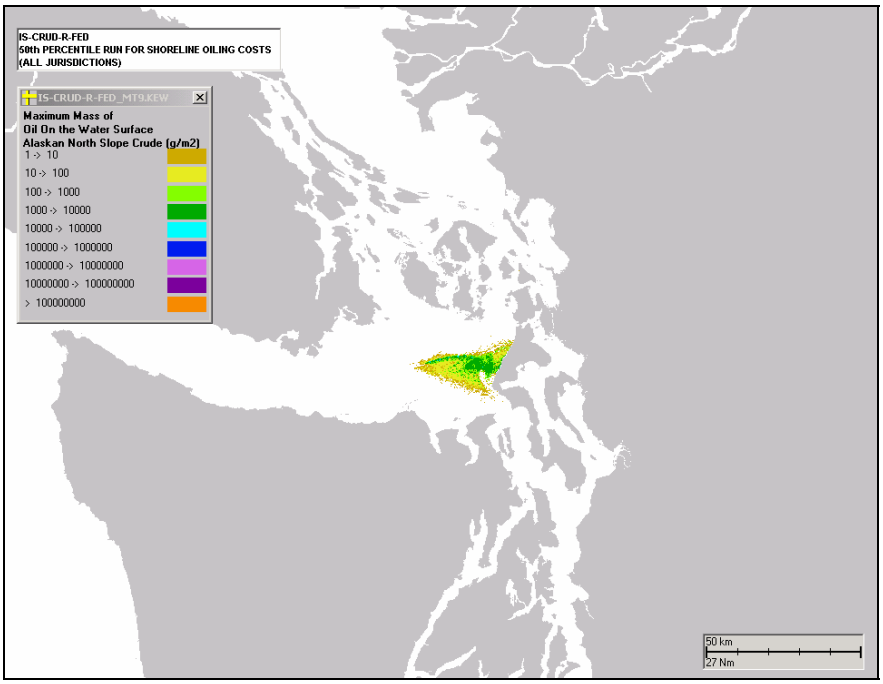


Figure XX. B.3-2. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

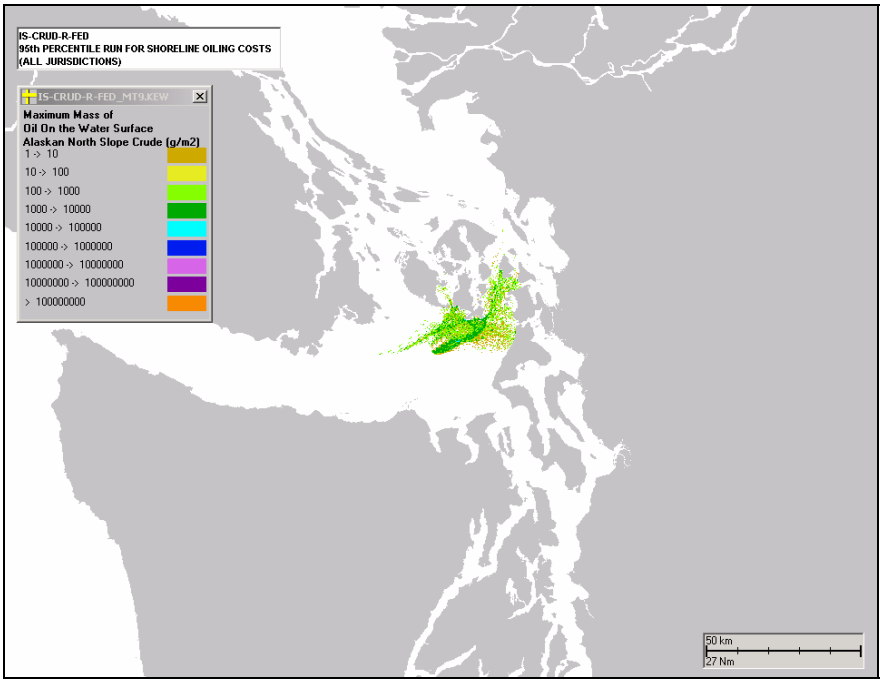


Figure XX. B.3-3. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

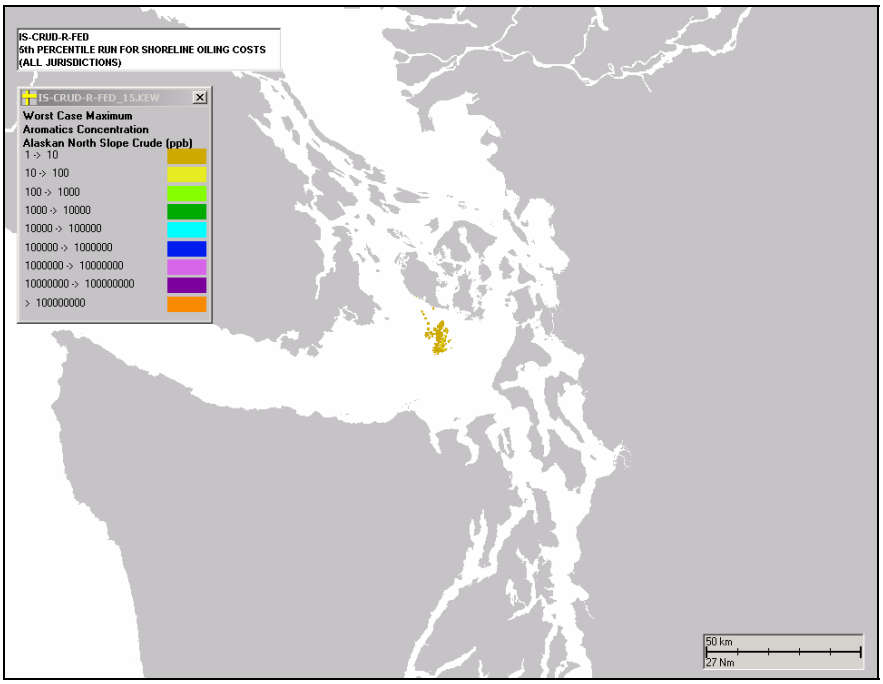


Figure XX.B.3-4. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

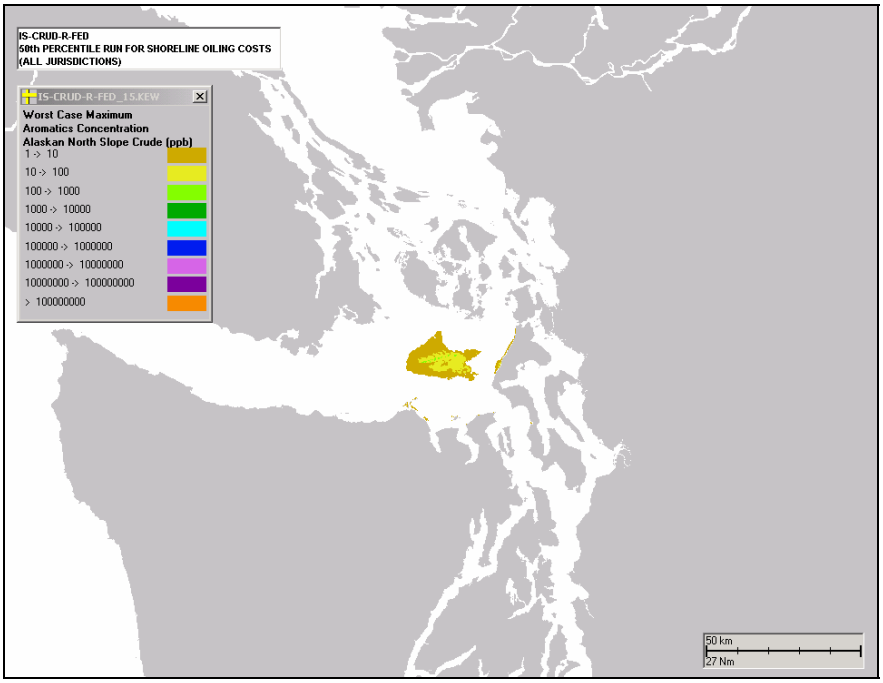


Figure XX.B.3-5. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

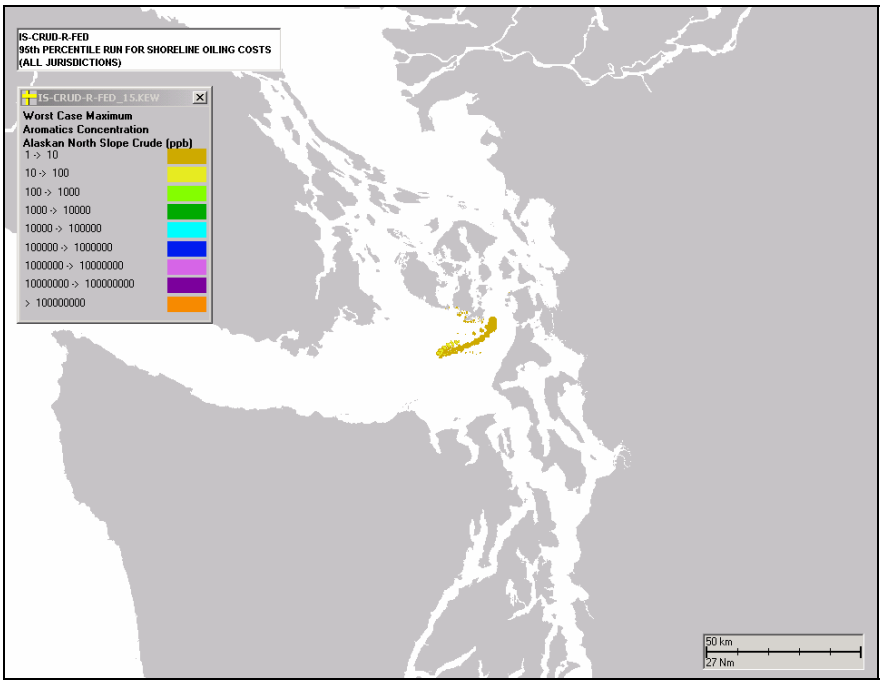


Figure XX.B.3-6. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XX.B.4. 3rd Alternative Mechanical Removal, Scenario IS-Crud-R-3

The response for this scenario includes the use of mechanical removal based on the 3rd alternative standards and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case.

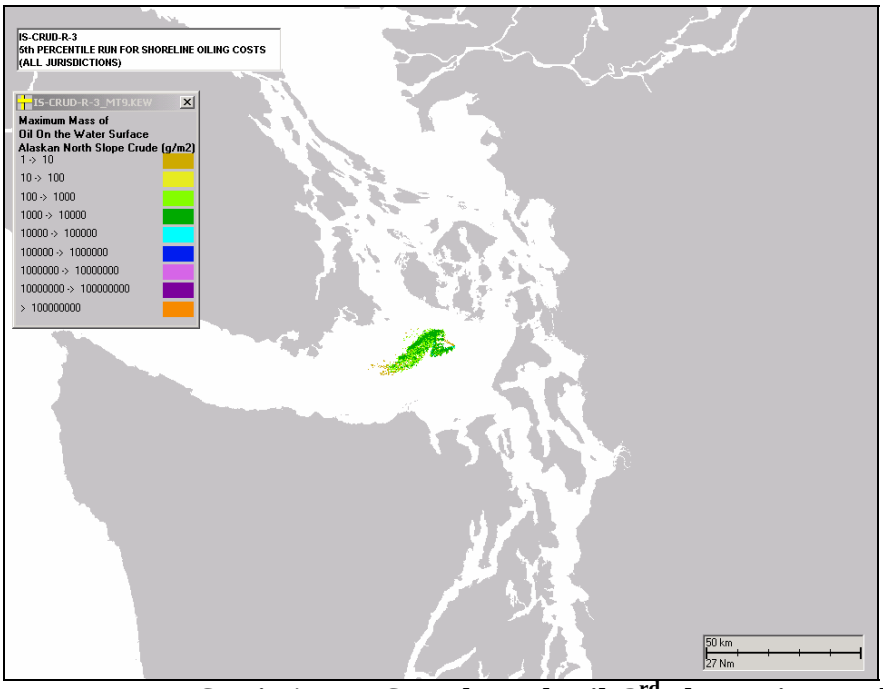


Figure XX.B.4-1. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

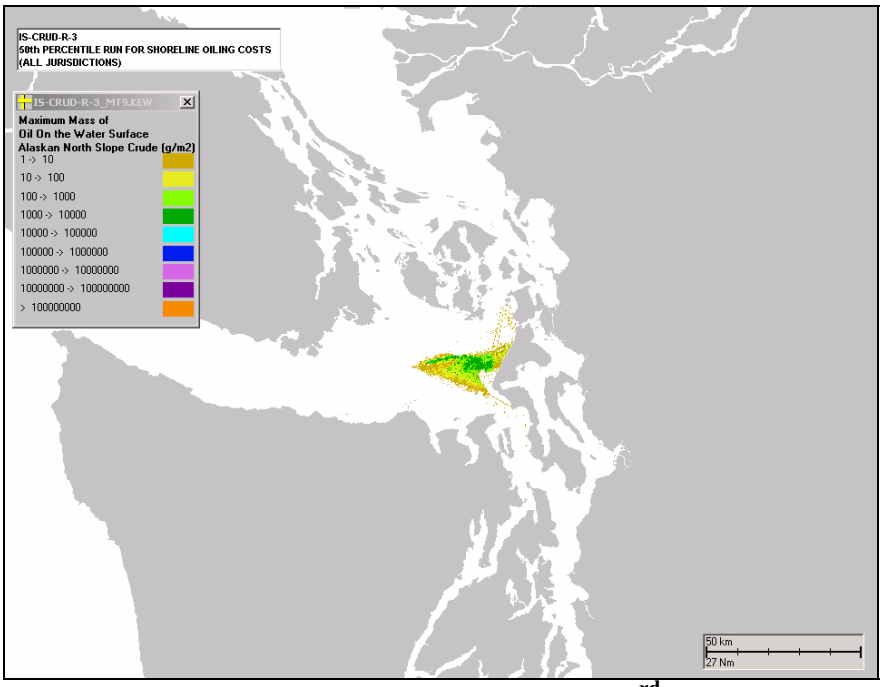


Figure XX.B.4-2. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

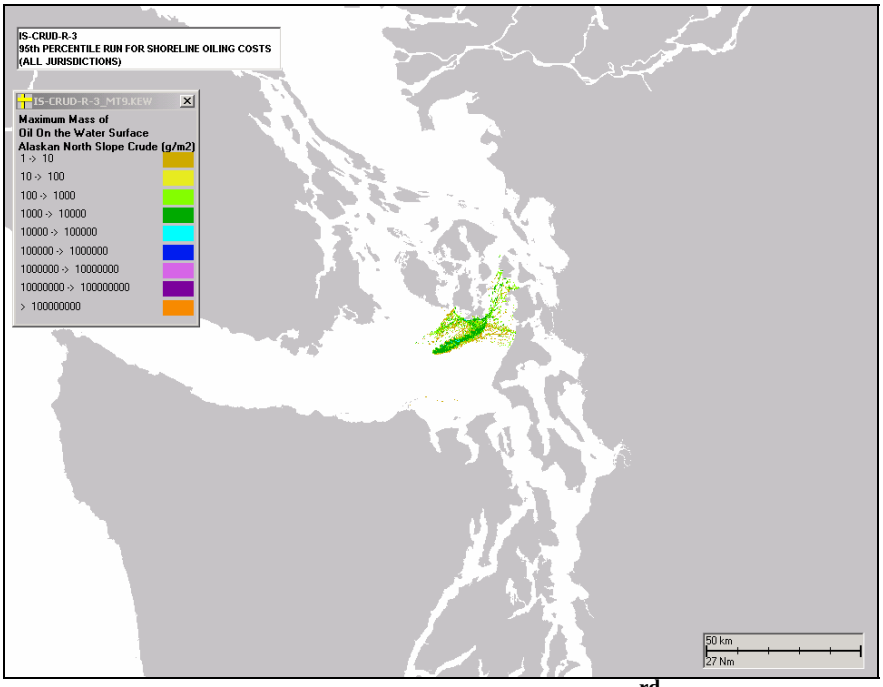


Figure XX.B.4-3. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

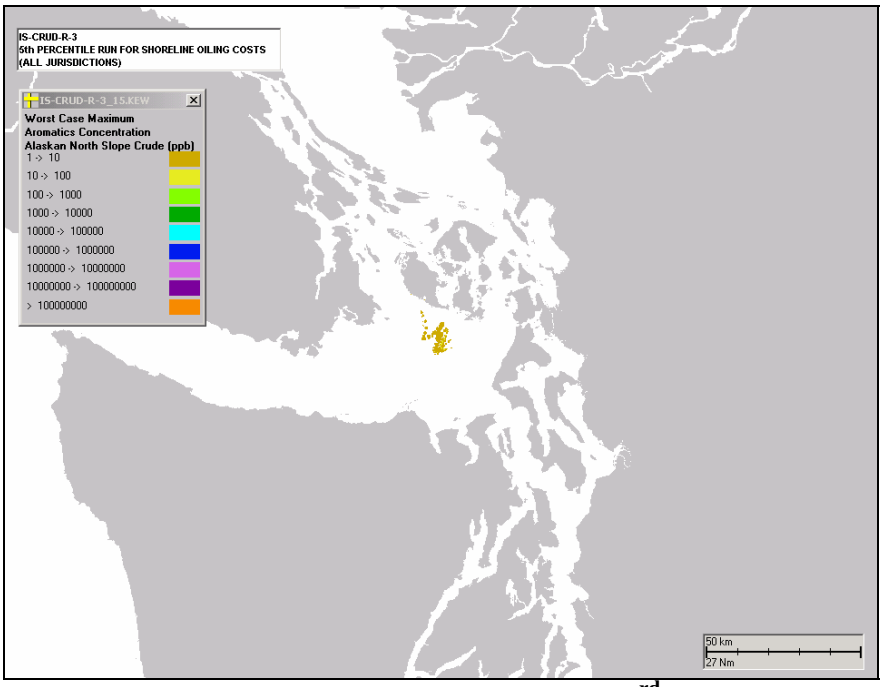


Figure XX.B.4-4. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

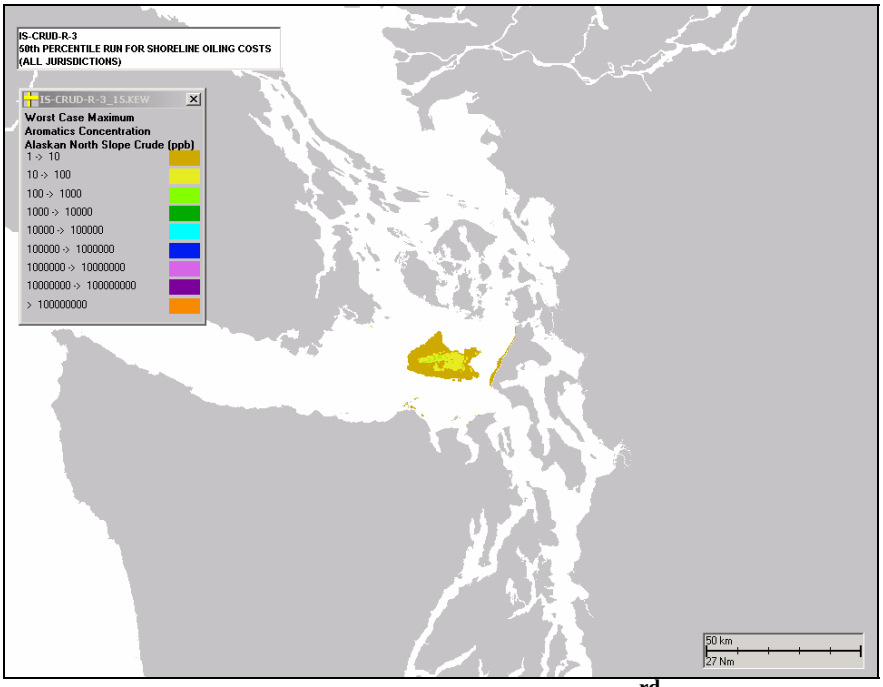


Figure XX.B.4-5. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

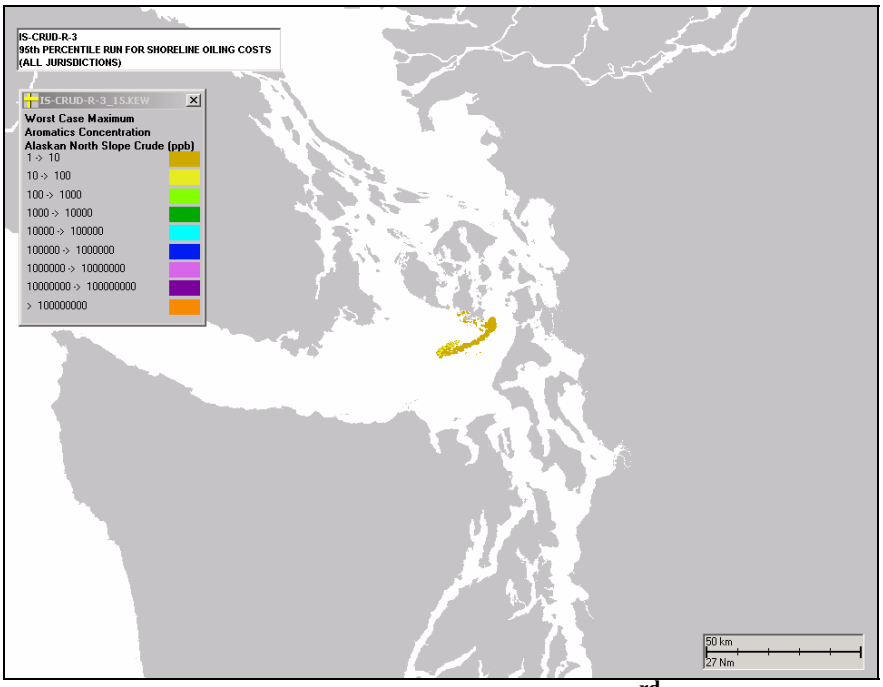


Figure XX.B.4-6. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XX.B.5. State Mechanical Removal and dispersant, Scenario IS-Crud-C-ST

The response for this scenario includes the use of mechanical removal based on state standards, dispersant and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case where no dispersant was applied.

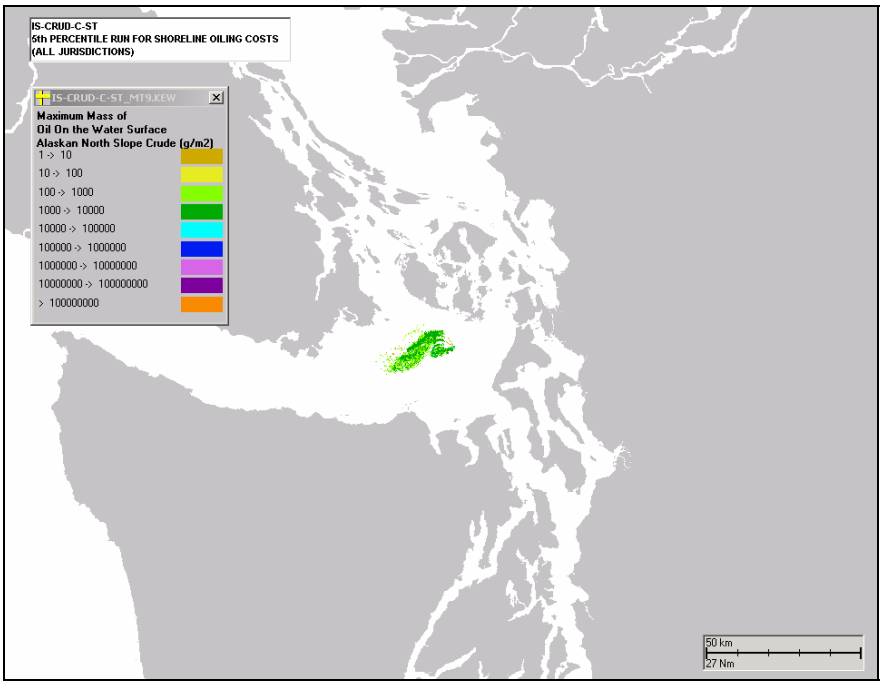


Figure XX.B.5-1. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

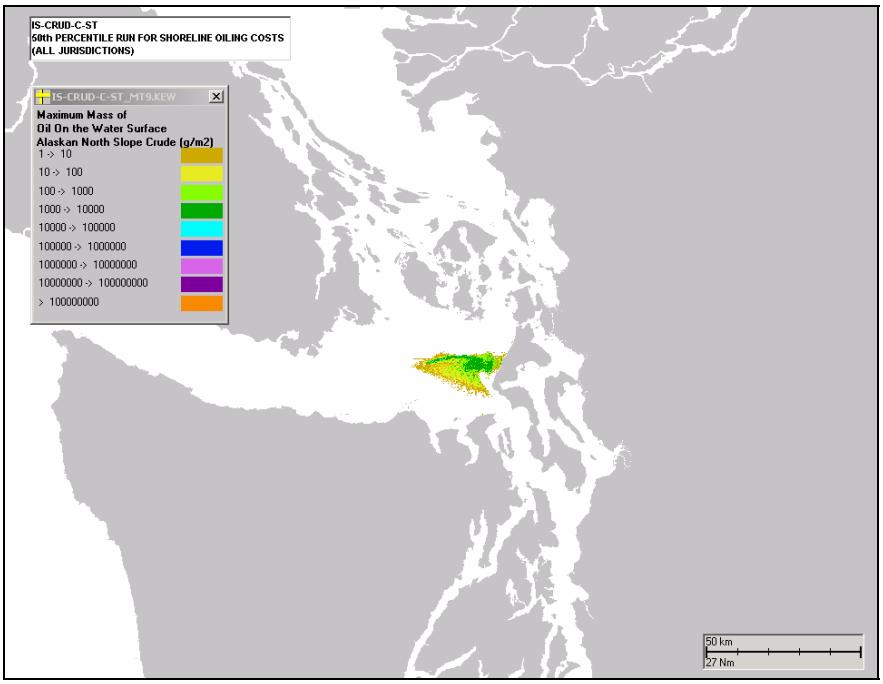


Figure XX.B.5-2. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

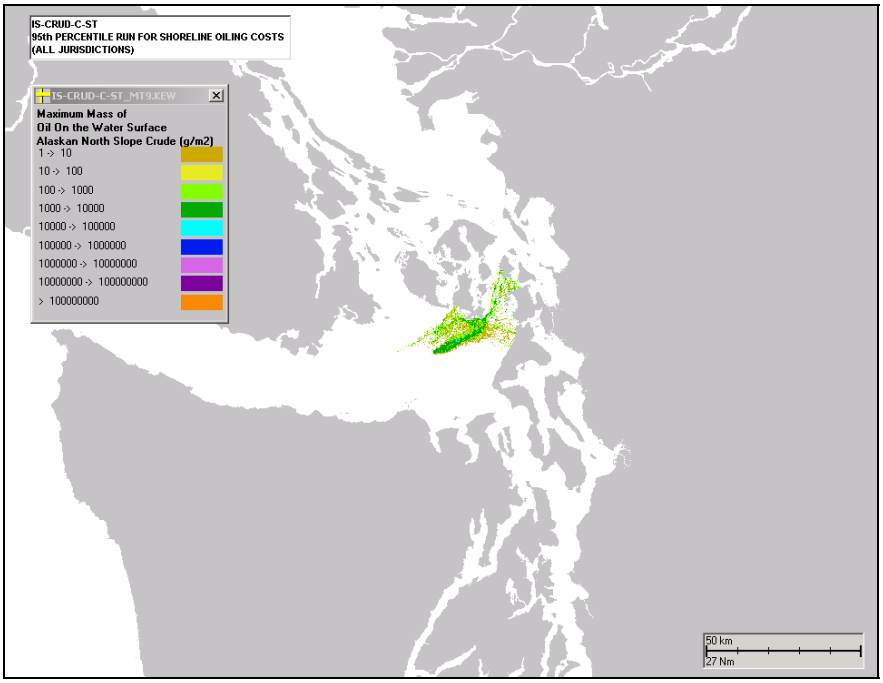


Figure XX.B.5-3. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

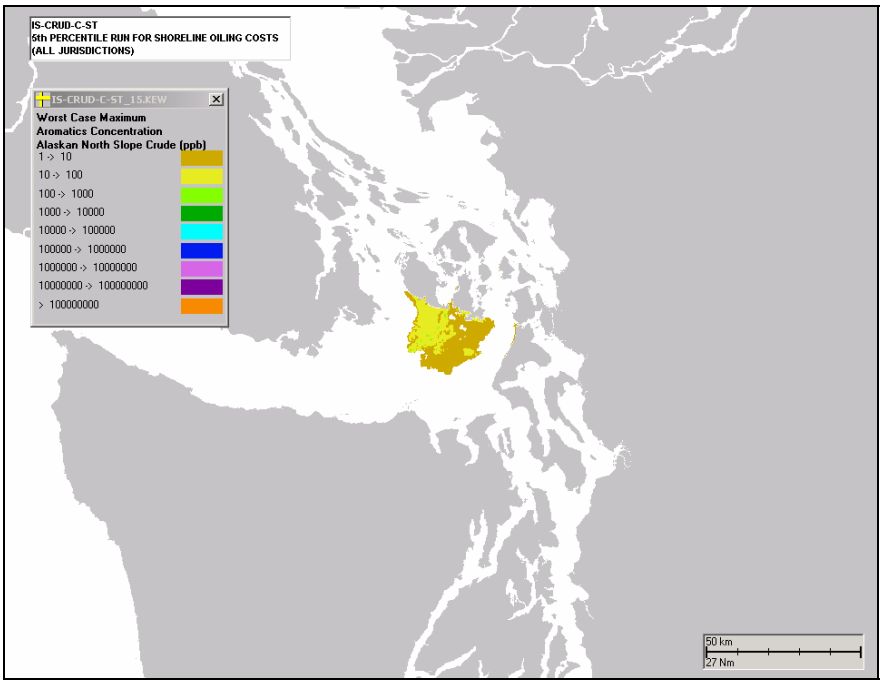


Figure XX.B.5-4. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

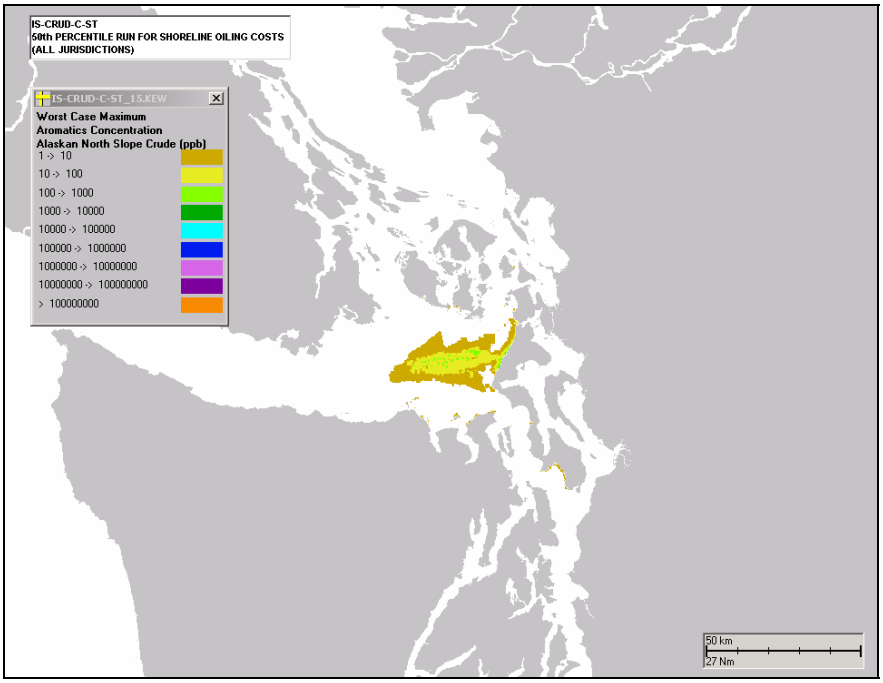


Figure XX.B.5-5. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

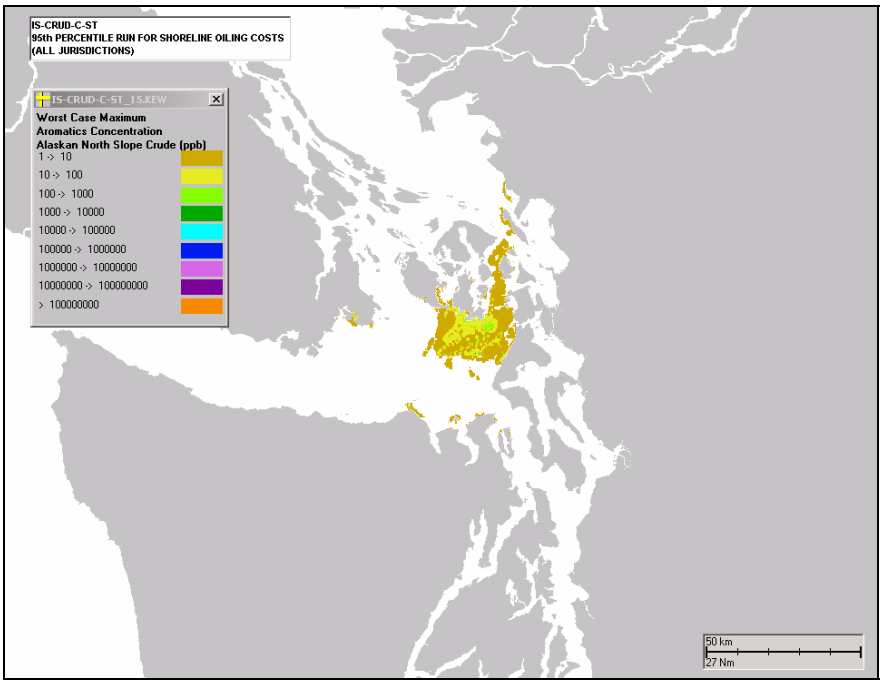


Figure XX.B.5-6. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XX.B.6. Federal Mechanical Removal and dispersant, Scenario IS-Crud-C-Fed

The response for this scenario includes the use of mechanical removal based on federal standards, dispersant and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case where no dispersant was applied.

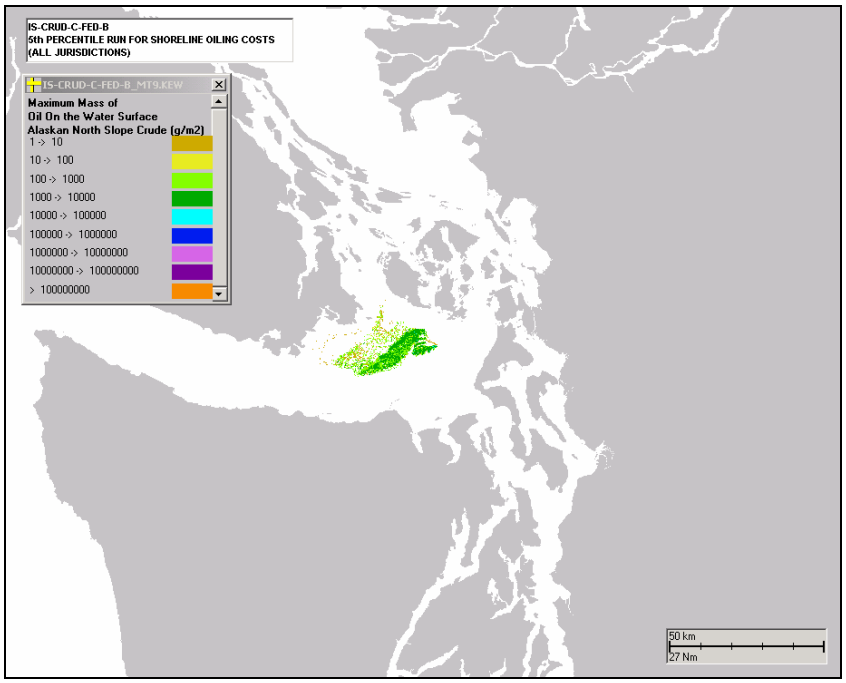


Figure XX.B.6-1. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

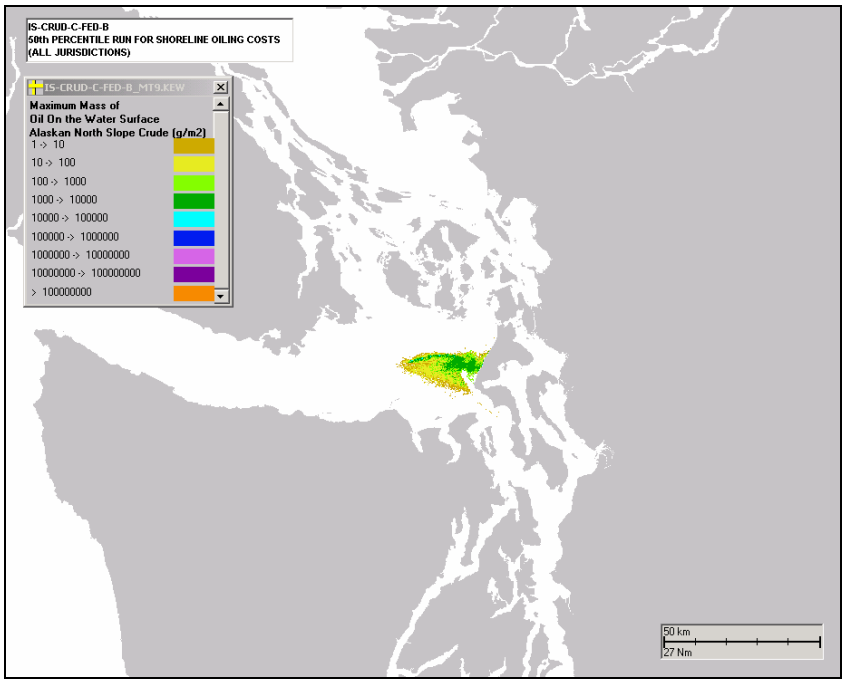


Figure XX.B.6-2. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

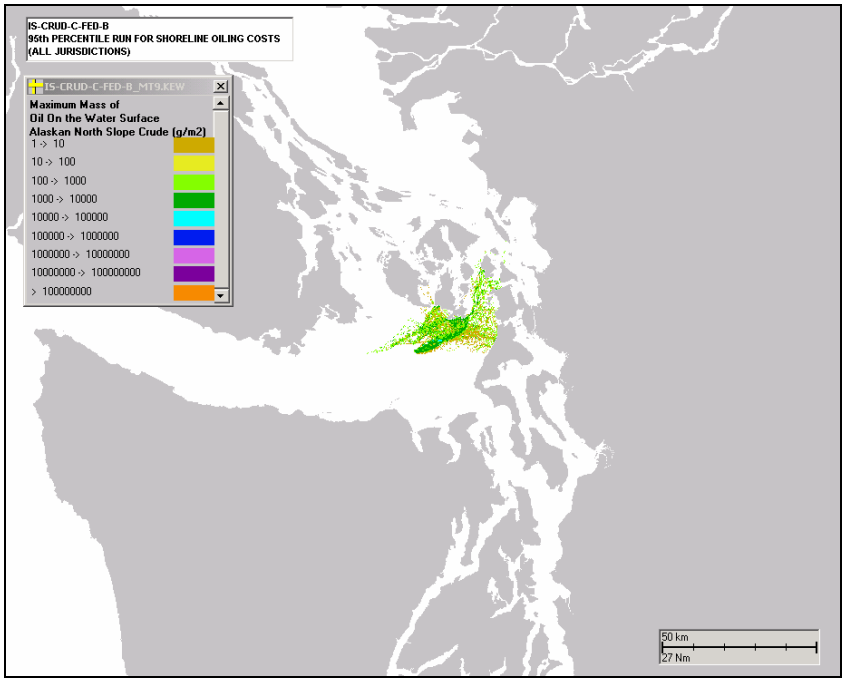


Figure XX.B.6-3. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

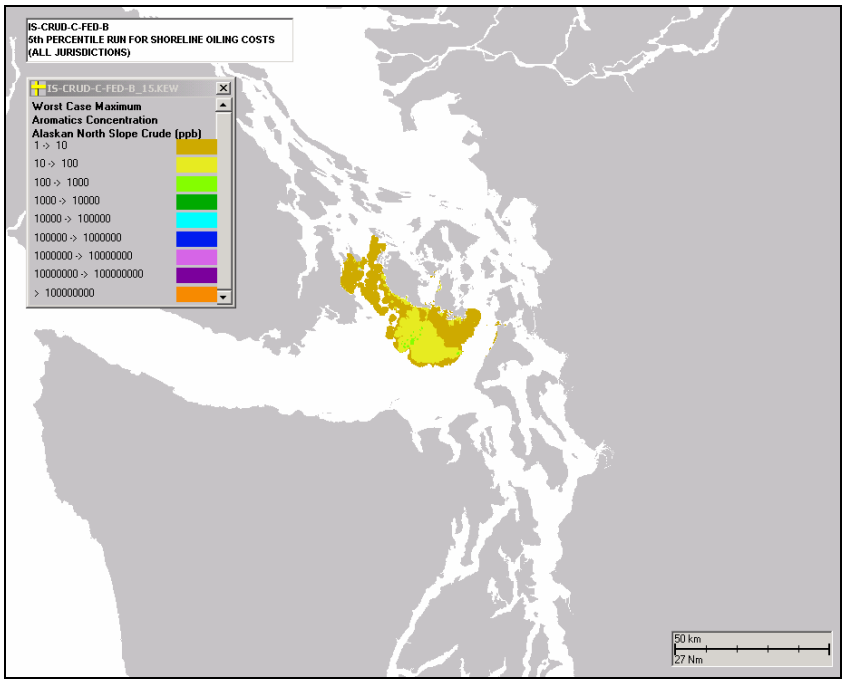


Figure XX.B.6-4. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

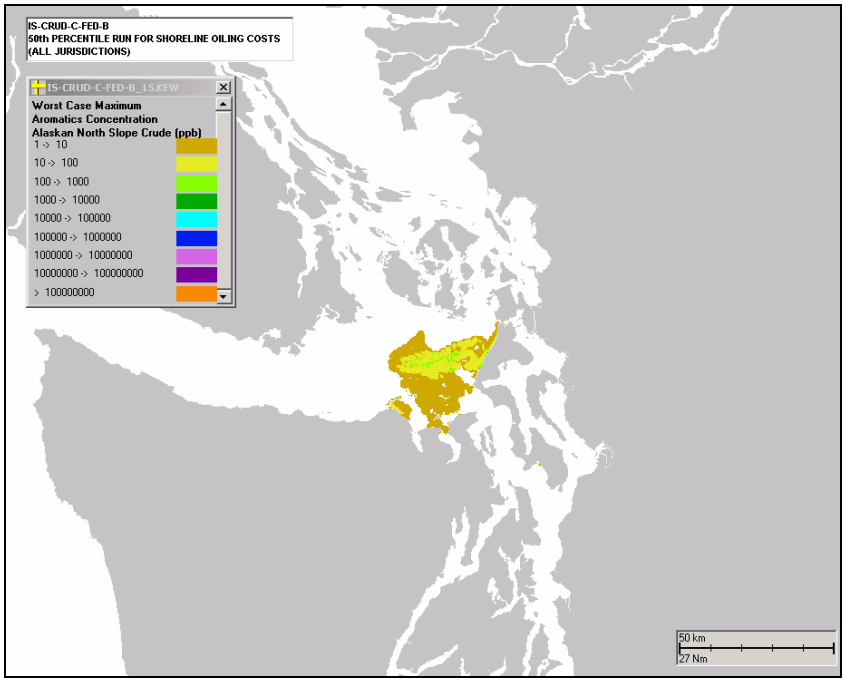


Figure XX.B.6-5. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

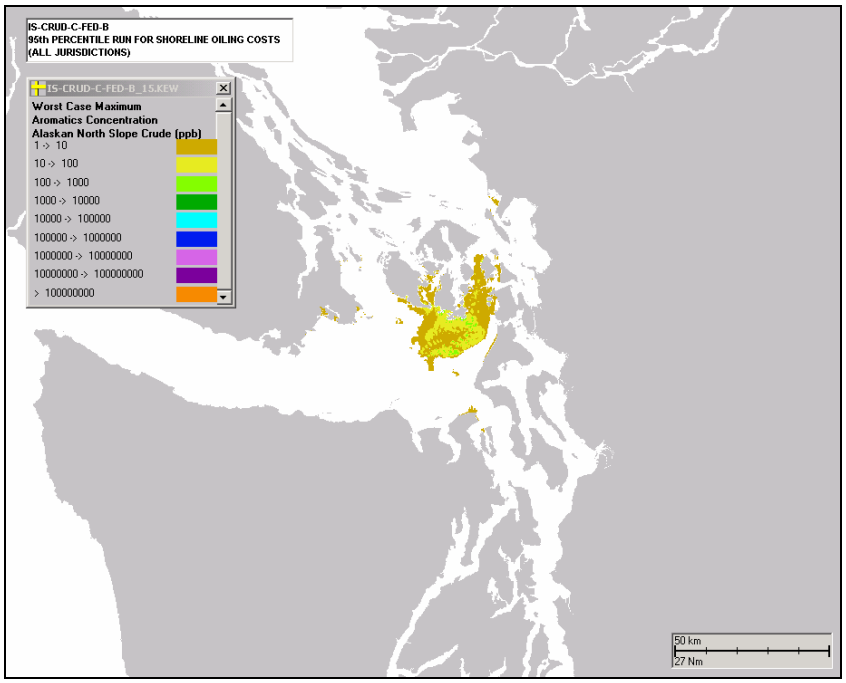


Figure XX.B.6-6. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XX.B.7. 3rd Alternative Mechanical Removal and dispersant, Scenario IS-Crud-C-3

The response for this scenario includes the use of mechanical removal based on the 3rd alternative standards, dispersant and protection booming using the three runs as identified as 5th, 50th and 95th percentile in the base case where no dispersant was applied.

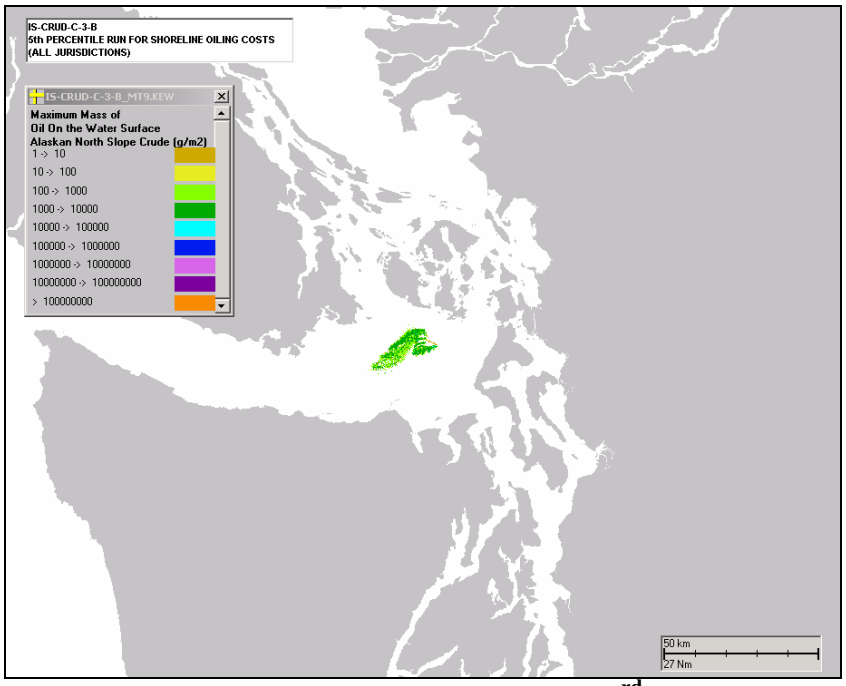


Figure XX.B.7-1. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

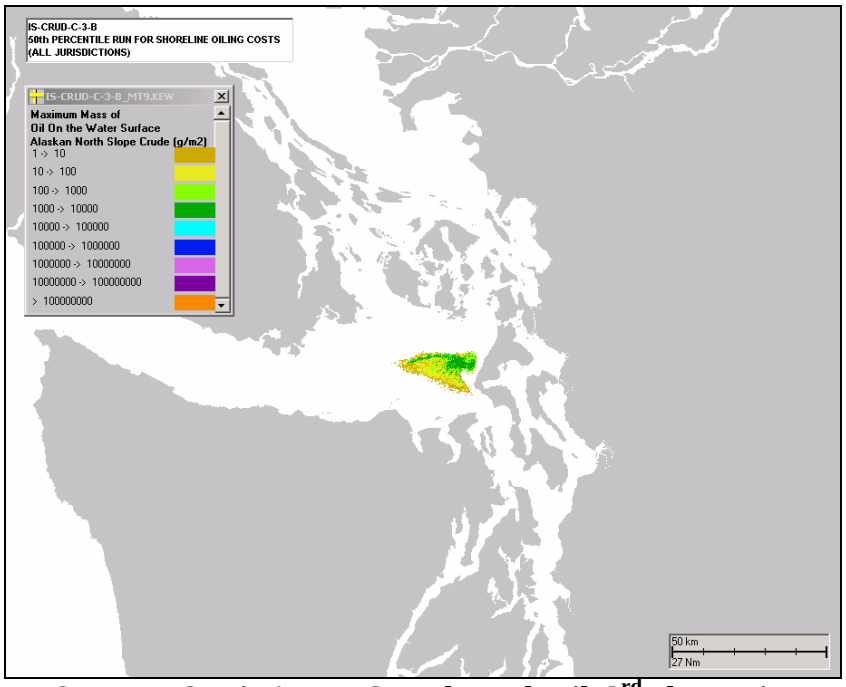


Figure XX.B.7-2. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

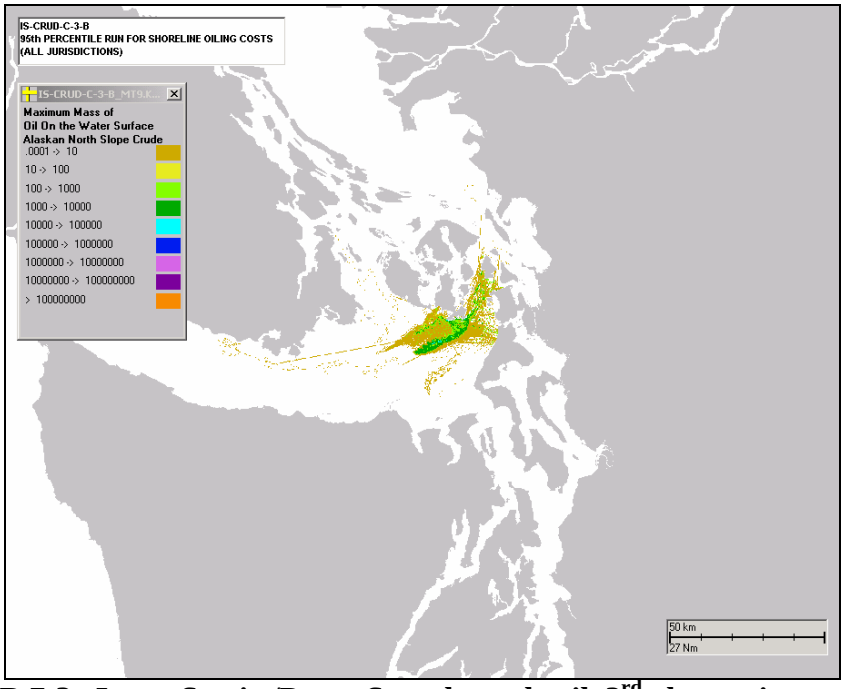


Figure XX.B.7-3. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

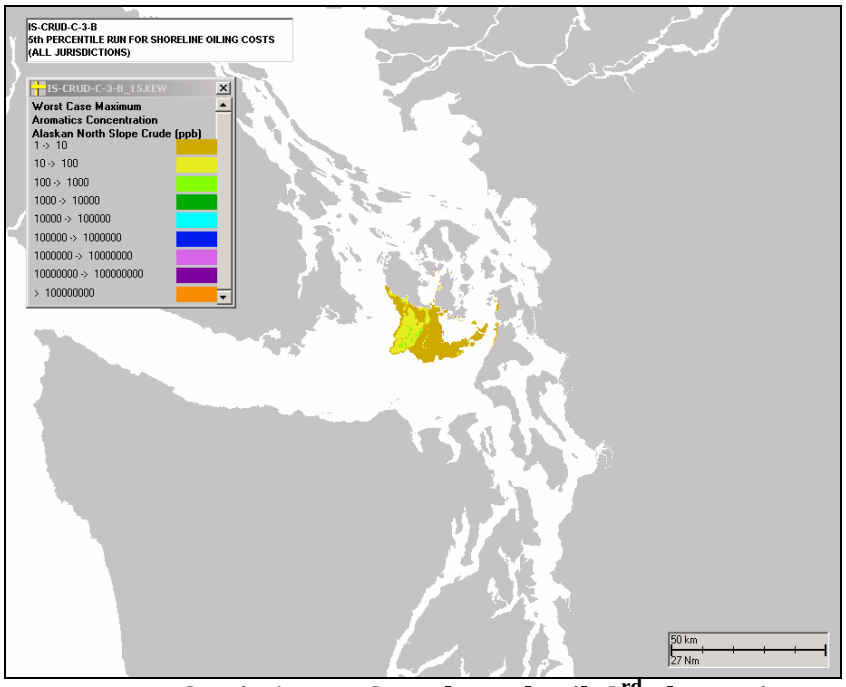


Figure XX.B.7-4. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

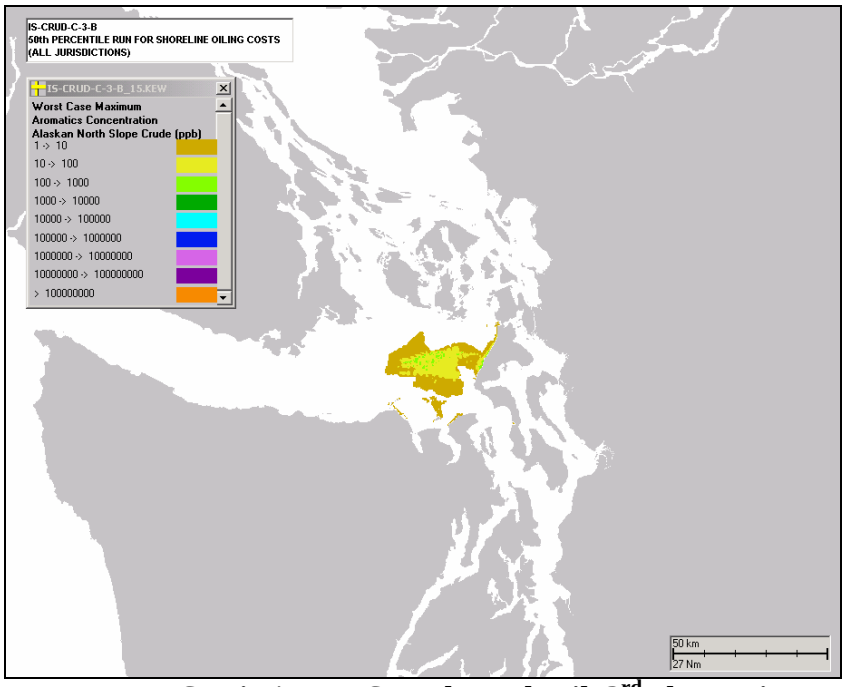


Figure XX.B.7-5. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

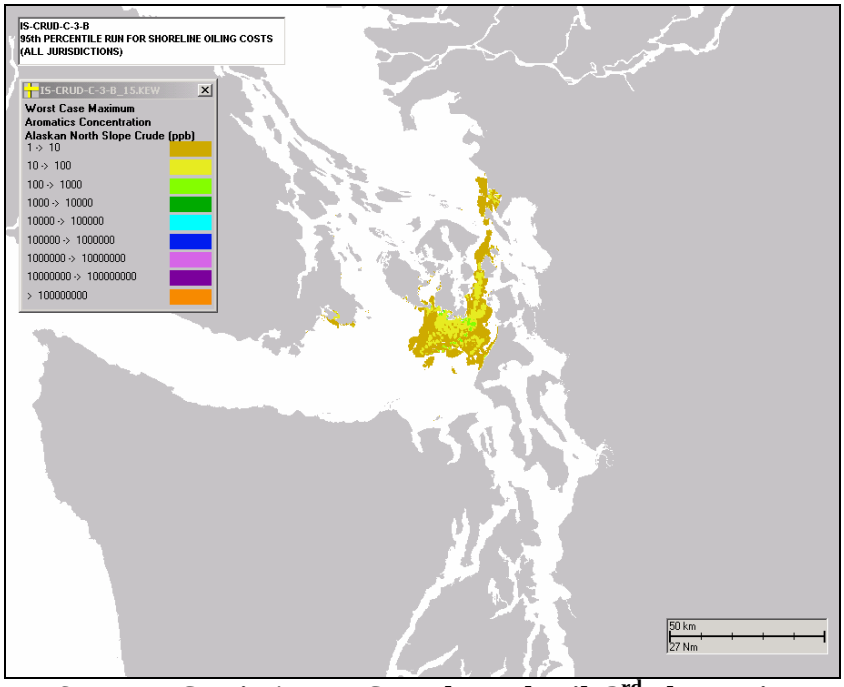


Figure XX.B.7-6. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XX.B.8. Oil Fate Over Time

The figures in this section summarize the fate of the oil over time for alternate response scenarios of the 5th, 50th and 95th percentile runs. Figures XX.B.8-1 to XX.B.8-21 list the mass balance of oil as a function of time. The oil on the water surface is floating oil (thick, sheen or tar balls) within the model grid. Oil in the water column is either entrained oil droplets or dissolved. The percent removed is by mechanical removal during the response to the spill. Figures XX.B.8-22 to XX.B.8-39 summarize the results, showing comparisons of the alternative responses for each of the individual runs.

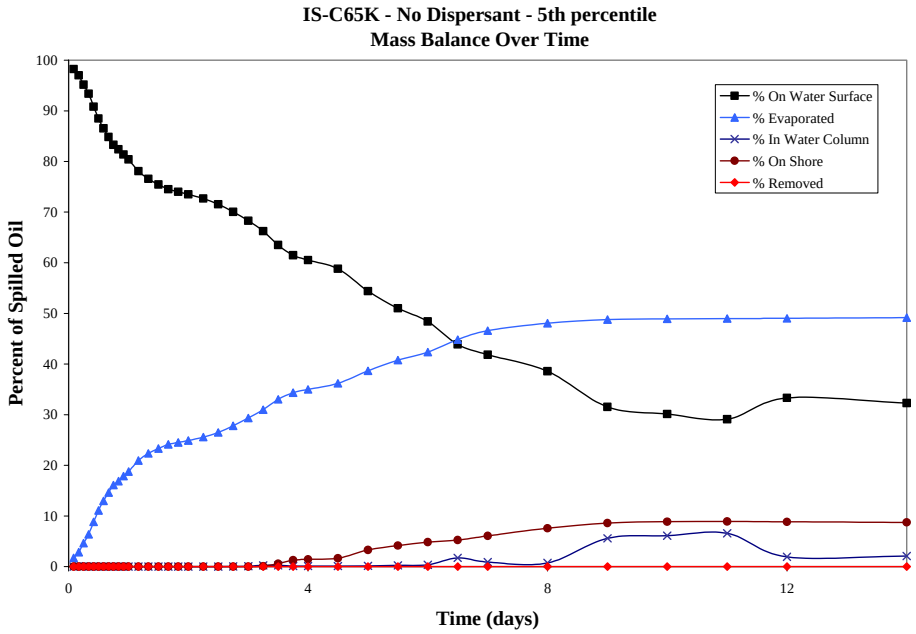


Figure XX.B.8-1 Inner Straits/Puget Sound - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

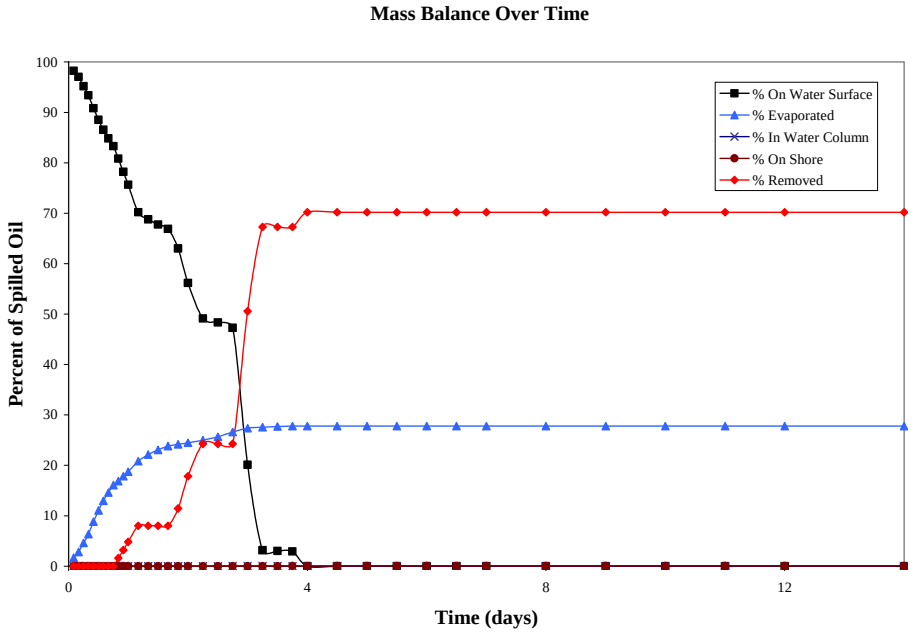


Figure XX.B.8-2 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

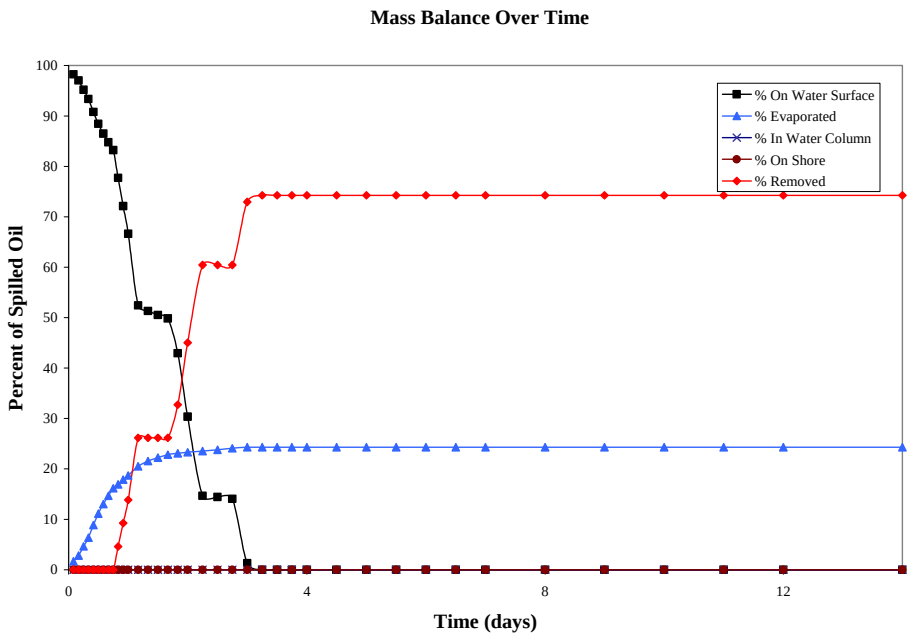


Figure XX.B.8-3 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

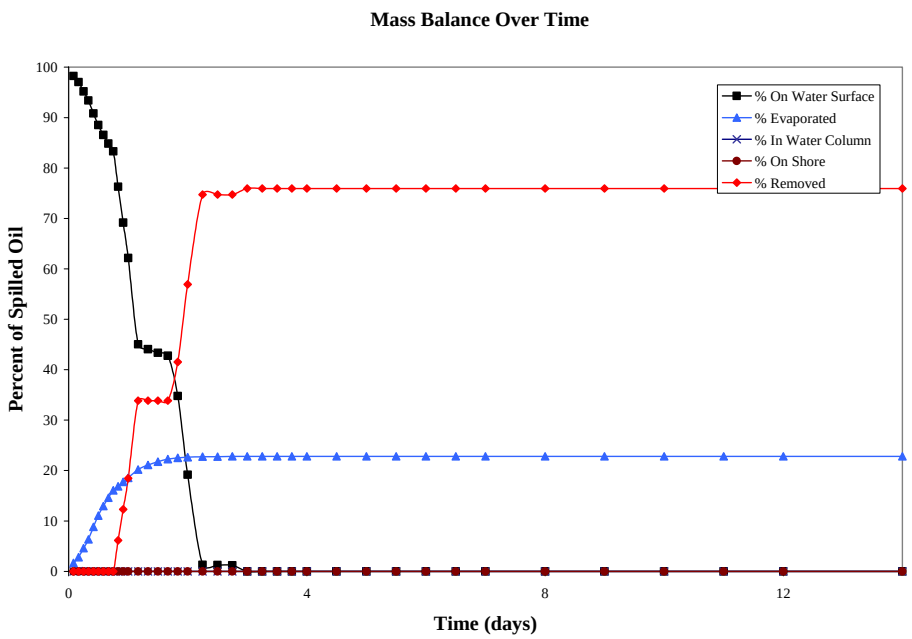


Figure XX.B.8-4 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

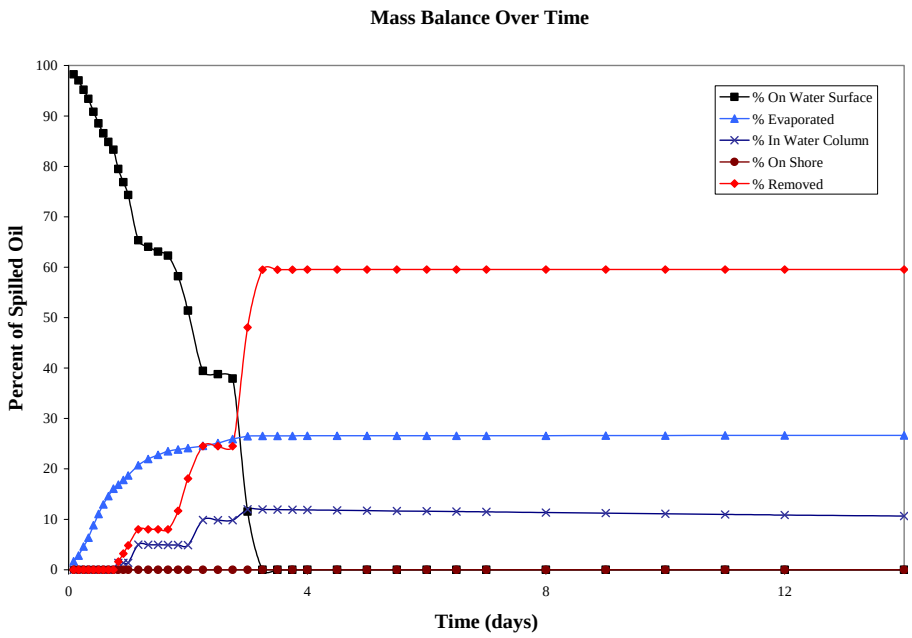


Figure XX.B.8-5 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

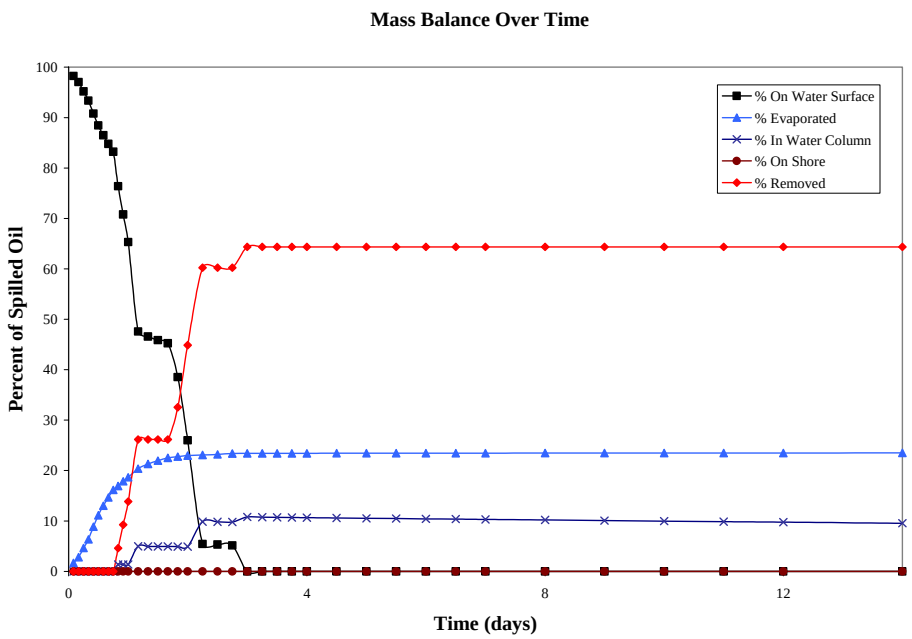


Figure XX.B.8-6 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

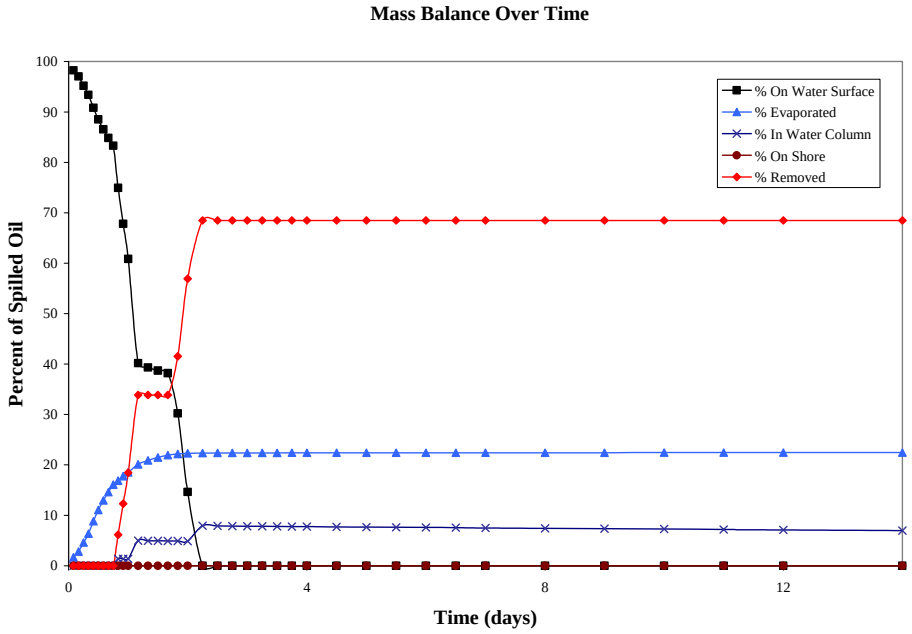


Figure XX.B.8-7 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

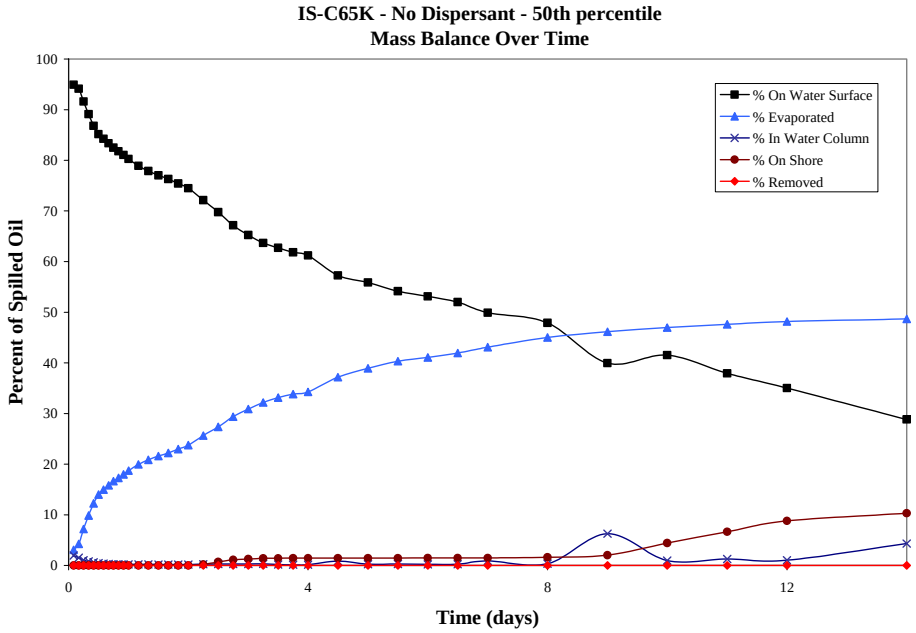


Figure XX.B.8-8 Inner Straits/Puget Sound - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

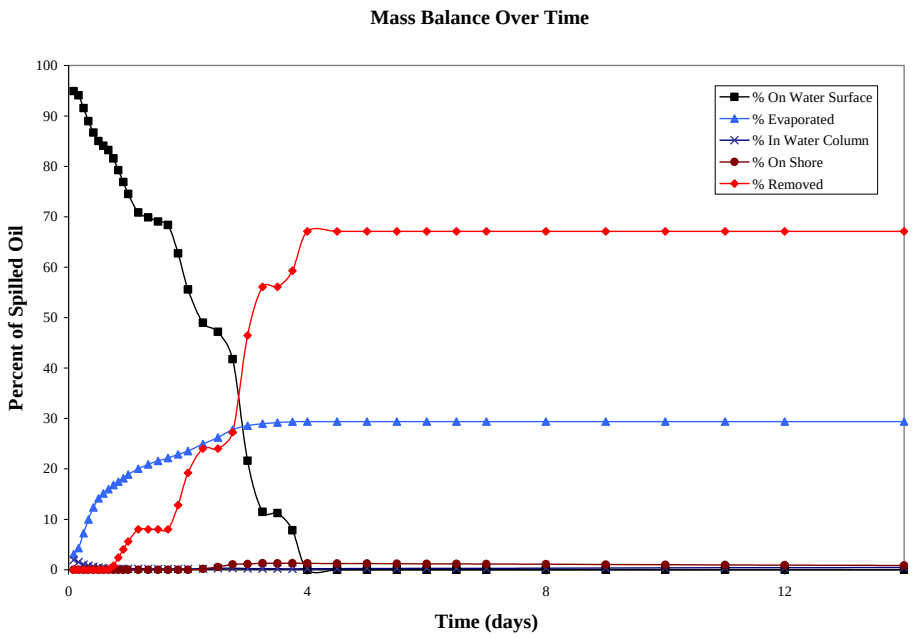


Figure XX.B.8-9 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

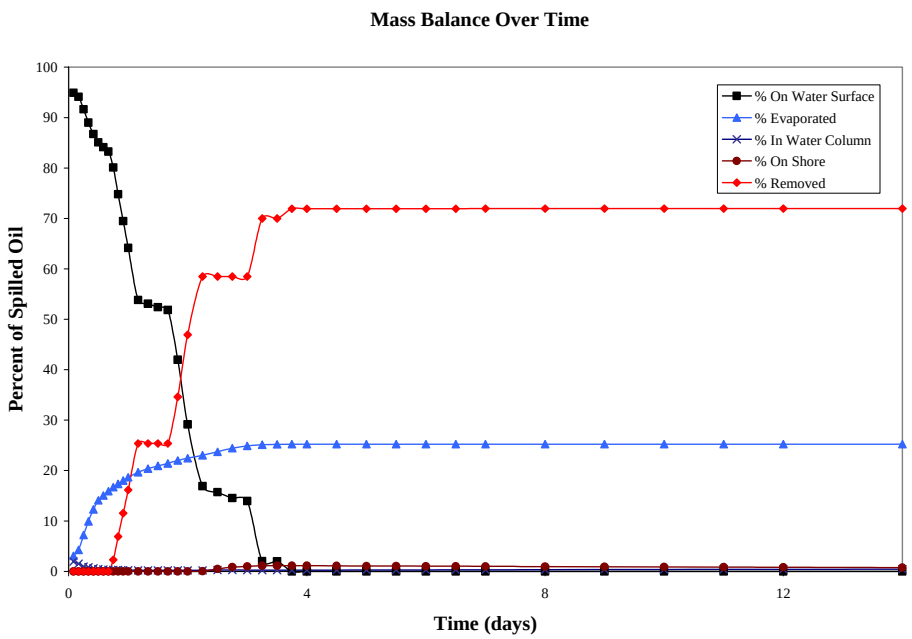


Figure XX.B.8-10 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

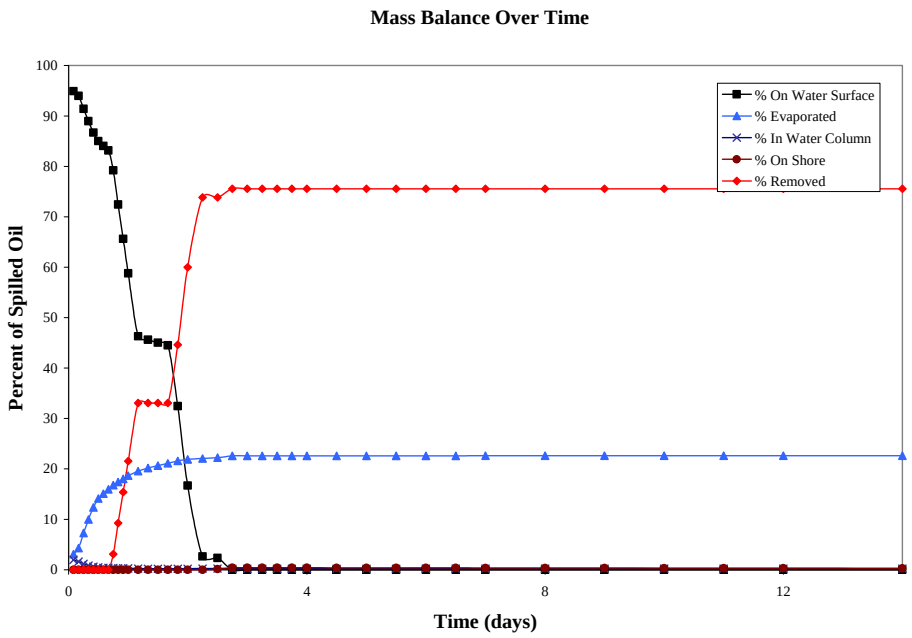


Figure XX.B.8-11 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

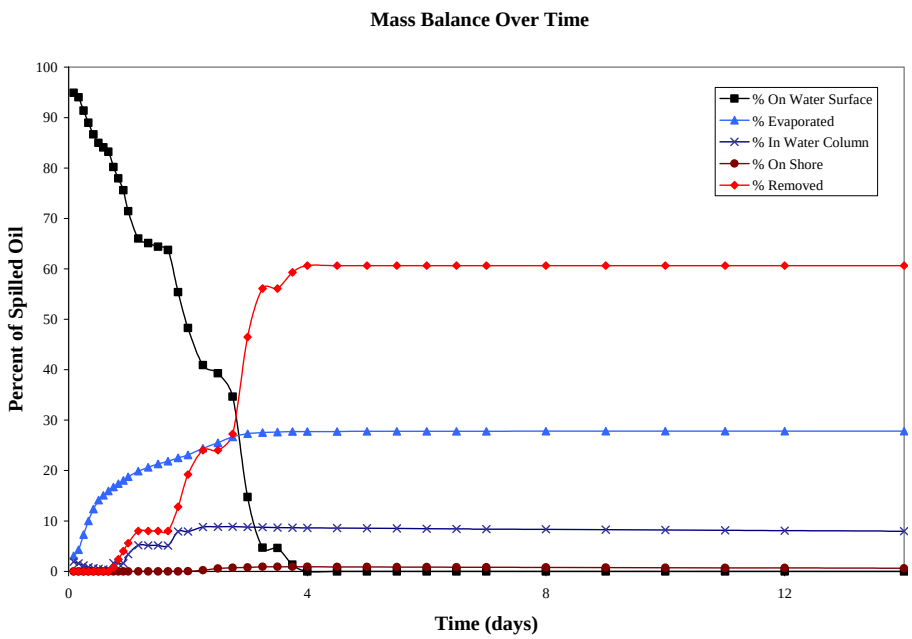


Figure XX.B.8-12 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

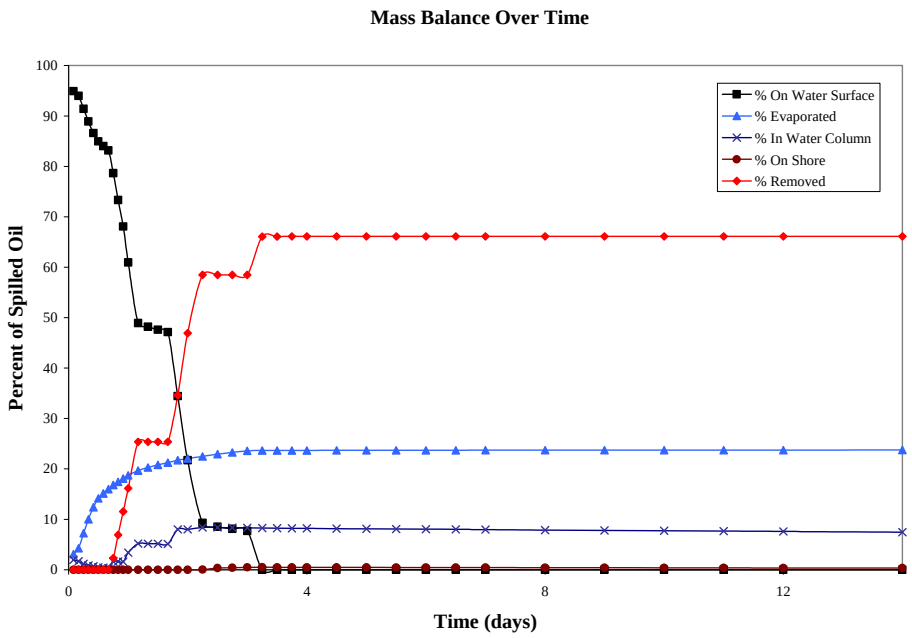


Figure XX.B.8-13 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

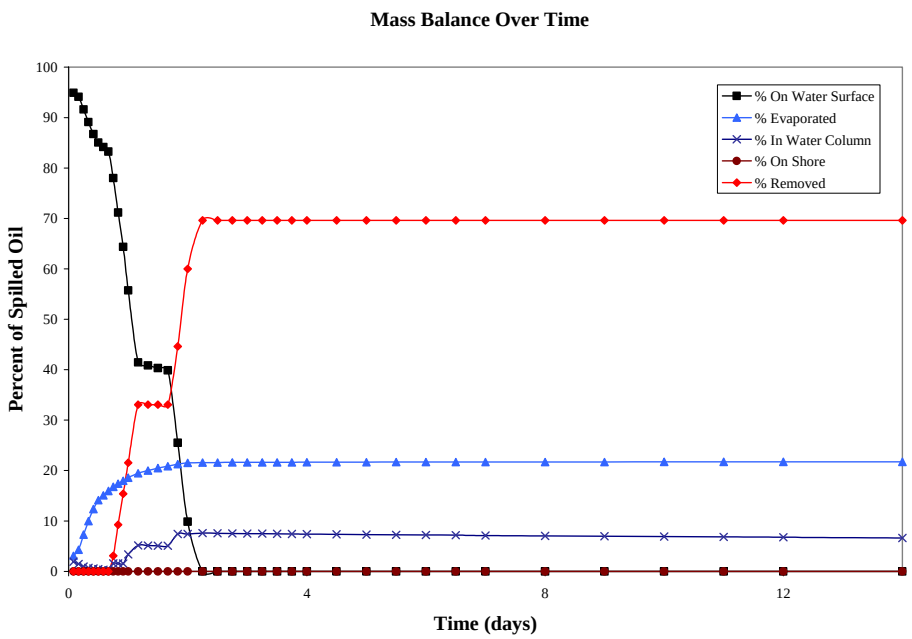


Figure XX.B.8-14 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

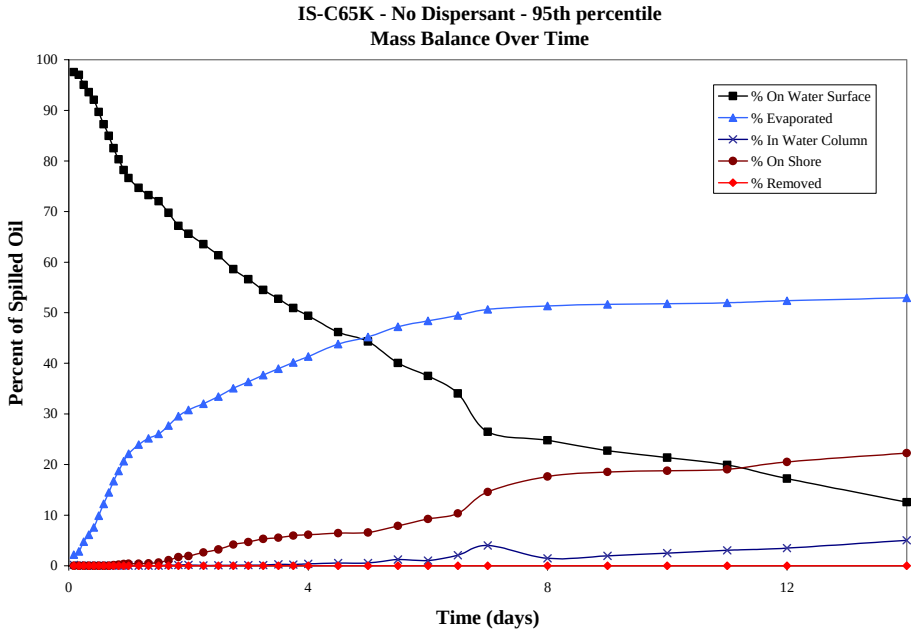


Figure XX.B.8-15 Inner Straits/Puget Sound - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

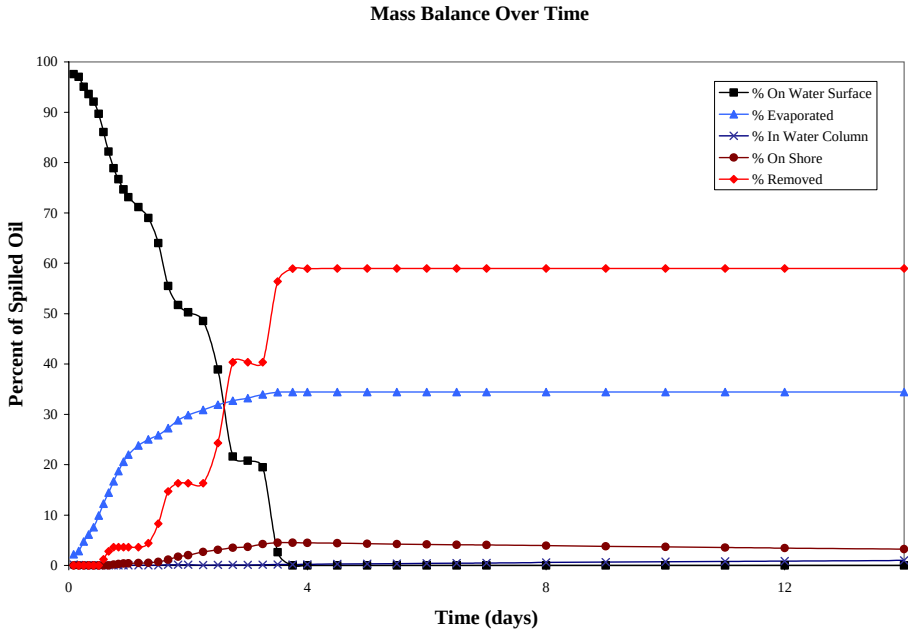


Figure XX.B.8-16 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

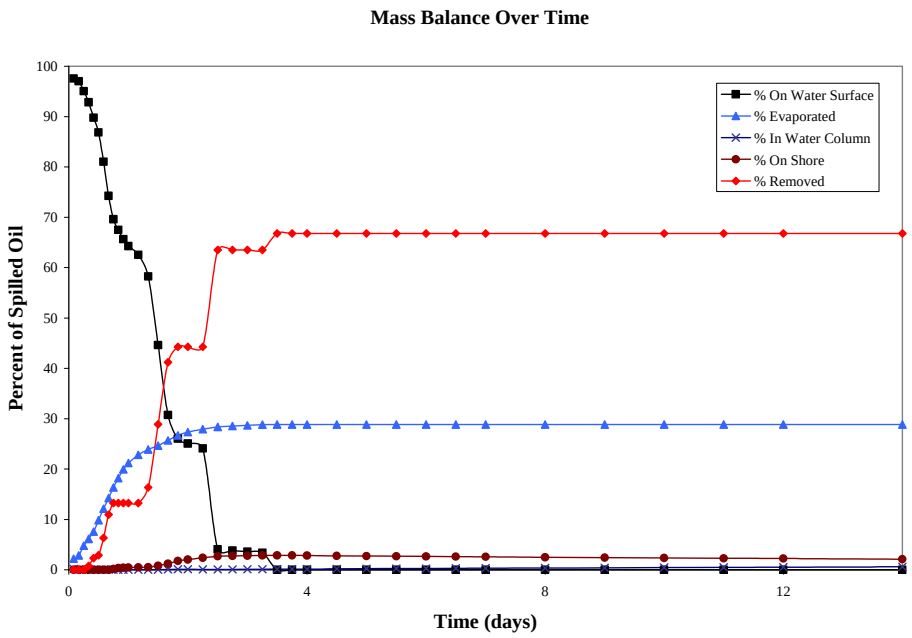


Figure XX.B.8-17 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

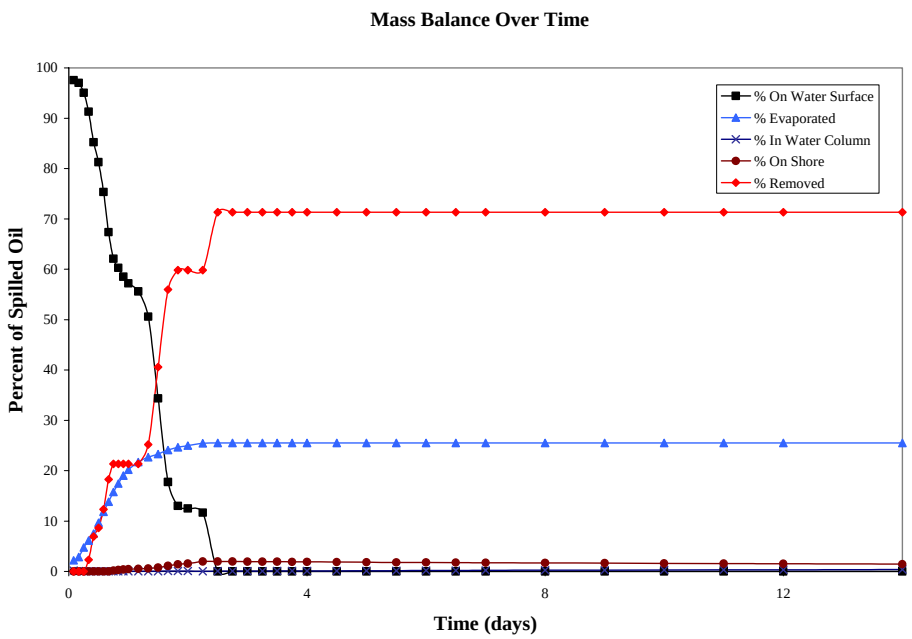


Figure XX.B.8-18 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

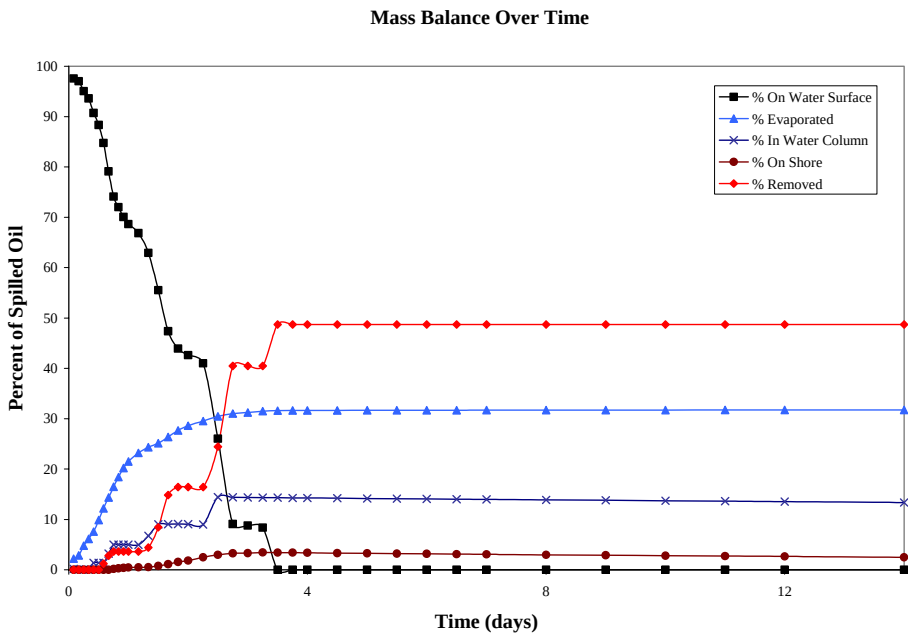


Figure XX.B.8-19 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

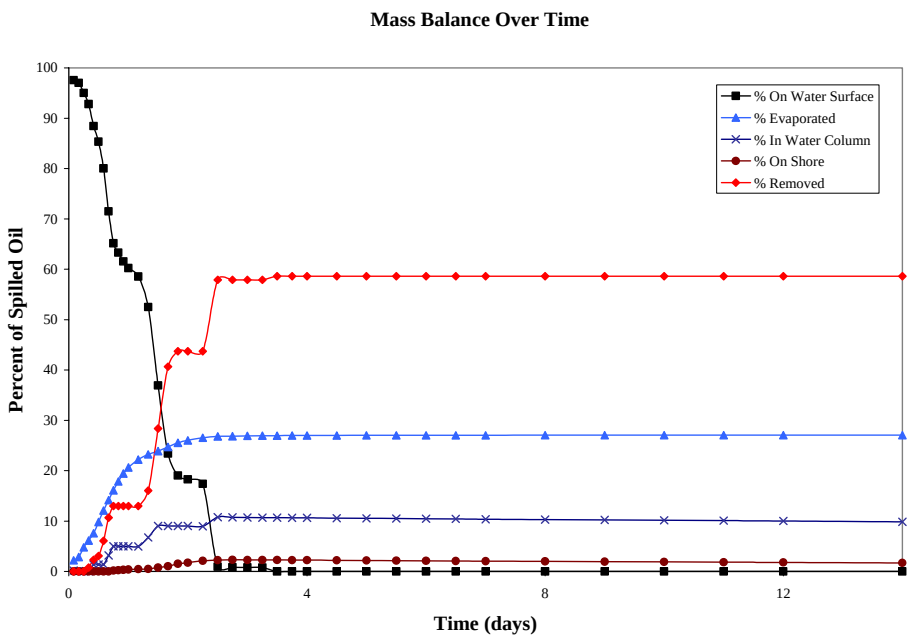


Figure XX.B.8-20 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

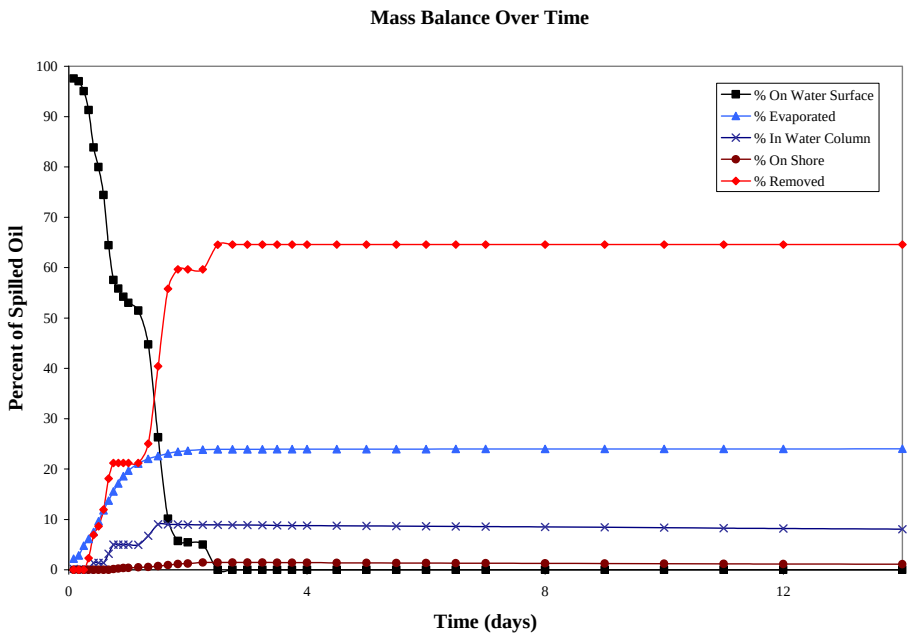
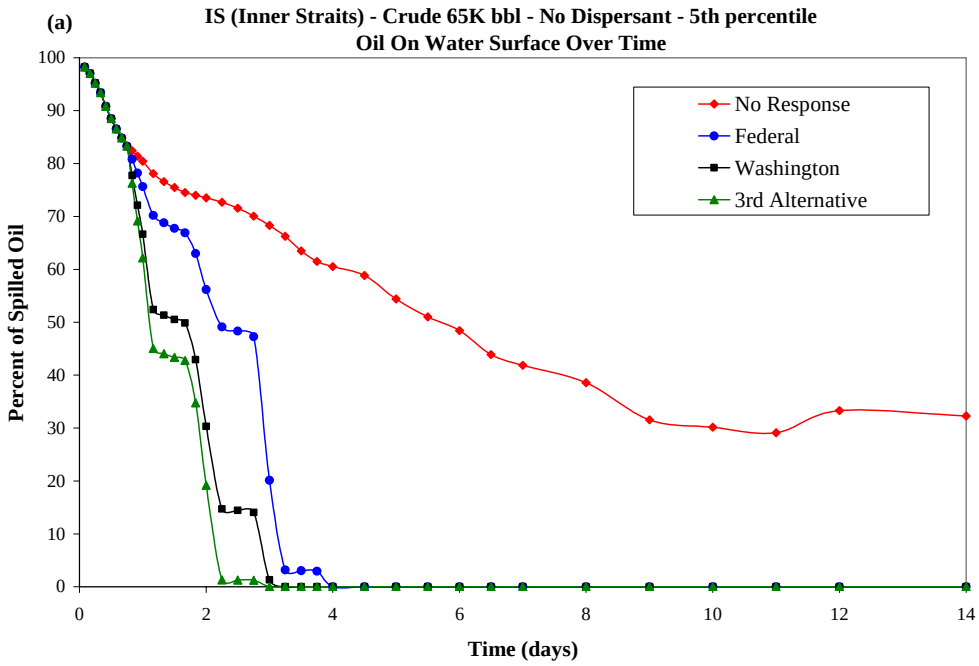


Figure XX.B.8-21 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).



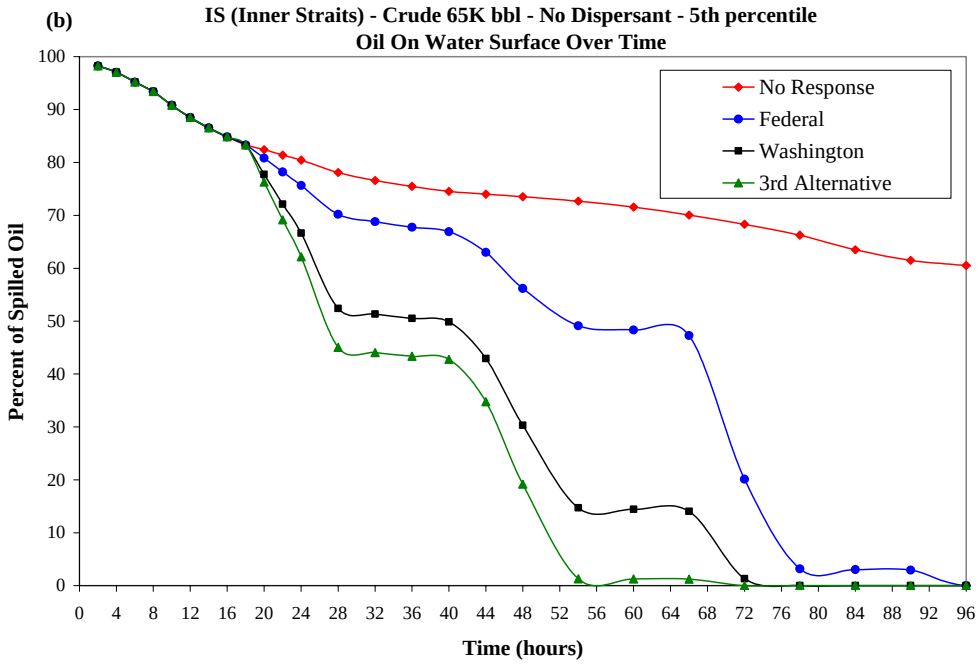
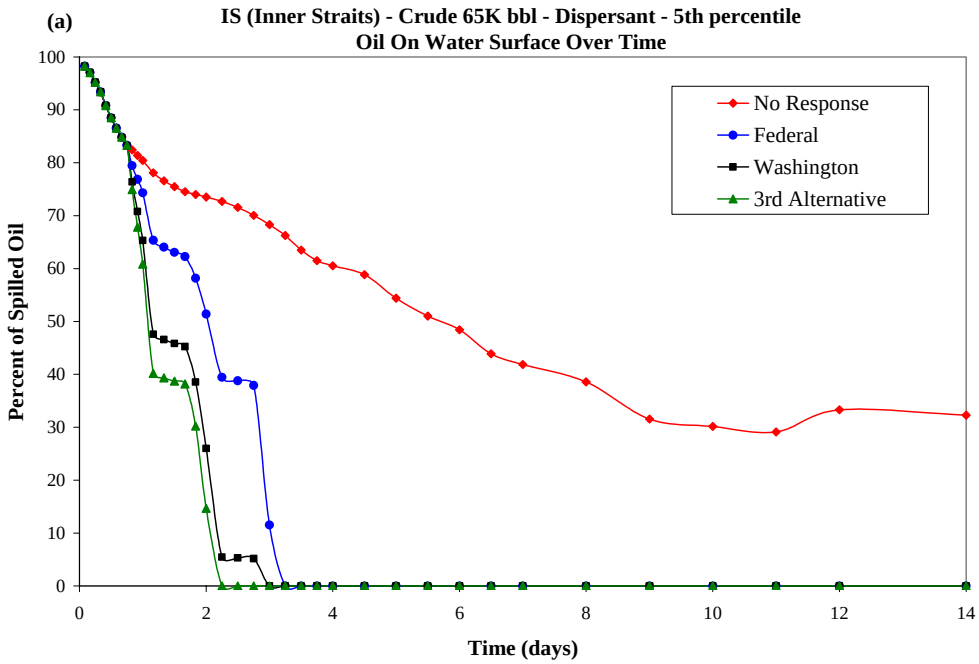


Figure XX.B.8-22 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



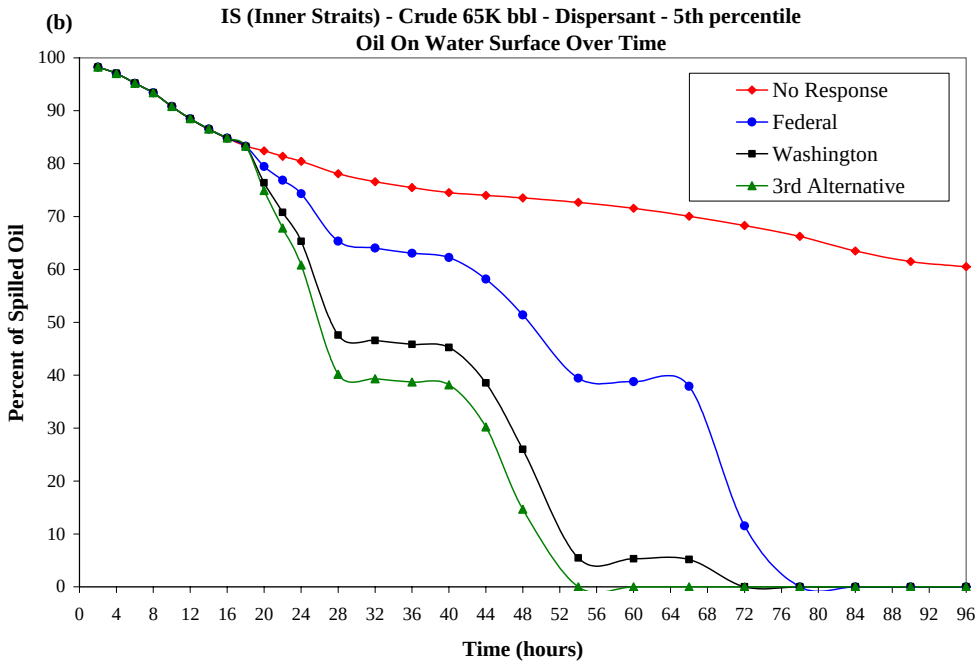
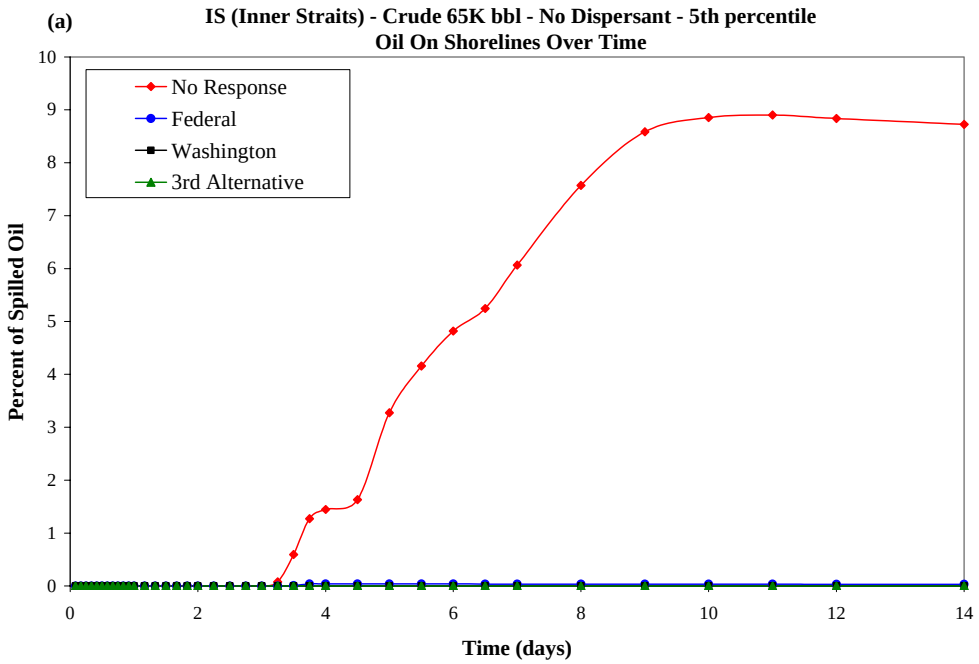


Figure XX.B.8-23 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



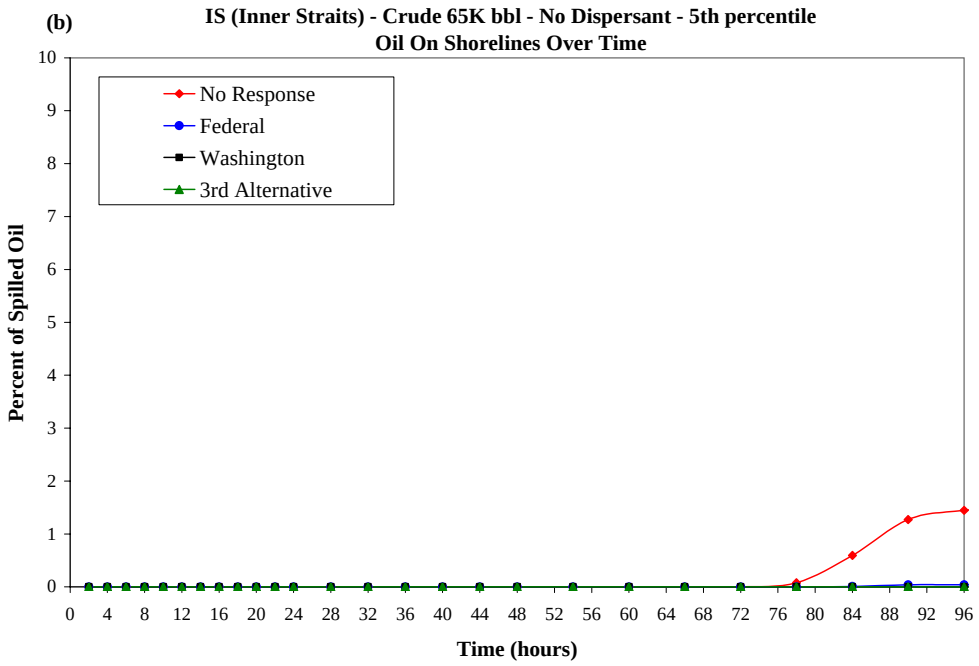
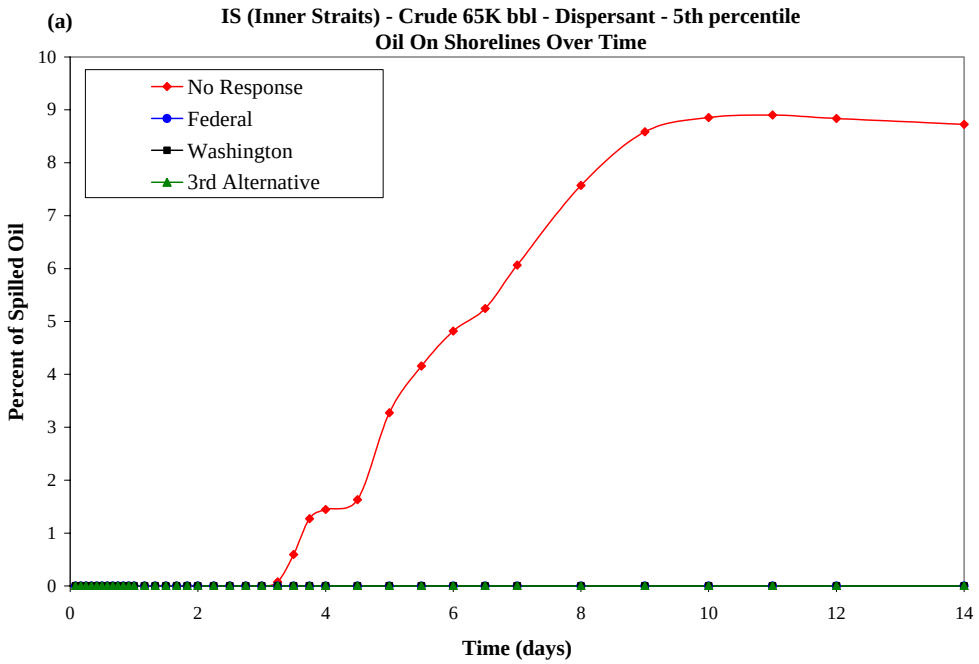


Figure XX.B.8-24 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



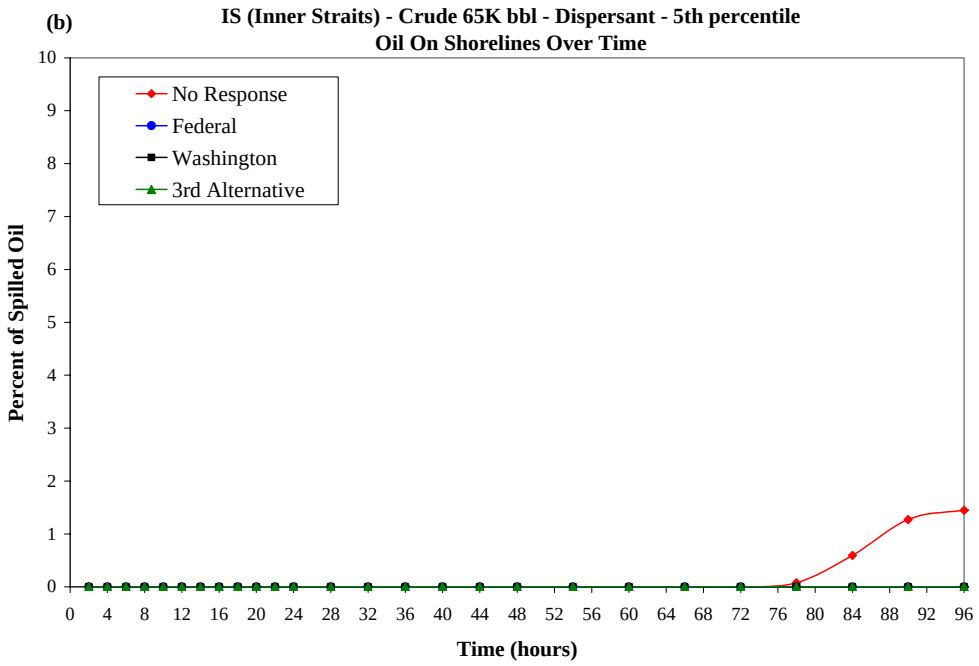
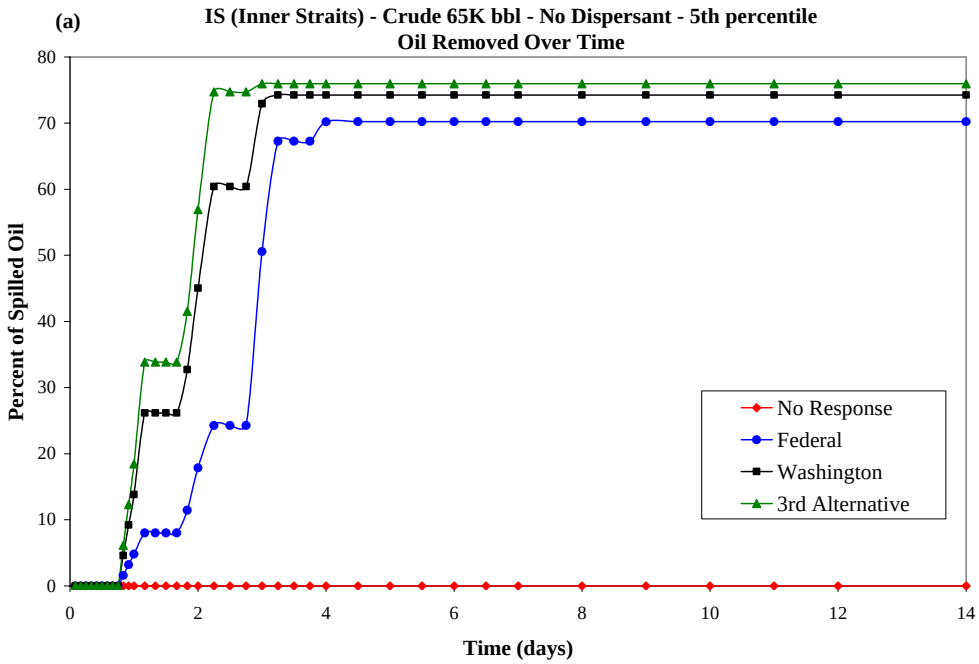


Figure XX.B.8-25 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



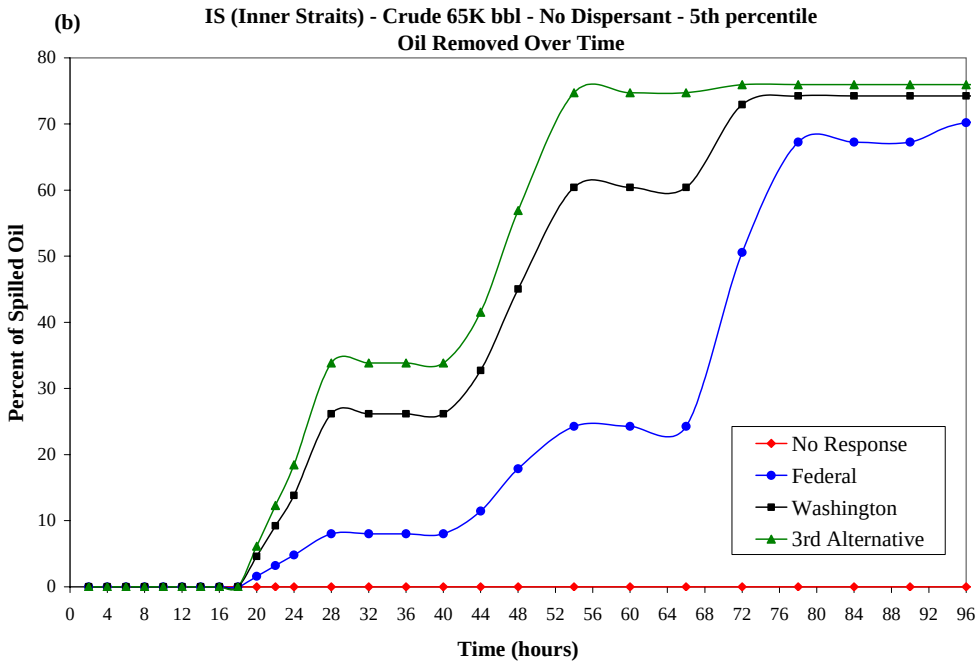
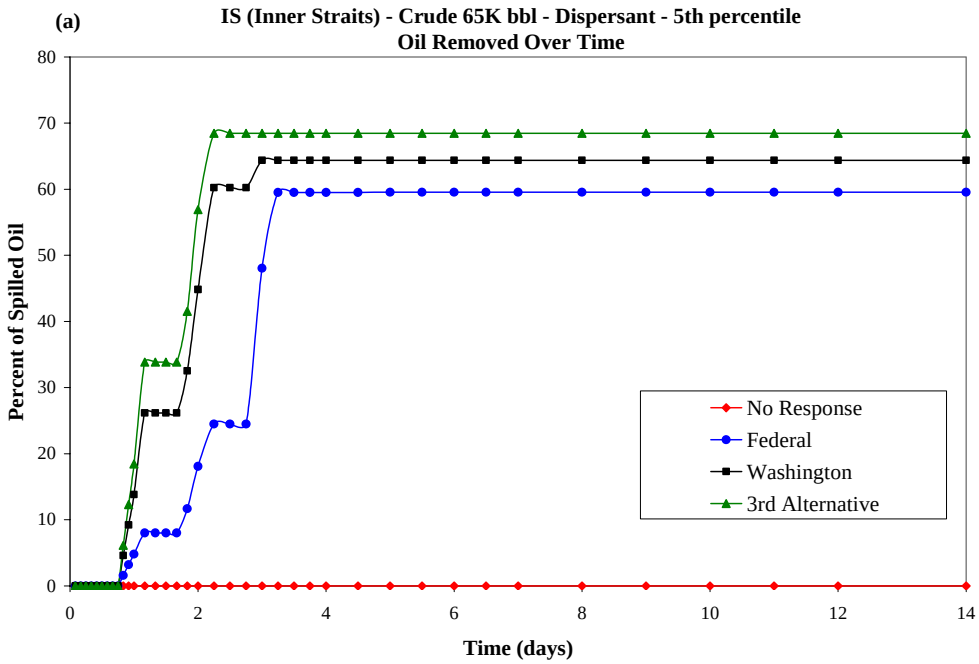


Figure XX.B.8-26 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



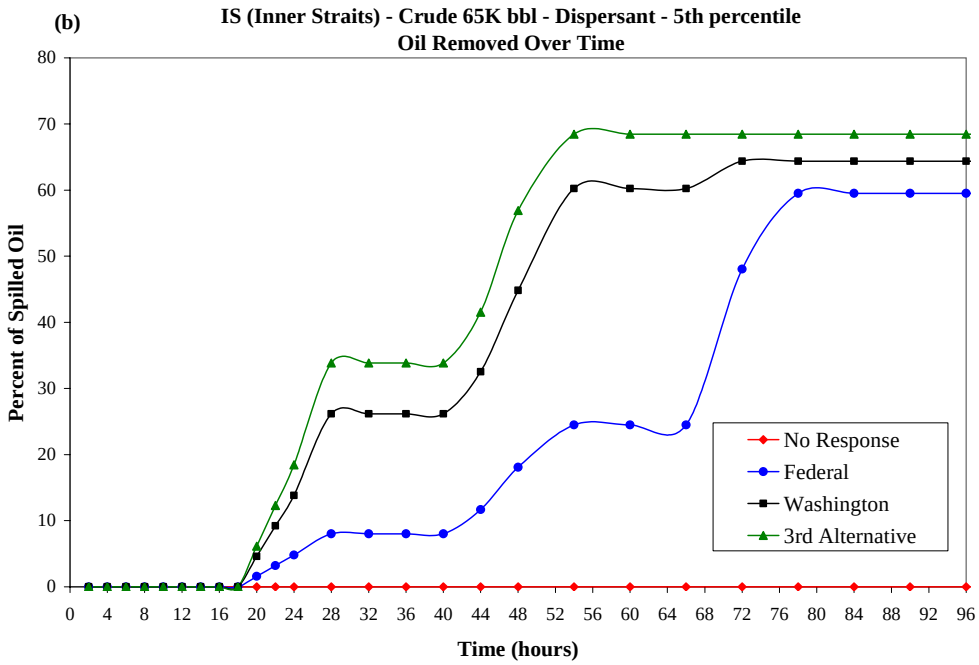
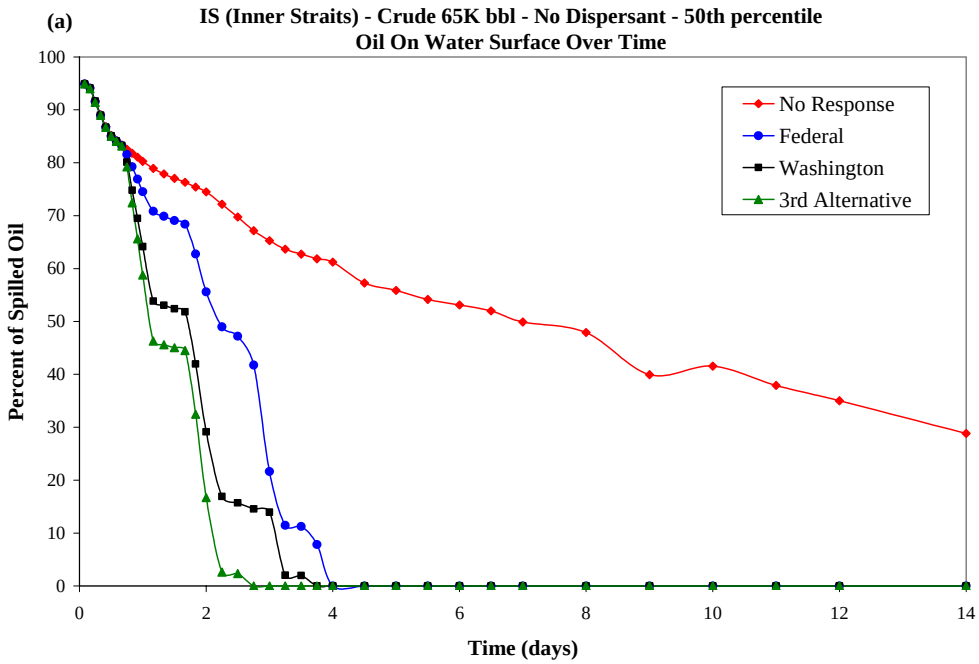


Figure XX.B.8-27 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



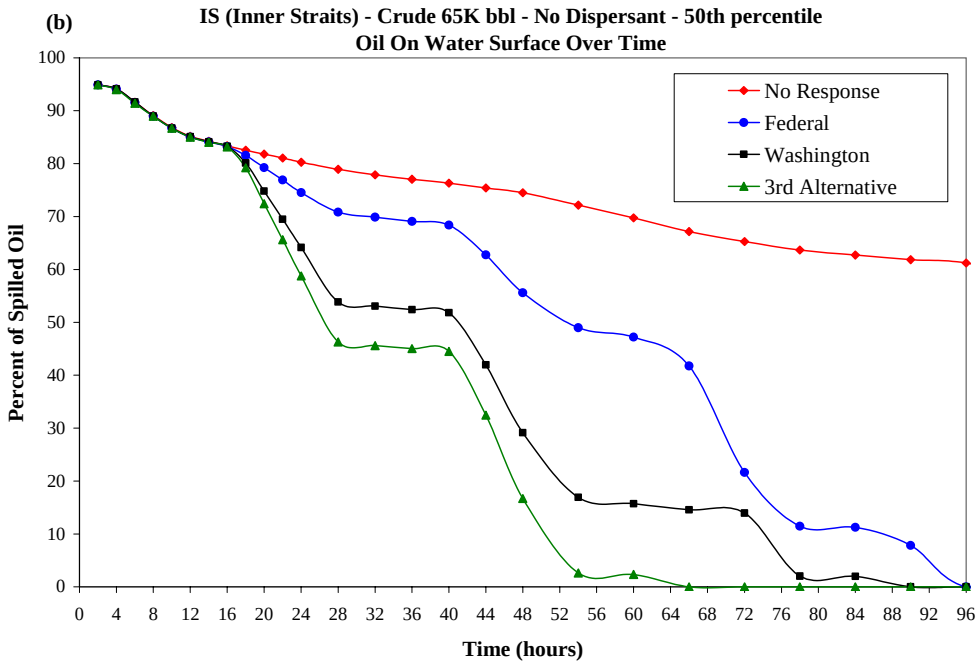
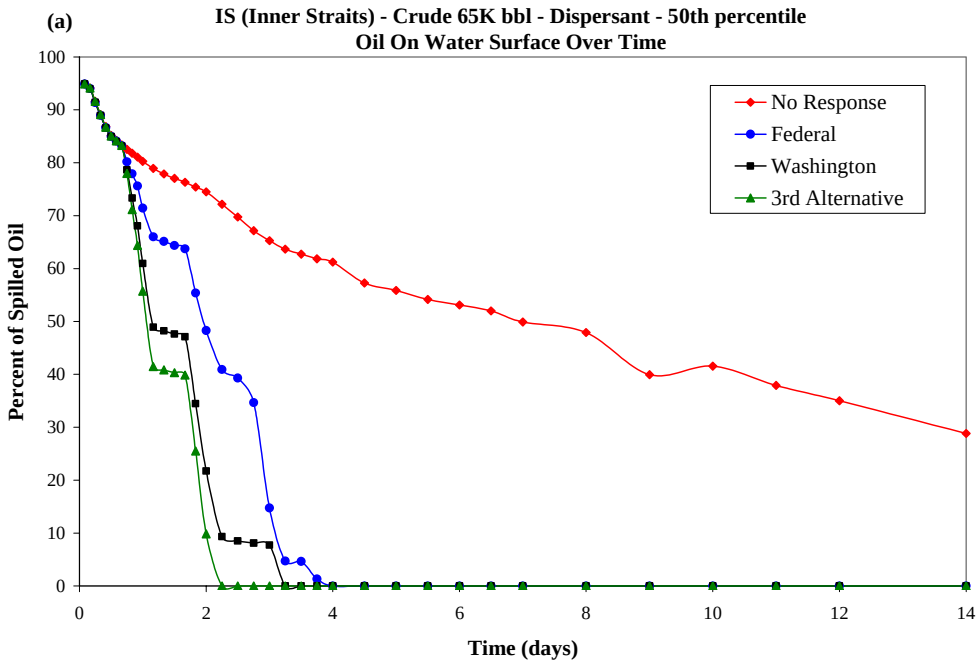


Figure XX.B.8-28 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



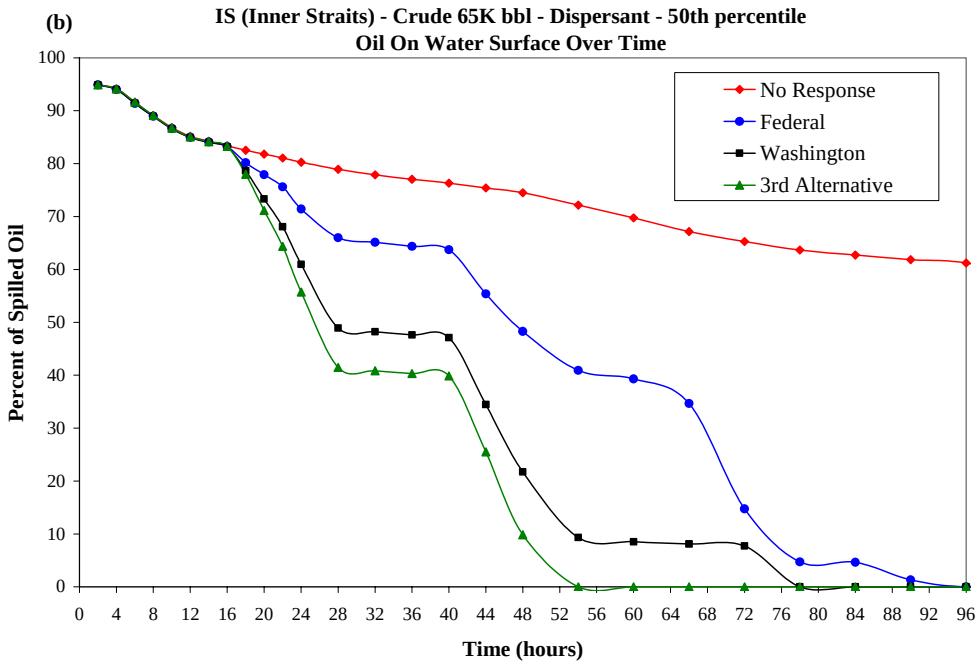
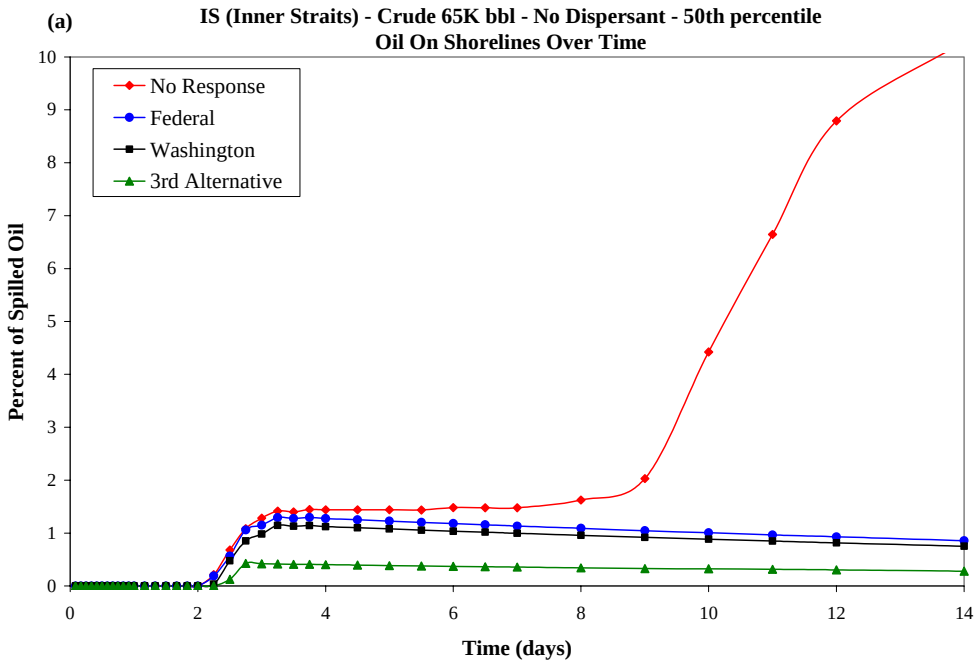


Figure XX.B.8-29 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



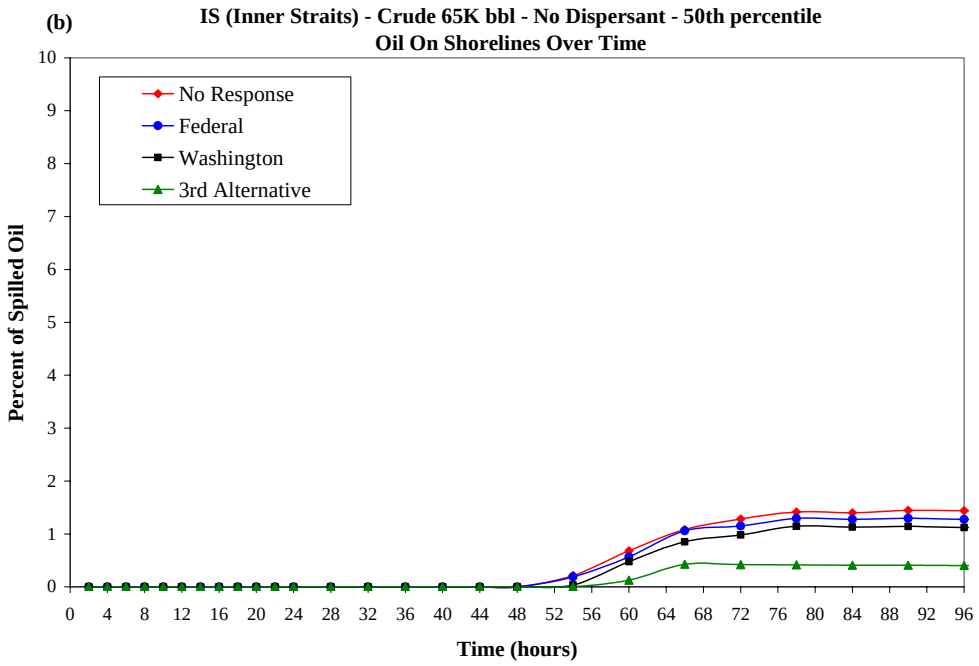
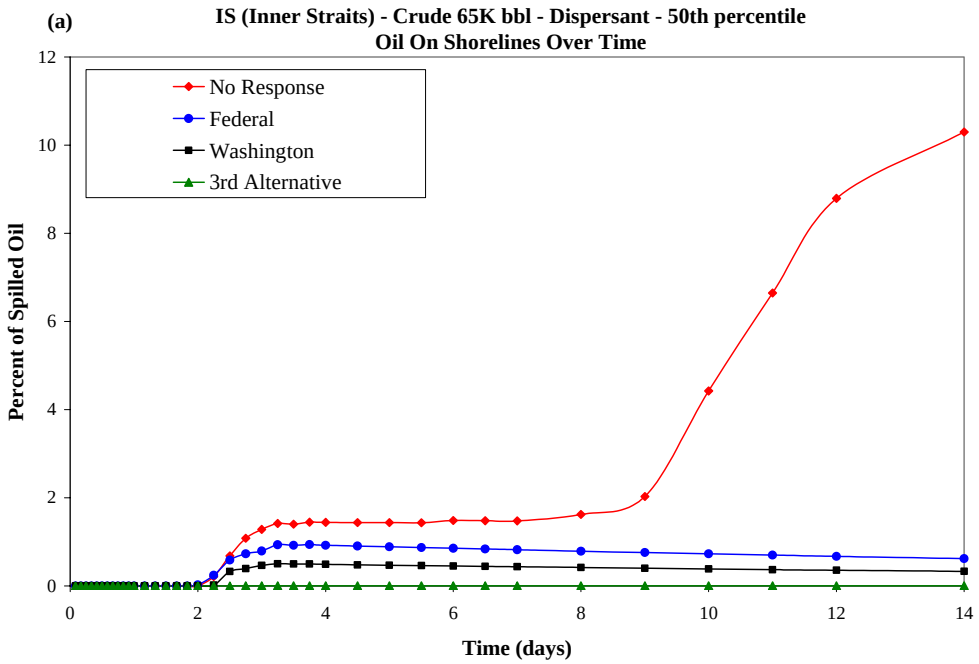


Figure XX.B.8-30 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



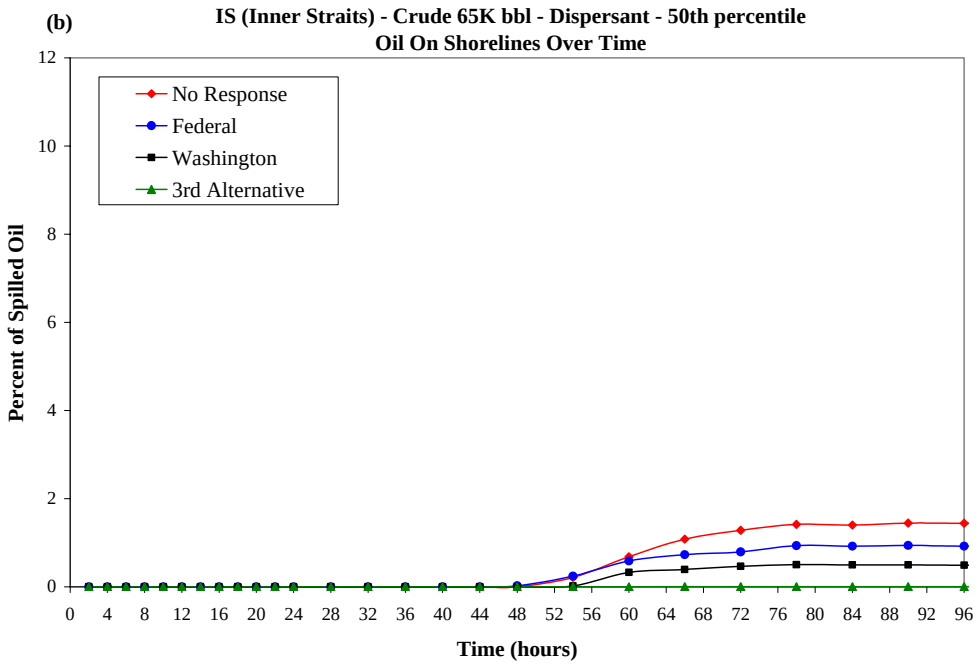
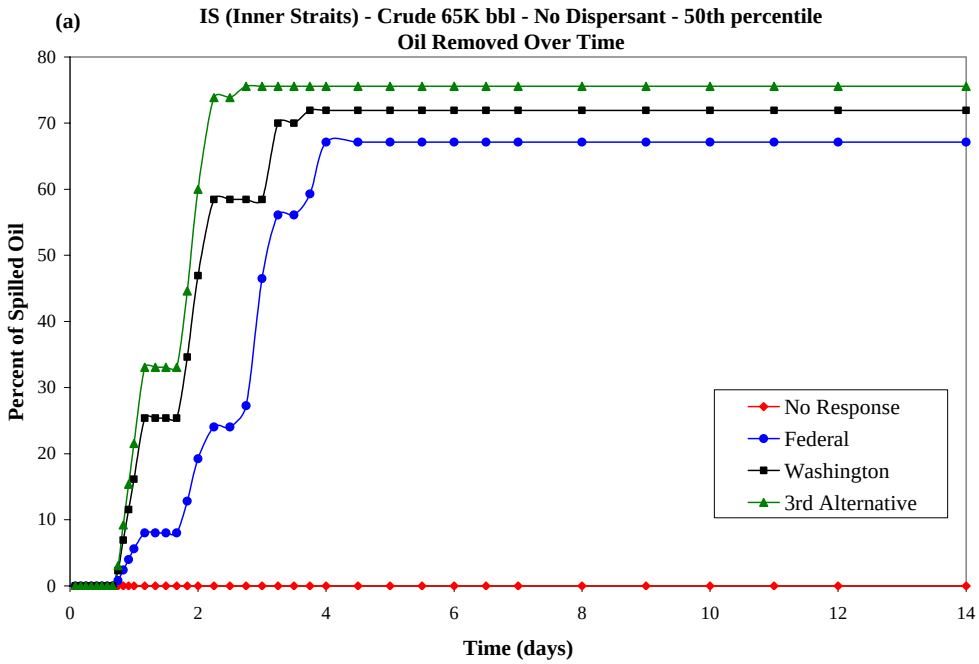


Figure XX.B.8-31 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



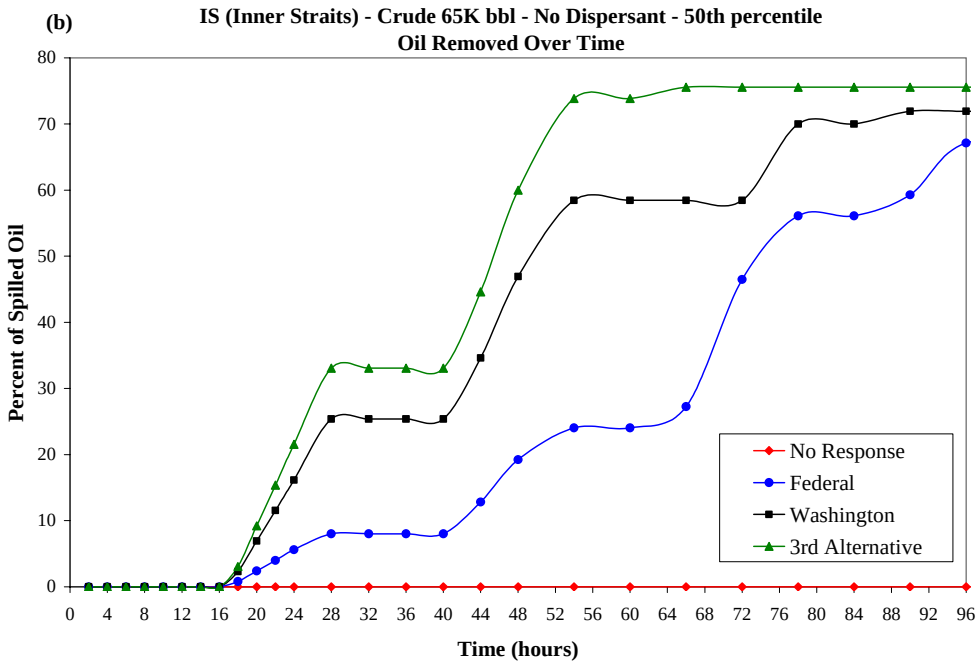
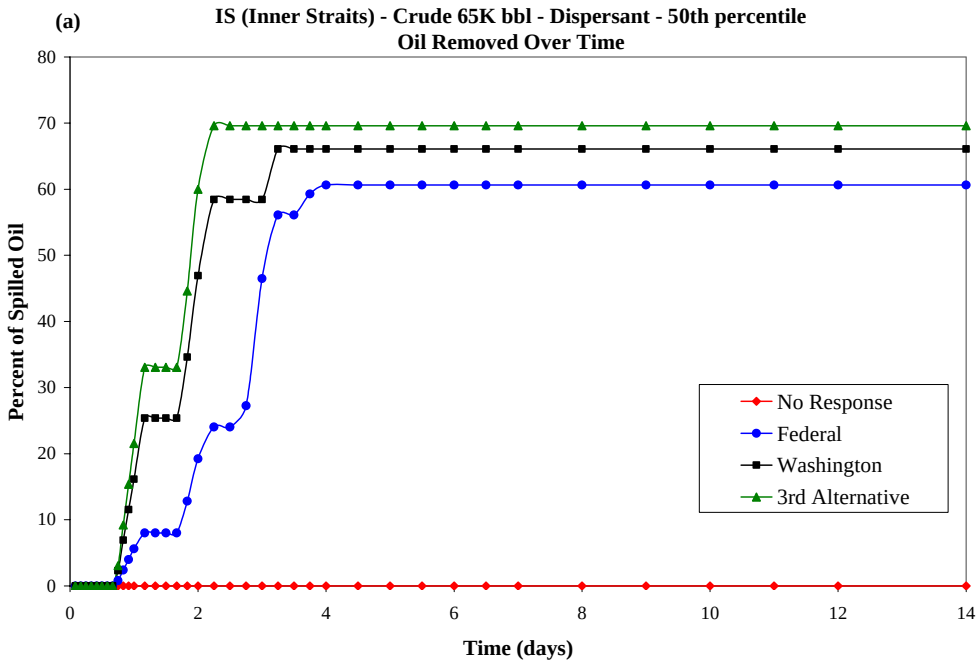


Figure XX.B.8-32 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



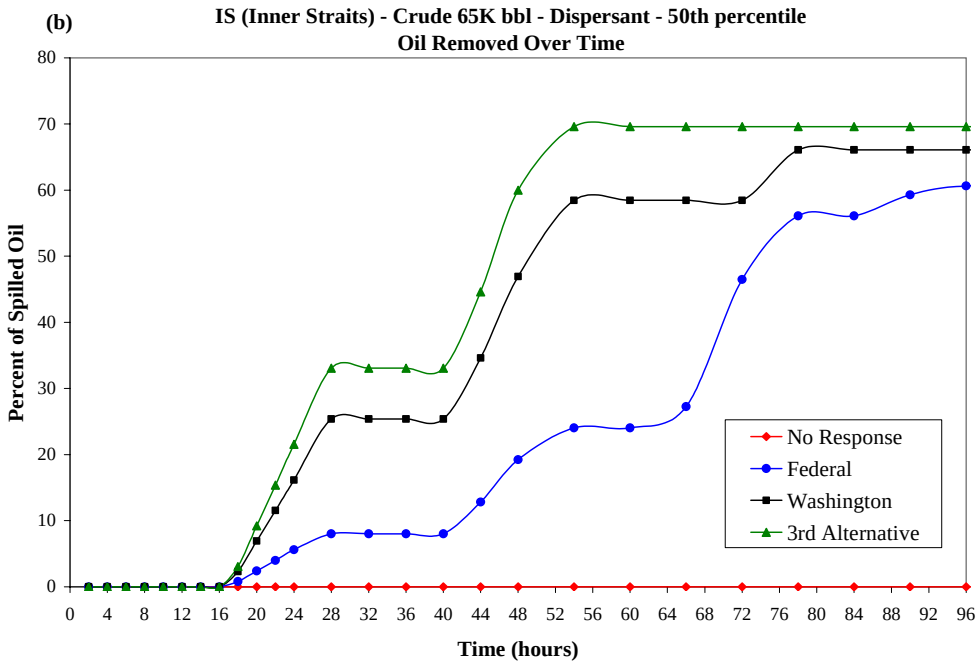
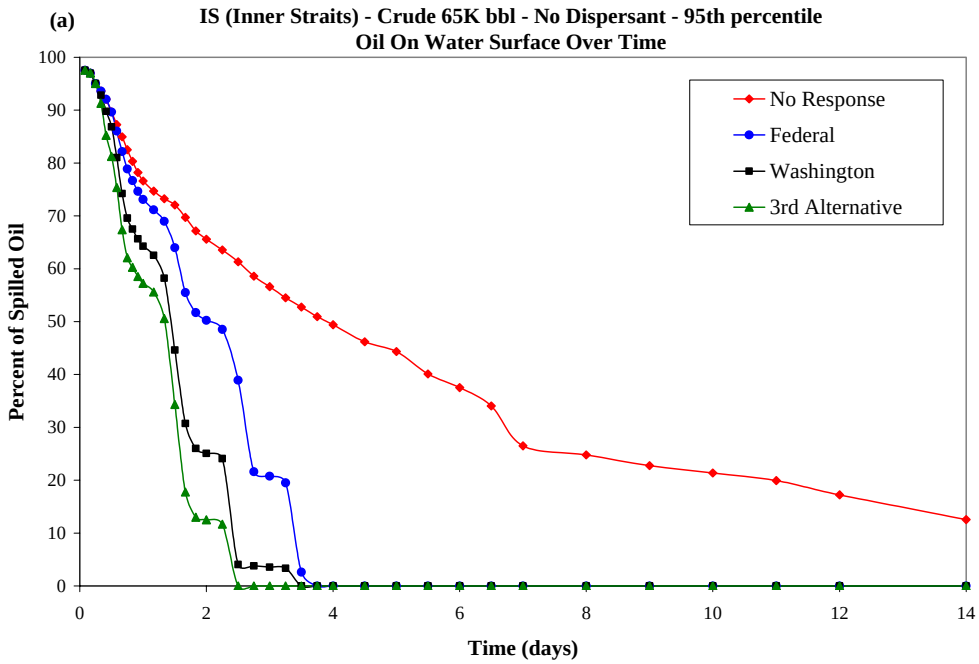


Figure XX.B.8-33 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



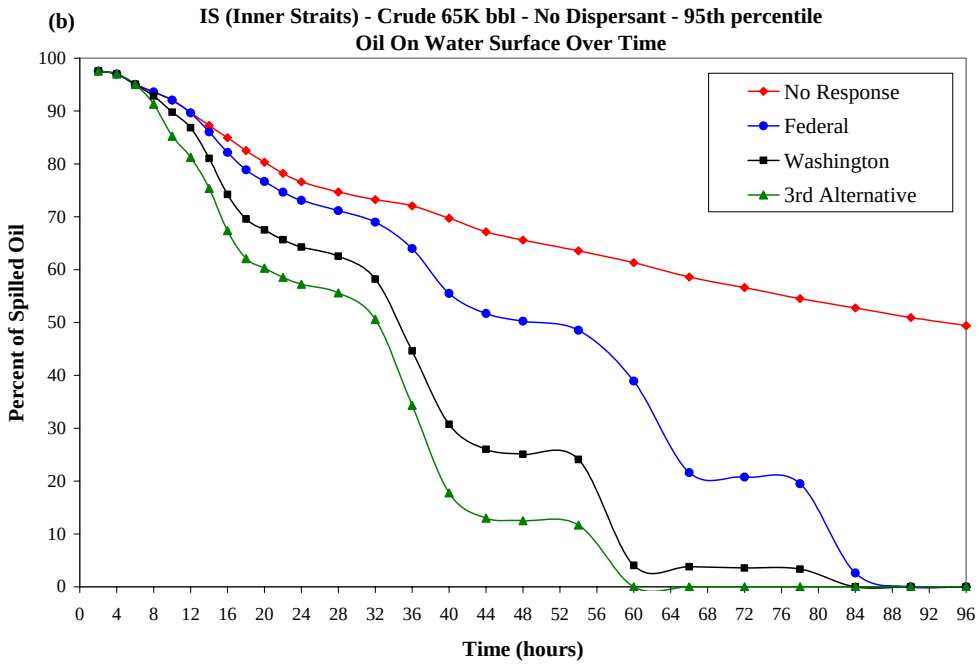
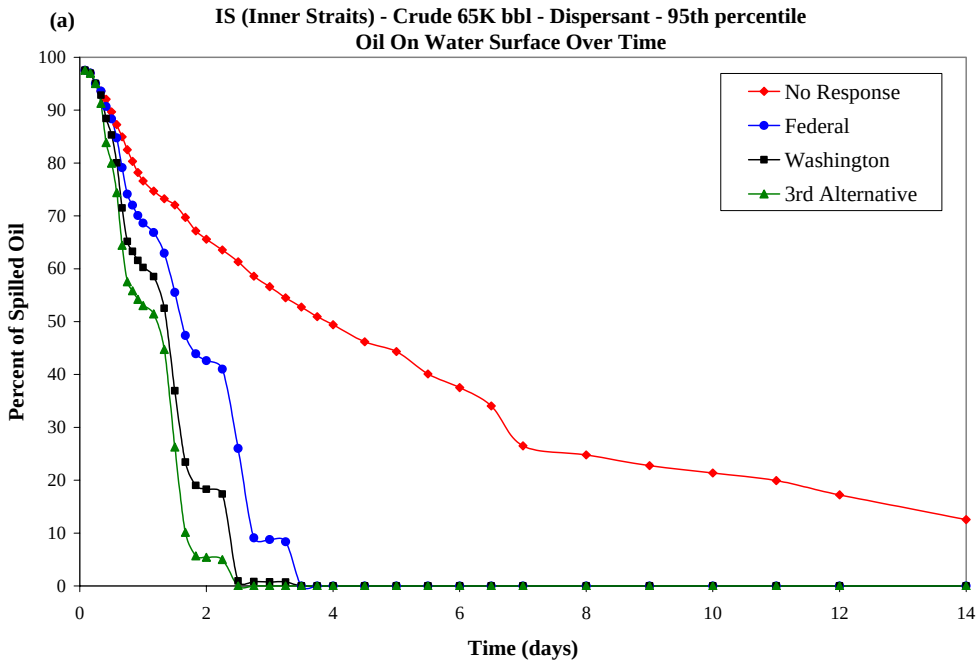


Figure XX.B.8-34 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



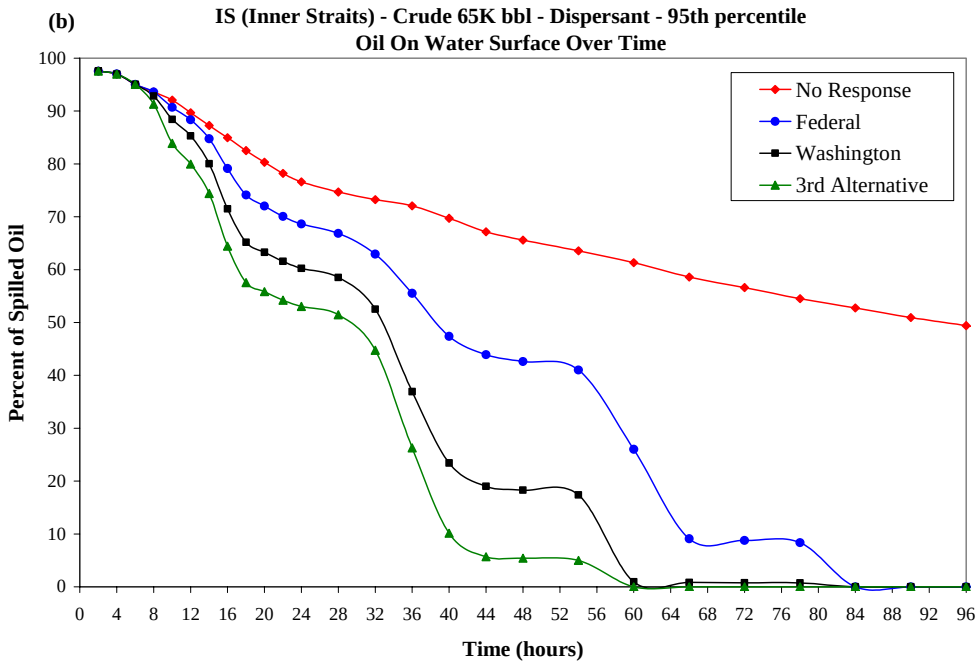
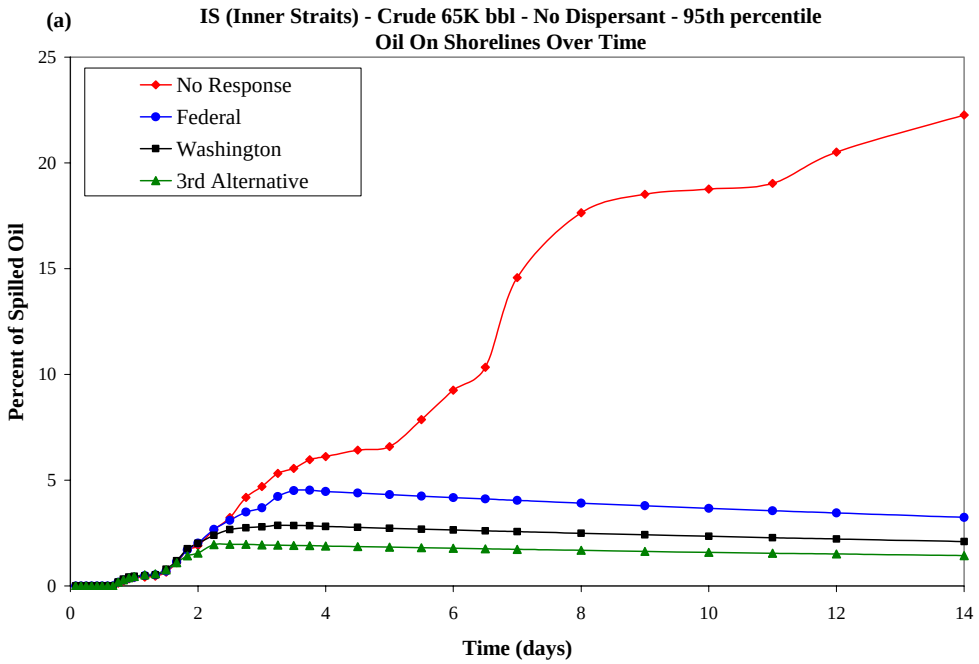


Figure XX.B.8-35 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



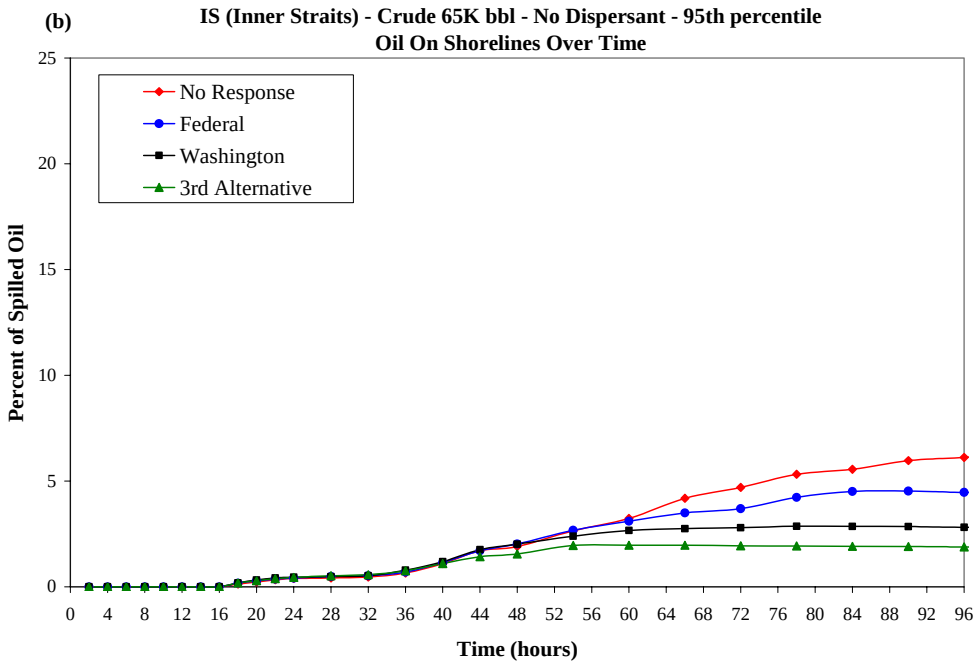
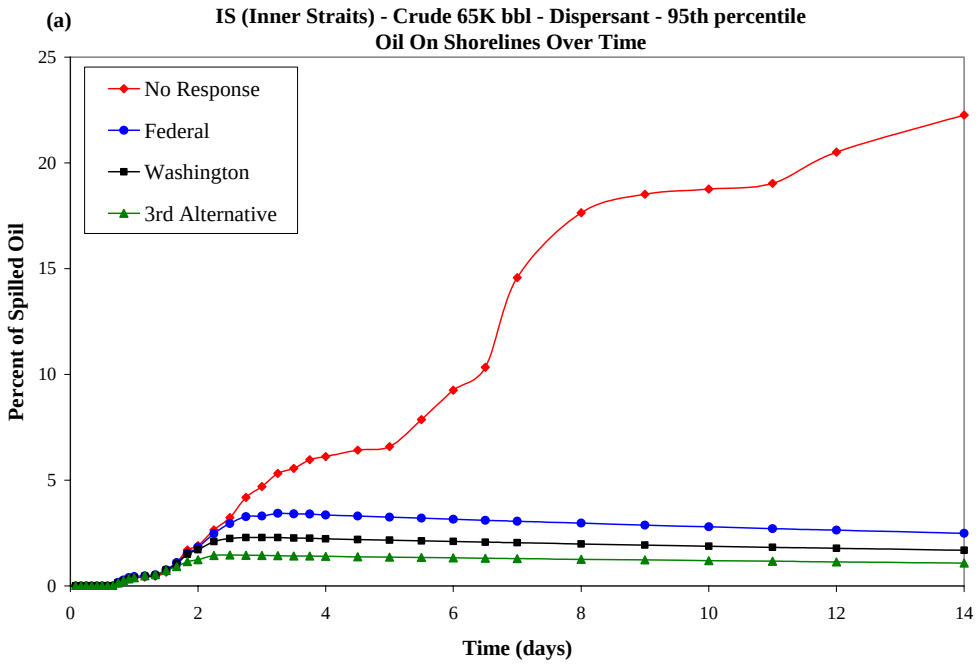


Figure XX.B.8-36 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



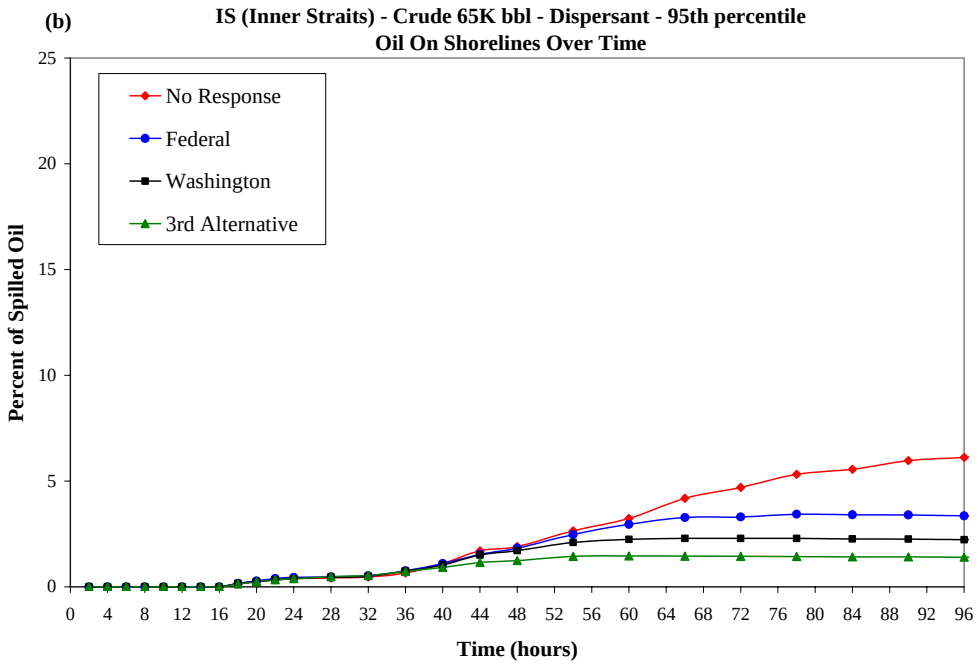
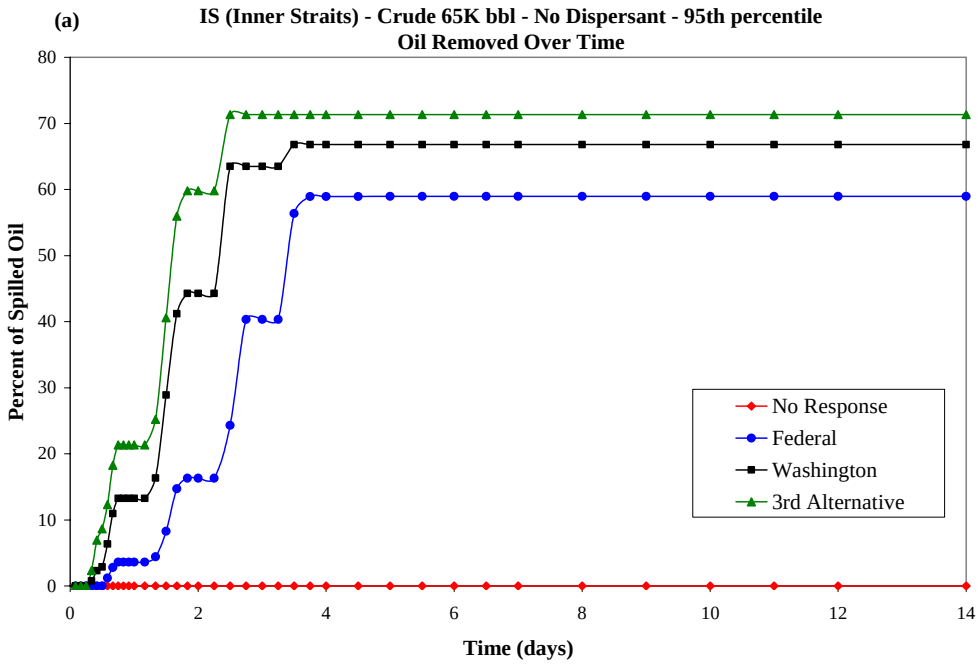


Figure XX.B.8-37 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



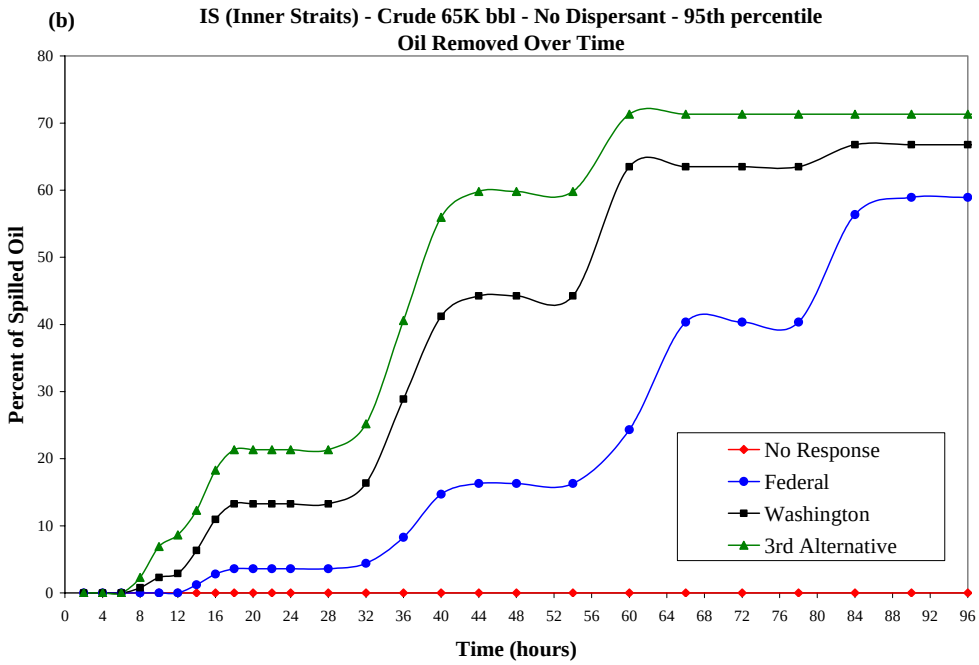
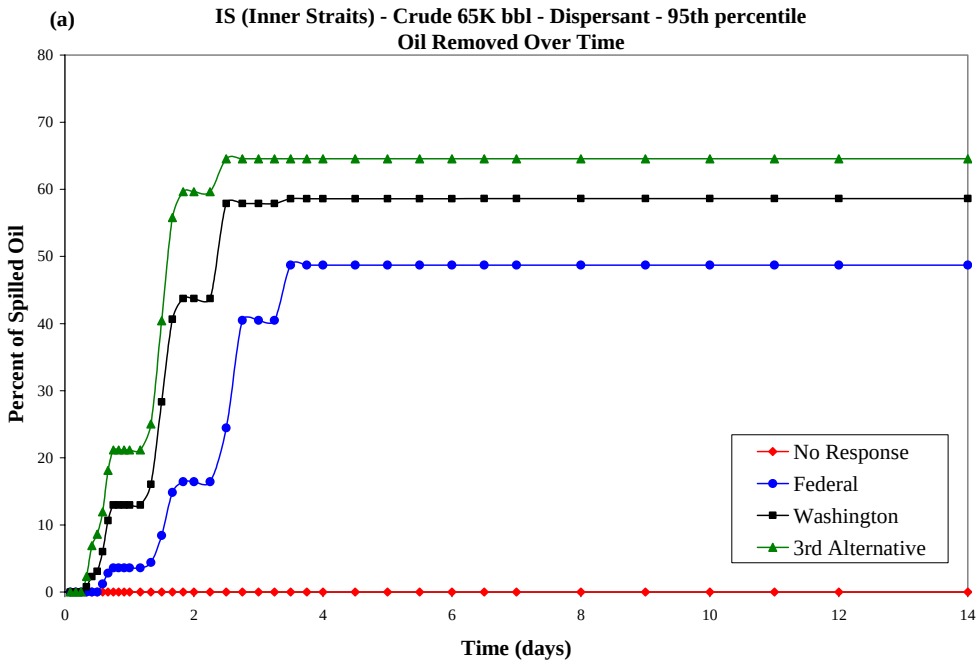


Figure XX.B.8-38 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run. Part b is a subset of Part a.



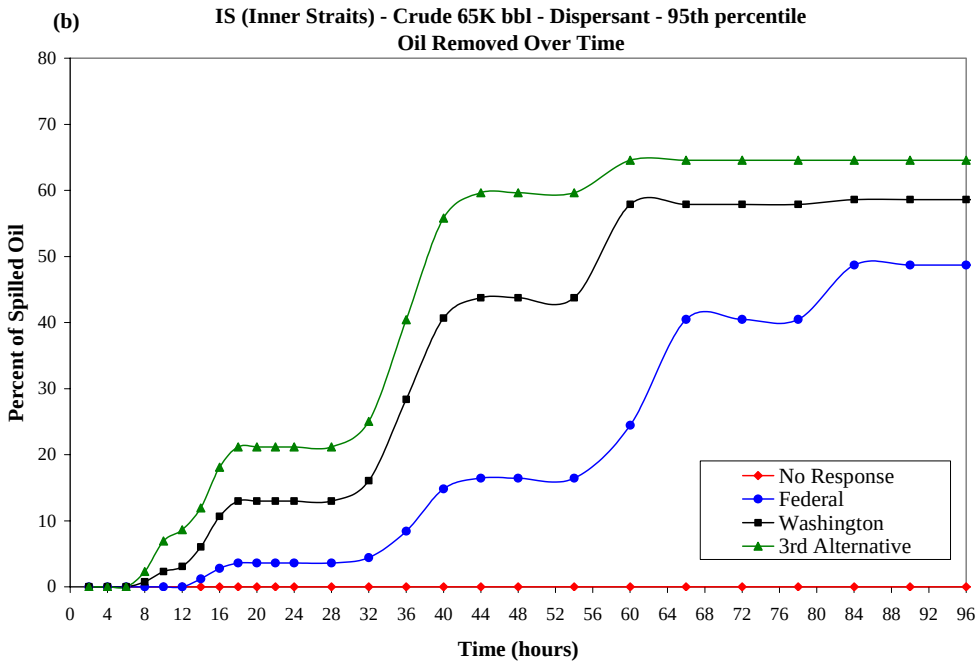


Figure XX.B.8-39 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run. Part b is a subset of Part a.

XX.C. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the appropriate seasonal abundance for each of the 5th, 50th and 95th percentile run dates. Impacts are proportional to pre-spill abundance. Thus, for the runs the results were corrected to use the annual mean abundance. Thus, all results are based on annual mean abundance. Note that the statistical data in the shaded cells are based only on 3 runs and so are highly uncertain.

Table IXX.C-1 Inner Straits/Puget Sound, no removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	17,753	19,795	0	34	1	-	3	-	37,587	37,584	3
50th Percentile Run (based on shore cost)	13,443	12,557	0	4	3	-	2	-	26,010	26,007	2
95th Percentile Run (based on shore cost)	38,410	54,478	0	26	12	-	9	-	92,936	92,927	9
Mean	23,202	28,943	0	21	6	-	5	-	52,178	52,173	5
Std Dev (SD)	13,346	22,408	0	15	6	-	3	-	35,769	35,766	3
Mean - 2SD	-	-	-	-	-	-	-	-	-	-	-
Mean + 2SD	49,894	73,760	1	52	17	-	12	-	123,716	123,704	12

Table IXX.C-2 Inner Straits/Puget Sound, WA state mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	7,022	1,777	0	1	-	-	1	-	8,801	8,800	1
50th Percentile Run (based on shore cost)	7,637	2,809	0	1	0	-	1	-	10,448	10,447	1
95th Percentile Run (based on shore cost)	7,404	2,418	0	2	0	-	1	-	9,826	9,825	1
Mean	7,596	2,764	0	2	0	-	1	-	10,364	10,363	0.83
Std Dev (SD)	1,542	2,557	0	4	3	-	0	-	4,099	4,098	0.39
Mean - 2SD	4,512	-	-	-	-	-	0	-	2,166	2,166	0.05
Mean + 2SD	10,679	7,879	0	9	6	-	2	-	18,561	18,559	1.62

Table IXX.C-3 Inner Straits/Puget Sound, federal mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	8,535	4,317	0	1	0	-	1	-	12,855	12,854	1
50th Percentile Run (based on shore cost)	7,831	3,134	0	1	0	-	1	-	10,967	10,966	1
95th Percentile Run (based on shore cost)	8,817	4,791	0	2	0	-	1	-	13,612	13,611	1
Mean	8,395	4,081	0	2	0	-	1	-	12,478	12,477	1
Std Dev (SD)	508	853	0	1	0	-	0	-	1,362	1,362	0
Mean - 2SD	7,378	2,374	0	0	-	-	1	-	9,753	9,752	1
Mean + 2SD	9,411	5,788	0	3	0	-	1	-	15,203	15,201	1

Table IXX.C-4 Inner Straits/Puget Sound, 3rd alternative mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	6,536	960	0	1	-	-	1	-	7,498	7,497	1
50th Percentile Run (based on shore cost)	7,266	2,187	0	1	0	-	1	-	9,455	9,454	1
95th Percentile Run (based on shore cost)	6,696	1,229	0	2	0	-	1	-	7,928	7,927	1
Mean	6,833	1,458	0	1	0	-	1	-	8,293	8,293	1
Std Dev (SD)	384	645	0	0	0	-	0	-	1,029	1,029	0
Mean - 2SD	6,065	169	0	1	-	-	0	-	6,236	6,235	0
Mean + 2SD	7,601	2,748	0	2	0	-	1	-	10,351	10,350	1

Table IXX.C-5 Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	6,766	1,346	0	1	-	-	1	-	8,113	8,113	1
50th Percentile Run (based on shore cost)	7,268	2,189	0	1	0	-	1	-	9,459	9,458	1
95th Percentile Run (based on shore cost)	7,187	2,053	0	2	0	-	1	-	9,242	9,241	1
Mean	7,073	1,862	0	1	0	-	1	-	8,938	8,937	1
Std Dev (SD)	270	453	0	0	0	-	0	-	723	722	0
Mean - 2SD	6,534	957	0	1	-	-	1	-	7,493	7,493	1
Mean + 2SD	7,613	2,768	0	2	0	-	1	-	10,383	10,382	1

Table IXX.C-6 Inner Straits/Puget Sound, federal mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	7,800	3,082	0	1	-	-	1	-	10,885	10,884	1
50th Percentile Run (based on shore cost)	7,657	2,842	0	1	0	-	1	-	10,501	10,500	1
95th Percentile Run (based on shore cost)	8,377	4,051	0	2	0	-	1	-	12,431	12,430	1
Mean	7,945	3,325	0	2	0	-	1	-	11,272	11,271	1
Std Dev (SD)	381	640	0	1	0	-	0	-	1,022	1,022	0
Mean - 2SD	7,182	2,045	0	0	-	-	1	-	9,229	9,228	1
Mean + 2SD	8,707	4,605	0	3	0	-	1	-	13,316	13,315	1

Table IXX.C-7 Inner Straits/Puget Sound, 3rd alternative mechanical removal and dispersant application: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile Run (based on shore cost)	6,482	869	0	1	-	-	1	-	7,352	7,352	1
50th Percentile Run (based on shore cost)	7,245	2,151	0	1	0	-	1	-	9,397	9,397	1
95th Percentile Run (based on shore cost)	6,521	935	0	2	0	-	1	-	7,458	7,457	1
Mean	6,749	1,318	0	1	0	-	1	-	8,069	8,069	1
Std Dev (SD)	430	722	0	0	0	-	0	-	1,152	1,151	0
Mean - 2SD	5,890	-	0	1	-	-	0	-	5,766	5,766	0
Mean + 2SD	7,609	2,761	0	2	0	-	1	-	10,372	10,371	1

XX.D. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates were calculated using the seasonal abundance for each of the spill dates included in the 3 runs. Note that the statistical data in the shaded cells are based only on 3 runs and so are highly uncertain.

Table XX.D-1. Inner Straits/Puget Sound, no removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	148.3	265.9	1.4	2.3	932.1	5,002	6,352
50th Percentile Run (shore cost)	3086.4	9180.2	23.8	20.9	8387.4	5,442	26,141
95th Percentile Run (shore cost)	0.0	0.0	0.0	0.0	0.0	16,578	16,578
Mean	1078.2	3148.7	8.4	7.7	3106.5	9,007	16,357
Std Dev (SD)	1740.7	5225.1	13.4	11.5	4597.1	6,560	18,148
Mean - 2SD	0.0	0.0	0.0	0.0	0.0	-	-
Mean + 2SD	4559.6	13599.0	35.1	30.7	12300.7	22,128	52,653

Table XX.D-2. Inner Straits/Puget Sound, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	-	-	-	-	-	-	-
50th Percentile Run (shore cost)	3,243.6	9,657.2	25.0	21.9	8,786.4	-	21,734
95th Percentile Run (shore cost)	-	-	-	-	-	724	724
Mean	1,299.4	3,857.9	10.0	8.9	3,559.6	506	9,242
Std Dev (SD)	2,071.6	6,222.8	15.9	13.6	5,446.5	554	14,325
Mean - 2SD	-	-	-	-	-	-	-
Mean + 2SD	5,442.6	16,303.4	41.8	36.0	14,452.6	1,615	37,891

Table XX.D-3. Inner Straits/Puget Sound, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	0.0	0.0	0.0	0.0	0.0	31	31
50th Percentile Run (shore cost)	2230.4	6583.2	17.3	15.5	6215.5	31	15,093
95th Percentile Run (shore cost)	0.0	0.0	0.0	0.0	0.0	1,007	1,007
Mean	743.5	2194.4	5.8	5.2	2071.8	357	5,377
Std Dev (SD)	1287.7	3800.8	10.0	8.9	3588.5	563	9,259
Mean - 2SD	0.0	0.0	0.0	0.0	0.0	-	-
Mean + 2SD	3318.9	9796.1	25.7	23.0	9248.8	1,483	23,895

Table XX.D-4. Inner Straits/Puget Sound, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	0.0	0.0	0.0	0.0	0.0	-	-
50th Percentile Run (shore cost)	2468.2	7304.6	19.1	17.0	6818.8	-	16,628
95th Percentile Run (shore cost)	0.0	0.0	0.0	0.0	0.0	409	409
Mean	822.7	2434.9	6.4	5.7	2272.9	136	5,679
Std Dev (SD)	1425.0	4217.3	11.0	9.8	3936.8	236	9,836
Mean - 2SD	0.0	0.0	0.0	0.0	0.0	-	-
Mean + 2SD	3672.7	10869.5	28.4	25.3	10146.6	609	25,351

Table XX.D-5. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	6020.8	18083.5	46.2	39.5	15833.6	-	40,024
50th Percentile Run (shore cost)	6777.0	20377.7	52.0	44.3	17752.3	-	45,003
95th Percentile Run (shore cost)	8067.3	24292.8	61.8	52.5	21026.6	315	53,816
Mean	6955.0	20918.0	53.4	45.4	18204.1	105	46,281
Std Dev (SD)	1034.8	3139.7	7.9	6.6	2625.8	182	6,996
Mean - 2SD	4885.4	14638.6	37.5	32.3	12952.5	-	32,546
Mean + 2SD	9024.7	27197.4	69.2	58.6	23455.8	468	60,274

Table XX.D-6. Inner Straits/Puget Sound, federal mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	10354.5	31232.2	79.3	67.0	26830.3	-	68,563
50th Percentile Run (shore cost)	9241.4	27854.9	70.8	59.9	24005.7	-	61,233
95th Percentile Run (shore cost)	7162.3	21546.9	54.9	46.7	18730.1	849	48,390
Mean	8919.4	26878.0	68.4	57.9	23188.7	283	59,395
Std Dev (SD)	1620.3	4916.0	12.4	10.3	4111.4	490	11,161
Mean - 2SD	5678.9	17046.0	43.6	37.3	14965.8	-	37,772
Mean + 2SD	12160.0	36710.0	93.1	78.4	31411.5	1,264	81,717

Table XX.D-7. Inner Straits/Puget Sound, 3rd alternative mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile Run (shore cost)	4204.2	12571.9	32.3	28.0	11224.0	-	28,060
50th Percentile Run (shore cost)	5951.2	17872.3	45.7	39.1	15656.9	31	39,597
95th Percentile Run (shore cost)	8048.4	24235.4	61.7	52.4	20978.6	189	53,565
Mean	6068.0	18226.5	46.6	39.8	15953.2	73	40,407
Std Dev (SD)	1924.8	5839.8	14.7	12.2	4884.0	101	12,777
Mean - 2SD	2218.4	6546.9	17.2	15.4	6185.1	-	14,983
Mean + 2SD	9917.5	29906.2	76.0	64.2	25721.3	276	65,961

XX.E. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All weights are as wet weight; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

NRDA costs were calculated for the 5th, 50th and 95th percentile run *based on shore cost*. Because impacts are not necessarily correlated with shore cost, the results for NRDA costs may not be in increasing order from 5th to 95th percentile run by shore cost.

Table XX.E-1. Inner Straits/Puget Sound, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	148.3	3,086.4	-	1,078.2	-	4,559.6
Large pelagic fish	265.9	9,180.2	-	3,148.7	-	13,599.0
Demersal fish	1.4	23.8	-	8.4	-	35.1
Decapods	2.3	20.9	-	7.7	-	30.7
Molluscs	5,934	13,829	16,578	12,114	-	34,428
Birds:						
Waterfowl (# * kg each)	7,101	9,679	29,960	15,580	-	40,620
Seabirds (# * kg each)	27,712	9,669	68,643	35,341	-	95,777
Waders (# * kg each)	0	0	0	0	-	1
Shorebirds (# * kg each)	1	0	1	1	-	2
Raptors (# * kg each)	7	14	62	28	-	87
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	468	318	871	552	-	1,124
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	6,352	26,141	16,578	16,357	-	52,653
Subtotal birds	34,822	19,363	98,666	50,950	-	136,487
Subtotal other wildlife	468	318	871	552	-	1,124
Total all species	41,642	45,821	116,115	67,859	-	190,264

Table XX.E-2. Inner Straits/Puget Sound, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	206	119	505	276	-	741
Saltmarsh Area (acres)	508	294	1,248	683	-	1,830
Saltmarsh Cost (millions of 2004$)	95.1	55.1	233.8	128.0	-	342.9
Eelgrass Area (m2)	128	74	316	173	-	463
Eelgrass Area (acres)	317	184	780	427	-	1,144
Eelgrass Cost (millions of 2004$)	37.9	21.9	93.1	51.0	-	136.5

Table XX.E-3. Inner Straits/Puget Sound, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	3,243.6	-	1,299.4	-	5,442.6
Large pelagic fish	-	9,657.2	-	3,857.9	-	16,303.4
Demersal fish	-	25.0	-	10.0	-	41.8
Decapods	-	21.9	-	8.9	-	36.0
Molluscs	-	8,786	724	4,065	-	16,067
Birds:						
Waterfowl (# * kg each)	5,477	5,957	5,775	5,925	3,519	8,330
Seabirds (# * kg each)	2,239	3,539	3,047	3,483	-	9,928
Waders (# * kg each)	0	0	0	0	-	0
Shorebirds (# * kg each)	0	0	0	0	-	0
Raptors (# * kg each)	-	0	0	2	-	31
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	69	84	79	83	5	162
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	-	21,734	724	9,242	-	37,891
Subtotal birds	7,716	9,496	8,823	9,410	3,519	18,289
Subtotal other wildlife	69	84	79	83	5	162
Total all species	7,785	31,314	9,625	18,735	3,524	56,342

Table XX.E-4. Inner Straits/Puget Sound, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	24	64	30	45	5	132
Saltmarsh Area (acres)	60	159	75	112	11	325
Saltmarsh Cost (millions of 2004$)	11.2	29.7	14.0	21.1	2.1	61.0
Eelgrass Area (m2)	15	40	19	28	3	82
Eelgrass Area (acres)	37	99	47	70	7	203
Eelgrass Cost (millions of 2004$)	4.5	11.8	5.6	8.4	0.8	24.3

Table XX.E-5. Inner Straits/Puget Sound, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	2,230.4	-	743.5	-	3,318.9
Large pelagic fish	-	6,583.2	-	2,194.4	-	9,796.1
Demersal fish	-	17.3	-	5.8	-	25.7
Decapods	-	15.5	-	5.2	-	23.0
Molluscs	31	6,247	1,007	2,428	-	10,731
Birds:						
Waterfowl (# * kg each)	3,414	5,638	6,878	5,310	1,800	8,820
Seabirds (# * kg each)	6,044	2,413	6,036	4,831	643	9,020
Waders (# * kg each)	0	0	0	0	0	0
Shorebirds (# * kg each)	0	0	0	0	0	0
Raptors (# * kg each)	0	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	147	122	115	128	94	161
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	31	15,093	1,007	5,377	-	23,895
Subtotal birds	9,458	8,051	12,914	10,141	2,443	17,840
Subtotal other wildlife	147	122	115	128	94	161
Total all species	9,636	23,266	14,036	15,646	2,537	41,896

Table XX.E-6. Inner Straits/Puget Sound, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	49	50	52	50	12	106
Saltmarsh Area (acres)	122	123	128	124	29	262
Saltmarsh Cost (millions of 2004$)	22.9	23.0	24.0	23.3	5.4	49.1
Eelgrass Area (m2)	31	31	32	31	7	66
Eelgrass Area (acres)	76	77	80	78	18	164
Eelgrass Cost (millions of 2004$)	9.1	9.1	9.5	9.3	2.2	19.5

Table XX.E-7. Inner Straits/Puget Sound, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	2,468.2	-	822.7	-	3,672.7
Large pelagic fish	-	7,304.6	-	2,434.9	-	10,869.5
Demersal fish	-	19.1	-	6.4	-	28.4
Decapods	-	17.0	-	5.7	-	25.3
Molluscs	-	6,819	409	2,409	-	10,755
Birds:						
Waterfowl (# * kg each)	2,614	5,232	5,223	4,356	1,339	7,374
Seabirds (# * kg each)	1,344	1,684	1,549	1,525	1,183	1,867
Waders (# * kg each)	0	0	0	0	0	0
Shorebirds (# * kg each)	0	0	0	0	0	0
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	77	102	60	80	38	122
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	-	16,628	409	5,679	-	25,351
Subtotal birds	3,958	6,916	6,772	5,882	2,522	9,242
Subtotal other wildlife	77	102	60	80	38	122
Total all species	4,035	23,646	7,241	11,641	2,560	34,715

Table XX.E-8. Inner Straits/Puget Sound, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	16	46	19	27	11	62
Saltmarsh Area (acres)	39	113	48	67	27	153
Saltmarsh Cost (millions of 2004$)	7.4	21.2	9.0	12.5	5.1	28.7
Eelgrass Area (m2)	10	29	12	17	7	39
Eelgrass Area (acres)	25	71	30	42	17	96
Eelgrass Cost (millions of 2004$)	2.9	8.4	3.6	5.0	2.0	11.4

Table XX.E-9. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	6,020.8	6,777.0	8,067.3	6,955.0	4,885.4	9,024.7
Large pelagic fish	18,083.5	20,377.7	24,292.8	20,918.0	14,638.6	27,197.4
Demersal fish	46.2	52.0	61.8	53.4	37.5	69.2
Decapods	39.5	44.3	52.5	45.4	32.3	58.6
Molluscs	15,834	17,752	21,341	18,309	12,952	23,924
Birds:						
Waterfowl (# * kg each)	2,706	5,233	5,606	4,515	1,360	7,670
Seabirds (# * kg each)	1,884	1,686	2,586	2,052	1,106	2,998
Waders (# * kg each)	0	0	0	0	0	0
Shorebirds (# * kg each)	0	0	0	0	0	0
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	85	102	73	87	57	116
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	40,024	45,003	53,816	46,281	32,546	60,274
Subtotal birds	4,590	6,919	8,192	6,567	2,466	10,668
Subtotal other wildlife	85	102	73	87	57	116
Total all species	44,699	52,024	62,081	52,935	35,069	71,058

Table XX.E-10. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	77	87	104	89	58	120
Saltmarsh Area (acres)	190	215	256	220	143	297
Saltmarsh Cost (millions of 2004$)	35.6	40.3	48.0	41.3	26.9	55.7
Eelgrass Area (m2)	48	54	65	56	36	75
Eelgrass Area (acres)	119	134	160	138	90	186
Eelgrass Cost (millions of 2004$)	14.2	16.1	19.1	16.4	10.7	22.2

Table XX.E-11. Inner Straits/Puget Sound, federal mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	3,700.3	3,300.3	2,553.1	3,184.6	2,020.1	4,349.1
Large pelagic fish	10,727.7	9,562.1	7,385.1	9,225.0	5,831.8	12,618.1
Demersal fish	26.1	23.3	18.0	22.5	14.3	30.7
Decapods	18.8	16.9	13.2	16.3	10.6	22.0
Molluscs	13	12	859	295	8	1,279
Birds:						
Waterfowl (# * kg each)	2,330	4,108	4,920	3,786	1,137	6,435
Seabirds (# * kg each)	1,571	841	1,564	1,325	487	2,163
Waders (# * kg each)	-	0	0	0	-	0
Shorebirds (# * kg each)	0	0	0	0	-	0
Raptors (# * kg each)	-	0	0	0	-	1
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	121	116	103	113	95	132
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	14,486	12,915	10,829	12,743	7,885	18,299
Subtotal birds	3,901	4,949	6,484	5,111	1,624	8,599
Subtotal other wildlife	121	116	103	113	95	132
Total all species	18,508	17,980	17,416	17,968	9,604	27,029

Table XX.E-12. Inner Straits/Puget Sound, federal mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	52	46	44	48	28	67
Saltmarsh Area (acres)	129	114	109	118	69	167
Saltmarsh Cost (millions of 2004$)	24.3	21.4	20.5	22.1	12.9	31.2
Eelgrass Area (m2)	33	29	28	30	17	42
Eelgrass Area (acres)	81	71	68	74	43	104
Eelgrass Cost (millions of 2004$)	9.7	8.5	8.2	8.8	5.1	12.4

Table XX.E-13. Inner Straits/Puget Sound, 3rd alternative mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	4,204.2	5,951.2	8,048.4	6,068.0	2,218.4	9,917.5
Large pelagic fish	12,571.9	17,872.3	24,235.4	18,226.5	6,546.9	29,906.2
Demersal fish	32.3	45.7	61.7	46.6	17.2	76.0
Decapods	28.0	39.1	52.4	39.8	15.4	64.2
Molluscs	11,224	15,688	21,167	16,027	6,185	25,997
Birds:						
Waterfowl (# * kg each)	2,593	5,216	5,086	4,298	1,341	7,256
Seabirds (# * kg each)	1,217	1,656	1,178	1,350	819	1,881
Waders (# * kg each)	0	0	0	0	0	0
Shorebirds (# * kg each)	0	0	0	0	0	0
Raptors (# * kg each)	-	0	0	0	-	0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	75	102	56	77	32	123
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	28,060	39,597	53,565	40,407	14,983	65,961
Subtotal birds	3,809	6,872	6,264	5,649	2,160	9,137
Subtotal other wildlife	75	102	56	77	32	123
Total all species	31,945	46,571	59,885	46,134	17,175	75,221

Table XX.E-14. Inner Straits/Puget Sound, 3rd alternative mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Run	50th Run	95th Run	Mean	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	55	79	93	76	29	122
Saltmarsh Area (acres)	135	195	230	187	72	302
Saltmarsh Cost (millions of 2004$)	25.4	36.5	43.2	35.0	13.5	56.5
Eelgrass Area (m2)	34	49	58	47	18	76
Eelgrass Area (acres)	85	122	144	117	45	188
Eelgrass Cost (millions of 2004$)	10.1	14.5	17.2	13.9	5.4	22.5

XX.F. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

The Washington Compensation Schedule was applied to the model results for the hypothetical spills simulated. The methods are described in Section 6.2 of Volume I. Note that the Compensation Schedule is designed to be a simplified procedure for small spills. Thus, for spills the size of those considered here, the OPA procedures using restoration costs (listed in section XX.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table XX.F-1. Inner Straits/Puget Sound, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	22.688	22.700	20.807	22.065	19.885	24.244
% Removed by 24 hours	-	-	-	-	-	-
Compensation (millions $)	61.9	62.0	56.8	60.2	54.3	66.2

Table XX.F-2. Inner Straits/Puget Sound, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	19.852	23.638	22.122	19.447	24.798
% Removed by 24 hours	13.8	16.2	13.3	12.7	-	27.0
Compensation (millions $)	48.9	45.4	56.0	52.7	45.9	59.5

Table XX.F-3. Inner Straits/Puget Sound, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	22.688	19.840	23.638	22.055	18.103	26.008
% Removed by 24 hours	4.8	5.6	3.6	4.7	2.7	6.7
Compensation (millions $)	59.0	51.1	62.2	57.4	46.7	68.1

Table XX.F-4. Inner Straits/Puget Sound, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	23.649	23.638	22.692	19.394	25.989
% Removed by 24 hours	18.5	21.5	21.4	20.5	17.0	23.9
Compensation (millions $)	46.3	50.7	50.8	49.3	40.4	58.1

Table XX.F-5. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	23.640	23.638	22.115	19.596	24.633
% Removed by 24 hours	13.8	16.2	13.0	12.7	-	26.9
Compensation (millions $)	48.9	54.1	56.2	52.7	46.3	59.1

Table XX.F-6. Inner Straits/Puget Sound, federal mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	19.855	23.638	21.427	17.485	25.369
% Removed by 24 hours	4.8	5.6	3.6	4.7	2.7	6.7
Compensation (millions $)	54.0	51.2	62.2	55.8	45.1	66.4

Table XX.F-7. Inner Straits/Puget Sound, 3rd alternative mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Run (shore cost)	50th Run (shore cost)	95th Run (shore cost)	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	20.788	20.788	23.638	21.738	18.447	25.029
% Removed by 24 hours	18.5	21.5	21.2	20.4	17.0	23.8
Compensation (millions $)	46.3	44.5	50.9	47.2	38.4	56.1

Phase II. Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume I: Model Description, Approach, and Analysis

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EXECUTIVE SUMMARY

Approach

Oil spill fate and effects modeling and analysis were performed to evaluate the implications of spill response options being considered by the Washington State Department of Ecology in their rulemaking related to oil spill preparedness (WA State Contingency Plan Rule). The impacts of potential spills in Washington's outer coast, sound and river environments were modeled varying response options and operational timing, involving the use of conventional mechanical containment and recovery operations. US Coast Guard federal response capability standards, current Washington State standards, and potential theoretical higher response capability standards were simulated for scenarios involving spills of crude oil, bunker fuel and diesel into Washington waters (Strait of Georgia (near the San Juan Islands), Strait of Juan de Fuca, lower and upper Columbia River, Outer Coast at Duntz Rock, Outer Coast-Sea Lanes and Grays Harbor).

The modeling was performed in probabilistic mode, randomly varying location along tanker routes, spill date, and time, and so environmental conditions during and after the release among potential conditions that would occur. The model results were analyzed to estimate mean, standard deviation, and 5th, 50th and 95th percentile results for surface water and shoreline oiling, water column and sediment contamination, biological impacts (to wildlife, fish, invertebrates, and habitats), and natural resource damages (NRD) for losses of ecological services. NRD costs were based on the Washington Compensation Schedule and the US Oil Pollution Act (OPA) NRD procedures involving compensatory restoration and associated costs. Response costs and socioeconomic damages were evaluated in a companion study by D. S. Etkin (Environmental Research Consulting). The results are being evaluated by the WA Department of Ecology as part of their rulemaking process and cost-benefit analyses.

The SIMAP (Spill Impact Model Application Package) modification of the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME) model (developed by Applied Science Associates (ASA) for use by the Department of the Interior in CERCLA NRDA type A regulations and for oil spill assessments under OPA) was used for this study. This model is comprised of three-dimensional oil fate and biological effects models that access impacts and provide data to estimate NRD, response, and socioeconomic costs of spills in marine and freshwater environments. The model was run in stochastic mode to produce results and statistics for multiple model runs under various possible environmental conditions.

The model uses wind data, current data, and transport and weathering algorithms to calculate mass balance in various environmental compartments (water surface, shoreline, water column, atmosphere, sediments, etc.), surface oil distribution over time (trajectory), and concentrations of the oil components in water and sediments. Geographical data (habitat mapping and shoreline location) were obtained from existing Geographical

Information System (GIS) databases based on Environmental Sensitivity Indices (ESI). Water depth was obtained from National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) soundings databases. Hourly wind speed and direction data over a long historical period were obtained from nearby meteorological stations. Tidal and other currents were modeled based on known water heights, using a hydrodynamic model based on physical laws (i.e., conserving mass and momentum). SIMAP was used to evaluate exposure of aquatic habitats and organisms to whole oil and potentially toxic components from the fuels, resulting mortality and ecological losses.

Nine spill scenarios were run in stochastic mode using combinations of seven spill locations (along transportation routes), 3 oil types (crude, bunker C fuel, and diesel) and response combinations including protective booming and mechanical removal. For each scenario, the model was run numerous times, randomly sampling environmental conditions during and after the spill. For each stochastic scenario, selected worst-case runs (of 100 randomly-selected events), in terms of environmental consequences, were examined in detail for NRDA, socioeconomic, and response costs. The runs with the most impact on selected sensitive sites or that oiled the most shoreline were selected. These 3 events were run with alternate response plans to evaluate the change in consequences resulting from different response implementations.

Specifications for the scenarios (amount, duration of release, etc.) were provided by the Department of Ecology based on Washington state planning standards, federal planning standards, and input from Stakeholders. The spill locations were along shipping routes in Washington state waters. Spill sites for each individual run were randomized along the designated route for that scenario. The oil types selected were those typically shipped (Alaska North slope crude and diesel fuel) or used to power vessels (Bunker C). The spill volumes were selected to be a relatively large spill, but of a size that would be handled primarily by the state rather than the federal government. The crude oil spills are all 250,000 bbl, the diesel spills are 65,000 bbl, and the Bunker C spills are 150,000 bbl or 25,000 bbl.

The 100 runs of each of the main stochastic scenarios were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are used) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling.

Because all impact indices are not necessarily correlated with shore cost, the 5th, 50th and 95th percentile results for the 100 values of the index were calculated by sorting only the index being considered. These are listed in the tables in the report, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard

deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Note that the response alters the resulting shoreline oiling and so different runs may become higher in shoreline impact if mechanical removal and booming are added to the scenario. In the results where alternative response options are examined, the individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

Table E-1 lists the scenarios examined. All the results are summarized in tables in Volume II, organized by location and oil type. The key results and discussion are described in Sections 4-6 of Volume I. Volume I also contains a description of the model used (Section 2), input data sources and assumptions (Section 3), and conclusions (Section 7).

Oil Recovery Rates

The Phase I modeling results, assuming recovery operations at the Effective Daily Recovery Capability (EDRC) rate, indicated that the mechanical removal capacities examined would be sufficient for cleaning up much of the spill volumes evaluated and could reduce impacts to biota and shorelines. However, the Phase I simulations assumed that everything goes according to plan and responders know where the oil is at all times. In reality, people and equipment will not be able to meet the schedules exactly and there will not be perfect knowledge of the oil movements allowing the responders to mechanically clean up as much oil as the results suggest. Thus, the percentage removed mechanically is the maximum possible given the equipment capacities. In addition, dispersant use, if performed with mechanical recovery, would likely account for more of the oil removal from the water surface in an actual spill event than is reflected by the Phase I results.

In Phase II modeling, the mechanical recovery rates were adjusted to take into account inefficiencies in applying mechanical recovery methods as observed in many actual spill responses and as indicated by research done by experts in the field (Etkin, 2005b). The modeled removal rate decreased over time due to the spreading of the oil on the water surface and decreasing opportunities to effectively corral and remove oil. As a result, most of the removal would occur in the first 72 hours, and the percent of oil removed by mechanical recovery was for most scenarios <10% of the spilled oil in the Phase II model simulations. However, recovery was a higher percentage of the spilled oil for the Bunker scenarios in the Strait of Juan de Fuca and Grays Harbor. The capacity standards input to the model were larger relative to the spill volume for the 25,000 bbl bunker fuel scenarios than for those using the other two oil types or for the Outer Coast-Sea Lanes 150,000 bbl bunker fuel spill scenario. In the Columbia River, the oil came ashore rapidly because of the relatively confined water body, often limiting the on-water recovery. There was not this limitation in the Strait of Juan de Fuca or near/in Grays Harbor. For all scenarios, the pattern is apparent where the amount of oil mechanically removed assuming the federal

standards was lower, and the amount removed under the 3rd alternative higher, than in the WA state standard simulation.

In both phases of the modeling, only the planning standard capacities were assumed deployed. With the high recovery efficiencies assumed in Phase I, this would appear sufficient. However, accounting for the increasing difficulties in recovering oil over time, more equipment would be needed to increase recovery, or, alternatively, recovery efficiency would need to be higher. The latter is the goal of spill planning, and the reality is that more equipment than the standard capacities require would be deployed in the event of spills as large as those simulated in this study.

Differences in Impacts with Alternative Response Scenarios

Because the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model, there is variability in the movements of oil spillets in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This results in variation in the specific water areas and shoreline locations oiled and in some cases the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported.

In addition, protection booming input to the model deflects oil offshore from the boomed site. In many cases the booms are located to protect inlets, coves and wetlands with small linear shoreline length. In the model, oil deflected off booms moves offshore and along the shore (down wind and with the currents) and may oil other shorelines. Thus, the deflected oil becomes more dispersed, allowing it to impact a larger area. The other shorelines oiled may be of a different type with less ability to “hold” oil (such as a sand beach, which holds less oil per length than a wetland), and so the length of shore oiled may actually be increased by the inclusion of booms in the model. In an actual spill, protective booming would often be accompanied by localized efforts to remove oil. However, simulation of this response detail was not included in the modeling reported here.

Because the differences in amounts of oil removed are small in the Phase II simulations, the differences between runs are in many cases less than the randomized variability in the model and are not significant. However, in some cases, the timing of oil removal and arrival on shore changes, as may be seen in the figures showing oil amounts in various environmental compartments (i.e., mass balance) as a function of time in Section B of Volumes V, VIII, XI, XIV, XVII, XX, XXIII, XXVI, and XXIX. The figures in Section B of these volumes are those Washington Department of Ecology will find most useful in evaluating the various planning standards. There are also figures in Section 4 of this volume (Figures 4-1 to 4-9) that summarize the time (hours after the spill) oil first reached shore for 100 runs of each of the no-response stochastic scenarios.

Potential Impacts of Spills for the Scenarios Examined

Tables E-2 to E-7 summarize the estimated impacts for the main stochastic scenarios, as the mean and standard deviation of the results for the 100 runs. The mean plus or minus two standard deviations gives the range of expected impacts for 95% of spills of the volume simulated.

Table E-2 summarizes the shoreline oiling, listing the length of shore where cleanup would occur. The scenario run for the Straits of Juan de Fuca using diesel fuel resulted in the lowest percentage of spilled hydrocarbons eventually coming ashore. This reflects the fact that diesel is more volatile and soluble than the other types of oil that were modeled. While a high percentage of Bunker fuel typically hit the shore, the overall area affected by shoreline oiling was largest in spills of crude oil due to the greater volume of spilled crude that was modeled. Furthermore, locations where shipping routes are closer to land (i.e., San Juan Islands, the Lower and Upper Columbia River, and Grays Harbor) usually had a higher percentage of oil coming ashore.

The majority of the biological impacts are to birds, particularly to seabirds and waterfowl (diving ducks). Table E-3 summarizes the bird impacts. The highest level of bird mortality was seen in the outer coast region, because the oil remained at sea longer and there were higher abundance of birds there compared to other areas, such as in the Straits of Juan de Fuca. The Upper Columbia River scenario impacted the fewest birds, since seabird and waterfowl density was less than along the Lower Columbia River and other areas.

Table E-4 shows that the mammal impacts are projected to be minor, with the exception of the outer coast and upper Columbia River scenarios. The mammals primarily impacted in the outer coast scenarios would be sea otters and fur seals, with lesser impacts to harbor seals and harbor porpoises. In the upper Columbia River, the mammals impacted would be mostly muskrat and mink.

Table E-5 summarizes estimated impacts to subtidal fish and invertebrates (those in the water exposed to water and submerged sediment concentrations). Diesel is much more readily dispersed naturally into the water column than crude oil, and so the impacts are projected to be much higher for diesel than for a larger volume of crude oil. This is because Alaskan crude oil emulsifies rapidly, minimizing entrainment and dissolution into the water. The Bunker C spills had low content of soluble and toxic components, and were not readily dispersed naturally into the water because of the high viscosity of the oil. For these reasons, the effects on fish and invertebrates for the Bunker C spills were very minimal in areas where there is rapid dilution, i.e., on the outer coast, in the Straits of Juan de Fuca or in the lower Columbia River. In the upper Columbia River, the impacts were primarily on demersal fish such as suckers, catfish and sunfishes. Once the effect of oil type on impacts to subtidal fish and invertebrates is filtered out, it is apparent that the outer coast scenarios (including Grays Harbor) had the least impacts because of the large dilution volumes involved.

Impacts to intertidal invertebrates (Table E-6) were evaluated for geoducks, soft-shell clams, razor clams, and hard clams in soft shoreline habitats (wetlands, mud flats and sand beaches). The impacts to clams are proportional to the shoreline area heavily oiled. Trends in the mortality of intertidal invertebrates closely followed the spatial distribution of geoduck abundance, resulting in greater mortality in areas, such as the Straits of Juan de Fuca, and the San Juan Islands, where geoduck density is highest. By examining the three Straits of Juan de Fuca scenarios, it becomes evident that spills of crude have the largest impact on intertidal mollusks. This reflects the facts that the spill volume of crude was greater and crude covered a larger shoreline area than the other two types of oil. Within the Juan de Fuca region, intertidal invertebrates experienced the lowest mortality levels in the diesel spill. The low impact of the diesel spill on mollusks can again be attributed to this oil's volatile nature, which causes smaller volumes of it to come ashore.

The natural resource damages (Table E-7) were based on estimated costs to restore equivalent resources and/or ecological services. This is the preferred method used by natural resource trustees, based on guidance in the OPA regulations. The Washington Compensation Schedule is designed for small spills, much less than the volumes considered here. Habitat Equivalency Analysis (HEA) was used to estimate the required amount of habitat (saltmarsh) restoration for NRD compensation of injuries to wildlife, fish and invertebrate species. Production by the restored habitat ultimately benefits wildlife, fish and invertebrates, and equivalency is assumed if equal production of similar species (i.e., the same general taxonomic group and trophic level) results. According to HEA-scaled calculations, the offshore crude oil scenario would be the most expensive to provide compensatory restoration because of the relatively large impact on birds.

The changes in natural resource damages with different response alternatives were estimated by examining individual runs, holding spill conditions constant so comparisons can be made. In most scenarios, the difference between no mechanical removal and any of the mechanical removal capacity assumptions (state, federal or 3rd alternative) was less than the variability in the model. In some scenarios, the state mechanical response capacities were higher than the federal, and the 3rd alternative capacities were higher than the state's, so that the damages typically were higher for the federal and lower for the 3rd alternative than for the state standards. Variability in some of the results involving mechanical response was insignificant and due to the randomization routine employed to simulate natural dispersion.

Table E-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed.

Scenario Name	Site	Location	Oil	bbls	Response
OC-C250K-N	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	No Removal
OC-C250K-Fed	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	Federal Caps
OC-C250K-WA	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	WA Caps
OC-C250K-3	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	3rd Caps
JF-B25K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	No Removal
JF-B25K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	Federal Caps
JF-B25K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	WA Caps
JF-B25K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	3rd Caps
JF-D65K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	No Removal
JF-D65K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	Federal Caps
JF-D65K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	WA Caps
JF-D65K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	3rd Caps
JF-C250K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	No Removal
JF-C250K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	Federal Caps
JF-C250K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	WA Caps
JF-C250K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	3rd Caps

Table E-1 (cont.) Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed.

Scenario Name	Site	Location	Oil	bbls	Response
SJ-C250K-N	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	No Removal
SJ-C250K-Fed	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	Federal Caps
SJ-C250K-WA	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	WA Caps
SJ-C250K-3	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	3rd Caps
CL-B25K-N	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	No Removal
CL-B25K-Fed	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	Federal Caps
CL-B25K-WA	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	WA Caps
CL-B25K-3	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	3rd Caps
CU-B25K-N	Upper Columbia River	Portland to Longview	Bunker C	25,000	No Removal
CU- B25K -Fed	Upper Columbia River	Portland to Longview	Bunker C	25,000	Federal Caps
CU- B25K -WA	Upper Columbia River	Portland to Longview	Bunker C	25,000	WA Caps
CU- B25K -3	Upper Columbia River	Portland to Longview	Bunker C	25,000	3rd Caps
OL-B150K-DESW1-N	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	No Removal
OL-B150K-DESW1-R-Fed	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait	Bunker C	150,000	Federal Caps

Scenario Name	Site	Location	Oil	bbls	Response
		of Juan de Fuca			
OL-B150K-DESW1-R-WA	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	WA Caps
OL-B150K-DESW1-R-3	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	3rd Caps
GH-B25K-N2	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	No Removal
GH-B25K-R-Fed	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	Federal Caps
GH-B25K-R-WA	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	WA Caps
GH-B25K-R-WA	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	3rd Caps

NOTE: For all responses, Canada is assumed to respond based on the equivalent of the US Federal CAPS standard and the state of Oregon is assumed to respond based on the Washington state CAPS standard.

Table E-2. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 0.01 g/m2 (where cleanup would occur).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,040	2,020	-	6,079
JF-Bunk-N	428	217	-	863
JF-Dies-N	588	481	-	1,550
JF-Crud-N	2,647	1,576	-	5,799
SJ-Crud-N	4,958	2,340	278	9,638
CL-Bunk-N	635	491	-	1,617
CU-Bunk-N	296	115	67	525
OL-Bunk-N	1,034	729	-	2,491
GH-Bunk-N	539	383	-	1,305

Table E-3. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	488,751	611,866	-	1,712,483
JF-Bunk-N	23,120	8,247	6,627	39,613
JF-Dies-N	31,010	13,852	3,306	58,714
JF-Crud-N	163,739	87,505	-	338,749
SJ-Crud-N	93,384	28,122	37,140	149,627
CL-Bunk-N	60,349	50,185	-	160,718
CU-Bunk-N	1,263	800	-	2,864
OL-Bunk-N	121,305	97,079	-	315,464
GH-Bunk-N	31,669	38,202	-	108,073

Table E-4. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	234.0	156.0	-	545.0
JF-Bunk-N	1.8	0.6	0.6	3.0
JF-Dies-N	2.4	1.3	-	5.1
JF-Crud-N	15.7	9.4	-	34.5
SJ-Crud-N	8.2	2.1	4.0	12.5
CL-Bunk-N	10.2	8.1	-	26.5
CU-Bunk-N	97.1	23.0	50.0	144.0
OL-Bunk-N	55.6	27.4	0.9	110.4
GH-Bunk-N	7.42	7.42	-	22.26

Table E-5. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	1,376	1,388	-	4,152
JF-Bunk-N	62	10	41	82
JF-Dies-N	49,500	29,488	-	108,476
JF-Crud-N	14,544	8,834	-	32,212
SJ-Crud-N	6,807	9,599	-	26,005
CL-Bunk-N	6	9	-	24
CU-Bunk-N	3,382	343	2,695	4,069
OL-Bunk-N	82	31	20	145
GH-Bunk-N	17	4	8	25

Table E-6. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (clams).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	9,026	10,561	-	30,149
JF-Bunk-N	33,955	35,399	-	104,752
JF-Dies-N	28,928	41,555	-	112,038
JF-Crud-N	174,703	117,105	-	408,913
SJ-Crud-N	305,639	130,644	44,351	566,926
CL-Bunk-N	1,086	860	-	2,805
CU-Bunk-N	-	-	-	-
OL-Bunk-N	7,986	6,753	-	21,492
GH-Bunk-N	5,181	3,769	-	12,718

Table E-7. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	502	584	-	1,669
JF-Bunk-N	26	13	2.4	51
JF-Dies-N	82	51	3.3	184
JF-Crud-N	179	74	53	327
SJ-Crud-N	99	29	53	157
CL-Bunk-N	41	40	0	121
CU-Bunk-N	1.3	0.6	0.4	2.4
OL-Bunk-N	112	85	0.1	282
GH-Bunk-N	25	32	0.01	88

1. INTRODUCTION

As part of their rulemaking related to oil spill preparedness (Washington State Contingency Plan Rule), the Washington State Department of Ecology (WDOE) needs to evaluate the implications of various spill response options being considered. Oil spill fate and effects modeling and analysis was performed to estimate the impacts of potential spills in Washington's outer coast, sound and river environments, assuming various response options and operational timing and using conventional mechanical containment and recovery operations. US Coast Guard federal response capability standards, current Washington State standards, and potential theoretical higher response capability standards were simulated for scenarios involving spills of crude oil, bunker fuel and diesel into Washington waters in seven geographic locations: Strait of Georgia (near the San Juan Islands), Strait of Juan de Fuca, Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, Grays Harbor, and lower and upper Columbia River. These locations were selected to be representative of potential spill sites along transportation routes. The upper Columbia River was used to evaluate implications of spills into large rivers of similar dimensions and river flow.

The SIMAP (Spill Impact Model Application Package) model system, comprised of three-dimensional oil fate and biological effects models, was used for this study. The modeling was performed in probabilistic (stochastic) mode, randomly varying location along shipping routes, spill date, and time, and so environmental conditions during and after the release among potential conditions that would occur. The model results from these stochastic scenarios were analyzed to estimate mean, standard deviation, and 5th, 50th and 95th percentile results for surface water and shoreline oiling, water column and sediment contamination, biological impacts (to wildlife, fish, invertebrates, and habitats), and natural resource damages (NRD) for losses of ecological services. NRD costs were based on the Washington Compensation Schedule and the US Oil Pollution Act (OPA) NRD procedures involving compensatory restoration and associated costs. Response costs and socioeconomic damages were evaluated in a companion study by D.S. Etkin (Environmental Research Consulting; Etkin, 2005b,c; Etkin et al., 2006).

This report describes the approach, model, data inputs, and results of the second phase of modeling performed to support WDOE's rule development. The modeling analysis now described as Phase I is described in the draft report of that work (French McCay et al., 2004b), and an updated report available in November 2005 (French McCay et al., 2005b). Summaries of the Phase I model results are in French McCay et al. (2005b). In addition, Etkin (2004a,b) and Etkin et al. (2005, 2006) describe the response modeling assumptions used as inputs to the oil spill modeling, as well as the response and socioeconomic costs estimated to result from the scenarios evaluated as part of Phase I.

In Phase I, mechanical recovery was modeled assuming that equipment to fulfill the various response capability levels was available, in good working condition, and handled by competent, trained personnel. Mechanical recovery and storage equipment was assumed to be operating at the Effective Daily Recovery Capability (EDRC) rate. It was also assumed that if oil was on the water surface and available for recovery, personnel

would be able to locate and reach that oil and recover it at the EDRC rate. With these assumptions, the model results indicated that up to 50-70% of the spilled oil would be recoverable. Moreover, the differences between the three alternative mechanical recovery standards were small because, with the high efficiencies assumed, the capacities were large enough in all three cases to eventually recover much of the oil.

However, in an actual spill response, there are a number of reasons why such high efficiencies and recovery rates would not be realized, including logistical problems, difficulty in tracking oil, breakdowns, etc. Thus, in Phase II of the modeling, reported here, increasing inefficiencies in recovery capability with time were built into the response model assumptions for all three alternative capacity standards. The response model assumptions for Phase II were developed by Dr. D. S. Etkin and WDOE, as described in Etkin (2005b) and Etkin et al. (2006). The inputs to the oil spill model are briefly summarized in Section 3.6 below.

Inputs to the oil spill model SIMAP include habitat and depth mapping, winds, currents, other environmental conditions, chemical composition and properties of the oils most likely to be spilled, specifications of the release (amount, location, etc.), toxicity parameters, and biological abundance. These model inputs were developed as part of Phase I. Descriptions of these data are contained in this Phase II report as well. Model results are displayed by a Windows graphical user interface that animates the trajectory and concentrations over time. The figures included here (Volumes II-XXIX) are snapshots taken from that output, synoptically (over time after the spill) showing the areas and volumes where oil or concentrations in the water would move if there were a spill of the assumed volume and conditions.

In Phase II, SIMAP was first run in stochastic mode for 9 scenarios assuming no response to estimate probabilities and degrees of oil exposure for each location in the vicinity of a spill. The output of the stochastic model includes time histories of a large number of spill trajectories. These distributions are used to (1) estimate the percent of these hypothetical spills where water surface, water column, and shoreline areas will be affected by a release; (2) determine the highest exposure concentration in time and for any possible environmental condition; and (3) identify the worst-case runs out of 100 randomly-selected events that either, had the most impact on selected sensitive sites or oiled the most shoreline.

For each of the 9 stochastic scenarios, 100 simulations were run for a given spill location (shipping route segment), oil and (no) response scenario, varying the spill date and time, and thus the environmental conditions, for each run. The results were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (the per area portion of the costs) are related to biological impacts on shorelines. Response and socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to degree of shoreline oiling.

In Phase II, the results for worst-case runs based on shore costs or impacts to selected sensitive sites were evaluated in detail. However, certain impacts, such as to waterfowl and seabirds, were more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) were related to water contaminated above a threshold for effects. Intertidal zone impacts to clams were related to degree of soft (sand, mud, or wetland) shoreline oiling. Because other impact indices were not necessarily correlated with shore cost, the results for other indices were not typically in increasing order from 5th to 95th percentile run by shore cost. The actual 5th, 50th and 95th percentile results for the 100 values of the index were calculated by sorting only the index being considered. The mean and standard deviation of the 100 results were also calculated. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

It should also be noted that the response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal and booming are added to the scenario. When alternative response options were examined, the individual run dates and times were held constant across alternate response scenarios so inter-comparisons could be made.

Table 1-1 lists the scenarios examined in Phase II. The 9 stochastic scenarios are those with no response assumed. The other scenarios were run for selected runs by altering the response assumed from the no-response base run. Thus, only the 3 runs were examined in the alternate scenarios. Figures 1-1 to 1-3 show the hypothetical spill locations examined.

Table 1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed.

Scenario Name	Site	Location	Oil	bbls	Response
OC-C250K-N	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	No Removal
OC-C250K-Fed	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	Federal Caps
OC-C250K-WA	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	WA Caps
OC-C250K-3	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	3rd Caps
JF-B25K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	No Removal
JF-B25K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	Federal Caps
JF-B25K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	WA Caps
JF-B25K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	3rd Caps
JF-D65K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	No Removal
JF-D65K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	Federal Caps
JF-D65K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	WA Caps
JF-D65K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	3rd Caps
JF-C250K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	No Removal
JF-C250K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	Federal Caps
JF-C250K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	WA Caps
JF-C250K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	3rd Caps

Table 1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed (continued).

Scenario Name	Site	Location	Oil	bbls	Response
SJ-C250K-N	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	No Removal
SJ-C250K-Fed	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	Federal Caps
SJ-C250K-WA	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	WA Caps
SJ-C250K-3	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	3rd Caps
CL-B25K-N	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	No Removal
CL-B25K-Fed	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	Federal Caps
CL-B25K-WA	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	WA Caps
CL-B25K-3	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	3rd Caps
CU-B25K-N	Upper Columbia River	Portland to Longview	Bunker C	25,000	No Removal
CU- B25K -Fed	Upper Columbia River	Portland to Longview	Bunker C	25,000	Federal Caps
CU- B25K -WA	Upper Columbia River	Portland to Longview	Bunker C	25,000	WA Caps
CU- B25K -3	Upper Columbia River	Portland to Longview	Bunker C	25,000	3rd Caps
OL-B150K-DESW1-N	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	No Removal
OL-B150K-DESW1-R-Fed	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	Federal Caps

Table 1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed (continued).

Scenario Name	Site	Location	Oil	bbls	Response
OL-B150K-DESW1-R-WA	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	WA Caps
OL-B150K-DESW1-R-3	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	3rd Caps
GH-B25K-N2	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	No Removal
GH-B25K-R-Fed	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	Federal Caps
GH-B25K-R-WA	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	WA Caps
GH-B25K-R-3	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	3rd Caps

NOTE: For all responses, Canada is assumed to respond based on the equivalent of the US Federal CAPS standard and the state of Oregon is assumed to respond based on the Washington state CAPS standard.

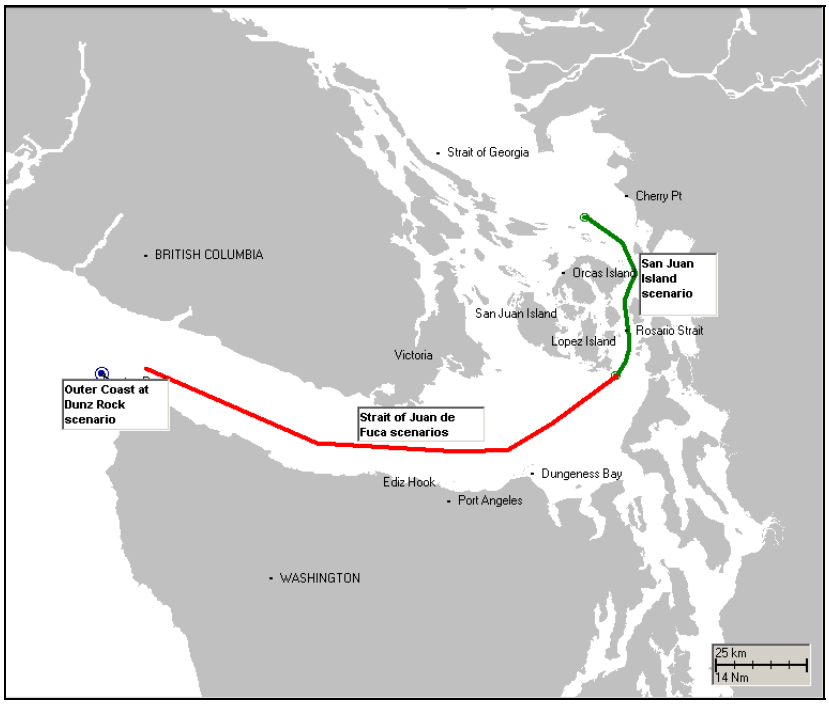

Figure 1-1. Shipping route segments where the hypothetical spills are assumed to occur: Straits and Outer Coast at Duntz Rock scenarios.

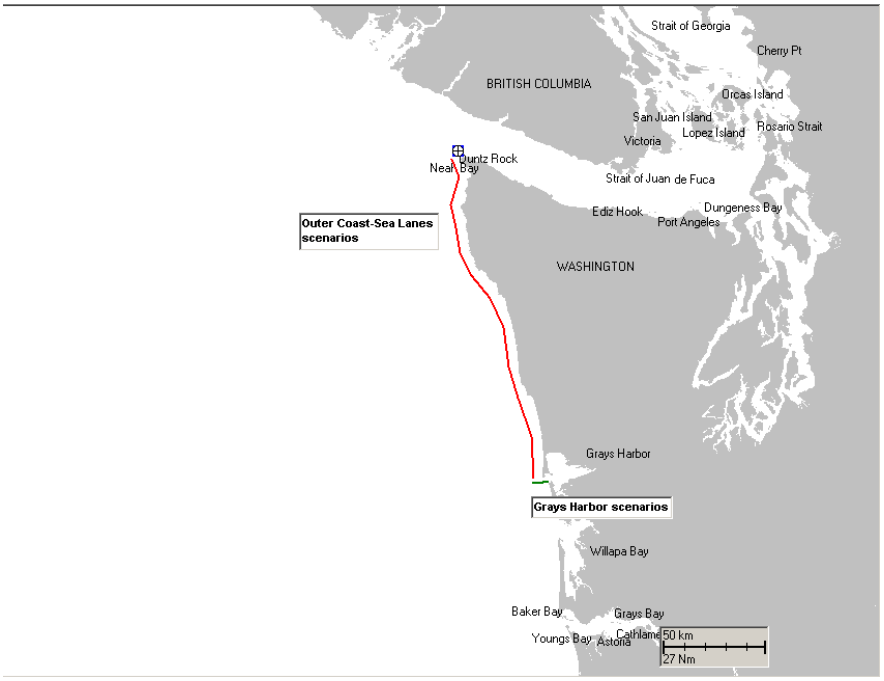

Figure 1-2. Shipping route segments where the hypothetical spills are assumed to occur: Outer Coast-Sea Lanes and Grays Harbor scenarios.

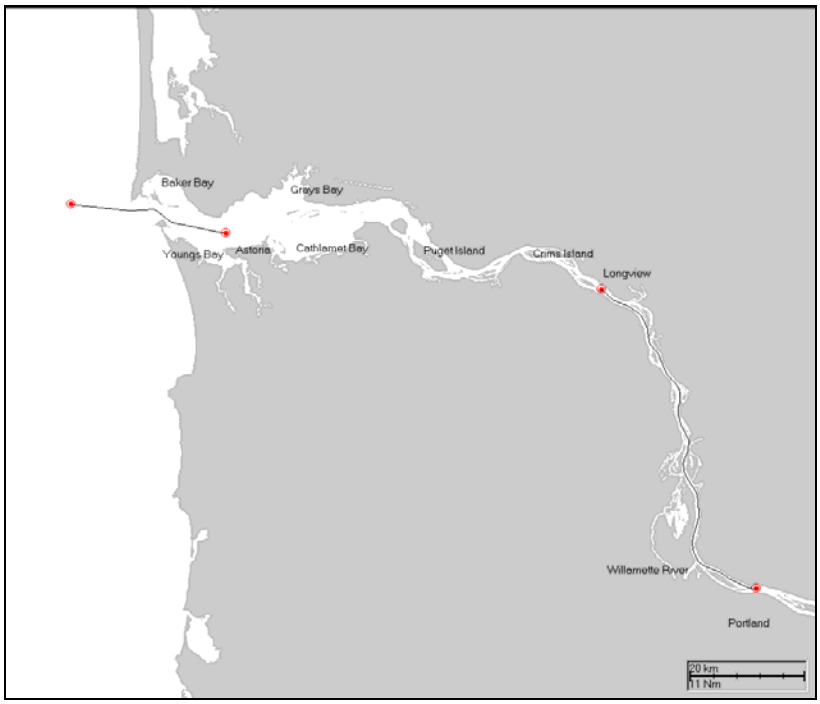

Figure 1-3. Shipping route segments where the hypothetical spills are assumed to occur: Columbia River scenarios.

In order to perform the modeling, the following input data sets were prepared for each area around where spills were simulated:

1. Shoreline location, shoreline/habitat type, and bathymetric (water depth) mapping for coastal Washington, the Vancouver Island region of British Columbia, and northern Oregon;
2. Wind data – long-term (10 year) wind record of hourly wind speed and direction;
3. Salinity and surface water temperature;
4. Current data – Tidal currents and freshwater discharge (both wet and dry seasons);
5. Oil properties and toxicity; and
6. Biological abundance.

The model results are summarized in tables of statistics describing water surface area exposed, shoreline oiled, numbers or biomass of organisms lost, and NRDA costs. Frequency distributions of model results for all runs and maps of oil exposure are also provided.

Section 2 describes the model used for both the Phase I and the Phase II analyses. Section 3 describes the model input data sources and assumptions (again, the same in both Phase I and II, with the exception of the response scenario assumptions and some of the spill volumes and locations). Thus, Sections 2 and 3 are very similar to the description in the Phase I report (Volume I of French McCay et al, 2004b, 2005b), with the exception of Section 3.6, which describes the scenarios simulated.

The Phase II results are described in Sections 4-7. Results of the physical fates model are in Section 4. Section 5 describes the biological impact results. Estimates of economic damages (NRDA costs) based on restoration of resources and their services are in Section 6. Discussion and conclusions are in Section 7, including a comparison of the Phase I and II results. Section 8 contains the references cited.

Details of the model input data and results for Phase II are in appended volumes to this main report, organized as follows. Volume II contains summary tables for all 28 scenarios. Volumes III to XXIX contain specific results for each location and oil type combination, in sets of 3 volumes: (1) model inputs, (2) results for stochastic model scenarios, and (3) results for alternate response scenarios.

2. SIMAP MODEL DESCRIPTION

The analysis was performed using the model system developed by Applied Science Associates (ASA) called SIMAP (Spill Impact Model Analysis Package). SIMAP includes (1) an oil physical fates model, (2) interfacing to a hydrodynamics model for simulation of currents, (3) a biological effects model, (4) an oil physical, chemical and toxicological database, (5) environmental databases (winds, currents, salinity, temperature), (6) geographical data (in a GIS), (7) a biological database, (8) a response module to analyze effects of response activities, (9) graphical visualization tools for outputs, and (10) exporting tools to produce text format output.

SIMAP originated from the oil fates and biological effects submodels in the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME), which ASA developed in the early 1990s for the US Department of the Interior for use in Natural Resource Damage Assessment (NRDA) regulations under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). The NRDAM/CME (Version 2.4, April 1996) was published as part of the CERCLA type A NRDA Final Rule (Federal Register, May 7, 1996, Vol. 61, No. 89, p. 20559-20614). The technical documentation for the NRDAM/CME is in French et al. (1996a,b,c). This technical development involved several in-depth peer reviews, as described in the Final Rule.

While the NRDAM/CME was developed for simplified natural resource damage assessments of small spills in the United States, SIMAP is designed to evaluate fates and effects of both real and hypothetical spills in marine, estuarine and freshwater environments worldwide. SIMAP may be run in stochastic mode to evaluate a distribution of spill results, rather than just a single result for a specific hind-cast. Additions and modifications to prepare SIMAP were made to increase model resolution, allow modification and site-specificity of input data, allow incorporation of temporally varying current data, evaluate subsurface releases and movements of subsurface oil, track multiple chemical components of the oil, enable stochastic modeling, and facilitate analysis of results.

The consideration of the impacts of subsurface oil is important, particularly in the evaluation of impacts on aquatic organisms. Surface floating oil primarily impacts wildlife and intertidal biota, and not aquatic biota in subtidal habitats. At higher wind speeds than about 12 knots (or at lower wind speeds if dispersant is applied), oil will entrain into the water column, unless it has become too viscous to do so after weathering and the formation of mousse. Once oil is entrained in the water in the form of small droplets, monoaromatics (MAHs) and polynuclear aromatic hydrocarbons (PAHs) dissolve into the water column. The dissolved MAHs and PAHs are the most bioavailable and toxic portion of the oil. The dissolution rate is very sensitive to the droplet size (because it involves mass transfer across the surface area of the droplet), and the amount of hydrocarbon mass dissolved is a function of the mass entrained and droplet size distribution. These are in turn a function of soluble hydrocarbon content of the oil, the amount of evaporation of these components before entrainment, oil viscosity (which

increases as the oil weathers and emulsifies), oil surface tension (which may be reduced by surfactant dispersants), and the energy in the system (the higher the energy the smaller the droplets). Large droplets (greater than a few hundred microns in diameter) resurface rapidly, and so dissolution from those is also inconsequential. Dispersant application facilitates the entrainment of oil into the water in a smaller size distribution than would occur naturally, with the median droplet size about 20 μm (Lunel, 1993a,b).

Thus, the fate of MAHs and PAHs in surface oil is primarily volatilization to the atmosphere, rather than to the water. If wind speeds exceed 12 knots, entrainment of the surface oil into the water becomes significant. Dispersant application can also facilitate entrainment into the water column. If oil is entrained before it has weathered and lost the lower molecular weight aromatics to the atmosphere, dissolved MAHs and PAHs in the water can reach concentrations where they can affect water column organisms or bottom communities (French McCay and Payne, 2001).

Below are brief descriptions of the fates and effects models implemented in SIMAP. Detailed descriptions of the algorithms and assumptions in the model are in published papers (French McCay 2002, 2003, 2004). The model has been validated with more than 20 case histories, including the *Exxon Valdez* and other large spills (French and Rines, 1997; French McCay, 2003, 2004; French McCay and Rowe, 2004) as well as test spills designed to verify the model (French et al., 1997).

2.1 Physical Fates Model

The three-dimensional physical fates model estimates distribution (as mass and concentrations) of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments. Oil fate processes included are spreading (gravitational and by shearing), evaporation, transport, randomized dispersion, emulsification, entrainment (natural and facilitated by dispersant), dissolution, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and semi-soluble aromatics to suspended sediments, sedimentation, and degradation.

Oil is a mixture of hydrocarbons of varying physical, chemical, and toxicological characteristics. Thus, oil hydrocarbons have varying fates and impacts on organisms. In the model, oil is represented by component categories, and the fate of each tracked separately. The “pseudo-component” approach (Payne et al., 1984, 1987; French et al., 1996a; Jones 1997; Lehr et al. 2000) is used, where chemicals in the oil mixture are grouped by physical-chemical properties, and the resulting component category behaves as if it were a single chemical with characteristics typical of the chemical group.

The most toxic components of oil to aquatic organisms are low molecular weight aromatic compounds (monoaromatic and polynuclear aromatic hydrocarbons, MAHs and PAHs), which are both volatile and soluble in water. Their acute toxic effects are by narcosis, where toxicity is related to the octanol-water partition coefficient (K_{ow}), a measure of hydrophobicity. The more hydrophobic the compound, the more toxic, but

the less soluble and so the less exposure there is to aquatic organisms. Compounds of $\log(K_{ow})>5.6$ are considered insoluble and so unavailable to aquatic biota (French McCay, 2002). Thus, impact is the result of a balance between bioavailability (exposure) and toxicity once exposed. French McCay (2002) contains a full description of the oil toxicity model in SIMAP.

Because of these considerations, the SIMAP fates model focuses on tracking the lower molecular weight aromatic components divided into chemical groups based on volatility, solubility, and hydrophobicity. In the model, the oil is treated as eight components (defined in Table 2-1). Six of the components (all but the two non-volatile residual components) evaporate at rates specific to the pseudo-component. Solubility is strongly correlated with volatility, and the solubility of aromatics is higher than aliphatics of the same volatility, with the MAHs the most soluble, the 2-ring PAHs semi-soluble, and the 3-ring PAHs slightly soluble Mackay et al. (1992a,b,c,d). Both the solubility and toxicity of the non-aromatic hydrocarbons are much less than for the aromatics and dissolution (and water concentrations) of non-aromatics is safely ignored. Thus, dissolved concentrations are calculated only for each of the three soluble aromatic pseudo-components.

Table 2-1. Definition of four distillation cuts and the eight pseudo-components in the model (monoaromatic hydrocarbons, MAHs; benzene + toluene + ethybenzene + xylene, BTEX; polynuclear aromatic hydrocarbons, PAHs).

Characteristic	**Volatile and and Highly Soluble**	**Semi-volatile and Soluble**	**Low Volatility and Slightly Soluble**	**Residual (non-volatile and insoluble)**
Distillation cut	1	2	3	4
Boiling Point (^oC)	< 180	180 - 265	265 - 380	>380
Molecular Weight	50 - 125	125 - 168	152 - 215	> 215
$\text{Log}(K_{ow})$	2.1-3.7	3.7-4.4	3.9-5.6	>5.6
Aliphatic pseudo-components: Number of Carbons	volatile aliphatics: C4 – C10	semi-volatile aliphatics: C10 – C15	low-volatility aliphatics: C15 – C20	non-volatile aliphatics: > C20
Aromatic pseudo-component name: included compounds	MAHs: BTEX, MAHs to C3-benzenes	2 ring PAHs: C4-benzenes, naphthalene, C1-, C2-naphthalenes	3 ring PAHs: C3-, C4-naphthalenes, 3-4 ring PAHs with $\log(K_{ow}) < 5.6$	$\geq$4 ring aromatics: PAHs with $\log(K_{ow}) > 5.6$ (insoluble)

This number of components provides sufficient accuracy for the evaporation and dissolution calculations, particularly given the time frame (minutes) over which dissolution occurs from small droplets and the rapid resurfacing of large droplets (see discussion above). The alternative of treating oil as a single compound with empirically-derived rates (e.g., Mackay et al, 1980; Stiver and Mackay, 1984) does not provide sufficient accuracy for impact analyses because the impacts to water column organisms are caused by MAHs and PAHs, which have specific properties that differ from the other

volatile and soluble compounds. Use of more pseudo components does not improve accuracy, as the major constituents of concern are well characterized (sufficiently similar in properties within the pseudo-component group of chemicals) by the modeled component properties used in SIMAP. The model has been validated both in predicting dissolved concentrations and resulting toxic effects, supporting the adequacy of the use of this number of pseudo-components (French McCay, 2003).

The lower molecular weight aromatics dissolve from the whole oil and are partitioned in the water column and sediments according to equilibrium partitioning theory (French et al., 1996a; French McCay 2004). The residual fractions in the model are composed on non-volatile and insoluble compounds that remain in the "whole oil" that spreads, is transported on the water surface, strands on shorelines, and disperses into the water column as oil droplets or remains on the surface as tar balls. This is the fraction that composes black oil, mousse, and sheen.

The schematic in Figure 2-1 shows oil fate processes simulated in the model in open water. The algorithms used to model these processes are described in French McCay (2004). Lagrangian elements (spillets) are used to simulate the movements of oil components in three dimensions over time. Surface floating oil, subsurface droplets, and dissolved components are tracked in separate spillets. Transport is the sum of advective velocities by currents input to the model, surface wind drift, vertical movement according to buoyancy, and randomized turbulent diffusive velocities in three dimensions. The vertical diffusion coefficient is computed as a function of wind speed in the wave-mixed layer. The horizontal and deeper water vertical diffusion coefficients are model inputs.

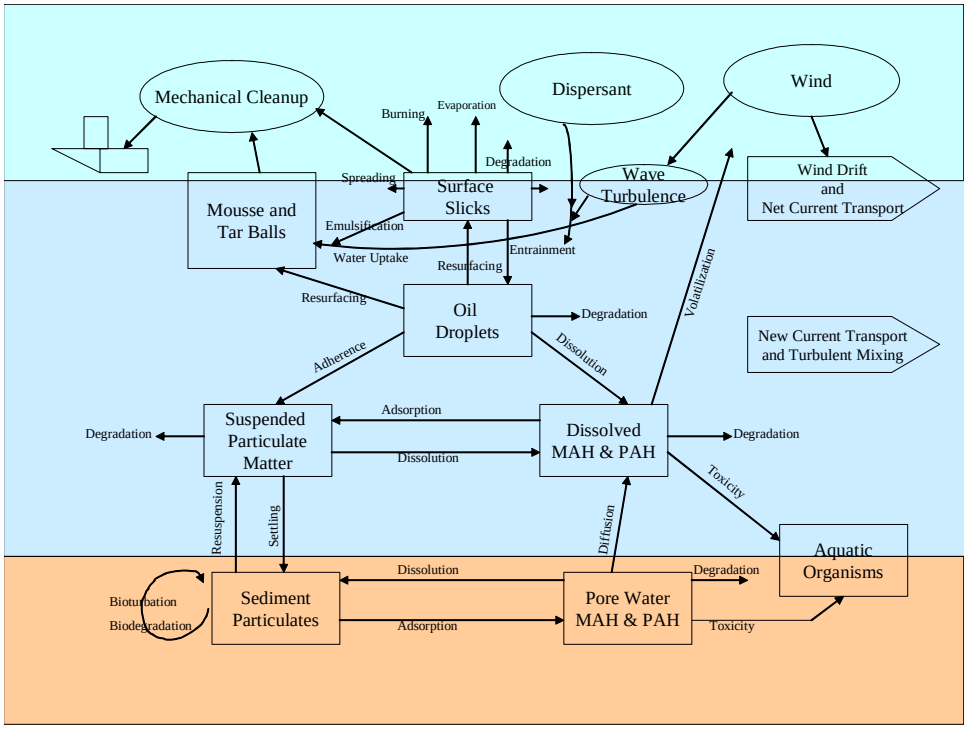

Figure 2-1. Simulated oil fates processes in open water

The oil (whole and as pseudo-components) separates into different phases or parts of the environment, i.e., surface slicks; emulsified oil (mousse) and tar balls; oil droplets suspended in the water column; dissolved lower molecular weight components (MAHs and PAHs) in the water column; oil droplets adhered and hydrocarbons adsorbed to suspended particulate matter in the water; hydrocarbons on and in the sediments; dissolved MAHs and PAHs in the sediment pore water; and hydrocarbons on and in the shoreline sediments and surfaces. The physical fates model creates output files recording the distribution of a spilled substance in three-dimensional space and time. The quantities recorded are:

- area covered by oil and thickness on the water surface ("swept area");
- volumes in the water column at various concentrations of dissolved aromatics;
- volumes in the water column at various concentrations of total hydrocarbons in suspended droplets;
- total hydrocarbon concentrations and dissolved aromatic concentrations in surface sediment;
- lengths and locations of shoreline impacted and volume of oil ashore in each segment.

The dissolved aromatic hydrocarbon concentration in the water column is calculated from the mass in the Lagrangian elements, as follows. Concentration is contoured on a three-dimensional Lagrangian grid system. This grid (of 200 X 200 cells in the horizontal and 5 vertical layers) is scaled each time step to just cover the volume occupied by aromatic particles, including the dispersion around each particle center. This maximizes the resolution of the contour map at each time step and reduces error caused by averaging mass over large cell volumes. Distribution of mass around the particle center is described as Gaussian in three dimensions, with one standard deviation equal to twice the diffusive distance ($2D_xt$ in the horizontal, $2D_zt$ in the vertical, where D_x is the horizontal and D_z is the vertical diffusion coefficient, and t is particle age). The plume grid edges are set at one standard deviation out from the outer-most particle. These data are used by the biological effects model to evaluate exposure, toxicity and impacts.

2.2 Biological Effects Model

The biological exposure model estimates the area, volume or portion of a stock or population affected by surface oil, concentrations of oil components in the water, and sediment contamination. The biological effects model estimates losses resulting from acute exposure after a spill (i.e., losses at the time of the spill and while acutely toxic concentrations remain in the environment) in terms of direct mortality and lost production because of direct exposure or the loss of food resources from the food web. Losses are estimated by species or species group for fish, invertebrates (i.e., shellfish and non-fished species) and wildlife (birds, mammals, sea turtles). Lost production of aquatic plants (microalgae and macrophytes) and lower trophic levels of animals are also estimated.

The area potentially affected by the spill is represented by a rectangular grid with each grid cell coded as to habitat type. The habitat grid is also used by the physical fates

model to define the shoreline location and type, as well as habitat and sediment type. A habitat is an area of essentially uniform physical and biological characteristics that is occupied by a group of organisms that are distributed throughout that area. A contiguous grouping of habitat grid cells with the same habitat code represents an ecosystem in the biological model. The density of fish, invertebrates and wildlife, and rates of lower trophic level productivity, are assumed constant for the duration of the spill simulation and evenly distributed across an ecosystem. While biological distributions are known to be highly variable in time and space, data are generally not sufficient to characterize this patchiness. Oil is also patchy in distribution. The patchiness is assumed to be on the same scale so that the intersection of the oil and biota is equivalent to overlays of spatial mean distributions.

Mobile fish, invertebrates and wildlife are assumed to move at random within each ecosystem during the simulation period. This is a reasonable assumption for the period of the simulation (generally a few weeks). Benthic organisms may also remain stationary on or in the bottom. Planktonic stages, such as pelagic fish eggs, larvae, and juveniles (i.e., young-of-the-year during their pelagic stage(s)), move with the currents.

Habitats include open water, wetland, sea grass, macroalgal (kelp) bed and shoreline environments. Habitat types are defined by depth, proximity to shoreline(s), bottom/shore type, dominant vegetation type, and the presence of invertebrate reefs. With respect to proximity to shoreline(s), habitats are designated as landward or seaward. Landward portions are the near-shore rivers, estuaries and inlets. The seaward portion is the more oceanic or main part of the water body. This designation allows different biological abundances to be simulated in landward and seaward zones of the same habitat type (e.g., open water with sand bottom).

2.2.1 Wildlife

In the model, surface slicks (or other floating forms such as tar balls) of oils and petroleum products impact wildlife (birds, marine mammals). For each of a series of surface spillets, the physical fates model calculates the location and size (radius of circular spreading spillet) as a function of time. The area swept by a surface spillet in a given time step is calculated as the quadrilateral area defined by the path swept by the spillet diameter. This area is summed over all time steps for the time period the spillet is present on the water surface and separately for each habitat type where the oil passes. Spillets sweeping the same area of water surface at the same time are superimposed. The total area swept over a threshold thickness by habitat type is multiplied by the probability that a species uses that habitat (0 or 1, depending upon its behavior) and a combined probability of oiling and mortality. This calculation is made for each surface-floating spillet and each habitat for the duration of the model simulation.

A portion of the wildlife in the area swept by the slick over a threshold thickness is assumed to die, based on probability of encounter with the slick multiplied by the probability of mortality once oiled. The probability of encounter with the slick is related to the percentage of the time an animal spends on the water or shoreline surface. The

probability of mortality once oiled is nearly 100% for birds and fur-covered mammals (assuming they are not successfully treated) and much lower for other wildlife. The products of the two probabilities for various wildlife behavior groups are in Table 2-2. Estimates for the probabilities are derived from information on behavior and field observations of mortality after spills (reviewed in French et al., 1996a). The threshold thickness of oil for inducing mortality at a given probability is 10 micron (~10g/m^2), based on data and calculations in French et al. (1996a). The wildlife mortality model has been validated with more than 20 case histories, including the *Exxon Valdez* and other large spills, verifying that these values are reasonable (French and Rines, 1997; French McCay 2003, 2004; French McCay and Rowe, 2004).

Table 2-2. Combined probability of encounter with oil and mortality once oiled, if present in the area swept by oil exceeding a threshold thickness. Area swept is calculated for the habitats occupied.

Wildlife Group	Probability	Habitats Occupied
Dabbling waterfowl	99%	Intertidal and landward subtidal
Nearshore aerial divers	35%	Intertidal and landward subtidal
Surface seabirds	99%	All intertidal and subtidal
Aerial seabirds	5%	All intertidal and subtidal
Wetland wildlife (waders and shorebirds)	35%	Wetlands, shorelines, seagrass beds
Cetaceans	0.1%	Seaward subtidal
Furbearing marine mammals	75%	All intertidal and subtidal
Pinnipeds, manatee, sea turtles	1%	All intertidal and subtidal
Surface birds in seaward only	99%	All seaward intertidal and subtidal
Surface diving birds in seaward only	35%	All seaward intertidal and subtidal
Aerial divers in seaward only	5%	All seaward intertidal and subtidal
Surface birds in landward only	99%	All landward intertidal and subtidal
Surface diving birds in landward only	35%	All landward intertidal and subtidal
Aerial divers in landward only	5%	All landward intertidal and subtidal
Surface diving birds in water only	35%	All subtidal
Aerial divers in water only	5%	All subtidal

Area swept is calculated for the habitats occupied by each of the behavior groups of wildlife listed in Table 2-2. Species or species groups are assigned to behavior groups to evaluate their loss. Wildlife mortality is directly proportional to abundance per unit area and the percent mortalities in Table 2-2.

2.2.2 Fish and Invertebrates

In the model, aquatic biota (e.g., fish, invertebrates) are affected by dissolved aromatic concentrations in the water or sediment. This rationale is supported by the fact that soluble aromatics are the most toxic constituents of oil (Neff *et al.*, 1976; Rice *et al.*, 1977; Tatem *et al.*, 1978; Neff and Anderson, 1981; Malins and Hodgins, 1981; National Research Council, 1985, 2002; Anderson, 1985; French McCay 2002). Exposures in the water column are short in duration. Therefore, effects there are the result of acute toxicity. In the sediments, exposure may be both acute and chronic, as the concentrations may remain elevated for longer periods of time.

The model evaluates mortality and sublethal effects of dissolved aromatic concentrations in the water or sediment. Mortality is a function of duration of exposure – the longer the duration of exposure, the lower the effects concentration (see review in French McCay, 2002). At a given concentration after a certain period of time, all individuals which will die have done so. The LC50 is the lethal concentration to 50% of exposed organisms. The incipient LC50 ($LC50_{\infty}$) is the asymptotic LC50 reached after infinite exposure time (or long enough that that level is approached, Figure 2-2). Percent mortality is a log-normal function of concentration, with the LC50 the center of the distribution.

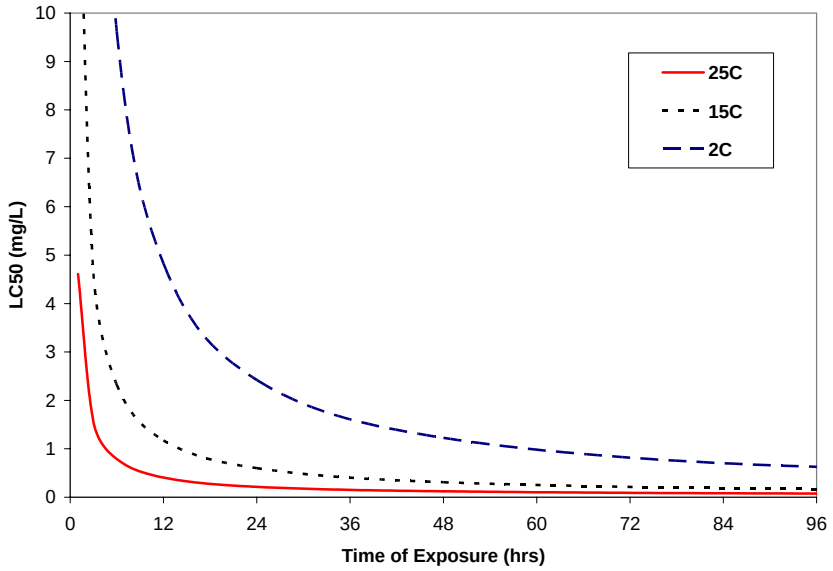

Figure 2-2. LC50 of dissolved PAH mixtures from oil, as a function of exposure duration and temperature.

The oil toxicity model in SIMAP utilizes the accepted toxic units approach for organic compounds whose primary acute effect is narcosis, which include MAHs and PAHs. The acute toxic effects of narcotic chemicals are additive (Swartz et al., 1995; French et al., 1996a; DiToro et al., 2000; DiToro and McGrath, 2000; French McCay, 2002). The approach is being used by the US Environmental Protection Agency (EPA) in the development of PAH water and sediment quality criteria (DiToro et al., 2000; DiToro and McGrath, 2000). French McCay (2002) provides estimates of $LC50_{\infty}$ for MAH and PAH mixtures in fuel and crude oils for spills under different environmental conditions. Figure 2-2 plots LC50s for total dissolved PAHs for species of average sensitivity under turbulent conditions ($LC50_{\infty}$ = 50 μg/L) for a range of exposure durations and temperatures. The $LC50_{\infty}$ for 95% of species fall in the range 6-400 μg/L (ppb). This oil toxicity model has been validated using laboratory oil bioassay data (French McCay, 2002).

In SIMAP, $LC50_{\infty}$ for the dissolved aromatic mixture of the spilled oil is input to the model. For each of a series of aquatic biota behavior groups, the model evaluates exposure duration, and corrects the LC50 for time of exposure and temperature to calculate mortality (Figure 2-2). The oil toxicity model is described in detail in French McCay (2002).

Movements of biota, either active or by current transport, are accounted for in determining time and concentration of exposure. Lagrangian elements are used to represent schools or groups of animals. The elements move or remain stationary according to the behavior of the animal type, and concentration and duration of exposure are recorded. Exposures are integrated over space and time by habitat type (open water, reef, or wetland in offshore or nearshore waters) to calculate a total percentage killed. The behavior groups, representing species or stages within species, are:

1) planktonic (move with currents),
2) demersal and stationary (on the bottom exposed to near bottom water),
3) benthic (in the sediments and stationary),
4) demersal fish and invertebrates (on the bottom exposed to near bottom (within 1 m) water and moving slowly),
5) small pelagic fish and invertebrates (moving randomly and slowly in the water column), and
6) large pelagic fish and invertebrates (moving randomly and rapidly in the water column).

Mortality is calculated as percent loss in specified areas. This is translated into the equivalent area of 100% loss. That area is divided by the total area of habitat available in the region of interest to estimate a percentage of the population in the area affected. The percent mortality of the exposure group is multiplied by abundance at the time exposed and in the habitat type to calculate the species' mortality as numbers or biomass (kg).

Lost production of lower trophic level plants and animals (not explicitly modeled as individual species) is also integrated in space and over time using EC50s, the effective concentration to reduce growth to 50% of normal, to parameterize a log-normal function of the same form as the mortality function. Total production loss (g dry weight) is summed over time and space. Production losses of lower trophic levels are typically very small because of their short generation times and quick recovery after a spill. They have not been measured in the field because the impact is less than natural variability.

2.2.3 Validation of the Biological Effects Model

The biological effects model has been validated using simulations of over 20 spill events where data are available for comparison (French and Rines, 1997; French McCay, 2003, 2004; French and Rowe, 2004). In most cases (French and Rines, 1997; French McCay, 2004; French and Rowe, 2004) only the wildlife impacts could be verified because of limitations of the available observational data. However, in the *North Cape* spill simulations, both wildlife and water column impacts (lobsters) could be verified (French McCay, 2003).

2.2.4 Quantification of Fish and Invertebrate Impacts as Lost Production

The biomass (kg) of animals killed represents biomass that had been produced before the spill. In addition, if the spill had not occurred, the killed organisms would have continued to grow until they died due to natural or fishing mortality. This lost future (somatic) production is estimated and added to the direct kill. The total impact is the total production foregone. The loss is expressed in present day (i.e., present year) values using a 3% annual discount rate for future losses. Restoration should compensate for this loss. The scale of restoration needed is equivalent to production lost when both are expressed in values indexed to the same year, i.e., the present year.

Interim losses are sustained in future years (pending recovery to baseline abundance) resulting from the direct kill at the time of the spill. Interim losses potentially include:

- Lost future uses (ecological and human services) of the killed organisms themselves;
- Lost future (somatic) growth of the killed organisms (i.e., production foregone, which provides additional services);
- Lost future reproduction, which would otherwise recruit to the next generation.

The approach used here for estimating natural resource damages is that the injury includes the direct kill and its future services, plus the lost somatic growth of the killed organisms, which would have provided additional services. Because the impact on each species, while locally significant, is relatively small compared to the scale of the total population in the area, it is assumed that density-dependent changes in survival rate are negligible, i.e., changes in natural and fishing mortality of surviving animals do not compensate for the killed animals during the natural life span of the animals killed.

It is also assumed that the impacts were not large enough to significantly affect future reproduction and recruitment in the long term. It is assumed that sufficient eggs will be produced to replace the lost animals in the next generation. The numbers of organisms affected, while locally significant, are relatively small portions of the total reproductive stock. Given the reproductive strategy of the species involved to produce large numbers of eggs, of which only a few survive, it is assumed that density-dependent compensation for lost reproduction occurs naturally.

The services provided by the injured organisms are measured in terms of production, i.e., biomass (kg wet weight) directly lost or not produced. Among other factors, services of biological systems are related to the productivity of the resources, i.e., to the amount of food produced, the usage of other resources (as food and nutrients), the production and recycling of wastes, etc. Particularly in aquatic ecosystems, the rate of turnover (production) is a better measure of ecological services than standing biomass (Odum, 1971). Thus, the sum of the standing stock killed (which resulted from production previous to the spill) plus lost future production is a more appropriate scaler, as opposed to standing stock alone (as number or kg), for measuring ecological services.

This method was developed and used previously in the injury quantification for the *North Cape* spill of January 1996 (French McCay et al., 2001, 2003a). The procedure makes use of the population model in SIMAP. Injuries are calculated in three steps:

1. The direct kill is quantified by age class using a standard population model used by fisheries scientists.
2. The net (somatic) growth normally to be expected of the killed organisms is computed and summed over the remainder of their life spans (termed lifetime production).
3. Future interim losses are calculated in present day values using discounting at a 3% annual rate.

The normal (natural in local waters) survival rates per year and length-weight by age relationships are used to construct a life table of numbers and kg for each annual age class. Lifetime production is estimated as the sum of the net (somatic) growth normally to be expected of the killed individual over the remainder of its life span. The age-class specific weight gain per year times percent expected to be left alive by the end of that year is summed over all years to calculate total lifetime production. Growth in future years is discounted 3% annually. Equations for these calculations are in French McCay et al. (2003a).

It should be noted that compensation is needed for lost production of each of the individual species injured, and that losses are additive. Restoration for a prey species killed will compensate for that prey killed and all the services that prey would have provided in the future to its predators and other resources. The predators that would eat that prey but were directly killed were produced before the spill from *different* prey individuals as food. Thus, the predator's production loss must be compensated in

addition to the prey animals directly killed. This may be accomplished by providing additional prey production to compensate for the direct predator loss.

Discounting at 3% per year is included to translate losses in future years (interim loss) to present-day values. The discounting multiplier for translating value n years after the spill to present value is calculated as $(1+d)^{-n} = 1/(1+d)^{n}$, where d=0.03. Thus, the losses in future years have a discounted value in the present. In this report, all discounting is calculated based on the number of years from the year of the spill. The present day is considered the year of the spill.

2.3 Stochastic Modeling

2.3.1 Approach

In order to determine the consequences of hypothetical spills on ecological resources, multiple scenarios and conditions need to be evaluated to estimate the probability and likely amount of oil reaching each site of concern. The stochastic oil fates model in SIMAP is used to determine the range of distances and directions oil spills are likely to travel from a particular site, given historical wind and current speed and direction data for the area. To sample the universe of possible environmental conditions, long-term wind and current data are compiled. For each model run used to develop the statistics, the spill date is randomized, which provides a probability distribution of wind and current conditions during the spill. The stochastic oil fates model performs a large number of simulations for a given spill site, varying the spill time, and thus the wind and current conditions, for each run. Output of the model is the time histories of the spill trajectories. These distributions are used to estimate the percent of these hypothetical spills where water surface, water column, sediments, and shoreline areas will be affected by a release from a spill at a given site, as well as the amount of oil exposure for each of the model runs.

The stochastic oil fates model quantifies, in space and over time, for each individual model run:

- oil thickness (microns or g/m^2) on water surface,
- oil thickness (microns or g/m^2) on shorelines,
- subsurface oil droplet concentration, as total hydrocarbons ($\mu g/L = mg/m^3 \sim ppb$),
- dissolved aromatic concentration in water ($\mu g/L = mg/m^3 \sim ppb$),
- total hydrocarbon loading on sediments (g/m^2), and
- dissolved aromatics concentration in sediment pore water ($\mu g/L = mg/m^3 \sim ppb$).

The results are summarized by mapping of each of these exposure measures onto the habitat grid as:

- the time of first exceedance of the oil thickness threshold for inducing mortality,
- maximum exposure (thickness or concentration) at any time after the spill, and
- an integrated dose measure of g/m^2-hours for floating oil and sediments or ppb-hrs for concentrations.

The results of multiple model runs are also evaluated to develop the following indicators of possible exposure for each location and for each of the components listed above:

- Probability of exposure (probability that a threshold thickness or concentration will be exceeded at each location at any time following the spill).
- Time (hours) before potential first exceedance of the threshold thickness at each location.
- Worst-case maximum exposure (thickness, volume or concentration) at any time after the spill, at a given location (i.e., maximum peak exposure for all the model runs), calculated as follows. For each individual run (for each spill date run), the maximum amount over all time after the spill is saved for each location in the model grid. Then the runs are evaluated to determine the greatest or highest amount possible at each location.
- Mean expected maximum exposure (thickness, volume or concentration) at any time after the spill, at a given location (i.e., mean peak exposure of all model runs), calculated as follows. For each individual run (for each spill date run), the maximum amount over all time after the spill is saved for each location in the model grid. The runs are evaluated to determine the mean expected peak exposure (mean exposure for all runs) at each location.

The SIMAP graphical user interface produces maps of these statistics, both for individual runs and summarizing all runs. Mapped geographical data of resources (biological and human use) may be compared when overlaid with model results. The results are also tabulated by location (grid cell) and habitat or shore type. Impacts by habitat or shoreline type are tabulated for each of several ranges of exposure conditions (thickness, mass loading (g/m^2) or concentration intervals).

The stochastic modeling outputs provide a distribution of spill results, which may be summarized by statistics such as mean and standard deviation. The results are ordered into a probability density function (PDF) such that the 50th (median) and other percentile spill dates-times are identified. Individual runs may be evaluated in greater detail to characterize the impacts of events of that probability in terms of weather conditions and fate. The worst-case exposure described above is the maximum case of the model runs performed (e.g., 99th percentile if 100 runs are made).

A PDF of a particular exposure measure, such as area swept by oil, may be scaled to estimate an impact that is proportional to the exposure measure, such as percentage or number of waterfowl in the area of interest which are oiled, by running the biological exposure model to estimate the impact for specific runs and developing a regression of the impact estimates (e.g., waterfowl oiled) as a function of the exposure measure (e.g., area swept by oil). This approach was used in the analysis of model results in this study. The impact on each biological resource was evaluated as proportional to the exposure measure by which the resource is most affected (such as surface area swept for waterfowl and seabirds, water column volume where dissolved aromatic concentration exceeds the threshold for effects for fish, percent of oil in the water column, etc.). The exposure included was only that in habitats occupied by the species group.

Table 2-3 lists biological resource categories and the exposure measures used to develop linear regressions for each group. Impacts to wildlife (birds and marine or aquatic mammals) and subtidal fish and invertebrates were calculated using the biological effects model for the following 12 runs selected from the stochastic model results (assuming no response).

- 5th, 50th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions for all scenarios except the Outer Coast – Sea Lanes and Grays Harbor;
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions for the Outer Coast – Sea Lanes and Grays Harbor scenarios only;
- 5th, 50th and 95th percentile runs based on shore cost, including only Washington state shorelines for all scenarios except the Outer Coast – Sea Lanes and Grays Harbor (nearly all shoreline impacts were in Washington for these scenarios);
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by >10g/m^2, which is the threshold thickness for oiling wildlife with a lethal dose.

The individual runs were for specific spill dates, using the abundances for the appropriate season. As impacts are proportional to pre-spill abundance, the wildlife results were corrected to be for an annual mean abundance using the ratio of annual mean to seasonal abundance before the regression slope and intercept were calculated. This correction was not made for fish and invertebrates as the results are not directly proportional because of the differences in distribution of young-of-the-year and older age classes.

Table 2-3. Biological resource types and exposure measure by which the resource is most affected.

Resource	**Exposure Measure**
Waterfowl	Water surface area swept by > 10 g/m^2 of oil and wetland area oiled by > 100 g/m^2
Seabirds	Water surface area swept by > 10 g/m^2 of oil
Raptors	Water surface area swept by > 10 g/m^2 of oil (nearshore and wetland)
Cetaceans	Water surface area swept by > 10 g/m^2 of oil (open waters only)
Pinnipeds (seals)	Water surface area swept by > 10 g/m^2 of oil
Other mammals	Water surface area swept by > 10 g/m^2 of oil (nearshore and wetland)
Wading birds	Wetland and soft shoreline area oiled by > 100 g/m^2
Shorebirds	Wetland and soft shoreline area oiled by > 100 g/m^2
Fish and invertebrates in water or on bottom, plankton	Maximum percentage of oil in the water column at any time after the spill
Benthic biota (in the sediments)	Sediment concentrations (>1 ppb dissolved aromatic concentration in pore water)

The regression slopes and intercepts were used to estimate the impacts for all 100 runs of the stochastic model scenarios. The regressions were also used to estimate the biological impacts for all runs of the alternative response scenarios. Also, the mean and standard deviation of impacts on biological resources were reported along with 95% confidence intervals, which were calculated by adding or subtracting two standard deviations from the mean.

For intertidal biota, the impacts were estimated directly from the habitat area oiled by > 100 g/m^2 of oil. The affected area was multiplied by density (biomass per unit area) in the habitat to estimate the impact.

The stochastic modeling approach described above has been used to estimate potential impacts as part of contingency planning, ecological risk assessments, net environmental benefit, and cost-benefit analyses (French et al, 1999; French McCay et al. 2002, 2003b, 2004a). The strength of the approach is that the range of possible environmental conditions is sampled randomly, providing an unbiased, quantitative estimate of the distribution of expected impacts.

3. MODEL INPUT DATA

3.1 Geographical and Model Grid

For geographical reference, SIMAP uses a rectilinear grid to designate the location of the shoreline, the water depth (bathymetry), and the shore or habitat type. The grid is generated from a digital coastline using the ESRI Arc/Info compatible Spatial Analyst program. The cells are then coded for depth and habitat type. Note that the model identifies the shoreline using this grid. Thus, in model outputs, the coastline map is only used for visual reference; it is the habitat grid that defines the actual location of the shoreline in the model.

The digital shoreline, shore type, and habitat mapping for the Strait of Juan de Fuca to Strait of Georgia (including Puget Sound) were obtained from the Washington State ShoreZone Inventory (Nearshore Habitat Program, Washington State Department of Natural Resources). The digital shoreline, shore type, and habitat mapping for the outer coast of Washington and the Columbia River were obtained from Environmental Sensitivity Index (ESI) Atlas database compiled for the area by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA). Shore type data for Vancouver Island and the Northern Strait of Georgia were obtained from the Government of British Columbia, Ministry of Sustainable Resource Management (http://srmwww.gov.bc.ca/dss/coastal/mris/coast2.htm).

Model grids were constructed for each spill location (i.e., shipping route segment), sized just large enough to include areas where oil would be transported after a spill. The grids were divided into as many cells as possible (within memory limits of the computer for the model code) to obtain the maximum resolution. The gridded habitat type data are shown in Section B.2 of Volumes III, VI, IX, XII, XV, XVIII, XXI, XXIV, and XXVII. The grid scale resolution and dimensions are indicated in Table E-3 of each volume.

As noted in Section 2, within a grid, habitats are designated as landward or seaward. Landward portions are the rivers, estuaries and inlets. The seaward portion is the more oceanic or main part of the water body. This designation allows different biological abundances to be simulated in landward and seaward zones of the same habitat type (e.g., open water with sand bottom). The biological database is coded to landward or seaward by species (see French et al., 1996a, c).

Ecological habitat types (Table 3-1) are broadly categorized into two zones: intertidal and subtidal. Intertidal habitats are those above spring low water tide level, with subtidal being all water areas below that level. Intertidal areas may be extensive, such that they are wide enough to be represented by an entire grid cell at the resolution of the grid. These are typically either mud flats or wetlands, and are coded 20 (seaward mudflat), 21 (seaward wetland), 50 (landward mudflat) or 51 (landward wetland). All other intertidal habitats are typically much narrower than the size of a grid cell. Thus, these fringing intertidal types (indicated by F in Table 3-1) have typical (for the region, French et al., 1996a) widths associated with them in the model. Boundaries between land and water

are fringing intertidal habitat types. On the waterside of fringing intertidal grid cells, there may be extensive intertidal grid cells if the intertidal zone is extensive. Otherwise, subtidal habitats border the fringing intertidal.

Table 3-1. Classification of habitats. Seaward (Sw) and landward (Lw) system codes are listed. (Fringing types indicated by (F) are only as wide as the intertidal zone in that province. Others (W = water) are a full grid cell wide and must have a fringing type on the land side.)

Habitat Code (Sw,lw)	Ecological Habitat	F or W
Intertidal		
1,31	Rocky Shore	F
2,32	Gravel Beach	F
3,33	Sand Beach	F
4,34	Fringing Mud Flat	F
5,35	Fringing Wetland (Saltmarsh)	F
6,36	Macrophyte Bed	F
7,37	Mollusk Reef	F
8,38	Coral Reef	F
Subtidal		
9,39	Rock Bottom	W
10,40	Gravel Bottom	W
11,41	Sand Bottom	W
12,42	Silt-mud Bottom	W
13,43	Wetland (Subtidal of Saltmarsh)	W
14,44	Macroalgal (Kelp) Bed	W
15,45	Mollusk Reef	W
16,46	Coral Reef	W
17,47	Seagrass Bed	W
Intertidal		
18,48	Man-made, Artificial	F
19,49	Ice Edge	F
20,50	Extensive Mud Flat	W
21,51	Extensive Wetland (Saltmarsh)	W

The intertidal habitats were assigned based on the shore types in the Washington State ShoreZone Inventory and ESI Atlases. These data were gridded using the ESRI Arc/Info compatible Spatial Analyst program. Open water areas were defaulted to sand bottom, as open water bottom type has no influence on the model results. Where data are missing, shore types are defaulted as in Table 3-2. Habitats inside bays, inlets and estuaries were designated as landward, and open coastal water as seaward.

Table 3-2. Default fringing intertidal habitat type, given adjacent subtidal or extensive intertidal habitat type.

Subtidal or Extensive Intertidal Habitat	Fringing Intertidal Habitat
Seagrass Bed (47)	Sand Beach (33)
Subtidal Sand Bottom (41)	Sand Beach (33)
Extensive Mudflat (50)	Fringing Mudflat (34)
Extensive Wetland (51)	Fringing wetland (35)

Depth data for the offshore and coastal waters were obtained from Hydrographic Survey Data supplied on CD-ROM by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center. Hydrographic survey data consist of large numbers of individual depth soundings. The depth soundings were interpolated into the model grid for each area, by averaging all soundings falling within a cell. The gridded depth data are shown in Section B.3 of Volumes III, VI, IX, XII, XV, XVIII, XXI, XXIV, and XXVII.

3.2 Environmental Data

The model uses hourly wind speed and direction for the time of the spill and simulation. A long-term wind record (>10 year) is sampled at random to develop a probability distribution of environmental conditions that might occur at the time of a spill. Several wind data sets were available for the state of Washington waters. Data for the nearest wind station were used for each location. Wind station data are described in Section E of Volumes III, VI, IX, XII, XV, XVIII, XXI, XXIV, and XXVII.

Surface water temperature varies by month, based on data for Washington waters in French et al. (1996b), as described in Section E of Volumes III, VI, IX, XII, XV, XVIII, XXI, XXIV, and XXVII. The air immediately above the water is assumed to have the same temperature as the water surface, this being the best estimate of air temperature in contact with floating oil.

Salinity is assumed to be the mean value for the location of the spill site, based on data compiled in French et al. (1996b), as listed in Section E of Volumes III, VI, IX, XII, XV, XVIII, XXI, XXIV, and XXVII. The salinity value assumed in the model runs has little influence on the fate of the oil, as salinity is used to calculate water density (along with temperature), which is used to calculate buoyancy, and none of the oils evaluated have densities near that of the water.

Suspended sediment is assumed to be 10 mg/l, a typical value for coastal waters (Kullenberg, 1982). The sedimentation rate is set at 1 m/day. These default values have no significant affect on the model trajectory. Sedimentation of oil and PAHs becomes

significant at about 100 mg/L suspended sediment concentration. There is no indication that high suspended sediment concentrations would occur in any of the areas where spills were simulated.

The horizontal diffusion (randomized mixing) coefficient is assumed as 1 m^2/sec. The vertical diffusion (randomized mixing) coefficient is assumed to be 0.0001 m^2/sec. These are reasonable values for coastal waters based on empirical data (Okubo and Ozmidov, 1970; Okubo, 1971) and modeling experience.

3.3 Currents

3.3.1 Tidal and Other Currents

Currents have significant influence on the trajectory and oil fate, and are critical data inputs. Wind-driven, tidal and background currents are included in the modeling analysis. The local surface wind drift is calculated within the oil spill model (as described in the next section). The tidal currents and background (other than tidal) currents are input to the oil fates and biological effects models from a current file that is prepared for this purpose.

3.3.1.1 Strait of Juan de Fuca, Outer Coast at Duntz Rock and Columbia River Scenarios

For the Strait of Juan de Fuca, outer coast at Duntz Rock and Columbia River scenarios, current data were generated using ASA's boundary fitted coordinate hydrodynamic model (BFHYDRO), which produces applicable hydrodynamic data sets suitable for use in the SIMAP model system. The hydrodynamic model's governing equations and validation are described in detail in Spaulding (1984), Muin (1993), Muin and Spaulding (1997a, b), Spaulding et al. (1999a), and Sankaranarayanan and Spaulding (2003). The boundary-fitted grid is a mesh of quadrilateral cells of varying size and included angles, which are capable of handling variable geometry and flow regimes. The boundary fitted coordinate system in BFHYDRO uses general curvilinear coordinates to map the model grid to the shoreline of the water body being studied. It also allows enormous versatility in grid sizing so that many of the smaller features may be resolved, along with the larger features, without being penalized by an excessive grid size (number of cells).

The boundary-fitted method uses a set of coupled quasi-linear elliptic transformation equations to map an arbitrary horizontal multi-connected region from physical space to a rectangular mesh structure in the transformed horizontal plane. The 3-dimensional conservation of mass and momentum equations, with approximations suitable for estuaries (Muin and Spaulding, 1997a, b) that form the basis of the model, are then solved in this transformed space. In addition, an algebraic transformation is used in the vertical to map the free surface and bottom onto coordinate surfaces. The resulting equations are solved using an efficient semi-implicit finite difference algorithm.

The hydrodynamic model (BFHYDRO) has been validated in numerous applications, including in Muin and Spaulding (1997a, b), Spaulding et al. (1999a), and Sankaranarayanan and Spaulding (2003) where the governing equations are described. Applications that have been validated include San Francisco Bay (Sankaranarayanan and French McCay, 2003a), the Narragansett Bay system (Swanson et al., 1998; Spaulding et al., 1999b; Kim and Swanson, 2001), Bay of Fundy (Sankaranarayanan and French McCay, 2003b), the Savannah River (Mendelsohn et al., 1999), and Charleston Harbor, SC (Peene et al., 1997; Yassuda et al., 2000a,b; Mendelsohn et al., 2001).

Existing sources of current data were considered for the oil spill modeling of the Strait of Juan de Fuca, outer coast at Duntz Rock and Columbia River scenarios. However, we need to model spills for sample dates from at least a decade, with the tidal and other forces for those dates, and in high resolution in the area of the spill site. Thus, we applied BFHYDRO, and compared the predictions to existing current data, as well as National Oceanic and Atmospheric Administration tidal predictions, as part of the calibration and verification of the hydrodynamic model results. The ASA model also is compatible with the oil trajectory model SIMAP and does not require a data processing step to input the current data to SIMAP.

BFHYDRO was applied in the three-dimensional mode in the Strait of Juan de Fuca and outer coast at Duntz Rock application, and two-dimensional model in the Columbia River applications. Known physical conditions are input to the model grid at the edges, termed "open boundaries". These inputs are described as "forcing factors". The forcing factors are water height (available from tidal height data) and river flow. Salinity driven (i.e., density driven) flows, were not considered for the present analysis. Forcing factors due to wind stress on the water surface were included in the wind drift calculation in the oil fates model.

Tidal currents are driven by a mix of forces with semi-diurnal and diurnal periodicity, causing the elevations of successive high and low tides to be unequal. The major 6 constituents are M_2, S_2, N_2, K_1, O_1 and P_1, where the letter and number codes for the tidal constituents are standard terminology based on harmonic analysis of tidal height data (Defant, 1961), with the number indicating the approximate frequency of the sinusoidal cycle per day (1 is diurnal and 2 is semi-diurnal). The letter indicates the sinusoidal periodicities included in the component. M_2 and S_2 are pure lunar and solar components, respectively. All the others are mixtures of signals resulting from various periodic changes in the position of the sun and moon relative to the earth. For more information, see Defant (1961) or a similar oceanographic text book.

Tidal forcing is accomplished by defining the water height over time at the model grid boundaries. The forcing is specified for each tidal constituent. The current vectors for each constituent are computed for each model grid cell and time step based on physical laws (conservation of mass and momentum). Current vectors for non-tidal flows (i.e., river) are computed in an analogous manner. In the oil spill model, the various tidal constituents and non-tidal current vectors are summed to determine the actual transport of oil components and plankton in the particular grid cell and time step of interest.

BFHYDRO current predictions were compared to existing current data, as well as National Oceanic and Atmospheric Administration tidal predictions, as part of the calibration and verification of the model results. The model grid and application are described in Section C of Volumes III, VI, IX, XII, XVIII, XXI, XXIV, and XXVII. These sections also contain current vector plots for the dominant tidal constituents at selected intervals relative to maximum flood and maximum ebb. The actual summed current vectors for all tidal and non-tidal constituents vary for each individual model run, as the 100 spill dates used in runs vary randomly over a long-term period.

3.3.1.2 San Juan Islands Scenario

Currents were based on hydrodynamic model data obtained from D.O. Hodgins (Seaconsult Marine Research Ltd, 8805 Osler Street, Vancouver V6P 4G1, Canada), who simulated currents in the Strait of Georgia (Hodgins, 1998). The surface currents from Hodgins' three-dimensional model outputs were formatted for use in SIMAP. The tidal forcing functions applied were the 9 harmonic constituents (M_2, S_2, N_2, K_2, MF, Q_1, K_1, O_1 and P_1).

The model grid and application are described in Section C of Volume XV. These sections also contain current vector plots for the dominant tidal constituents at selected intervals relative to maximum flood and maximum ebb. The actual summed current vectors for all tidal and non-tidal constituents vary for each individual model run, as the 100 spill dates used in runs vary randomly over a long-term period.

3.3.1.3 Outer Coast-Sea Lanes and Grays Harbor Scenarios

The barotropic hydrodynamic model, HYDROMAP (Isaji et al., 2002) was used to obtain the depth-averaged tidal currents in this study. HYDROMAP is a globally re-locatable hydrodynamic model, capable of simulating complex circulation patterns due to tidal forcing and wind stress. HYDROMAP operates over a spatially-nested, rectangular, grid that may have up to six step-wise changes in resolution in the horizontal plane. The spatial nesting capability allows the model resolution to step up as land or complex bathymetry is approached. HYDROMAP has been recently applied to study the tidal circulation in South China Sea, northeast coast of US (Isaji et al., 2001) and Moreton Bay, Australia (Zigic et al, 2003). The spatial nesting of the grid provided the hydrodynamic model with a good resolution on the offshore and a fine resolution near the coast, especially in Grays Harbor, Grays Bay, and Willapa Bay. The grid used in this study consisted of 22,200 active water cells, with cell size varying from 5 km x 5 km in the off-shore to about 625 m x 625 m near the coast. The tidal forcing for the 5 major harmonic constituents (M_2, S_2, N_2, K_1, and O_1), derived from the Global Ocean Tidal Model (TPOX5.1) developed at the Oregon State University (Egbert et. al. 1994), was applied along the offshore open boundaries.

Seasonal components (climatic winter and summer) of the offshore currents for the present study were assembled from results of the three-dimensional hydrodynamic simulations from a high-resolution global ocean circulation model, Parallel Ocean

Program (POP). The time-averaged daily outputs of the results from POP, for the global ocean at a horizontal resolution of 1/6 degree, forced by observed temperature and wind stress during 1985-1995 (Maltrud et al., 1998), was used to obtain the seasonally averaged currents used in the present study. The seasonal currents thus assembled from POP compared well with a schematic of the large-scale boundary currents off the US west coast given in Hickey (1998).

3.3.2 Wind-driven Surface Currents

Local wind-driven surface currents are calculated within the SIMAP fates model, based on local wind speed and direction. Surface wind drift of oil has been observed in the field to be 1-6% (average 3-4%) of wind speed in a direction 0-30 degrees to the right (in the northern hemisphere) of the down-wind direction (ASCE, 1996). In restricted waters with little fetch, the angle tends to be near zero, while in open waters the angle develops to be 20°-30° to the right of down wind.

Wind drift speed and angle were studied in detail by Youssef and Spaulding (Youssef, 1993; Youssef and Spaulding, 1993, 1994). Wind drift speed is a percentage of wind speed over the water, highest at low wind speed and decreasing as wind speed increases. The range of drift speed for winds up to 20 kts (averaged over time) is 2-4% of wind speed. At 10 kts or less, the percent of wind speed is about 3.5-4% at the water surface, decreasing to 2% at 0.1m below the surface. The angle to the right of down wind is highest at low wind speed, on the water surface ranging from about 20°-30° at 10 kts or less. The drift speed decreases, and the drift angle increases, deeper into the water column.

Youssef and Spaulding (Youssef, 1993; Youssef and Spaulding, 1993, 1994) developed a set of equations to describe the percent of wind speed and angle as functions of wind speed and depth in the water. This algorithm has been incorporated into SIMAP. The wind drift is applied to the upper 5 meters of the water column. The SIMAP algorithm was validated with observations of the drift of floating fuel and bitumen in surface water after an intentional (test) Orimulsion spill (French et al., 1997). This Youssef and Spaulding algorithm was used in model runs for surface wind drift.

3.4 Oil Properties, Toxicity, and Impact Thresholds

The oil types modeled were crude oil, Bunker C (heavy fuel oil), and diesel (light fuel oil). Physical and chemical data on the oils were taken from the NRDAM/CME database (French et al., 1996b) and the Environment Canada catalogue of crude oil and oil product properties (Whiticar et al., 1992; Jokuty et al., 1996, 1999). PAH concentrations were based on data in French McCay (2002) or Lee et al. (1992); MAH concentrations were from Jokuty et al. (1996, 1999) or Wang et al. (1995); and the volatile aliphatic concentrations were calculated from boiling curves (in Jokuty et al. 1996, 1999), subtracting the volatile aromatics. The volatile aliphatics are evaporated and volatilize from the surface water and so their mass is accounted for in the overall mass balance.

However, as they do not dissolve in significant amounts, they have no influence on the biological effects on water column and benthic organisms. Minimum oil slick thickness was assumed 1 mm, based on McAuliffe (1987). Properties assumed in the modeling are in Section D of Volumes III, VI, IX, XII, XV, XVIII, and XXI.

There are two categories of components in oil that need to be considered as to their potential for impact to aquatic organisms.

1. Whole oil (floating and subsurface)
2. Low molecular weight aromatics (MAHs and PAHs)

Each of these components has a separate fate and is tracked separately in the model. For surface floating and shoreline oil, a threshold was identified above which there is some potential for impacts. Aquatic toxicity is caused by the sum of the contributions from each of the components in the water column.

3.4.1 Whole oil

French et al. (1996a) reviewed the literature regarding the necessary dose to affect birds and other wildlife. This was translated to a minimum thickness of floating oil, which is 10 g/m^2 (10 micron thick oil).

The threshold for effects on intertidal vegetation has been observed to be much higher than this level (by 2-3 orders of magnitude, French et al., 1996a). On the other hand, intertidal invertebrates have been observed to be more sensitive than vegetation. Thus, 100 g/m^2 was assumed as the threshold for potential effects on fauna due to smothering and/or toxic exposures of oil in intertidal habitats.

Whole oil droplets in the water column may affect fish and invertebrates by interfering with feeding or clogging gills. However, data quantifying a threshold level for effects has not been identified. A conservative threshold of 10 ppb for fish and invertebrates was used in the modeling as a minimum for inclusion in model outputs. This level is based on literature reviewed by Markarian et al. (1993) and French et al. (1996a).

3.4.2 Low molecular weight aromatics

For crude oil, diesel and heavy fuel oil spills at the water surface, MAHs do not have a significant impact on aquatic organisms for the following reasons. MAH concentrations are typically $\leq$3% in fresh oils. MAHs are soluble, and so some becomes bioavailable (dissolved). MAH compounds are also very volatile, and will volatilize (from the water surface and water column) very quickly after a spill. The threshold for toxic effects for these compounds is about 500 ppb for sensitive species (French McCay, 2002). MAHs evaporate faster than they dissolve, such that toxic concentrations are not reached. The small concentrations of MAHs in the water will quickly be diluted to levels well below toxic thresholds immediately after a spill. Thus, the assumed values for MAH concentrations in the oil, as well as their fates, have little influence on model results. The

percentage of PAHs has a significant influence on the model results. Thus, data for well-defined oils were used in the model runs, and the LC50s assumed were for total dissolved PAH concentrations in the water ($LC50_{mix}$).

To estimate $LC50_{mix}$ values for dissolved PAHs in the water, the additive model described in French McCay (2002) was used. French McCay (2002) estimated $LC50_{mix}$ = 50 ppb for typical fuels at infinite exposure time and for the average species. Ninety-five percent of species have LC50s between 6 and 400 μg/L (ppb). In the assessment of impacts, all species are assumed to be of average sensitivity to oil hydrocarbons.

The LC50s above are for the concentration of *dissolved* PAHs that would be lethal to 50% of exposed organisms for a long enough times of exposure for mortality to occur. For PAHs, this is for at least 2 weeks of exposure at warm temperature. For chemicals in general, toxicity is higher, and the LC50 lower, at longer time of exposure and higher temperature (French et al, 1996a; French McCay, 2002). The model corrects this LC50 to temperature and duration of exposure for each group of organisms exposed.

3.4.3 Toxicity Thresholds of Concern

The literature shows that, for most organic and inorganic chemicals, the threshold for sublethal effects is approximately 10 times lower than the 96-hour LC50 (Call et al., 1985; Gobas, 1989; Giesy and Graney, 1989). The only chemicals where higher ratios occur are those that have very high $\log(K_{ow})$, and so bioaccumulate. PAHs have ratio of up to 10. Thus, the sublethal effect threshold for PAHs in oils would be about 1 ppb. Dissolved PAH concentrations below 1 ppb would not be expected to have toxic effects on aquatic organisms. Note that exceedance of the chronic threshold would need to be for long time periods (>1 week) for effects to occur.

The model results show that the duration of water column exposures are on the order of hours. Thus, the exposures are acute rather than long-term, and the LC50 for infinite exposure time is very conservative in considering potential for effects. Sublethal effects would also be expected to vary by duration of exposure. Table 3-3 lists acute toxicity values for soluble fuel components in oil, and for sensitive (5th percentile) and average (50th percentile) species, at different durations of exposure at $25^{o}C$ (based on equations in French McCay, 2002). The LC50s for short exposure times are higher at colder temperatures (Figure 2-2).

For PAHs, the LC50 for six hours of exposure for the 2.5^{th} percentile species is 100 μg PAH/L (Table 3-3). To account for variation among individuals of the sensitive species, 10% of this LC50 is assumed as the threshold for potential effects. Thus, to the nearest order of magnitude, peak exposure PAH concentrations below 10 ppb would have no significant impact on aquatic organisms for short exposure times.

The thresholds for effects were used in the stochastic model analysis to determine potential for impacts and the needed duration of model simulations. In the individual

model runs and biological model analysis, the LC50 is corrected for temperature and time of exposure.

Table 3-3. LC50s for fuel components and varying exposure times.

	BTEX (μg/l)	**C3 Benzenes (μg/l)**	**MAHs (μg/l)**	**PAHs (μg/l)**
Sensitive Species (2.5th percentile):				
LC50, 6 hours	1600	632	1190	99
LC50, 96 hours	506	136	374	9
LC50 (infinite exposure)	505	133	373	6
Average Species (50th percentile):				
LC50, 6 hours	13,400	5300	9920	789
LC50, 96 hours	4230	1140	3123	76
LC50 (infinite exposure)	4230	1115	3115	48

3.5 Shoreline Oil Retention

Retention of oil on a shoreline depends on the shoreline type, width and angle of the shoreline, viscosity of the oil, the tidal amplitude, and the wave energy. In the NRDAM/CME (French et al., 1996a,b,c), shore holding capacity was based on observations from the *Amoco Cadiz* spill in France and the *Exxon Valdez* spill in Alaska (based on Gundlach (1987) and later work summarized in French et al., 1996a). These data are used here (Table 3-4). The shore width (intertidal zone width where oiling would occur) varies by shore type, based on the typical slope of the shore type and the average tide range. The shore widths were developed by French et al. (1996a) and used here.

Table 3-4. Maximum surface oil thickness for various beach types as a function of oil viscosity (from French et al., 1996a, based on Gundlach, 1987).

	Oil Thickness (mm) by Oil Type		
Shore Type	Light (<30 cSt)	Medium (30-2000 cSt)	Heavy (>2000 cSt)
Rocky shore	1	5	10
Gravel beach	2	9	15
Sand beach	4	17	25
Mud flat	6	30	40
Wetland	6	30	40
Artificial	1	2	2

3.6 Scenarios

Table 1-1 lists the scenarios examined, including 9 main stochastic scenarios and 27 alternate response scenarios for selected worst-case runs (i.e., most impact on sensitive sites and the largest amount of shoreline oiled) in the main stochastic scenario base case. Figures 1-1 and 1-2 show the hypothetical spill locations examined. For scenarios involving Alaskan North Slope crude oil, the spill volume is assumed to be 250,000 bbl; the spill volume for the diesel is 65,000 bbl, and for Bunker C fuel spills, the spill volumes are either 150,000 bbl (for the Outer Coast – Sea Lanes scenario) or 25,000 bbl (for scenarios related to shipping into harbors). All spills were assumed to be at or near the water surface and over 4 hours. In the upper Columbia River scenario and the Juan de Fuca scenario involving diesel fuel, the model was run for 4 weeks and 2 weeks, respectively, by which time most of the oil came ashore or dispersed. In all other scenarios, a 56-day model duration was used.

Specifics of the spill response scenarios were developed by Etkin (2005b) and Etkin et al. (2006) based on state and federal planning standards and assumptions provided by WDOE. In all scenarios, *excluding* no response, protective booming was included. The mechanical removal capacities were assumed to be one of three options (when included in the scenario), in increasing order of capacity: (1) US Coast Guard federal response capability standards, (2) current Washington State standards, and (3) a theoretical higher response capability, which is referred to as the third alternative throughout this report.

Modeled response capabilities for mechanical containment and recovery for each of the scenarios was based on the location type-specific response capability standard or guideline as described in Etkin (2005b) and Etkin et al. (2006). In the modeling, protective booms were located at sensitive areas as indicated in Geographic Response Plans (GRPs) according to the schedule of booming in the appropriate standards. It was assumed that enough boom was available to make the modeled placements at the times required and that the placements were performed successfully according to the plan. In Phase II, protective booms were assumed to have an effectiveness (keeping oil out) of 80% as opposed to 100% as assumed in Phase I (French McCay et al. 2004b), i.e., in Phase II modeling it is assumed that there would be some errors in deployment and boom condition, as would be seen in many actual applications in the field.

The Phase II mechanical recovery modeling (Etkin, 2005b; Etkin et al., 2006)) involved simulating (1) only the capacities of the *response planning standards* (not all equipment that might be used in a large spill such as those examined), (2) the decreasing efficiency of oil removal as time goes on and oil spreads making it more difficult to locate and recover, and (3) changes in the timing and capacities of removal activities only in the first 96 hours after the spill. Mechanical removal *from the water surface* was assumed to occur and be accomplished at the rates (EDRC rate times a reduction in efficiency that increases over time) in Tables 3-5 to 3-12 in the time intervals listed, as long as:

(1) oil was on the water surface in the designated area(s) in the time interval;
(2) current speed at the oil location did not exceed 1 knot (evaluated each time step) ;

(3) wave heights (calculated for each oil spillet and time step from wind speed, duration and fetch [distance upwind to land], using the algorithms in CERC, 1984) did not exceed 3 feet;
(4) oil on the water surface was of sufficient thickness for effective containment and skimming operations (13 microns, based on API, et al. 2001)

Maps of the boom locations and areas where removal activities were assumed to occur are in Section B.4 of Volumes III, VI, IX, XII, XV, XVIII, XXI, XXIV and XXVII. Section E of these volumes contains a list of model inputs for the SIMAP physical fates model.

Note that the response requirements are based not on the spill volume but on the potential worst-case discharge (total release of oil cargo/fuel) from the hypothetical vessel involved (tankers or barges). This is the way in which both the state and federal response capability standards have been developed. There is a maximum capacity ("cap") at which the amount of equipment is not required to increase regardless of any increase in worst-case discharge size. (Note that the equipment amounts are cumulative, e.g., if at 24 hours there is 12,500 bpd recovery and 25,000 bpd is required at 48 hours, an additional 12,500 bpd worth of equipment arrives by 48 hours.)

Table 3-5. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Outer Coast at Duntz Rock Spill 250,000 bbl ANS Crude (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			12,000
6			12,000
12			12,000
15		36,000	36,000
24	12,500	48,00	48,000
48	25,000	60,000	60,000

Table 3-6. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Strait of Juan de Fuca Spill 25,000 bbl Bunker (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			3,087
6		1,234.8	3,087
12	6,483	3,087	9,261
15	6,483	7,408.8	12,348
24	10,805	7,408.8	12,348
48	10,805	10,495.8	15,435

Table 3-7. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Strait of Juan de Fuca Spill 65,000 bbl Diesel (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			36,000
6		12,000	36,000
12	12,500	36,000	48,000
15	12,500	48,000	60,000
24	25,000	48,000	60,000
48	25,000	60,000	72,000

Table 3-8. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Strait Juan de Fuca Spill 250,000 bbl ANS Crude (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			
6		5,000	12,500
12	12,500	12,500	37,500
15	12,500	30,000	50,000
24	25,000	30,000	50,000
48	25,000	42,500	62,500

Table 3-9. Modeled mechanical Spill Response Capability (bbl/day recovery rate): San Juan Islands Spill 250,000 bbl ANS Crude (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			
6		5,000	12,500
12	12,500	12,500	37,500
15	12,500	30,000	50,000
24	25,000	30,000	50,000
48	25,000	42,500	62,500

Table 3-10. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Columbia River Spill 25,000 bbl Bunker (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			3,087
6		1,234.8	3,087
12		3,087	9,261
15	5,186	7,408.8	12,348
24	5,186	7,408.8	12,348
48	6,915	10,495.8	15,345

Table 3-11. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Outer Coast-Sea Lanes Spill 150,000 bbl Bunker (Etkin et al., 2006).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			12,000
6			12,000
12			12,000
15		36,000	36,000
24	12,500	48,000	48,000
48	25,000	60,000	60,000

Table 3-12. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Grays Harbor Spill 25,000 bbl Bunker (Etkin et al., 2006).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			3,087
6		1,234.8	3,087
12	6,483	3,087	9,261
15	6,483	7,408.8	12,348
24	10,805	7,408.8	12,348
48	10,805	10,495.8	15,435

3.7 Biological Abundance

Wildlife species include aquatic birds, marine mammals and other mammals common in freshwater environments (e.g., muskrat, mink, beaver, otters). The model uses average number per unit area (#/km^2) in appropriate habitats. Section 2.2 describes the assignment of each species to a set of habitats that it uses. The species is assumed to have a uniform distribution across its preferred habitats. Thus, the habitat grid defines the habitat map, and so the abundance of each species.

Fish and invertebrates are also input as average density by species (or group) per unit area in assigned habitats. Fish and invertebrates abundance varies by landward open water, seaward open water, and structured habitat (i.e., wetlands, reefs, and macroalgal beds, Table 3-1). In the NRDAM/CME (French et al., 1996c), the abundances are for fished stocks and the biomass includes those animals greater than the age of recruitment to fishing. In the biological effects model the age/size distribution is computed from fishery modeling parameters (natural and fishing instantaneous mortality rates, length as a function of age, and weight-length relationships), such that the mortality is calculated for all age classes from age 1-year up (and assuming the various age classes live in the same habitat in that age structure).

Young-of-the-year mortality is quantified separately. The biological database includes number of age 1-year (365 day old) individuals per km^2. The young-of-the-year abundances in the NRDAM/CME (French et al., 1996c) were calculated from the spawning stock and life history information as to where those animals would live for each month of their first year of life. The numbers are those needed to recruit to the stock at age 1-year in order to maintain a stable population size. Thus, young-of-the-year mortality is for only those that would have survived their first year if not for the spill.

The NRDAM/CME (French et al., 1996c) contains mean seasonal or monthly abundances for 77 biological provinces in US coastal and marine waters. The biological data for wildlife, fish, invertebrates and lower trophic levels in the province of the spill are used for the SIMAP simulations in the lower Columbia River (province 48 in the NRDAM/CME), outer coast (province 49 in the NRDAM/CME, for Outer Coast at Duntz Rock, Outer Coast – Sea Lanes, and Grays Harbor scenarios) and Strait of Juan de Fuca and San Juan Islands area (province 51 in the NRDAM/CME) areas.

The bird densities for NRDAM/CME province 49 were updated for common murre abundance using data from Thompson (1999), which surveyed marbled murrelets and common murres on the outer coast of Washington from the summer of 1997 to the winter of 1998-1999. The wading bird and shorebird densities for the Strait of Juan de Fuca and San Juan Islands area were from NRDAM/CME province 51. However, the winter densities for diving bird species were updated from NRDAM/CME province 51 using Nysewander et al. (2001).

For the upper Columbia River, biological data compiled by French et al. (1993a,b) were used. These data were compilations of typical fish and wildlife densities (by season) in Pacific Northwest Rivers and wetlands. Invertebrate impacts were assessed by evaluating lost production of lower trophic levels, as described in French et al. (1996a).

Tables 3-13 to 3-16 list the wildlife densities and Tables 3-17 through 3-20 and Tables 3-26 to 3-30 list the fish and invertebrate densities in the four biological databases used. Tables 3-21 to 3-25 describe the taxonomic codes that were used to define the behavior of fish and invertebrate species used in the model. Production rates of lower trophic levels are described in French et al. (1996b).

Table 3-13. Wildlife densities assumed for the Strait of Juan de Fuca to San Juan Islands area (seaward) and Puget Sound (landward), as seasonal means in number per km^2.

Species group	Winter	Spring	Summer	Fall
Black brant	2.0	6.1	0.0	0.7
Bufflehead	60.0	6.0	0.3	5.2
Common loon	0.8	0.03	0.1	1.8
Goldeneyes	15.0	0.3	0.0	3.0
Harlequin duck	13.0	0.5	0.3	0.4
Horned grebe	2.0	0.7	0.5	3.1
Loons, general	1.8	0.03	0.1	1.8
Mergansers, gen.	13.0	1.0	0.3	3.5
Red-necked grebe	0.5	0.4	0.5	1.2
Scaups	8.0	3.7	0.4	4.9
Scoters	35.0	28.1	4.2	19.0
Western grebe	2.0	4.1	0.8	11.6
Cormorants, general	7.0	1.3	2.7	3.8
Double-crested cormorant	2.0	0.7	1.0	1.3
Gulls, general	75.0	3.5	26.2	14.3
Marbled murrelet	0.2	0.4	1.0	0.9
Pigeon guillemot	0.7	2.7	2.2	1.0
Great blue heron	4.0	12.7	12.7	4.0
Black oystercatcher	0.0	0.2	0.2	0.0
Shorebirds, gen.	961.0	378.0	0.0	766.0
Bald eagle	0.1	0.2	0.2	0.02
Killer whales	0.01	0.01	0.01	0.01
Harbor seal	0.3	0.3	0.3	0.3
Sea lions, general	0.1	0.1	0.0	0.0
Group Totals:				
Waterfowl	153.1	50.8	7.5	56.2
Seabirds	84.9	8.6	33.0	21.2
Wading birds	4.0	12.7	12.7	4.0
Shorebirds	961.0	378.2	0.2	766.0
Raptors	0.1	0.2	0.2	0.0
Kingfishers	0.0	0.0	0.0	0.0
Cetaceans	0.0	0.0	0.0	0.0
Pinnipeds (seals)	0.3	0.3	0.3	0.3
Other mammals	0.0	0.0	0.0	0.0
Total all species	1203.4	450.8	53.9	847.6

Table 3-14. Wildlife densities assumed for the outer coast of Washington (Outer Coast at Duntz Rock, Outer Coast-Sea Lanes and Grays Harbor scenarios) as seasonal means in number per km^2.

Species group	Winter	Spring	Summer	Fall
Arctic loon	0.02	0.1	0.1	0.1
Dabblers, general	138.1	138.1	0.0	0.0
Diving ducks, gen.	3.7	3.7	0.0	0.0
Geese, general	13.4	13.4	0.0	0.0
Scoters	1.0	1.0	0.0	0.0
Trumpeter swan	0.1	0.0	0.0	0.0
Western grebe	0.04	0.02	0.10	0.01
Whistling swan	1.2	0.0	0.0	0.0
Alcids, general	6.8	3.9	5.7	7.1
Blackfoot. Albatross	0.0	0.1	0.1	0.0
Black-leg. kittiwake	0.7	0.01	0.003	0.2
California gull	0.2	0.01	0.5	0.1
Caspian tern	0.0	1.0	1.0	0.0
Cassin's auklet	1.8	0.5	2.0	2.8
Common murre	6.2	29.9	31.8	6.2
Cormorants, general	0.1	0.1	0.1	0.4
Forktail. Stormpet.	0.04	0.1	0.6	0.01
Glaucous-winged gull	0.3	0.2	0.4	0.7
Gulls, general	0.1	0.3	1.0	1.1
Herring gull	0.3	0.04	0.2	0.3
Leach's storm-petrel	0.0	0.004	0.01	0.0
Marbled murrelet	0.03	0.1	0.1	0.03
Northern fulmar	0.1	0.1	2.9	0.1
Parakeet auklet	0.01	0.2	0.2	0.01
Pinkfoot. Shearwater	0.0	0.05	0.3	0.02
Sooty shearwater	0.01	3.6	18.9	0.1
Western gull	0.1	0.3	0.6	0.01
Great blue heron	4.0	12.7	12.7	4.0
Black oystercatcher	0.0	0.7	0.7	0.0
Sandpipers, general	961.0	378.0	0.0	766.0
Kingfishers, general	1.6	2.6	2.6	1.6
Dall's porpoise	0.0	0.01	0.02	0.02
Gray whale	0.2	0.03	0.02	0.01
Harbor porpoise	1.4	1.4	1.4	1.4
Humpback whale	0.0	0.004	0.004	0.004
Killer whales	0.001	0.001	0.001	0.001
Risso's dolphin	0.0003	0.01	0.0003	0.004
California sea lion	0.01	0.003	0.001	0.01
Harbor seal	0.3	0.3	0.3	0.3

Northern fur seal	0.02	0.02	0.003	0.003
Species group	**Winter**	**Spring**	**Summer**	**Fall**
Northern sea lion	0.01	0.02	0.02	0.03
Sea otter	0.01	0.01	0.01	0.01
Group Totals:				
Waterfowl	157.6	156.3	0.2	0.1
Seabirds	16.7	40.4	66.4	19.2
Wading birds	4.0	12.7	12.7	4.0
Shorebirds	961.0	378.7	0.7	766.0
Raptors	0.0	0.0	0.0	0.0
Kingfishers	1.6	2.6	2.6	1.6
Cetaceans	1.7	1.5	1.5	1.5
Pinnipeds (seals)	0.3	0.3	0.3	0.3
Other mammals	0.0	0.0	0.0	0.0
Reptiles	0.0	0.0	0.0	0.0
Amphibians	0.0	0.0	0.0	0.0
Total all species	1142.9	592.6	84.4	792.7

Table 3-15. Wildlife densities assumed for the lower Columbia River, as seasonal means in number per km^2.

Species group	Winter	Spring	Summer	Fall
Diving ducks, gen.	769.0	425.0	637.0	442.0
Grebes, general	12.7	6.3	0.0	3.8
Loons, general	0.3	0.0	0.0	0.3
Alcids, general	0.1	0.1	0.1	0.1
Caspian tern	93.0	93.0	93.0	93.0
Cormorants, general	1.3	1.0	0.9	1.3
Glaucous-winged gull	9.3	9.3	9.3	9.3
Mew gull	400.0	193.0	0.0	193.0
Heron family, gen.	3.8	3.8	0.4	7.6
Shorebirds, general	961.0	378.0	0.0	766.0
Kingfishers, general	0.2	0.2	0.2	0.2
California sea lion	0.2	0.3	0.0	0.03
Harbor seal	3.4	3.4	3.4	3.4
Northern sea lion	0.1	0.0	0.0	0.01
Group Totals:				
Waterfowl	782.0	431.3	637.0	446.0
Seabirds	503.7	296.4	103.3	296.7
Wading birds	3.8	3.8	0.4	7.6
Shorebirds	961.0	378.0	0.0	766.0
Raptors	0.0	0.0	0.0	0.0
Kingfishers	0.2	0.2	0.2	0.2
Cetaceans	0.0	0.0	0.0	0.0
Pinnipeds (seals)	3.7	3.7	3.4	3.5
Other mammals	0.0	0.0	0.0	0.0
Reptiles	0.0	0.0	0.0	0.0
Amphibians	0.0	0.0	0.0	0.0
Total all species	2254.3	1113.5	744.3	1520.0

Table 3-16. Wildlife densities assumed for the upper Columbia River, as seasonal means in number per km^2. [lwd = landward, i.e., tributaries and bays; swd = seaward, i.e., main river; wetl = wetland]

Species group	Winter	Spring	Summer	Fall
American coot, lwd	0.0	7.3	0.0	7.3
American coot, wetl	0.0	7.3	0.0	7.3
American widgeon	0.0	1.6	0.0	1.6
Blue-winged teal	0.0	6.5	0.0	6.5
Bufflehead, lwd	0.0	0.02	0.0	0.02
Bufflehead, wetl	0.0	0.02	0.0	0.02
Canvasback, lwd	0.0	0.03	0.0	0.03
Canvasback, wetl	0.0	0.03	0.0	0.03
Common goldeneye, lwd	0.0	0.4	0.0	0.4
Common goldeneye, wetl	0.0	0.4	0.0	0.4
Coots, lwd	1.7	0.0	0.0	0.0
Coots, wetl	1.7	0.0	0.0	0.0
Dabbling ducks, wetl	59.2	0.0	0.0	0.0
Diving ducks, lwd	14.5	0.0	0.0	0.0
Diving ducks, wetl	14.5	0.0	0.0	0.0
Gadwall	0.0	1.3	0.0	1.3
Geese, lwd	7.1	0.0	0.0	0.0
Geese, wetl	7.1	0.0	0.0	0.0
Green-winged teal	0.0	1.1	0.0	1.1
Mallard	0.0	14.3	0.0	14.3
Merganser, lwd	0.0	0.04	0.0	0.04
Merganser, wetl	0.0	0.04	0.0	0.04
Northern pintail	0.0	1.3	0.0	1.3
Northern shoveler	0.0	1.3	0.0	1.3
Redhead, lwd	0.0	2.6	0.0	2.6
Redhead, wetl	0.0	2.6	0.0	2.6
Ring-necked duck, lwd	0.0	0.5	0.0	0.5
Ring-necked duck, wetl	0.0	0.5	0.0	0.5
Ruddy duck, lwd	0.0	1.9	0.0	1.9
Ruddy duck, wetl	0.0	1.9	0.0	1.9
Scaup, lwd	0.0	1.5	0.0	1.5
Scaup, wetl	0.0	1.5	0.0	1.5
Swans, wetl	0.5	0.0	0.0	0.0
White wing. scoter lwd	0.0	0.01	0.0	0.0
White wing. scoter wetl	0.0	0.01	0.0	0.0
Wood duck	0.0	1.7	0.0	0.0
Glaucous-wing gull lwd	4.1	4.1	4.1	4.1
Glaucous-wing gull swd	4.1	4.1	4.1	4.1
Glaucous-wing gull wetl	4.1	4.1	4.1	4.1

Species group	Winter	Spring	Summer	Fall
Ringbill-CA gull lwd	0.03	3.4	3.4	3.4
Ringbill-CA gull swd	0.03	3.4	3.4	3.4
Ringbill-CA gull wetl	0.03	3.4	3.4	3.4
Heron family, gen.	3.8	3.8	0.4	7.6
Shorebirds, general	961.0	378.0	0.0	766.0
Bald eagle, lwd	0.0	0.04	0.04	0.04
Bald eagle, wetl	0.0	0.04	0.04	0.04
Beaver	0.6	0.6	0.6	0.6
Mink	0.1	0.1	0.1	0.1
Muskrat	50.0	50.0	50.0	50.0
River otter	0.01	0.01	0.01	0.01
Group Totals:				
Waterfowl	106.1	57.7	0.0	55.9
Seabirds	12.4	22.6	22.6	22.6
Wading birds	3.8	3.8	0.4	7.6
Shorebirds	961.0	378.0	0.0	766.0
Raptors	0.0	0.1	0.1	0.1
Kingfishers	0.0	0.0	0.0	0.0
Cetaceans	0.0	0.0	0.0	0.0
Pinnipeds (seals)	0.0	0.0	0.0	0.0
Other mammals	50.7	50.7	50.7	50.7
Reptiles	0.0	0.0	0.0	0.0
Amphibians	0.0	0.0	0.0	0.0
Total all species	1133.9	512.8	73.7	902.9

Table 3-17. Fish and invertebrate densities (kg/km^2) assumed for the Strait of Juan de Fuca and San Juan Islands area (seaward) and Puget Sound (landward), as seasonal mean by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Pacific herring	Seaward Open Water	1608.0	1608.0	1608.0	1608.0
	Landward Open Water	1608.0	1608.0	1608.0	1608.0
	Wetland and Seagrass	1608.0	1608.0	1608.0	1608.0
Smelts, general	Seaward Open Water	3.3	3.3	3.3	3.3
	Landward Open Water	3.3	3.3	3.3	3.3
	Wetland and Seagrass	3.3	3.3	3.3	3.3
Chinook	Seaward Open Water	0.0	0.0	153.0	1.5
	Landward Open Water	0.0	0.0	153.0	1.5
	Wetland and Seagrass	0.0	0.0	153.0	1.5
Chum = keta salmon	Seaward Open Water	0.0	0.0	331.0	9.8
	Landward Open Water	0.0	0.0	331.0	9.8
	Wetland and Seagrass	0.0	0.0	331.0	9.8
Coho	Seaward Open Water	0.0	0.0	268.0	2.7
	Landward Open Water	0.0	0.0	268.0	2.7
	Wetland and Seagrass	0.0	0.0	268.0	2.7
Pink salmon	Seaward Open Water	0.0	0.0	487.0	14.4
	Landward Open Water	0.0	0.0	487.0	14.4
	Wetland and Seagrass	0.0	0.0	487.0	14.4
Sockeye	Seaward Open Water	0.0	0.0	914.0	27.1
	Landward Open Water	0.0	0.0	914.0	27.1
	Wetland and Seagrass	0.0	0.0	914.0	27.1
Dogfish, general	Seaward Open Water	1485.0	1485.0	1485.0	1485.0
	Landward Open Water	148.5	148.5	148.5	148.5
	Wetland and Seagrass	148.5	148.5	148.5	148.5
Lingcod	Seaward Open Water	122.6	122.6	122.6	122.6
	Landward Open Water	122.6	122.6	122.6	122.6
	Wetland and Seagrass	122.6	122.6	122.6	122.6
Pacific cod	Seaward Open Water	114.8	114.8	114.8	114.8
	Landward Open Water	114.8	114.8	114.8	114.8
	Wetland and Seagrass	114.8	114.8	114.8	114.8
Pacific halibut	Seaward Open Water	0.0	13.2	13.2	13.2
	Landward Open Water	0.0	13.2	13.2	13.2
	Wetland and Seagrass	0.0	13.2	13.2	13.2
Rockfish, scorpionfish	Seaward Open Water	161.2	161.2	161.2	161.2
	Landward Open Water	161.2	161.2	161.2	161.2
	Wetland and Seagrass	161.2	161.2	161.2	161.2
Walleye pollock	Seaward Open Water	147.0	147.0	147.0	147.0
	Landward Open Water	147.0	147.0	147.0	147.0
	Wetland and Seagrass	147.0	147.0	147.0	147.0
Flatfish	Seaward Open Water	537.6	537.6	537.6	537.6
	Landward Open Water	537.6	537.6	537.6	537.6
	Wetland and Seagrass	537.6	537.6	537.6	537.6

Species group	Habitat	Winter	Spring	Summer	Fall
Midshipman	Seaward Open Water	0.7	0.7	0.7	0.7
	Landward Open Water	0.7	0.7	0.7	0.7
	Wetland and Seagrass	0.7	0.7	0.7	0.7
Surfperches	Seaward Open Water	18.5	18.5	18.5	18.5
	Landward Open Water	18.5	18.5	18.5	18.5
	Wetland and Seagrass	18.5	18.5	18.5	18.5
Dungeness crab	Landward Open Water	450.0	450.0	450.0	450.0
Northern pink shrimp	Seaward Open Water	1.0	1.0	1.0	1.0
Geoduck	Seaward Open Water	164000.0	164000.0	164000.0	164000.0
	Landward Open Water	164000.0	164000.0	164000.0	164000.0
Hard clams, general	Landward Open Water	7400.0	7400.0	7400.0	7400.0
Pacific oyster	Seaward Reef	109000.0	109000.0	109000.0	109000.0
	Landward Reef	109000.0	109000.0	109000.0	109000.0
Softshell clams	Landward Open Water	1037.0	1037.0	1037.0	1037.0
Sea urchins	Seaward Open Water	117.0	117.0	117.0	117.0
	Landward Open Water	117.0	117.0	117.0	117.0
Total all species	Seaward Open Water	168316.7	168329.9	170482.9	168385.4
	Landward Open Water	175866.2	175879.4	178032.4	175934.9
	Wetland and Seagrass	2862.2	2875.4	5028.4	2930.9

Table 3-18. Fish and invertebrate densities (kg/km^2) assumed for the outer coast of Washington (Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Grays Harbor scenarios) as seasonal mean by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Longfin smelt	Landward Open Water	241.0	241.0	241.0	241.0
	Wetland and Seagrass	241.0	241.0	241.0	241.0
Pacific = N. anchovy	Seaward Open Water	3509.0	3509.0	3509.0	3509.0
Pacific herring	Landward Open Water	11381.0	0.0	0.0	0.0
	Wetland and Seagrass	11381.0	0.0	0.0	0.0
Chinook	Landward Open Water	0.0	0.0	0.0	24.8
	Wetland and Seagrass	0.0	0.0	0.0	24.8
Coho	Landward Open Water	0.0	0.0	0.0	45.3
	Wetland and Seagrass	0.0	0.0	0.0	45.3
Sockeye	Landward Open Water	0.0	0.0	0.0	3.2
	Wetland and Seagrass	0.0	0.0	0.0	3.2
Pacific tomcod	Landward Open Water	291.0	291.0	291.0	291.0
	Wetland and Seagrass	291.0	291.0	291.0	291.0
English sole	Landward Open Water	156.1	156.1	156.1	156.1
	Wetland and Seagrass	156.1	156.1	156.1	156.1
Surfperches	Landward Open Water	260.0	260.0	260.0	260.0
	Wetland and Seagrass	260.0	260.0	260.0	260.0
Dungeness crab	Landward Open Water	527.0	527.0	527.0	527.0
Market squid	Landward Open Water	13000.0	13000.0	13000.0	13000.0
Hard clams, general	Landward Open Water	7400.0	7400.0	7400.0	7400.0
Pacific razor clam	Landward Open Water	1893.0	1893.0	1893.0	1893.0
Softshell clams	Landward Open Water	1037.0	1037.0	1037.0	1037.0
Sea urchins	Landward Open Water	704.0	704.0	704.0	704.0
Total all species	Seaward Open Water	3509.0	3509.0	3509.0	3509.0
	Landward Open Water	36890.1	25509.1	25509.1	25582.4
	Wetland and Seagrass	12329.1	948.1	948.1	1021.4

Table 3-19. Fish and invertebrate densities (kg/km^2) assumed for the lower Columbia River, as seasonal mean by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Eulachon	Seaward Open Water	1793.0	1793.0	1793.0	1793.0
	Landward Open Water	1793.0	1793.0	1793.0	1793.0
	Wetland and Seagrass	1793.0	1793.0	1793.0	1793.0
Pacific herring	Seaward Open Water	11381.0	0.0	0.0	0.0
	Landward Open Water	11381.0	0.0	0.0	0.0
	Wetland and Seagrass	11381.0	0.0	0.0	0.0
Chinook	Seaward Open Water	0.0	0.0	0.0	34.4
	Landward Open Water	0.0	0.0	0.0	34.4
	Wetland and Seagrass	0.0	0.0	0.0	34.4
Coho	Seaward Open Water	0.0	0.0	0.0	20.3
	Landward Open Water	0.0	0.0	0.0	20.3
	Wetland and Seagrass	0.0	0.0	0.0	20.3
Rockfish, scorpion fish	Seaward Open Water	0.4	0.4	0.4	0.4
	Landward Open Water	0.4	0.4	0.4	0.4
	Wetland and Seagrass	0.4	0.4	0.4	0.4
Flatfish	Seaward Open Water	70.9	70.9	70.9	70.9
	Landward Open Water	70.9	70.9	70.9	70.9
	Wetland and Seagrass	70.9	70.9	70.9	70.9
Razor clam	Seaward Open Water	884.0	884.0	884.0	884.0
	Landward Open Water	884.0	884.0	884.0	884.0
	Wetland and Seagrass	884.0	884.0	884.0	884.0
Softshell clams	Seaward Open Water	1037.0	1037.0	1037.0	1037.0
	Landward Open Water	1037.0	1037.0	1037.0	1037.0
Total all species	Seaward Open Water	15166.3	3785.3	3785.3	3840.0
	Landward Open Water	15166.3	3785.3	3785.3	3840.0
	Wetland and Seagrass	14129.3	2748.3	2748.3	2803.0

Table 3-20. Fish and invertebrate densities (kg/km^2) assumed for the upper Columbia River, as seasonal mean by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
American shad	Seaward Open Water	1663.0	1663.0	1663.0	1663.0
Longfin smelt	Swd Wetland/Seagrass	994.0	994.0	994.0	994.0
Chinook	Seaward Open Water	2286.0	2286.0	2286.0	2286.0
	Landward Open Water	0.0	0.0	0.0	34.4
	Wetland and Seagrass	0.0	0.0	0.0	34.4
Chum = keta salmon	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Coho	Seaward Open Water	1030.0	1030.0	1030.0	1030.0
	Landward Open Water	0.0	0.0	0.0	20.3
	Wetland and Seagrass	0.0	0.0	0.0	20.3
Sockeye salmon	Seaward Open Water	255.0	255.0	255.0	255.0
Walleye	Seaward Open Water	424.0	424.0	424.0	424.0
	Wetland and Seagrass	847.0	847.0	847.0	847.0
Brown trout	Seaward Open Water	520.0	520.0	520.0	520.0
Cutthroat trout	Seaward Open Water	420.0	420.0	420.0	420.0
Dolly vardon	Seaward Open Water	2483.0	2483.0	2483.0	2483.0
Rainbow trout	Seaward Open Water	404.0	404.0	404.0	404.0
Black bullhead	Seaward Open Water	50.0	50.0	50.0	50.0
Black crappie	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Bluegill	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Bridgelip sucker	Seaward Open Water	9254.0	9254.0	9254.0	9254.0
Brown bullhead	Seaward Open Water	803.0	803.0	803.0	803.0
	Landward Open Water	803.0	803.0	803.0	803.0
	Wetland and Seagrass	1606.0	1606.0	1606.0	1606.0
Carp	Landward Open Water	268.0	268.0	268.0	268.0
	Wetland and Seagrass	535.0	535.0	535.0	535.0
Channel catfish	Seaward Open Water	3189.0	3189.0	3189.0	3189.0
	Landward Open Water	3189.0	3189.0	3189.0	3189.0
	Wetland and Seagrass	6378.0	6378.0	6378.0	6378.0
Green sunfish	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Largemouth bass	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Longnose sucker	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Mountain sucker	Seaward Open Water	9254.0	9254.0	9254.0	9254.0
	Landward Open Water	9254.0	9254.0	9254.0	9254.0

Species group	Habitat	Winter	Spring	Summer	Fall
Mountain whitefish	Seaward Open Water	7752.0	7752.0	7752.0	7752.0
	Wetland and Seagrass	89.0	89.0	89.0	89.0
Pumpkinseed	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Smallmouth bass	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Swd Wetland/Seagrass	18505.0	18505.0	18505.0	18505.0
White crappie	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
White sturgeon	Seaward Open Water	50.0	50.0	50.0	50.0
Yellow perch	Landward Open Water	2252.0	2252.0	2252.0	2252.0
	Wetland and Seagrass	4504.0	4504.0	4504.0	4504.0
Razor clam	Seaward Open Water	884.0	884.0	884.0	884.0
	Landward Open Water	884.0	884.0	884.0	884.0
	Wetland and Seagrass	884.0	884.0	884.0	884.0
Softshell clams	Seaward Open Water	1037.0	1037.0	1037.0	1037.0
	Landward Open Water	1037.0	1037.0	1037.0	1037.0
Total all species	Seaward Open Water	111184.0	111184.0	111184.0	111184.0
	Landward Open Water	17687.0	17687.0	17687.0	17741.7
	Wetland and Seagrass	182382.0	182382.0	182382.0	182436.7

Table 3-21. Fish and invertebrate taxonomic grouping used in modeling.

Code	Taxonomic group	Group - Injury Summary
1	small pelagic fish	small pelagic fish
2	lg pelagic fish	lg pelagic fish[1]
3	semi demersal	lg pelagic fish[1]
4	demersal fish	demersal fish
5	crustaceans	crustaceans
6	squid	lg pelagic fish[1]
7	mollusks = bivalves mostly	mollusks = bivalves mostly
8	other invertebrates	other invertebrates

[1]Note that semi-demersal fish and squid have been combined with large pelagic fish.

Table 3-22. Fish and invertebrate taxa codes for species in Strait of Juan de Fuca, San Juan Islands, and Puget Sound.

Species	Taxa #
Chum = keta salmon	2
Dogfish, general	3
Dungeness crab	5
Flatfish	4
Geoduck	7
Hard clams, general	7
Pacific cod	3
Pacific halibut	3
Pacific herring	1
Pacific oyster	7
Pink salmon	2
Rockfish, scorpion fish	3
Sea urchins	8
Softshell clams	7
Walleye pollock	3

Table 3-23. Fish and invertebrate taxa codes for species for the outer coast of Washington (Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Grays Harbor scenarios).

Species	Taxa #
Chinook	2
Chum = keta salmon	2
Coho	2
Dogfish, general	3
Dungeness crab	5
English sole	4
Flatfish	4
Hard clams, general	7
Longfin smelt	1
Market squid	6
Pacific = N. anchovy	1
Pacific cod	3
Pacific halibut	3
Pacific herring	1
Pacific ocean perch	3
Pacific oyster	7
Pacific razor clam	7
Pacific tomcod	3
Pink salmon	2
Rockfish, scorpionfish	3
Sablefish	3
Sea urchins	8
Sockeye	2
Softshell clams	7
Surfperches	4
Walleye pollock	3

Table 3-24. Fish and invertebrate taxa codes for species for the lower Columbia River.

Species	Taxa #
Chinook	2
Coho	2
Eulachon	1
Flatfish	4
Pacific herring	1
Razor clam	7
Rockfish, scorpion fish	3
Softshell clams	7

Table 3-25. Fish and invertebrate taxa codes for species for the upper Columbia River.

Species	**Taxa #**
American shad	1
Black bullhead	4
Black crappie	4
Bluegill	4
Bridgelip sucker	4
Brown bullhead	4
Brown trout	3
Carp	4
Channel catfish	4
Chinook	2
Chum = keta salmon	2
Coho	2
Cutthroat trout	3
Dolly vardon	3
Green sunfish	4
Largemouth bass	4
Longfin smelt	1
Longnose sucker	4
Mountain sucker	4
Mountain whitefish	4
Pumpkinseed	4
Rainbow trout	3
Razor clam	7
Smallmouth bass	4
Sockeye salmon	2
Softshell clams	7
Walleye	2
White crappie	4
White sturgeon	4
Yellow perch	4

Table 3-26. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the Strait of Juan de Fuca and San Juan Islands area (seaward) and Puget Sound (landward), as seasonal means by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Pacific herring	Seaward Open Water	9039.7	9039.8	9040.0	9040.0
	Landward Open Water	9039.7	9039.8	9040.0	9040.0
	Wetland and Seagrass	9039.7	9039.8	9040.0	9040.0
Chum = keta salmon	Seaward Open Water	620.6	706.8	1944.0	1944.0
	Landward Open Water	620.6	706.8	1944.0	1944.0
	Wetland and Seagrass	620.6	706.8	1944.0	1944.0
Pink salmon	Landward Open Water	2244.0	14303.7	0.0	0.0
Dogfish, general	Seaward Open Water	9291.0	9291.0	9291.0	9291.0
	Landward Open Water	9291.0	9291.0	9291.0	9291.0
	Wetland and Seagrass	9291.0	9291.0	9291.0	9291.0
Pacific cod	Seaward Open Water	170.3	170.3	170.3	170.3
	Landward Open Water	170.3	170.3	170.3	170.3
	Wetland and Seagrass	170.3	170.3	170.3	170.3
Pacific halibut	Seaward Open Water	1.0	1.0	1.0	1.0
	Landward Open Water	1.0	1.0	1.0	1.0
	Wetland and Seagrass	1.0	1.0	1.0	1.0
Rockfish, scorpion fish	Seaward Open Water	26.1	26.1	26.1	26.1
	Landward Open Water	26.1	26.1	26.1	26.1
	Wetland and Seagrass	26.1	26.1	26.1	26.1
Walleye pollock	Seaward Open Water	201.4	201.4	201.4	201.4
	Landward Open Water	201.4	201.4	201.4	201.4
	Wetland and Seagrass	201.4	201.4	201.4	201.4
Flatfish	Seaward Open Water	0.3	0.3	0.3	0.3
	Landward Open Water	0.3	0.3	0.3	0.3
	Wetland and Seagrass	0.3	0.3	0.3	0.3
Dungeness crab	Landward Open Water	580.5	580.4	580.4	580.4
Geoduck	Seaward Open Water	4239.1	4238.8	4238.5	4239.0
	Landward Open Water	4239.1	4238.8	4238.5	4239.0
	Wetland and Seagrass	4239.1	4238.8	4238.5	4239.0
Hard clams, general	Landward Open Water	192102.3	192086.7	192081.2	192100.0
Pacific oyster	Landward Open Water	0.0	14846.7	70320.0	8316.7
Softshell clams	Landward Open Water	18750.3	18749.7	18748.6	18750.0
Sea urchins	Seaward Open Water	140.5	140.6	140.5	140.5
	Landward Open Water	140.5	140.6	140.5	140.5
	Wetland and Seagrass	140.5	140.6	140.5	140.5
Total all species	Seaward Open Water	23730.0	23815.9	25053.1	25053.6
	Landward Open Water	237407.1	264383.0	306783.4	244800.7
	Wetland and Seagrass	23730.0	23815.9	25053.1	25053.6

Table 3-27. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the outer coast of Washington (Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Grays Harbor scenarios) as seasonal means by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Longfin smelt	Landward Open Water	1868.90	1868.90	1869.00	1869.00
Pacific = N. anchovy	Seaward Open Water	169700.00	169700.00	169700.00	169700.00
	Landward Open Water	169700.00	169700.00	169700.00	169700.00
	Wetland/Seagrass	169700.00	169700.00	169700.00	169700.00
Pacific herring	Landward Open Water	123686.66	123683.34	123700.00	123700.00
Chum = keta salmon	Seaward Open Water	620.60	0.00	749.16	1944.00
	Landward Open Water	0.00	35898.60	61796.67	0.00
Pink salmon	Landward Open Water	15453.33	98536.66	0.00	0.00
Dogfish, general	Seaward Open Water	830.10	830.10	830.10	830.10
Pacific cod	Seaward Open Water	231.80	231.80	231.80	231.80
Pacific halibut	Seaward Open Water	1.02	1.02	1.02	1.02
Pacific ocean perch	Seaward Open Water	65.26	65.26	65.26	65.26
	Landward Open Water	65.26	65.26	65.26	65.26
	Wetland/Seagrass	65.26	65.26	65.26	65.26
Rockfish, scorpionfish	Seaward Open Water	590.80	590.80	590.80	590.80
	Landward Open Water	590.80	590.80	590.80	590.80
	Wetland/Seagrass	590.80	590.80	590.80	590.80
Sablefish	Seaward Open Water	619.10	619.10	619.10	619.10
Walleye pollock	Seaward Open Water	184.90	184.90	184.90	184.90
Flatfish	Seaward Open Water	0.19	0.19	0.19	0.19
	Landward Open Water	0.19	0.19	0.19	0.19
	Wetland/Seagrass	0.19	0.19	0.19	0.19
Dungeness crab	Seaward Open Water	337.60	326.53	0.00	0.00
	Landward Open Water	17747.27	18319.33	35211.33	35210.00
	Wetland/Seagrass	337.60	326.53	0.00	0.00
Hard clams, general	Landward Open Water	192102.33	192086.67	192081.23	192100.00
Pacific oyster	Landward Open Water	0.00	27366.67	129600.00	15333.33
Softshell clams	Landward Open Water	18750.33	18749.67	18748.58	18750.00
Sea urchins	Seaward Open Water	891.87	891.90	891.89	891.90
	Landward Open Water	891.87	891.90	891.89	891.90
	Wetland/Seagrass	891.87	891.90	891.89	891.90
Total all species	Seaward Open Water	174073.22	173441.59	173864.19	175059.06
	Landward Open Water	540856.88	687758.00	734255.00	558210.44
	Wetland/Seagrass	171585.70	171574.69	171248.12	171248.14

Table 3-28. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the lower Columbia River, as seasonal means by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
Pacific herring	Seaward Open Water	63980.00	63980.34	63980.00	63980.00
	Landward Open Water	63980.00	63980.34	63980.00	63980.00
	Wetland/Seagrass	63980.00	63980.34	63980.00	63980.00
Rockfish, scorpionfish	Seaward Open Water	0.06	0.06	0.06	0.06
	Landward Open Water	0.06	0.06	0.06	0.06
	Wetland/Seagrass	0.06	0.06	0.06	0.06
Flatfish	Seaward Open Water	0.04	0.04	0.04	0.04
	Landward Open Water	0.04	0.04	0.04	0.04
	Wetland/Seagrass	0.04	0.04	0.04	0.04
Softshell clams	Landward Open Water	18750.33	18749.67	18748.58	18750.00
Total all species	Seaward Open Water	63980.11	63980.44	63980.11	63980.11
	Landward Open Water	82730.43	82730.10	82728.69	82730.10
	Wetland/Seagrass	63980.11	63980.44	63980.11	63980.11

Table 3-29. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the upper Columbia River, as seasonal means by habitat.

Species group	Habitat	Winter	Spring	Summer	Fall
American shad	Seaward Open Water	469.00	469.17	468.83	469.00
Longfin smelt	Wetland/Seagrass	133263.33	133000.00	133000.00	133000.00
Chinook	Seaward Open Water	181.00	181.00	180.50	180.80
Chum = keta salmon	Seaward Open Water	298.35	298.80	299.00	298.83
Coho	Seaward Open Water	106.03	106.00	106.03	106.00
Sockeye salmon	Seaward Open Water	2.67	2.67	2.67	2.67
Walleye	Seaward Open Water	421.00	420.57	421.00	421.00
	Wetland/Seagrass	841.00	840.33	841.00	841.00
Brown trout	Seaward Open Water	1092.77	1091.00	1090.00	1092.67
Cutthroat trout	Seaward Open Water	2570.00	4825.67	2480.00	2480.00
Dolly vardon	Seaward Open Water	6441.90	6440.00	6439.67	6440.27
Rainbow trout	Seaward Open Water	805.97	806.00	805.87	806.00
Black bullhead	Seaward Open Water	9300.00	9300.00	9300.00	9300.00
Black crappie	Seaward Open Water	298.35	298.80	299.00	298.83
Bluegill	Seaward Open Water	298.35	298.80	299.00	298.83
Bridgelip sucker	Seaward Open Water	808000.00	12262277.00	813500.00	808000.00
Brown bullhead	Seaward Open Water	9300.00	9300.00	9300.00	9300.00
	Landward Open Water	9190.00	9190.00	9190.00	9190.00
	Wetland/Seagrass	18400.00	18400.00	18400.00	18400.00
Carp	Landward Open Water	32.29	32.29	32.30	32.30
	Wetland/Seagrass	64.41	64.46	64.40	64.40
Channel catfish	Seaward Open Water	9300.00	9300.00	9300.00	9300.00
	Landward Open Water	9190.00	9190.00	9190.00	9190.00
	Wetland/Seagrass	18400.00	18400.00	18400.00	18400.00
Green sunfish	Seaward Open Water	298.35	298.80	299.00	298.83
Largemouth bass	Seaward Open Water	298.35	298.80	299.00	298.83
Longnose sucker	Seaward Open Water	808000.00	12262277.00	813500.00	808000.00
	Wetland/Seagrass	570000.00	561250.00	570200.00	570000.00
Mountain sucker	Seaward Open Water	808000.00	12262277.00	813500.00	808000.00
	Landward Open Water	285000.00	284966.66	285033.31	285000.00
Mountain whitefish	Seaward Open Water	36800.00	36800.00	36800.00	36813.33
	Wetland/Seagrass	419.83	420.00	420.00	251.07
Pumpkinseed	Seaward Open Water	298.35	298.80	299.00	298.83
Smallmouth bass	Seaward Open Water	298.35	298.80	299.00	298.83
White crappie	Seaward Open Water	298.35	298.80	299.00	298.83
White sturgeon	Seaward Open Water	36800.00	36800.00	36800.00	36813.33
Yellow perch	Landward Open Water	11800.00	11800.00	11800.00	11800.00
	Landward Reef	23600.00	23586.67	23600.00	23600.00
Softshell clams	Landward Open Water	18750.33	18749.67	18748.58	18750.00
Total all species	Seaward Open Water	2539976.25	36905076.00	2556387.00	2539915.00
	Landward Open Water	333962.62	333928.59	333994.22	333962.31
	Wetland/Seagrass	764988.56	755961.44	764925.38	764556.38

Table 3-30. Intertidal invertebrate densities (kg/km^2) by location.

Location	NRDAM/CME Province	Species	kg/km^2
Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Grays Harbor	49	Hard Clams	7400
		Soft Shell Clams	1,037
		Pacific Razor Clam	1,893
		Total Clams	10,330
Straits of Juan de Fuca, San Juan Islands, and Puget Sound	51	Geoduck	164,000
		Hard Clams	7,400
		Soft Shell Clams	1,037
		Total Clams	172,437
Lower Columbia River	48	Soft Shell Clams	1,037
		Pacific Razor Clam	884
		Total Clams	1,921
Upper Columbia River	Inland	Total Clams	-

4. OIL FATES MODEL RESULTS

4.1 Explanation of Model Outputs

4.1.1 Stochastic Output to Estimate Probabilities and Degrees of Exposure

The model evaluates the oil mass per unit area and concentration over time after the spill, recording the maximum exposure and time first exposed in each grid cell. The probability of exposure and area exposed over threshold thicknesses are calculated from these data. Exposure measures and thresholds used to evaluate the probabilities of oil reaching each grid cell in the model domain were:

- Surface slick or floating oil: $\geq$ 0.01 g/m^2 (average thickness $\geq$ 0.01 micron)
- Shoreline: average mass loading over the shore segment (length of one grid cell times typical width for the habitat type) $\geq$ 0.01 g/m^2
- Dissolved aromatics: average over the water cell $\geq$ 1 ppb (1 mg/m^3)
- Subsurface oil (entrained in water): average over the water cell $\geq$ 10 ppb (10 mg/m^3)
- Sediment total hydrocarbons: average over the cell $\geq$ 0.0001 g/ m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10 cm)
- Sediment dissolved aromatic concentrations: average over the cell $\geq$ 0.0001 g/ m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10 cm)

Section B of Volumes IV, VII, X, XIII, XVI, XVIV, XXII**,** XXV, and XXVIII contains maps for each of the 9 main stochastic scenarios of the following statistics:

- Probability of exposure greater than the threshold listed above (probability that the threshold thickness or concentration will be exceeded at each location at any time following the spill). For surface oil, the model records if any oil of greater than that thickness (0.01 μm) passes through the grid cell, regardless of the area coverage of the oil. In addition, a map of the probability that dissolved aromatic concentrations will exceed 1 ppb is included in volumes describing scenarios in which the spill involved diesel fuel. For all other oil types, dissolved aromatic concentrations (averaged over a grid cell 0.03-0.14 km^2 in area and over the top 10 m) never exceeded the 1 ppb threshold during any model runs. The average concentration in the grid cell is used to determine if the threshold is exceeded.
- Time (hours) to first exceedance of the threshold at each location

These maps are the maximum exposure at any time after the spill. The time of exposure may be as short as 1 hour. In addition, the plots are composites of results for multiple runs for varying spill dates and times. These results may be used to determine what the highest possible exposure is at any time after a spill.

Floating oil thickness is calculated as g/m^2, where 1 g/m^2 is approximately 1 micron thick oil. Table 4-1 gives approximate thickness ranges for surface oil of varying appearance. Dull brown sheens are about 1000 mg/m^2 thick. Rainbow sheen is about 200-800 mg/m^2 and silver sheens are 50-800 mg/m^2 thick (NRC, 1985). Crude and heavy (Bunker C) fuel oil that is greater than 1mm thick appears as black oil. Light fuels and diesel that are

greater than 1mm thick are not black in appearance, but appear brown or reddish. Floating oil will not always have these appearances, however, as weathered oil would be in the form of scattered floating tar balls and tar mats where currents converge.

Table 4-1. Oil thickness (microns ~ g/m^2) and appearance on water (NRC, 1985).

Minimum	Maximum	Appearance
0.05	0.2	Colorless and silver sheen
0.2	0.8	Rainbow sheen
1	4	Dull brown sheen
10	100	Dark brown sheen
1,000	10,000	Black oil

The thresholds for potential biological effects were discussed in Section 3.4.3. For surface floating oil, the threshold is 10 g/m^2 (about 10 microns thick). For shoreline oil, the threshold is 100 g/m^2 (about 100 microns thick). Since the exposures for dissolved aromatics are primarily to PAHs for hours to days, the threshold of concern would be that for acute effects of short exposures (for the most sensitive species) of about 10 ppb. For gasoline the threshold for potential effects would be 120 ppb. Exposures of < 1ppb would not be expected to have effects under any circumstances.

4.1.2 Estimated Exposure for the Sampled Range of Environmental Conditions

Model output for a scenario were saved for the following matrix:

- For each model run (i.e., for each of the runs in a scenario)
- For each habitat or shore type
- For each exposure level over 6 order-of-magnitude intervals (i.e., if H = threshold used in the modeling: 1H-10H, 10H-100H, 100H-1,000H, 1,000H-10,000H, 10,000H-100,000H, >100,000H)

The following impact measures were calculated and saved for each combination of the above matrix for maximum extent (m^2) of contamination (where exposure level = peak exposure of each grid cell at any time after the spill):

- Water surface oiling (area) for each exposure level (mass/area or thickness)
- Shoreline oiling (area or length) for each exposure level (mass/area or thickness)
- Dissolved aromatic contamination in water: peak exposure (area) for each exposure level (concentration)
- Subsurface oil (total hydrocarbon) contamination in water: peak exposure (area) for each exposure level (concentration)
- Sediment total hydrocarbons: (area) for each exposure level (mass/area or concentration)
- Sediment dissolved aromatic: (area) for each exposure level (concentration)

The results for each oil constituent (water surface, shoreline, etc.) and resource (habitat or shore) type are analyzed over all 100 runs of the main stochastic scenarios to determine worst-case runs for shoreline oiling and selected sensitive sites for that scenario. [The worst case run is the most adverse of the 100 runs that were simulated, and, therefore, is the 99th percentile case. The "worst case" would have a likelihood of 1% for spills of the simulated size, i.e., 1% of spills would have more adverse impacts and 99% of spills would have less impact.] The runs producing the worst-case result for shoreline impact were indexed by shoreline cleanup cost. As noted above, the cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are used) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Therefore, total costs related to a spill are for the most part related to shoreline oiling.

Note that the same model run does not typically produce the worst-case impacts to water surface, shoreline, and water column impacts. In fact, when shoreline impacts are highest, water column impacts tend to be relatively low, and *visa versa*. The impact measures from the stochastic modeling provide a quantitative method for determining which runs are the worst-case runs for the resource of interest.

Birds and other wildlife are impacted in proportion to the water and shoreline surface area oiled above a threshold thickness for effects. Shoreline habitat impacts and intertidal mollusks are proportional to surface area oiled above a threshold thickness for effects. Impacts to fish and invertebrates in the water and on the sediments are related to water column and sediment pore water concentrations of dissolved aromatics, or more simply to the amount of oil entrained into the water column after the spill.

Contamination in the water column changes rapidly in space and time, such that a dosage measure as the product of concentration and time is a more appropriate index of impacts than simply peak concentration. As described above, toxicity to aquatic organisms increases with time of exposure, such that organisms may be unaffected by brief exposures to the same concentration that is lethal at long times of exposure. Toxicity data indicate that the 96-hour LC50 (which may serve as an acute lethal threshold) for dissolved aromatics (primarily PAHs) averages about 50 μg/l (ppb). Thus, this exposure dosage is 5,000 ppb-hours. The threshold for chronic and tainting effects is (for sensitive species) about 1% of the LC50, or 0.5 ppb (50 ppb-hours). Contamination in sediments remains longer than 100 hours, such that the use of 50 ppb for acute impacts, and 0.5 ppb for chronic effects, is appropriate as an index. The biological exposure model, which considers duration of exposure, was used to evaluate the actual expected impacts of the spill scenarios examined.

Recreational, tourism, boating/shipping, and other socioeconomic impacts are functionally related to the length of shore and area of water oiled. Cleanup costs are related to volume spilled, portion remaining on the water surface, and area (or length) of shore oiled. Response costs and socioeconomic damages were evaluated in companion

studies by Etkin (2005b,c), Etkin et al. (2006) and Etkin and French-McCay (2005) using the model outputs.

The histograms in Section C of Volumes IV, VII, X, XIII, XVI, XVIV, XXII**,** XXV, and XXVIII show the distribution of model results for all 100 runs within a stochastic scenario, indicating the range of possible impacts depending on the weather conditions and currents at the time of the spill. The following impact indices are plotted as rank order distributions:

- Percent of spilled hydrocarbon mass eventually going ashore
- Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill

In many cases, there is a smooth frequency distribution about the median case. However, occasionally extreme events occur, i.e., the weather conditions are just right to cause the most impact. These figures indicate the median and distribution of impact indices, including the degree of variability and likelihood of extreme events.

Section D of Volumes IV, VII, X, XIII, XVI, XVIV, XXII**,** XXV, and XXVIII contains summary tables for the main stochastic scenarios of shoreline areas exposed above a range of threshold levels. The results are provided by shore type and for all shorelines. These data were used in the calculations of shoreline cleanup costs (Etkin, 2005b,c; Etkin et al., 2006).

4.1.3 Exposure Results for Individual Runs

Section E of Volumes IV, VII, X, XIII, XVI, XVIV, XXII**,** XXV, and XXVIII contains summary graphics for individual model runs for worst-case scenarios for either shoreline impacts or for selected sensitive sites. These maps display information on water surface exposure to floating hydrocarbons (g/ m^2). For scenarios in which diesel was modeled, there are also maps that contain information on the maximum water column exposure to dissolved aromatics at any time after the spill.

Note that the fate of the oil is very dynamic, moving rapidly in space over time. What is shown in the maps is the cumulative path of the contamination. Thus, this contamination is not present in all locations at one time.

4.2 Stochastic Model Results

The general trajectory and fate of the oil may be summarized as follows:

- Outer Coast at Duntz Rock off Cape Flattery (crude): Oil reaches Vancouver Island or the outer coast of Washington, depending on wind direction after the spill, after days or weeks of drifting. Because the spill site is at the entrance of the Strait of Juan de Fuca, extensive oiling of the outer coast further south than the Cape Flattery area is not simulated.

- Strait of Juan de Fuca (crude and Bunker): Requires winds of consistent direction and several days to first reach shore; widespread oiling
- Strait of Juan de Fuca (diesel): Most of the diesel evaporates before it reaches shore.
- San Juan Islands (crude): Oil reaches shore in a few hours to two days; widespread oiling
- Columbia River (Bunker): Oil may reach shore in a few hours (inside the river) or after days (if spilled offshore of river mouth)
- Outer Coast-Sea Lanes (Bunker): Oil reaches the shore parallel to the release line along Sea Lanes within six hours to two days, and reaches Grays Harbor, Willapa Bay, the Columbia River, and the Strait of Juan de Fuca in greater than two days.
- Grays Harbor (Bunker): Oil reaches the shore in a few hours (inside Grays Harbor) or within a few hours to days (outside Grays Harbor).

The time before oil first reached shore varied by each of the 100 runs within a scenario. Figures 4-1 to 4-9 plot the distribution of times for oil to come ashore for the 100 runs. These figures are rank ordered, such that the run with the minimum time to shore is on the left, and the run with the longest time to shore is on the right end of the histogram. Differences between scenarios are primarily due to the proximity of the shorelines to the spill locations.

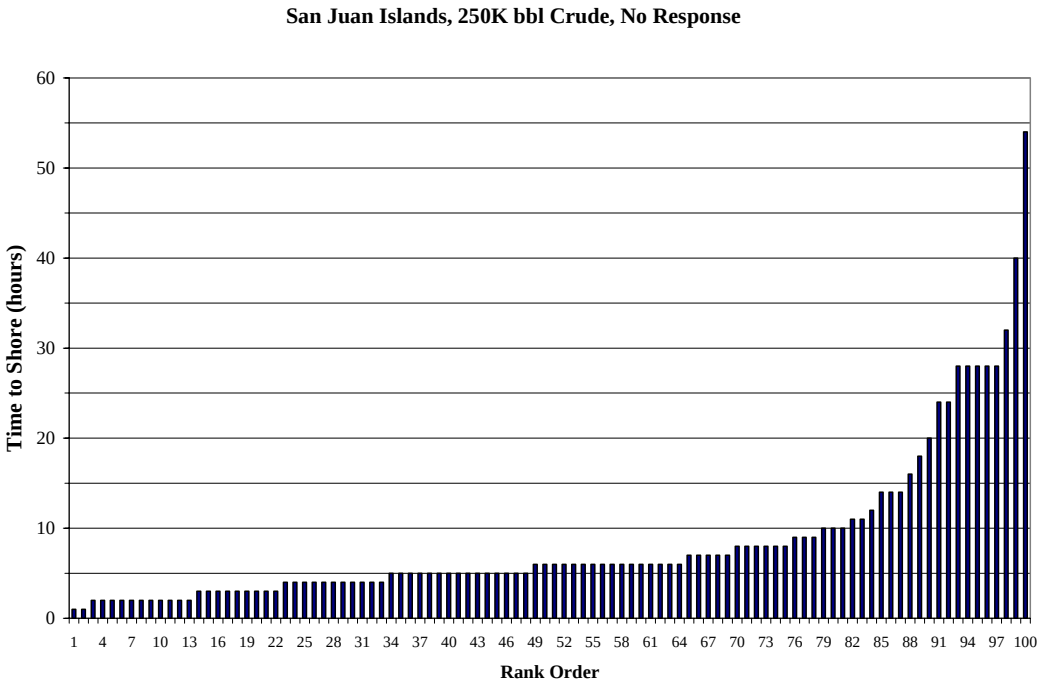

Figure 4-1. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the San Juan Island crude oil spill (no response assumed).

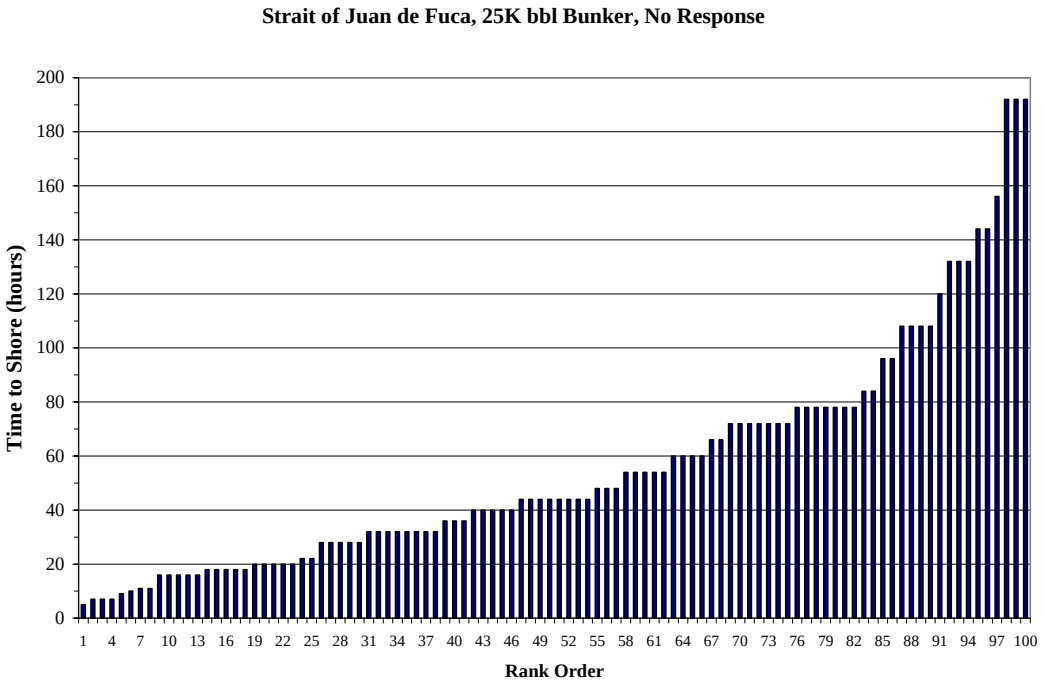

Figure 4-2. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Strait of Juan de Fuca bunker fuel spill (no response assumed).

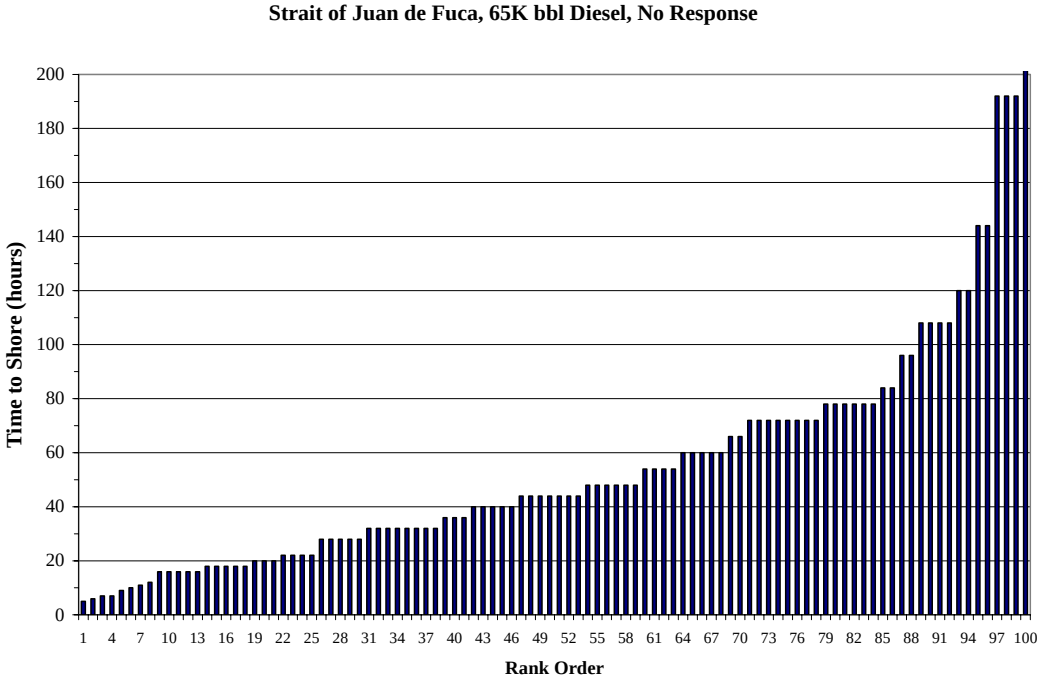

Figure 4-3. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Strait of Juan de Fuca diesel fuel spill (no response assumed).

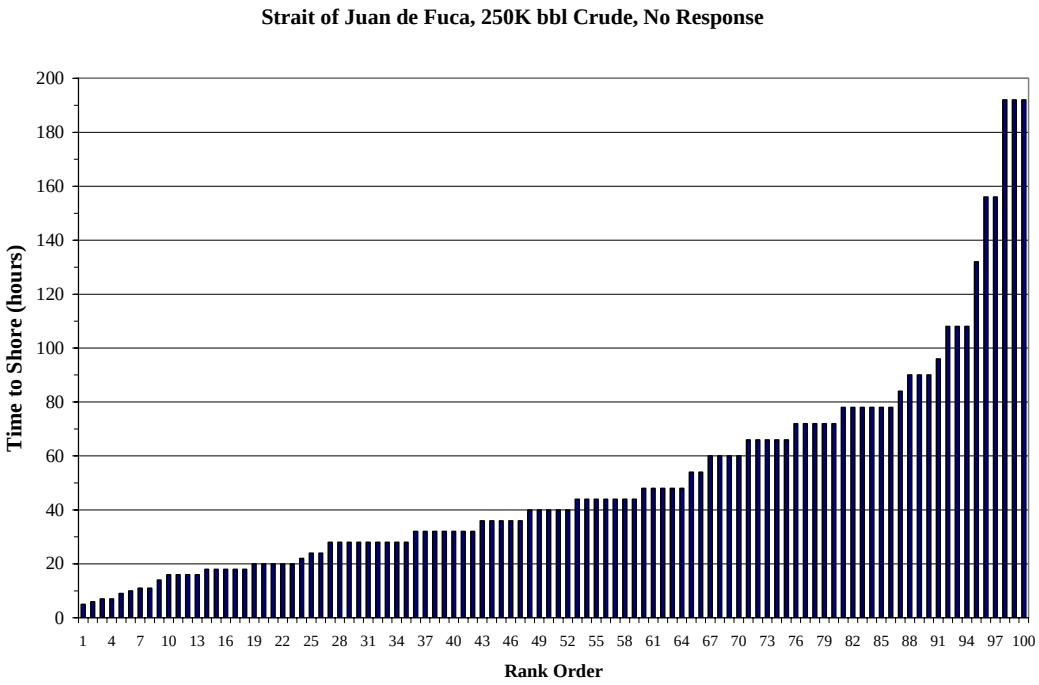

Figure 4-4. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Strait of Juan de Fuca crude oil spill (no response assumed).

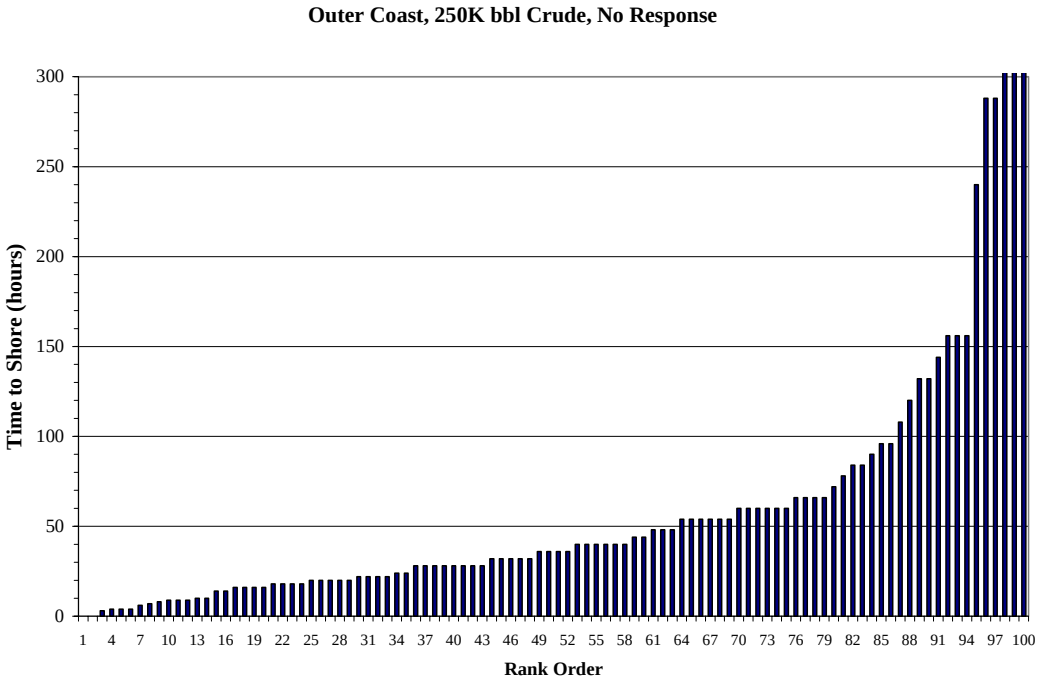

Figure 4-5. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Outer Coast at Duntz Rock crude oil spill (no response assumed).

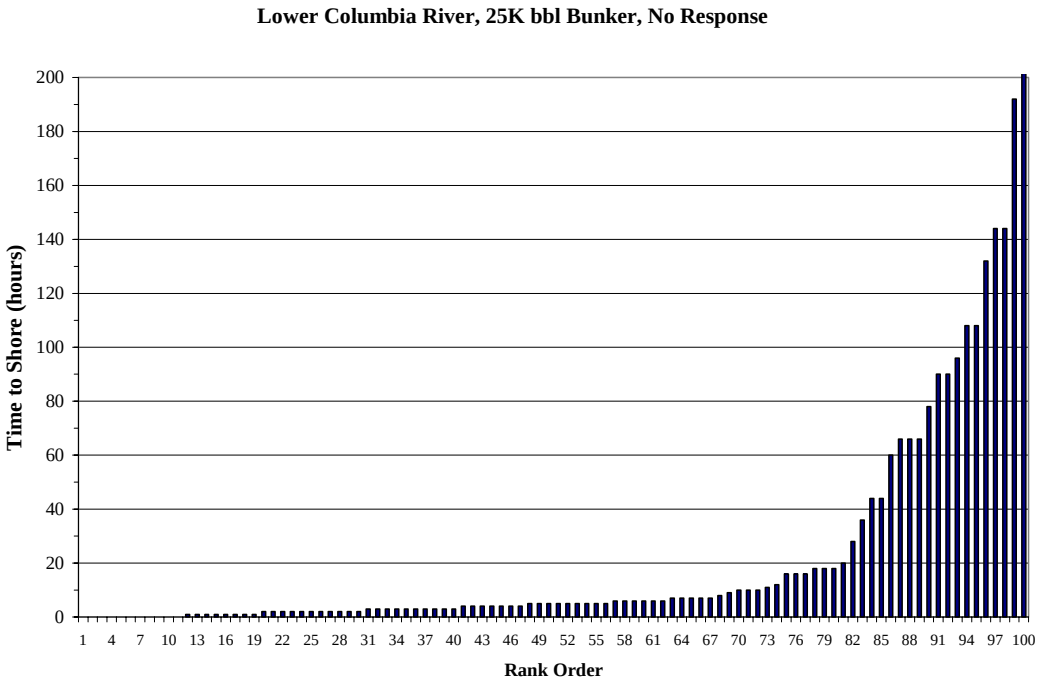

Figure 4-6. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Lower Columbia River bunker fuel spill (no response assumed).

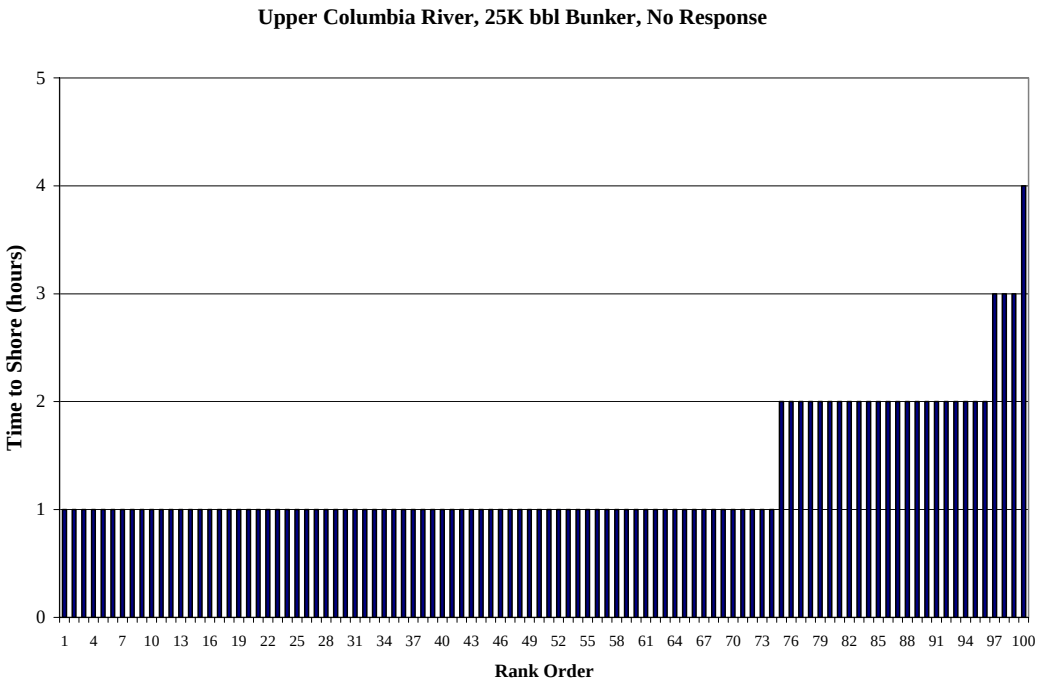

Figure 4-7. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Upper Columbia River bunker fuel spill (no response assumed).

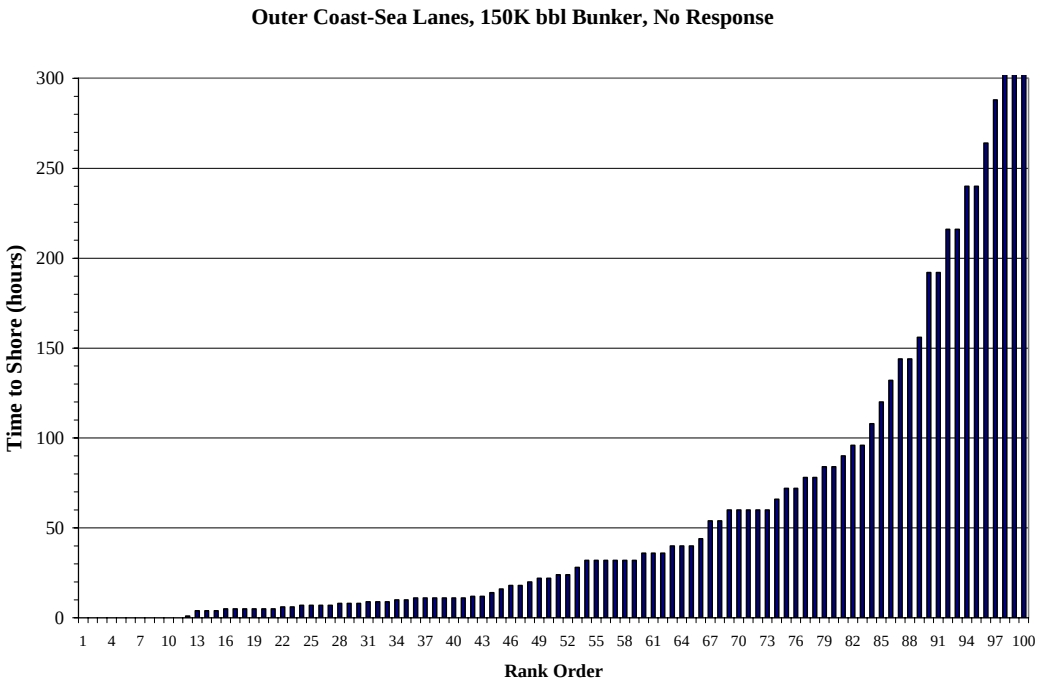

Figure 4-8. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Outer Coast-Sea Lanes bunker spill (no response assumed).

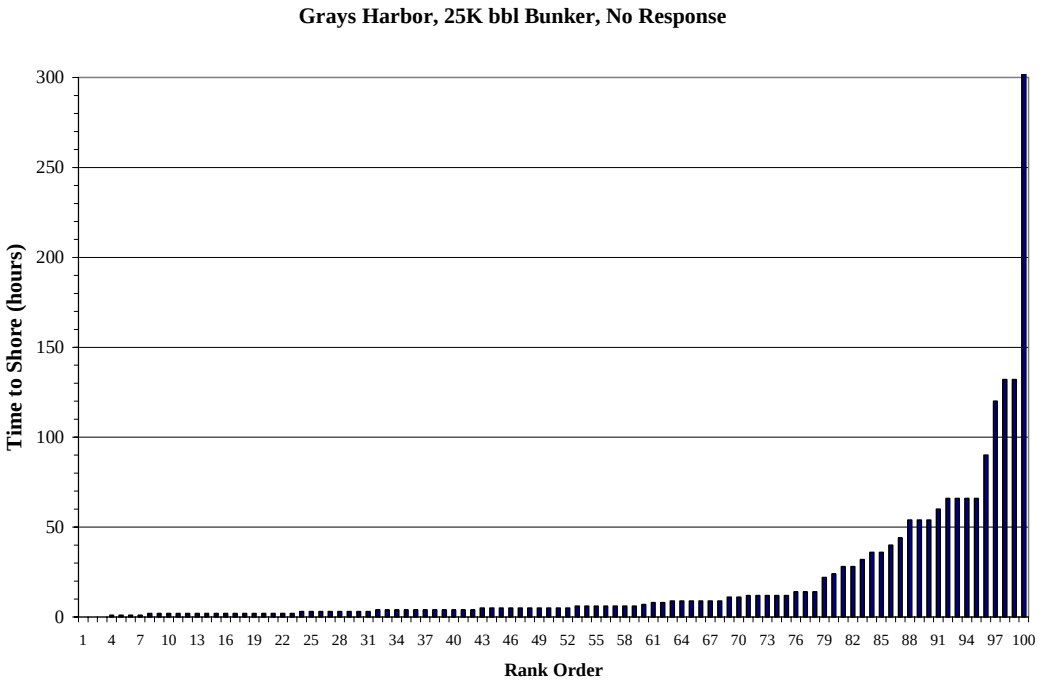

Figure 4-9. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Grays Harbor spill (no response assumed).

Volume II, Section 2 contains summary tables of water surface, shoreline, water column and sediment areas oiled or contaminated for the 9 main stochastic scenarios. The tables contain mean; standard deviation; mean plus or minus two standard deviations (the range for 95 percent of results, assuming a normal (Gaussian) distribution) and the expected 5th, 50th, and 95th percentile result based on the specific exposure index being tabulated. The tables in this section summarize these results for some of the exposure indices examined.

Tables 4-2 and 4-3 summarize the shoreline oiling, listing the percent of oil coming ashore and the length of shore where cleanup would occur. Areas and lengths of shoreline oiling for other thresholds are summarized in Section 2 of Volume II, as are the per area portion of the cleanup costs. The scenario run for the Straits of Juan de Fuca using diesel fuel resulted in the lowest percentage of spilled hydrocarbons eventually coming ashore. This reflects the fact that diesel is more volatile and soluble than the other types of oil that were modeled. While a high percentage of Bunker fuel typically hit the shore, the overall area affected by shoreline oiling was largest in spills of crude oil due to the greater volume of spilled crude that was modeled. The Outer Coast – Sea lanes scenario of 150,000 bbl of bunker would oil more shoreline than the 25,000 bbl Grays Harbor scenario. Furthermore, locations where shipping routes are closer to land (i.e., San Juan Islands and the Lower and Upper Columbia River) usually had a higher percentage of oil coming ashore.

Table 4-2. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	11.7	7.3	-	26.3
JF-Bunk-N	54.7	9.1	36.6	72.8
JF-Dies-N	4.2	4.0	-	12.2
JF-Crud-N	18.2	7.3	3.6	32.7
SJ-Crud-N	26.0	6.6	12.7	39.3
CL-Bunk-N	54.6	23.9	6.7	102.5
CU-Bunk-N	69.1	9.8	49.6	88.7
OL-Bunk-N	29.0	15.7	-	60.5
GH-Bunk-N	61.2	15.8	29.6	92.7

Table 4-3. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 0.01 g/m2 (where cleanup would occur).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,040	2,020	-	6,079
JF-Bunk-N	428	217	-	863
JF-Dies-N	588	481	-	1,550
JF-Crud-N	2,647	1,576	-	5,799
SJ-Crud-N	4,958	2,340	278	9,638
CL-Bunk-N	635	491	-	1,617
CU-Bunk-N	296	115	67	525
OL-Bunk-N	1,034	729	-	2,491
GH-Bunk-N	539	383	-	1,305

The percentage of the spilled oil reaching the sediments is smallest in offshore regions, such as for the Outer Coast at Duntz Rock scenario (Table 4-4), because the spills examined occurred in open, deep water with low suspended sediment concentrations. The percent settling is much higher in the upper Columbia River scenario, because of the shallower water and more extensive shoreline interaction. Also, oil type had a large effect on the percentage of spilled hydrocarbon that eventually settles to the sediment. Due to its characteristic volatility, a very small percentage of diesel tends to enter the sediments. In contrast, approximately one-third or more of the oil from Bunker spills reached subtidal and intertidal sediments (in part after erosion off the oiled shorelines).

Table 4-4. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	4.9	3.8	-	12.4
JF-Bunk-N	33.8	9.2	15.4	52.2
JF-Dies-N	0.076	0.57	-	1.2
JF-Crud-N	12.8	5.1	2.5	23.0
SJ-Crud-N	14.9	6.2	2.5	27.2
CL-Bunk-N	31.2	20.5	0	72.2
CU-Bunk-N	38.7	14.8	9.0	68.4
OL-Bunk-N	29.2	16.4	-	62.0
GH-Bunk-N	51.2	16.4	18.5	83.9

The maximum percent of the oil mass entrained in the water column at any time after the spill (Table 4-5) gives an indication of the amount of oil dispersed naturally. The diesel is much more easily dispersed, being a light non-viscous fuel, and so the amount in the water column is the highest for this scenario.

Table 4-5. Summary of results for all stochastic scenarios of 100 runs each: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	7.0	3.6	-	14.2
JF-Bunk-N	1.4	0.9	-	3.2
JF-Dies-N	44.4	12.9	18.5	70.2
JF-Crud-N	1.5	1.2	-	3.8
SJ-Crud-N	1.1	1.6	-	4.3
CL-Bunk-N	5.2	3.9	-	13.1
CU-Bunk-N	1.6	0.9	-	3.5
OL-Bunk-N	7.0	4.5	-	15.9
GH-Bunk-N	3.4	2.2	-	7.8

The water surface areas swept by floating oil are listed in Tables 4-6 and 4-7. Sheen has a thickness of >0.01 g/m^2. The thresholds for mechanical removal (skimming), effective dispersant use, in situ burning, and biological effects (on wildlife) are all about 10 g/m^2 (10 microns thick). In all scenarios, except for the spills of bunker fuel (which does not spread significantly thinner than 10 microns), the area of the water surface covered by oil with a thickness greater than 10 g/m^2 was smaller than the area covered by a thinner sheen or by scattered tar balls later in the simulation after the oil weathered. The area covered by sheen or tarballs was largest in the outer coast scenarios, due to the unrestricted waters and because less of the oil came ashore due to the offshore location of the modeled spills. Scenarios in which crude was spilled typically resulted in the largest area swept due to the larger volume spilled (the bunker spills were of 1/10th the volume) and the fact that crude is a more viscous oil than diesel that will not readily volatize or become entrained into the water column in large amounts.

Table 4-6. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	9,255	10,391	-	30,037
JF-Bunk-N	533	238	57	1,010
JF-Dies-N	396	228	-	852
JF-Crud-N	1,945	897	152	3,739
SJ-Crud-N	1,201	954	-	3,110
CL-Bunk-N	199	171	-	541
CU-Bunk-N	6	3	-	12
OL-Bunk-N	2,279	1,756	-	5,791
GH-Bunk-N	300	351	-	1,003

Table 4-7. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	7,101	8,167	-	23,436
JF-Bunk-N	530	237	56	1,005
JF-Dies-N	326	204	-	734
JF-Crud-N	1,529	727	76	2,983
SJ-Crud-N	771	649	-	2,070
CL-Bunk-N	196	166	0	527
CU-Bunk-N	6	3	-	11
OL-Bunk-N	2,256	1,715	-	5,685
GH-Bunk-N	295	340	-	976

4.3 Results for Individual Scenarios

Results for alternate response scenarios are tabulated in Volume II, Sections II.3 to II.11, as well as in Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX, . The percent of oil removed by mechanical recovery was for most scenarios <10% of the spilled oil in the Phase II model simulations (Tables 4-8 to 4-16). However, recovery was a higher percentage of the spilled oil for the Bunker scenarios in Grays Harbor and the Strait of Juan de Fuca. The capacity standards input to the model were larger relative to the spill volume for the 25,000 bbl bunker fuel scenarios than for those using the other two oil types or for the Outer Coast-Sea Lanes 150,000 bbl bunker fuel spill scenario. In the Columbia River, the oil came ashore rapidly because of the relatively confined water body, often limiting the on-water recovery. There was not this limitation in the Grays Harbor and the Strait of Juan de Fuca scenarios. For all scenarios, the pattern is apparent where the amount of oil mechanically removed assuming the federal standards was lower, and the amount removed under the 3rd alternative higher, than in the WA state standard simulation.

These recovery amounts are much less than those simulated in Phase I, because (1) the recovery efficiencies were assumed to decrease as time progressed, and (2) removal was only simulated for the first 72 hours because the efficiencies become very low after that time and no more equipment is assumed to be brought in and applied. In Phase I the capacities were assumed operational at optimal efficiencies indefinitely. In both phases of the modeling, only the planning standard capacities were assumed deployed. With the high recovery efficiencies assumed in Phase I, this would appear sufficient. However, accounting for the increasing difficulties in recovering oil over time, more equipment would be needed to increase recovery, or, alternatively, recovery efficiency would need to be higher. The latter is the goal of spill planning, and the reality is that more equipment than the standard capacities require would be deployed in the event of spills as large as those simulated in this study.

Table 4-8. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Outer Coast spills of crude oil at Duntz Rock.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
OC-C250K-N	-	-	-
OC-C250K-Fed	0.04	0.72	0.95
OC-C250K-WA	0.04	3.30	3.54
OC-C250K-3	0.48	3.95	4.31

* The Federal and Washington State responses involved the same removal amounts and timing.

Table 4-9. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-B25K-N	-	-	-
JF-B25K-Fed	5.8	5.8	12.7
JF-B25K-WA	8.5	14.6	28.4
JF-B25K-3	11.6	24.1	42.1

Table 4-10. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	-	-	-
JF-D65K-Fed	2.8	4.1	3.8
JF-D65K-WA	3.9	9.2	8.4
JF-D65K-3	4.8	13.3	12.2

Table 4-11. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-C250K-N	-	-	-
JF-C250K-Fed	2.0	0.9	1.9
JF-C250K-WA	4.5	2.3	4.2
JF-C250K-3	6.7	3.6	6.3

Table 4-12. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for San Juan Island spills of crude oil.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	Worst run for Lummi Island	Worst run for Padilla Bay	50th Percentile Run (based on shore cost)
SJ-C250K-N	-	-	-	-	-	-
SJ-C250K-Fed	1.8	2.0	2.0	1.6	1.8	1.3
SJ-C250K-WA	4.2	4.6	4.4	3.7	3.6	3.4
SJ-C250K-3	5.9	6.8	6.5	5.5	5.2	5.0

Table 4-13. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Lower Columbia River spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	-	-	-
CL-B25K-Fed	1.6	2.2	1.6
CL-B25K-WA	3.4	4.4	3.4
CL-B25K-3	6.7	8.1	6.7

Table 4-14. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Upper Columbia River spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	-	-	-
CU-B25K-Fed	1.8	2.2	2.2
CU-B25K-WA	3.3	3.3	3.8
CU-B25K-3	5.3	6.6	7.4

Table 4-15. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Outer Coast-Sea Lanes spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	-	-	-
OL-B150K -Fed	1.9	1.7	1.8
OL-B150K -WA	6.6	5.6	5.6
OL-B150K -3	6.8	6.1	5.7

Table 4-16. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Grays Harbor spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
GH-B25K-N	-	-	-
GH-B25K -Fed	9.8	3.8	6.4
GH-B25K -WA	25.8	8.4	11.1
GH-B25K-3	42.5	14.2	15.5

Figures 4-10 to 4-12 summarize the mass balance of oil over time after the spill for three representative runs assuming no response, one for each of the oil types. About 55% of the crude oil evaporated after weathering for 2 weeks, which substantially decreased the amount of oil on the water surface and coming ashore (Figure 4-10). Only about 15% of the bunker fuel evaporated (Figure 4-11), while 50% of the diesel evaporated by 6 days after release (Figure 4-12). Most of the crude oil and bunker fuel that did not volatilize (evaporate), eventually came ashore. A considerable percentage of the diesel was entrained in the water column (40% in the example scenario, Figure 4-12) because of its low viscosity making it easily dispersed.

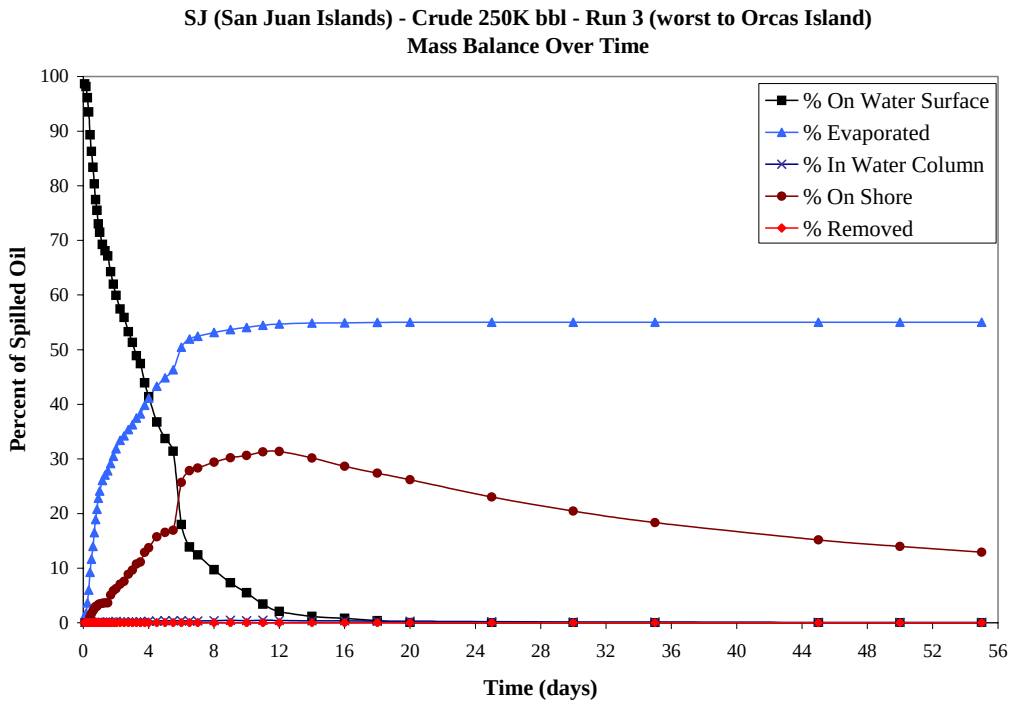

Figure 4-10. Mass balance over time for a crude oil spill simulation in the San Juan Island location (worst run for impacts on Orcas Island).

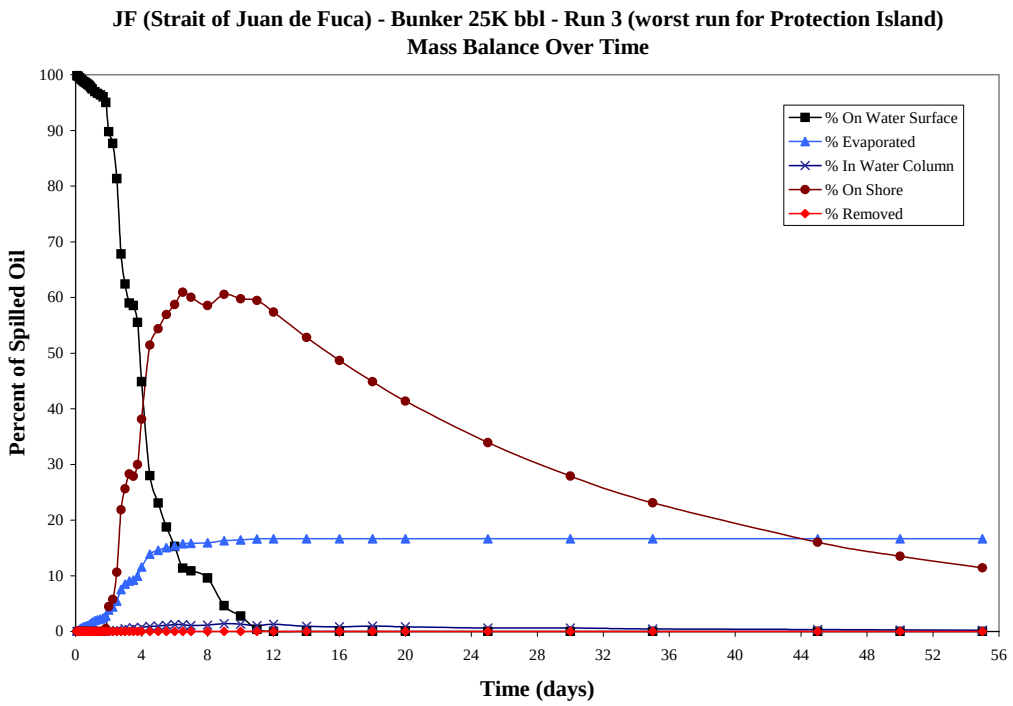

Figure 4-11. Mass balance over time for a bunker fuel spill simulation in the Strait of Juan de Fuca location (worst run for impacts on Protection Island).

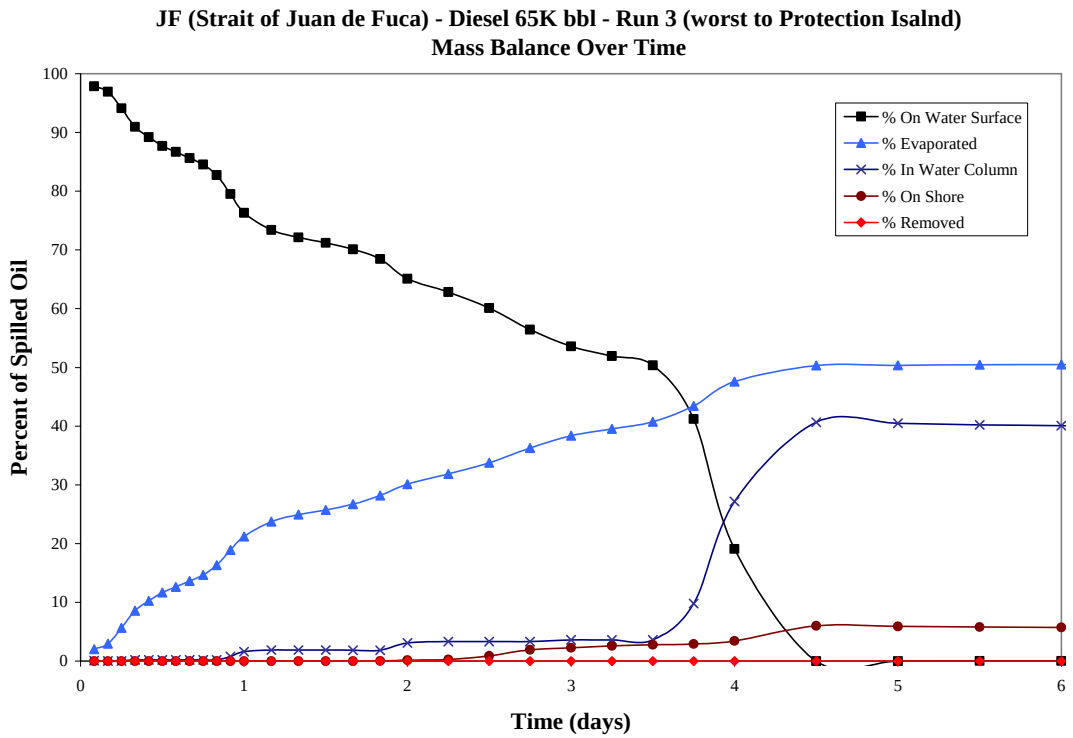

Figure 4-12. Mass balance over time for a diesel fuel spill simulation in the Strait of Juan de Fuca location (worst run for impacts on Protection Island).

Section B in Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contain figures summarizing the mass balance of oil over time after the spill and comparing the four alternative response simulations (no response, federal standards, WA standards and the 3rd alternative standard). There are 3 or 4 figures for each of the individual runs examined, containing results for the four alternative response runs on a single graph so they may be compared:

- Percent of oil floating on the water surface
- Percent of oil on the shoreline
- Percent of oil mechanically removed
- Amount of oil coming ashore within the sensitive site of interest for that run (for worst-case runs for sensitive sites)

The results generally show the expected pattern of less oil on the water surface and on shore at a given time related to higher removal capacity deployed sooner (i.e., in the order no response > federal > WA > 3rd alternative). The bunker fuel results for the Strait of Juan de Fuca and Grays Harbor show these patterns most clearly. However, for many of the runs examined, the differences between the response alternatives are small.

It should be noted that the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model. This results in variability in the movements of oil spillets in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This results in variation in the specific water areas and shoreline locations oiled and in some cases the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported. If this uncertainty were not included in the model simulations, the oil would all move along a single trajectory path to one shoreline location down wind and down current, clearly an unrealistic event to analyze.

In addition, protection booming input to the model deflects oil offshore from the boomed site. In many cases the booms are located to protect inlets, coves and wetlands with small linear shoreline length. In the model, oil deflected off booms moves offshore and along the shore (down wind and with the currents) and may oil other shorelines. Thus, the deflected oil becomes more dispersed, allowing it to impact a larger area. The other shorelines oiled may be of a different type with less ability to "hold" oil (such as a sand beach, which holds less oil per length than a wetland), and so the length of shore oiled may actually be increased by the inclusion of booms in the model. In an actual spill, protective booming would often be accompanied by localized efforts to remove oil. However, simulation of this response detail was not included in the modeling reported here.

The results of the modeling of the alternative response scenarios are summarized in the tables in Section II.3 to II.11 of Volume II, organized by location. More detailed results of the alternate response scenarios are in Volumes V, VIII, XI, XIV, XVII, XX, XXIII, , XXVI, and XXIX including the mass balance figures described above.

The results in Section II.3 to II.11 of Volume II are tabulations of percentage of oil in various environmental compartments *at the end of the simulation*, the maximum areas impacted above various thresholds *at any time after the spill* (the timing of which may vary from one run to the next), numbers or weights of organisms impacted by the end of the simulation, and estimated natural resource damage costs using various methods (see Section 6 below).

Changes in the specific locations where spillets hit shore may result in differences in the amount of shoreline oiled by more than or less than selected thresholds. For example, in one simulation two spillets might hit a single location and be additive in the amount of oil on shore in that segment, while in another simulation the two spillets might hit adjacent shorelines and be additive in area of shore oiled, but not in thickness of oiling. This results in different thicknesses of oil on each shore segment from one simulation to the next. Thus, it should be noted that impact to the shoreline at any threshold level is not necessarily proportional to the shore length or area oiled. This explains some of the variability seen in the results.

Since the Phase II modeling involved simulating (1) only the capacities of the *response planning standards* (not all equipment that might be used in a large spill such as those examined), (2) the decreasing efficiency of oil removal as time goes on, and (3) changes in the timing and capacities of removal activities only in the first 96 hours after the spill, the differences in amounts of oil removed are small. Thus, in many cases, the differences between runs as shown in the figures and listed in the tables in Volume II are less than the randomized variability in the model and are not significant. However, in some cases, the timing of oil removal and arrival on shore changes, as may be seen in the figures showing oil amounts in various environmental compartments (i.e., mass balance) as a function of time in Section B of Volumes V, VIII, XI, XIV, XVII, XX, XXIII, XXVI, and XXIX. The figures in Section B of these volumes are those Washington Department of Ecology will find most useful in evaluating the various planning standards. In addition, Figures 4-1 to 4-9 (above) summarize the time (hours after the spill) oil first reached shore for 100 runs of each of the no-response stochastic scenarios.

5. BIOLOGICAL EFFECTS MODEL RESULTS

5.1 Intertidal Habitats

Section D of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII summarizes the intertidal areas oiled by shore type, including wetlands, above different threshold levels. Complete mortality of the vegetation in saltmarsh wetlands occurs above about 14 mm of oil, based on the literature reviewed in French et al. (1996a). However, oiling by more than 1 mm would likely affect the vegetation to some degree.

Intertidal (shoreline) habitats oiled by more than 0.1mm (>100 g/m^2) of oil were assumed to impact intertidal invertebrates (Section 3.4.3). Impacts were evaluated for geoducks, soft-shell clams, razor clams, and hard clams in soft shoreline habitats (wetlands, mud flats and sand beaches). The main species affected in the straits scenarios (JF and SJ) was the geoduck, an important fishery species. On the outer coast, the other clam species are more abundant. The area of soft shoreline (wetland, mud or sand) impacted was multiplied by clam density to estimate impacts to intertidal invertebrates. Clam abundance along upper Columbia River shorelines was assumed zero, so no intertidal impact to invertebrates was assessed for the upper Columbia River scenario.

Table 5-1 summarizes the results for the 9 main stochastic scenarios. Trends in the mortality of intertidal invertebrates closely followed the spatial distribution of geoduck abundance, resulting in greater mortality in areas, such as the Straits of Juan de Fuca and the San Juan Islands, where geoduck density is highest. By examining the three Straits of Juan de Fuca scenarios, it becomes evident that spills of crude have the largest impact on intertidal mollusks. This reflects the facts that the spill volume of crude was greater and crude covered a larger shoreline area than the other two types of oil. Within the Juan de Fuca region, intertidal invertebrates experienced the lowest mortality levels in the diesel spill. The low impact of the diesel spill on mollusks can again be attributed to this oil's volatile nature, which causes smaller volumes of it to come ashore.

Results for the alternate response scenarios may be found in Volumes V, VIII, XI, XIV, XVII, XX, XXIII, XXVI, and XXIX in Section D. Differences between the three alternative responses in terms of intertidal invertebrate mortality are small and can be largely attributed to the randomized variability that is incorporated into this model. This randomization can cause oil to move closer or farther away from shorelines even when the same speed and direction of wind and currents are used. This can result in near misses of some shoreline areas, thus, affecting the number of geoducks and other intertidal invertebrates affected by an oil spill.

Table 5-1. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (clams).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	9,026	10,561	-	30,149
JF-Bunk-N	33,955	35,399	-	104,752
JF-Dies-N	28,928	41,555	-	112,038
JF-Crud-N	174,703	117,105	-	408,913
SJ-Crud-N	305,639	130,644	44,351	566,926
CL-Bunk-N	1,086	860	-	2,805
CU-Bunk-N	-	-	-	-
OL-Bunk-N	7,986	6,753	-	21,492
GH-Bunk-N	5,181	3,769	-	12,718

5.2 Wildlife

Tables 5-2 and 5-3 summarize the model-estimated bird and mammal kills for the main stochastic scenario simulations. Section F of Volumes IV, VII, X, XIII, XVI, XVIV, and XXII contains the impact estimates by species group for the main 9 scenarios. Section C of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contains impact estimates for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.11 for the alternate response scenarios.

The estimates are proportional to the habitat area oiled by > 10 g/m^2 and to the pre-spill abundance assumed. If the pre-spill abundance were, for example, a factor two different, the model kill estimate would change by that same factor. Abundance varies by season as well as many other factors, such as long term trends in abundance, patchiness in the prey base, variability in habitat characteristics and so on. Thus, there is considerable variability and uncertainty in the estimates. Consequently, the results should be used in a comparative sense and to indicate expected orders of magnitude of injury and damages. In a specific incident, the details of the biological distributions should be evaluated to develop a specific result for that spill.

Table 5-2. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	488,751	611,866	-	1,712,483
JF-Bunk-N	23,120	8,247	6,627	39,613
JF-Dies-N	31,010	13,852	3,306	58,714
JF-Crud-N	163,739	87,505	-	338,749
SJ-Crud-N	93,384	28,122	37,140	149,627
CL-Bunk-N	60,349	50,185	-	160,718
CU-Bunk-N	1,263	800	-	2,864
OL-Bunk-N	121,305	97,079	-	315,464
GH-Bunk-N	31,669	38,202	-	108,073

Table 5-3. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	234	156	-	545
JF-Bunk-N	1.8	0.6	0.6	3.0
JF-Dies-N	2.4	1.3	-	5.1
JF-Crud-N	15.7	9.4	-	34.5
SJ-Crud-N	8.2	2.1	4.0	12.5
CL-Bunk-N	10.2	8.1	-	26.5
CU-Bunk-N	97.1	23	50	144
OL-Bunk-N	55.6	27	0.9	110
GH-Bunk-N	7.4	7.4	-	22.3

The majority of the biological impacts are to birds, particularly to seabirds and waterfowl (diving ducks). The breakdowns by species groups are available in Volume II for the 9 main scenarios (Section II.2) and alternate scenarios (Sections II.3 to II.11). The worst impacts to birds were observed during spills of crude oil. This, in turn, reflects the fact that crude oil swept a large area of the water surface (owing to the large spill volume) as shown in Tables 4-6 and 4-7 of this volume. The highest level of bird mortality was seen in the outer coast region, because the oil remained at sea longer and there were higher abundances of birds on the outer coast compared to other areas, such as the Straits of Juan de Fuca. The Upper Columbia River scenario impacted the fewest birds, since seabird and waterfowl density was less than along the Lower Columbia River and other areas. As was the case with intertidal invertebrates, the differences between the three alternate responses in terms of impacts to birds were frequently less than the randomized variability in the model.

The Alaskan North Slope crude oil spill scenario examined here is the same spill volume as the *Exxon Valdez* oil spill in Prince William Sound, Alaska (March 1989). The mean model-estimated impacts to birds for the Outer Coast at Duntz Rock spill are of the same

order as those that occurred after the *Exxon Valdez* (Exxon Valdez Oil Spill Trustee Council, 1989 Piatt et al., 1990) while the 95% confidence range is very large, from only a few to 1.7 million birds killed. Piatt et all. (1990) estimated 100-690 thousand birds (best estimate 250 thousand) were oiled and died as the result of the *Exxon Valdez* oil spill. The model variability is due to the different possible trajectories depending upon weather and current conditions immediately after a spill. There is similar uncertainty in the densities of birds in the path of a spill, depending on season and natural variability in distributions. Fewer birds are predicted to be oiled by 250,000 bbl crude oil spills in the straits (Strait of Juan de Fuca and near the San Juan Islands) because of lower densities there than on the outer coast and in Prince William Sound.

Table 5-3, which summarizes the results for the 9 main stochastic scenarios, shows that the mammal impacts are projected to be minor, with the exception of the Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Upper Columbia River scenarios. The mammals primarily impacted in the Outer Coast at Duntz Rock and Outer Coast-Sea Lanes scenarios would be sea otters and fur seals, with lesser impacts to harbor seals and harbor porpoises. In the Upper Columbia River, the mammals impacted would be mostly muskrat and mink.

5.3 Fish and Invertebrates

Table 5-11 summarizes estimated impacts to subtidal fish and invertebrates (those in the water exposed to water and submerged sediment concentrations) for the 9 main stochastic scenarios. Section G of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII contains the impact estimates by species group for the main 9 scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios.

Diesel is much more readily dispersed naturally into the water column than crude oil, and so the impacts are projected to be much higher for diesel than for the same volume of crude oil. This is because Alaskan crude oil emulsifies rapidly, minimizing entrainment and dissolution into the water.

The Bunker C spills had low content of soluble and toxic components, and were not readily dispersed naturally into the water because of the high viscosity of the oil. For these reasons, the effects on fish and invertebrates for the Bunker C spills were very minimal in areas where there is rapid dilution, i.e., on the outer coast, in the Straits of Juan de Fuca or in the lower Columbia River. In the upper Columbia River, the impacts were primarily on demersal fish such as suckers, catfish and sunfishes. Once the effect of oil type on impacts to subtidal fish and invertebrates is filtered out, it is apparent that the outer coast scenarios (including Grays Harbor) had the least impacts because of the large dilution volumes involved.

It should be noted that these fish and invertebrate impacts were calculated assuming all the species were of average sensitivity to dissolved aromatics. Some species will be much more sensitive, and impacts to those species would be higher. There would also

likely be species less sensitive than average. As there are insufficient toxicity data available to quantify the degree of sensitivity to aromatics for all species in Washington waters, there is considerable uncertainty around the results based on average sensitivity. Experience with past modeling efforts indicate the uncertainty in the impact estimate related to species sensitivity is on the order of a factor ten higher or lower (95% confidence range). As there is a mix of species sensitivity present, the uncertainty in the total fish and invertebrate impact would be less than a factor ten.

Section D of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contains impact estimates for the alternate response scenarios. These results are also summarized in Sections II.3 to II.11 of Volume II. Frequently, differences between the alternate responses are smaller than the randomized variability incorporated into this model. Also, when booming is applied, the oil that is deflected offshore stays on the water surface for longer, thus, allowing more oil to be potentially entrained into the water column. This can result in a higher rate of mortality to subtidal fishes and invertebrates.

Table 5-4. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	1,376	1,388	-	4,152
JF-Bunk-N	62	10	41	82
JF-Dies-N	49,500	29,488	-	108,476
JF-Crud-N	14,544	8,834	-	32,212
SJ-Crud-N	6,807	9,599	-	26,005
CL-Bunk-N	6	9	-	24
CU-Bunk-N	3,382	343	2,695	4,069
OL-Bunk-N	82	31	20	145
GH-Bunk-N	17	4	8	25

Table 5-5 contains a summary of the total estimated impacts to fish and invertebrates in all subtidal and intertidal habitats. Again, Section G of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII contains the impact estimates by species group for the main 9 scenarios and Section D of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contains those for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.11 for the alternate response scenarios.

With two notable exceptions, the majority of impacts to fishes and invertebrates affected intertidal biota. Due to diesel's high solubility and toxicity, spills involving this type of oil result in greater mortality to subtidal organisms. In the Juan de Fuca scenario in which diesel was used, 63% of the impacted organisms were subtidal fishes and invertebrates. All of the impacted biota in the upper Columbia River spill were subtidal, because no intertidal losses were assessed for this scenario.

Table 5-5. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal and intertidal fish and invertebrates.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	10,403	11,949	-	34,301
JF-Bunk-N	34,016	35,409	41	104,834
JF-Dies-N	78,428	71,042	-	220,513
JF-Crud-N	189,247	125,939	-	441,125
SJ-Crud-N	312,446	140,243	44,351	592,931
CL-Bunk-N	1,092	868	-	2,829
CU-Bunk-N	3,382	343	2,695	4,069
OL-Bunk-N	8,068	6,784	20	21,637
GH-Bunk-N	5,198	3,773	8	12,743

6. POTENTIAL NATURAL RESOURCE DAMAGES

6.1 NRD Based on Restoration Costs

Historically, NRDA costs associated with impacts were based on economic valuation methods and that approach was used in the CERCLA regulations (including the type A model, the NRDAM/CME). However, under the 1990 Oil Pollution Act NRDA regulations published in January of 1996 by NOAA, the federal approach to NRDA has been focused on use of compensatory restoration costs rather than the economic valuation. Present practice by NRDA trustees is to use the cost of restoration of resources similar in value to the injured resources when primary restoration of the injured resources is not feasible (i.e., the recovery rate of the injured resources cannot be accelerated over natural recovery). Thus, this refocusing of the NRDA cost functions is used in the current analysis and restoration costs are used for both primary and compensatory restoration of injured resources.

The scaling of the compensatory restoration uses methods currently practiced by NOAA and other trustees, i.e., Habitat Equivalency Analysis (HEA). Scaling methods used here were initially developed for use in the *North Cape* case, as described in French et al. (2001), French McCay and Rowe (2003) and French McCay et al. (2003a). These methods have also been used in several other cases, as well as in successful claims for 23 cases submitted by the Florida Department of Environmental Protection to the US Coast Guard, National Pollution Fund Center (French McCay et al., 2003c).

Restoration should provide equivalent quality fish and invertebrate biomass to compensate for the lost fish and invertebrate production. The restoration should also replace the wildlife lost. Equivalent quality implies same or similar species with equivalent ecological role and value for human uses. The equivalent production or replacement should be discounted to present-day values to account for the interim loss between the time of the injury and the time when restoration provides equivalent ecological and human services.

Habitat creation or preservation projects have been used to compensate for injuries of wildlife, fish and invertebrates. The concept is that the restored habitat leads to a net gain in wildlife, fish and invertebrate production over and above that produced by the location before the restoration. The size of the habitat (acreage) is scaled to just compensate for the injury (interim loss).

In the model used here, the habitat may be seagrass bed, saltmarsh, oyster reef, freshwater or brackish wetland, or other structural habitats that provide such ecological services as food, shelter, and nursery habitat and are more productive than open bottom habitats. The injuries are scaled to the new primary (plant) or secondary (e.g., benthic) production produced by the created habitat, as the entire food web benefits from this production. A preservation project that would avoid the loss of habitat could also be scaled to the production preserved. The latter method would only be of net gain if the

habitat is otherwise destined to be destroyed. In this analysis we assume only habitat creation projects would be undertaken.

The approach to scaling the size of the needed project is to use primary production to measure the benefits of the restoration. The total injuries in kg are translated into equivalent plant (angiosperm) production as follows. Plant biomass passes primarily through the detrital food web via detritivores consuming the plant material and attached microbial communities. When macrophytes are consumed by detritivores, the ecological efficiency is low because of the high percentage of structural material produced by the plant, which must be broken down by microorganisms before it can be used by the detritivore. Each species group is assigned a trophic level relative to that of the detritivores. If the species group is at the same trophic level as detritivores, it is assumed 100% equivalent, as the resource injured would presumably have the same ecological value in the food web as the detritivores. If the injured resource preys on detritivores or that trophic level occupied by the detritivores, the ecological efficiency is that for trophic transfer from the prey to the predator. Values for production of predator per unit production of prey (i.e., ecological efficiency) are taken from the ecological literature, as reviewed by French McCay and Rowe (2003). The ecological efficiencies assumed are in Table 6-1.

Table 6-1. Assumed ecological efficiencies for one trophic step.

Consumer	Prey/food	% Efficiency
Invertebrate detritivore	Angiosperm	6.6
Invertebrate	Microalgae	10
Invertebrate	Microorganisms	20
Invertebrate or fish bottom feeder	Detritivores, microalgae	10
Invertebrate or fish	Invertebrate	20
Invertebrate or fish filter feeder	Plankton	20
Invertebrate or fish piscivore	Finfish	20
Sea turtles	Macrophytes, invertebrates	4
Birds, mammals	Invertebrate	2
Birds, mammals, piscivores	Finfish	2

The equivalent compensatory amount of angiosperm (plant) biomass of the restored resource is calculated as kg of injury divided by ecological efficiency. The ecological efficiency is the product of the efficiency of transfer from angiosperm to invertebrate detritivore and efficiency from detritivore to the injured resource, accounting for each step up the food chain from detritivore to the trophic level of concern. Table 6-2 lists the composite ecological efficiency relative to benthic invertebrate production for each trophic group evaluated in the modeling.

Table 6-2 Composite ecological efficiency relative to benthic invertebrate production by trophic group.

Species Category	Trophic Level	Ecological Efficiency Relative to Benthic Detritivores (%)
Fish and Invertebrates:		
Small pelagic fish	planktivorous	20
Large pelagic fish	Piscivores/predators	0.8
Demersal fish	bottom feeders	10
Mollusks	filter/bottom feeder	20
Benthic invertebrates (non-molluscan)	filter/bottom feeder	20
Demersal macroinvertebrate predators	predate bottom feeders	4
Birds:		
Waterfowl	bottom feeders	2
Seabirds	piscivores	0.4
Waders	piscivores	0.4
Shorebirds	bottom feeders	2
Raptors	piscivores	0.4
Other wildlife:		
Sea turtles	secondary consumers	4
Sea otters	secondary consumers	2
Pinnipeds	piscivores	0.4
Cetaceans	piscivores	0.4

The productivity gained by the created habitat is corrected for less than full functionality during recovery using a sigmoid recovery curve. Discounting at 3% per year is included for delays in production because of development of the habitat, and delays between the time of the injury and when the production is realized in the restored habitat. The equations and assumptions may be found in French McCay and Rowe (2003).

The needed data for the scaling calculations are:

- number of years for development of full function;
- annual primary production rate per unit area (P) of restored habitat at full function (which may be less than that of natural habitats);
- delay before restoration project begins; and
- project lifetime (years the restored habitat will provide services).

In Washington, it is most likely that saltmarsh restoration would be undertaken as restoration for wildlife, fish and invertebrate injuries. Seagrass (eelgrass) bed restoration is also an option. However, this requires good water quality and appropriate environmental conditions to be successful. The calculatations for both habitats are included here for comparative purposes. However, the best estimate for NRDA costs is that based on (saltmarsh) wetland restoration, as this is most likely to be pursued.

6.1.1 Saltmarsh Restoration

HEA calculations for saltmarsh are performed following the methods in French McCay and Rowe (2003). It is assumed that the saltmarsh requires 15 years to reach 99% of full function (based on PERL, 1990; Zedler, 1992; Seneca and Broome, 1992; French et al., 1996a), ultimately reaching 80% of natural habitat productivity, the restoration begins 3 years after the spill, and the project lifetime is 50 years.

Above-ground primary production rate of saltmarsh cord grasses on the Oregon coast was estimated from data in Continental Shelf Associates (1991) as 2,636 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 93 g dry weight m^{-2} (Phillips, 1984). Thus, estimated total primary production rate in saltmarshes is 2,729 g dry weight m^{-2} yr^{-1}. It is assumed that created marshes reach 80% of the production rate in natural marshes, i.e., 2,184 g dry weight m^{-2} yr^{-1}.

For the injured resources, all weights are as wet weight and dry weight is assumed 22% of wet weight. For the wildlife, the body mass per animal (from French et al 1996b) is used to estimate injury in kg (multiplying by number killed and summing each species category). Saltmarsh creation cost ($46.30/$m^2$) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year.

The amounts of saltmarsh required in compensation for the quantified wildlife, fish and invertebrate injuries and the cost of the restoration are summarized for the 9 main stochastic scenarios in Tables 6-3 and 6-4. Section H of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII contains the restoration scale (area required for compensation) and cost estimates by species group for the main 9 scenarios. The results are summarized in Volume II, Section II.2. The executive summary also contains summary tables of the NRDA cost estimates for all species groups, so that these costs may be carried forward into the cost-benefit analysis performed by the Department of Ecology.

According to HEA-scaled calculations, the offshore crude oil scenario would be the most expensive to provide compensatory restoration because of the relatively large impact on birds. In general, spills of crude oil required larger amounts of wetland creation, while spills of Bunker C typically resulted in the smallest restoration efforts. These patterns reflect both the impacts to biota and the spill volume that was modeled.

Section E of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contains those for the alternate response scenarios, which are also summarized in Sections II.3 to II.11 of Volume II. As was the case with most of the biological response variables considered in this report, the differences between the three alternative responses in terms of the cost of saltmarsh creation was smaller than the amount of randomized variability that was incorporated into this model.

Table 6-3. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,677	3,114	-	8,905
JF-Bunk-N	137	68	13	273
JF-Dies-N	436	273	17	981
JF-Crud-N	953	396	284	1,744
SJ-Crud-N	527	156	283	838
CL-Bunk-N	221	212	0	645
CU-Bunk-N	7	3	2	13
OL-Bunk-N	598	454	0.6	1,506
GH-Bunk-N	133	169	0.1	472

Table 6-4. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	502	584	-	1,669
JF-Bunk-N	26	13	2.4	51
JF-Dies-N	82	51	3.3	184
JF-Crud-N	179	74	53	327
SJ-Crud-N	99	29	53	157
CL-Bunk-N	41	40	0	121
CU-Bunk-N	1.3	0.6	0.4	2.4
OL-Bunk-N	112	85	0.1	282
GH-Bunk-N	25	32	0.01	88

6.1.2 Seagrass Bed Restoration

HEA calculations for seagrass are performed following the methods in French McCay and Rowe (2003). It is assumed that the habitat requires 3 years to reach 99% of full function (French et al., 1996a; Fonseca et al., 1998), ultimately reaching 80% of natural habitat productivity, the restoration begins 3 years after the spill, and the project lifetime is 50 years.

The estimated primary production rate for eelgrass in Puget Sound (Phillips 1984) is 1,079 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 93 g dry weight m^{-2} (Phillips, 1984). Thus, estimated total primary production rate in seagrass beds is 1,172 g dry weight m^{-2} yr^{-1}. It is assumed that created seagrass bed reach 80% of the production rate in natural beds, i.e., 938 g dry weight m^{-2} yr^{-1}.

For the injured resources, all weights are as wet weight and dry weight is assumed 22% of wet weight. For the wildlife, the body mass per animal (from French et al 1996b) is used to estimate injury in kg (multiplying by number killed and summing each species category). Seagrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

The amounts of seagrass bed required in compensation for the quantified wildlife, fish and invertebrate injuries and the cost of the restoration are summarized for the 9 main stochastic scenarios in Tables 6-5 and 6-6. Section H of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII contains the restoration scale and cost estimates by species group for the main 9 scenarios and Section E of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI,and XXIX contains those for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.11 for the alternate response scenarios.

The results based on seagrass restoration show the same patterns as for saltmarsh restoration (discussed above in Section 6.1.1), as the values are proportional to the injuries. The area of saltmarsh required for compensation is 1.6 times the area of seagrass bed, and the total costs for saltmarsh compensation are 2.5 times those for seagrass bed. However, it is likely that saltmarsh would be the restoration option selected by NRD trustees because it is more likely to be successfully implemented. Thus, the saltmarsh costs, and not the seagrass costs, are the best and most conservative estimates to carry forward to the cost-benefit analysis.

Table 6-5. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming seagrass bed creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	1,673	1,946	-	5,565
JF-Bunk-N	85	43	8	171
JF-Dies-N	272	170	11	613
JF-Crud-N	595	247	177	1,090
SJ-Crud-N	329	97	177	524
CL-Bunk-N	138	132	0	403
CU-Bunk-N	4.4	1.9	1.3	8.2
OL-Bunk-N	374	284	0.4	941
GH-Bunk-N	83	106	0.0	295

Table 6-6. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is seagrass bed creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	200	232	-	664
JF-Bunk-N	10	5	1.0	20
JF-Dies-N	33	20	1.3	73
JF-Crud-N	71	30	21	130
SJ-Crud-N	39	12	21	63
CL-Bunk-N	16.5	15.8	0	48.1
CU-Bunk-N	0.5	0.2	0.2	1.0
OL-Bunk-N	45	34	43	112
GH-Bunk-N	10	13	0.004	35

6.2 Washington State Compensation Schedule

The Washington Compensation Schedule, as described in the State of Washington's Chapter 173-183 WAC, Preassessment Screening and Oil Spill Compensations Schedule Regulations, was applied to the model results for hypothetical spills simulated in estuarine and marine waters. The Compensation Schedule is designed to be a simplified procedure for small spills. Thus, for spills the size of those considered here, the OPA procedures using restoration costs (Section 6.1) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

The resource damage assessment using Compensation Schedule includes:

- Relative ranking for each class of oil based on factors that affect severity and persistence of spill on environment.
- Relative vulnerability ranking of the environment, which involves:
    - location of spill;
    - habitat and public resource sensitivity to oil;
    - seasonal distribution of the public resource;
    - areas of recreational use and aesthetic importance;
    - proximity of the spill to important habitats for birds, mammals, fish, and endangered species; and
    - other areas of special ecological or recreational importance.
- A quantitative method for determining public resource damages based on oil effects and vulnerability rankings designed to compensate people of the state; i.e., the damages range from $1 to $50 per gallon spilled, scaled by the vulnerability score based on the above considerations.
- A method to adjust damages calculated under the compensation schedule to account for actions taken by responsible party; i.e., the amount of oil recovered in the first 24 hours is subtracted from the amount spilled in performing the calculations.

The Compensation Schedule procedures for marine and estuarine waters, excluding the estuarine waters of the Columbia River, were applied using the spill volume less the amount of oil mechanically recovered in the first 24 hours. The results, including $/gal, percent removed in the first 24 hours, and total damages (in millions of dollars) are listed in Section I of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, XXVII for the main 9 scenarios and Section F of Volumes V, VIII, XI, XIV, XVII, XVV, and XXIII, XXVI, and XXIX for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.11 for the alternate response scenarios. Table 6-7 summarizes the results for the 9 main stochastic scenarios. The Compensation Schedule was not applied to the upper Columbia River spills as that application is performed by field observations and so cannot be easily modeled. Since the damages calculated by the Washington Compensation Schedule are based on $/gallon figures that are related to the sensitivity of geographical regions (as well as habitat, biota and oil type) and the area of impact can be fairly similar for the 100 runs within a given

scenario, there is little variability between the results of different runs within a scenario. This is also the case when comparing the alternate response scenarios for a single run (summarized in Sections II.3 to II.11 of Volume II): there is almost no variation between them because they impact the same resources geographically and the spill volume is the same.

Table 6-7. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of $), using the WA Compensation Schedule.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	246	8	230	261
JF-Bunk-N	29.1	1.5	26.1	32.0
JF-Dies-N	45.8	1.9	42.1	49.5
JF-Crud-N	238	15	208	267
SJ-Crud-N	249	17	214	284
CL-Bunk-N	19.9	12.3	0.0	44.6
CU-Bunk-N	*	*	*	*
OL-Bunk-N	174	23.8	126	222
GH-Bunk-N	30.4	5.5	19.4	41.4

* WA Compensation Schedule damages were not calculated for the Upper Columbia River.

7. DISCUSSION AND CONCLUSIONS

7.1 Use of the Probabilistic Approach – Stochastic Modeling

The use of stochastic modeling in this project to produce results and statistics for multiple model runs under various possible environmental conditions demonstrates a statistically quantifiable method for estimating potential impacts and financial consequences that may be used in ecological risk assessment and cost-benefit analyses. The statistically-defined consequences provide an objective measure of the magnitude, range and variability of impacts to wildlife, aquatic organisms and shorelines, and of damages that could be claimed by (US) federal and state natural resource trustees.

7.2 Oil Recovery Rates

The Phase I modeling results, assuming recovery operations at the Effective Daily Recovery Capability (EDRC) rate, indicated that the mechanical removal capacities examined would be sufficient for cleaning up much of the spill volumes evaluated and could reduce impacts to biota and shorelines. However, the Phase I simulations assumed that everything goes according to plan and responders know where the oil is at all times. In reality, people and equipment will not be able to meet the schedules exactly and there will not be perfect knowledge of the oil movements allowing the responders to mechanically clean up as much oil as the results suggest. Thus, the percentage removed mechanically is the maximum possible given the equipment capacities. In addition, dispersant use, if performed with mechanical recovery, would likely account for more of the oil removal from the water surface in an actual spill event than is reflected by the Phase I results.

In Phase II modeling, the mechanical recovery rates were adjusted to take into account inefficiencies in applying mechanical recovery methods as observed in many actual spill responses and as indicated by research done by experts in the field (Etkin, 2005b). The modeled removal rate decreased over time due to the spreading of the oil on the water surface and decreasing opportunities to effectively corral and remove oil. As a result, most of the removal would occur in the first 72 hours, and the percent of oil removed by mechanical recovery was for most scenarios <10% of the spilled oil in the Phase II model simulations. However, recovery was a higher percentage of the spilled oil for the Bunker scenarios in the Strait of Juan de Fuca and Grays Harbor. The capacity standards input to the model were larger relative to the spill volume for bunker fuel than the other two oil types. In the Columbia River, the oil came ashore rapidly because of the relatively confined water body, often limiting the on-water recovery. There was not this limitation in the Strait of Juan de Fuca or near/in Grays Harbor. For all scenarios, the pattern is apparent where the amount of oil mechanically removed assuming the federal standards was lower, and the amount removed under the 3rd alternative higher, than in the WA state standard simulation.

In both phases of the modeling, only the planning standard capacities were assumed deployed. With the high recovery efficiencies assumed in Phase I, this would appear

sufficient. However, accounting for the increasing difficulties in recovering oil over time, more equipment would be needed to increase recovery, or, alternatively, recovery efficiency would need to be higher. The latter is the goal of spill planning, and the reality is that more equipment than the standard capacities require would be deployed in the event of spills as large as those simulated in this study.

7.3 Differences in Impacts with Alternative Response Scenarios

Because the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model, there is variability in the movements of oil spillets in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This results in variation in the specific water areas and shoreline locations oiled and in some cases the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported.

In addition, protection booming input to the model deflects oil offshore from the boomed site. In many cases the booms are located to protect inlets, coves and wetlands with small linear shoreline length. In the model, oil deflected off booms moves offshore and along the shore (down wind and with the currents) and may oil other shorelines. Thus, the deflected oil becomes more dispersed, allowing it to impact a larger area. The other shorelines oiled may be of a different type with less ability to “hold” oil (such as a sand beach, which holds less oil per length than a wetland), and so the length of shore oiled may actually be increased by the inclusion of booms in the model. In an actual spill, protective booming would often be accompanied by localized efforts to remove oil. However, simulation of this response detail was not included in the modeling reported here.

Because the differences in amounts of oil removed are small in the Phase II simulations, the differences between runs are in many cases less than the randomized variability in the model and are not significant. However, in some cases, the timing of oil removal and arrival on shore changes, as may be seen in the figures showing oil amounts in various environmental compartments (i.e., mass balance) as a function of time in Section B of Volumes V, VIII, XI, XIV, XVII, XX, XXIII, XXVI, and XXIX. The figures in Section B of these volumes are those Washington Department of Ecology will find most useful in evaluating the various planning standards. There are also figures in Section 4 of this volume (Figures 4-1 to 4-9) that summarize the time (hours after the spill) oil first reached shore for 100 runs of each of the no-response stochastic scenarios.

7.4 Biological Impacts

The majority of the biological impacts are to birds, particularly to seabirds and waterfowl (diving ducks). The highest level of bird mortality occurred in the outer coast region, because the oil remained at sea longer and there were higher abundance of birds there

compared to other areas, such as in the Straits of Juan de Fuca. The Upper Columbia River scenario impacted the fewest birds, since seabird and waterfowl density was less than along the Lower Columbia River and other areas.

The mammal impacts are projected to be minor, with the exception of the outer coast scenarios and upper Columbia River scenarios. The mammals primarily impacted in the outer coast would be sea otters and fur seals, with lesser impacts to harbor seals and harbor porpoises. In the upper Columbia River, the mammals impacted would be mostly muskrat and mink.

Diesel is much more readily dispersed naturally into the water column than crude oil, and so the impacts to subtidal fish and invertebrates (those in the water exposed to water and submerged sediment concentrations) are projected to be much higher for diesel than for a larger volume of crude oil. This is because Alaskan crude oil emulsifies rapidly, minimizing entrainment and dissolution into the water. The Bunker C spills had low content of soluble and toxic components, and were not readily dispersed naturally into the water because of the high viscosity of the oil. For these reasons, the effects on fish and invertebrates for the Bunker C spills were very minimal in areas where there is rapid dilution, i.e., on the outer coast, in the Straits of Juan de Fuca, or in the lower Columbia River. In the upper Columbia River, the impacts were primarily on demersal fish such as suckers, catfish and sunfishes. Once the effect of oil type on impacts to subtidal fish and invertebrates is filtered out, it is apparent that the outer coast scenarios (including Grays Harbor) had the least impacts because of the large dilution volumes involved.

Impacts to intertidal invertebrates were evaluated for clams in soft shoreline habitats (wetlands, mud flats and sand beaches). The impacts to clams are proportional to the shoreline area heavily oiled. Trends in the mortality of intertidal invertebrates closely followed the spatial distribution of geoduck clam abundance, resulting in greater mortality in areas, such as the Straits of Juan de Fuca, and the San Juan Islands, where geoduck density is highest. By examining the three Straits of Juan de Fuca scenarios, it becomes evident that spills of crude have the largest impact on intertidal mollusks. This reflects the facts that the spill volume of crude was greater and crude covered a larger shoreline area than the other two types of oil. Within the Juan de Fuca region, intertidal invertebrates experienced the lowest mortality levels in the diesel spill. The low impact of the diesel spill on mollusks can again be attributed to this oil's volatile nature, which causes smaller volumes of it to come ashore.

7.5 Natural Resource Damages

The natural resource damages were based on estimated costs to restore equivalent resources and/or ecological services, as this is the preferred method used by natural resource trustees based on guidance in the OPA regulations. The Washington Compensation Schedule is designed for small spills, much less than the volumes considered here. Habitat Equivalency Analysis (HEA) was used to estimate the required amount of habitat restoration for NRD compensation of injuries to wildlife, fish and invertebrate species. Production by the restored habitat ultimately benefits wildlife, fish

and invertebrates, and equivalency is assumed if equal production of similar species (i.e., the same general taxonomic group and trophic level) results.

The estimated costs of saltmarsh restoration required in compensation for the quantified wildlife, fish and invertebrate injuries are summarized for the 9 stochastic scenarios in the executive summary. The total costs for saltmarsh compensation are 2.5 times those estimated assuming seagrass beds would be restored in compensation. However, it is likely that saltmarsh would be the restoration option selected by NRD trustees because it is more likely to be successfully implemented. Thus, the saltmarsh costs, and not the seagrass costs, are the best and most conservative estimates to carry forward to a cost-benefit analysis.

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Phase II. Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume II: Summary of Results for All Scenarios

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II.1. INTRODUCTION

Table II-1.1 lists the oil spill modeling scenarios for the Phase II modeling, defined by spill location, oil type and response assumed. The 7 scenarios that assume no mechanical removal and no booming (i.e., no response) were all run in stochastic mode, where 100 randomly selected dates were run for each. For each no response (stochastic) scenario, alternate scenarios were also run, where mechanical removal and booming were added at three levels: federal planning standards (US Federal Caps), Washington state planning standards (WA Caps), and a third removal planning standard (3rd Alternative Caps). These planning standards are listed in order of increasing amounts and/or earlier placement of mechanical removal equipment. They assume the same set of booming locations but with varying placement times. (See Volume I, Etkin (2005b,c) and Etkin and French-McCay (2005) for specifics of the response assumptions).

For the alternate response (planning standard) scenarios, 3 or 6 runs (i.e., dates and times) were selected from the 100 stochastic runs in the no response scenario. The runs that were selected represent:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at sensitive site #1;
3. the worst case run for impacts at sensitive site #2;
4. the worst case run for impacts at sensitive site #3 (San Juan Islands only);
5. the worst case run for impacts at sensitive site #4 (San Juan Islands only); and
6. the 50th percentile run based on shoreline oiling and area-based costs for cleanup (San Juan Islands only).

Table II-1.2 lists the sensitive sites for each location. The locations of these sites are shown in maps in Section A of Volumes V, VIII, XI, XIV, XVII, XX, and XXIII. The individual run dates and times, geographic data, current data, and model inputs are the same for each of the alternate response scenarios as was used for the no response runs so inter-comparisons may be made. The no-response stochastic scenario was used to identify which run was worst case (99th percentile because it is selected from 100 runs) in terms of shoreline cleanup cost. Other representative runs were selected as those most impacting the shoreline at sensitive sites of concern.

The 100 stochastic scenario runs of the no response base case scenario were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs [only the per area portion of the costs are listed here] are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects or to percentage of the oil entering the water column (by natural dispersion). Intertidal zone impacts to clams are related to degree of soft (sand, mud, or

wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

The results of the modeling are summarized in the tables in Section II.2 to II.9, organized by location. Each of the stochastic no-response scenarios for the location are presented first (Section II.2), followed by comparisons of the alternative response scenarios (Sections II.3 to II.9). The discussion of these results may be found in Volume I. Details of the model inputs and results are in Volumes III to XXIII. More detailed results of the alternate response scenarios are in Volumes V, VIII, XI, XIV, XVII, XX, and XXIII.

The results below are tabulations of percentage of oil in various environmental compartments *at the end of the simulation*, the maximum areas impacted above various thresholds *at any time after the spill* (the timing of which may vary from one run to the next), numbers or weights of organisms impacted by the end of the simulation, and estimated natural resource damage costs using various methods (Section 6 of Volume I).

It should be noted that the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model. This results in variability in the movements of oil spillets in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This results in variation in the specific water areas and shoreline locations oiled and in some cases the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported. If this uncertainty were not included in the model simulations, the oil would all move along a single trajectory path to one shoreline location down wind and down current, clearly an unrealistic event to analyze.

In addition, protection booming input to the model deflects oil offshore from the boomed site. In many cases the booms are located to protect inlets, coves and wetlands with small linear shoreline length. In the model, oil deflected off booms moves offshore and along the shore (down wind and with the currents) and may oil other shorelines. Thus, the deflected oil becomes more dispersed, allowing it to impact a larger area. The other shorelines oiled may be of a different type with less ability to “hold” oil (such as a sand beach, which holds less oil per length than a wetland), and so the length of shore oiled may actually be increased by the inclusion of booms in the model. In an actual spill, protective booming would often be accompanied by localized efforts to remove oil. However, simulation of this response detail was not included in the modeling reported here.

Changes in the specific locations where spillets hit shore may result in differences in the amount of shoreline oiled by more than or less than selected thresholds. For example, in one simulation two spillets might hit a single location and be additive in the amount of oil on shore in that segment, while in another simulation the two spillets might hit adjacent shorelines and be additive in area of shore oiled, but not in thickness of oiling. This

results in different thicknesses of oil on each shore segment from one simulation to the next. Thus, it should be noted that impact to the shoreline at any threshold level is not necessarily proportional to the shore length or area oiled. This explains some of the variability seen in the results.

Since the Phase II modeling involved simulating (1) only the capacities of the *response planning standards* (not all equipment that might be used in a large spill such as those examined), (2) the decreasing efficiency of oil removal as time goes on, and (3) changes in the timing and capacities of removal activities only in the first 96 hours after the spill, the differences in amounts of oil removed are small. Thus, in many cases, the differences between runs as listed in the tables in this volume are less than the randomized variability in the model and are not significant. However, in some cases, the timing of oil removal and arrival on shore changes, as may be seen in the figures showing oil amounts in various environmental compartments (i.e., mass balance) as a function of time in Section B of Volumes V, VIII, XI, XIV, XVII, XX, and XXIII. The figures in Section B of these volumes are those Washington Department of Ecology will find most useful in evaluating the various planning standards.

Table II.1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed.

Scenario Name	Site	Location	Oil	bbls	Response
OC-C250K-N	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	No Removal
OC-C250K-Fed	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	Federal Caps
OC-C250K-WA	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	WA Caps
OC-C250K-3	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	3rd Caps
JF-B25K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	No Removal
JF-B25K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	Federal Caps
JF-B25K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	WA Caps
JF-B25K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	3rd Caps
JF-D65K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	No Removal
JF-D65K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	Federal Caps
JF-D65K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	WA Caps
JF-D65K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	3rd Caps
JF-C250K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	No Removal
JF-C250K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	Federal Caps
JF-C250K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	WA Caps
JF-C250K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	3rd Caps

Table II.1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed (continued).

Scenario Name	Site	Location	Oil	bbls	Response
SJ-C250K--N	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	No Removal
SJ-C250K-Fed	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	Federal Caps
SJ-C250K-WA	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	WA Caps
SJ-C250K-3	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	3rd Caps
CL-B25K-N	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	No Removal
CL-B25K-Fed	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	Federal Caps
CL-B25K-WA	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	WA Caps
CL-B25K-3	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	3rd Caps
CU-B25K-N	Upper Columbia River	Portland to Longview	Bunker C	25,000	No Removal
CU- B25K -Fed	Upper Columbia River	Portland to Longview	Bunker C	25,000	Federal Caps
CU- B25K -WA	Upper Columbia River	Portland to Longview	Bunker C	25,000	WA Caps
CU- B25K -3	Upper Columbia River	Portland to Longview	Bunker C	25,000	3rd Caps

NOTE: For all responses, Canada is assumed to respond based on the equivalent of the US Federal CAPS standard and the state of Oregon is assumed to respond based on the Washington state CAPS standard.

Table II.1-2 Sensitive sites evaluated with worst case runs, by location and oil type.

Scenario	Sensitive Site #1	Sensitive Site #2	Sensitive Site #3	Sensitive Site #4
OC-C250K	Olympia Coast National Marine Sanctuary	Tatoosh Island	-	-
JF-B25K	Dungeness Spit	Protection Island	-	-
JF-D65K	Dungeness Spit	Protection Island	-	-
JF-C250K	Dungeness Spit	Protection Island	-	-
SJ-C250K	Lopez Island	Orcas Island	Lummi Island	Padilla Bay
CL-B25K	Baker Bay	Columbia National Wildlife Refuge	-	-
CU-B25K	Ridgefield National Wildlife Refuge	Ridgefield National Wildlife Refuge	-	-

II.2. SUMMARY OF IMPACT STATISTICS FOR THE NO-RESPONSE STOCHASTIC SCENARIOS

The tables in this section summarize the model results for the stochastic scenarios, where 100 randomly selected dates were run for each scenario and no spill response was assumed. The results are tabulations of percentage of oil in various environmental compartments at the end of the simulation, the maximum areas impacted above various thresholds at any time after the spill, numbers or weights of organisms impacted by the end of the simulation, and estimated natural resource damage costs using various methods (Section 6 of Volume I).

Impacts to intertidal organisms and shoreline cleanup costs are related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects or to percentage of the oil entering the water column (by natural dispersion). Intertidal zone impacts to clams are related to degree of soft (sand, mud, or wetland) shoreline oiling.

Because degree of impact for a specific run varies by the index or organism group, in the tables, the 5th, 50th and 95th percentile results for the 100 values of the index were calculated *by sorting only the index being considered*. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution. These statistics provide the expected degree and range of impacts that would occur if spills of the simulated oil type and volume occur somewhere along the location's transportation route. Impacts would be different for spills released at different locations than those included in the modeling matrix, as well as different (and not necessarily proportional) for other spill volumes. The results are discussed in Volume I, Sections 4-6.

Table II.2-1. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	0.04	11.5	23.9	11.7	7.3	-	26.3
JF-Bunk-N	36.2	56.3	66.3	54.7	9.1	36.6	72.8
JF-Dies-N	0.93	3.2	12.3	4.2	4.0	-	12.2
JF-Crud-N	6.1	18.6	29.9	18.2	7.3	3.6	32.7
SJ-Crud-N	14.5	26.1	36.2	26.0	6.6	12.7	39.3
CL-Bunk-N	0	63.2	77.0	54.6	23.9	6.7	102.5
CU-Bunk-N	51.3	71.1	80.5	69.1	9.8	49.6	88.7

Table II.2-2. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	0.022	4.3	11.4	4.9	3.8	-	12.4
JF-Bunk-N	19.1	33.7	47.1	33.8	9.2	15.4	52.2
JF-Dies-N	-	-	0.0015	0.076	0.57	-	1.2
JF-Crud-N	4.7	13.8	20.0	12.8	5.1	2.5	23.0
SJ-Crud-N	2.3	16.6	23.1	14.9	6.2	2.5	27.2
CL-Bunk-N	0.0001	33.4	61.5	31.2	20.5	0	72.2
CU-Bunk-N	11.0	42.2	56.7	38.7	14.8	9.0	68.4

Table II.2-3. Summary of results for all stochastic scenarios of 100 runs each: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2.0	7.0	15.2	7.0	3.6	-	14.2
JF-Bunk-N	0.6	1.2	3.2	1.4	0.9	-	3.2
JF-Dies-N	24.9	43.2	66.3	44.4	12.9	18.5	70.2
JF-Crud-N	0.3	1.0	4.1	1.5	1.2	-	3.8
SJ-Crud-N	0.2	0.6	2.8	1.1	1.6	-	4.3
CL-Bunk-N	0.0	5.1	14.5	5.2	3.9	-	13.1
CU-Bunk-N	0.4	1.4	3.4	1.6	0.9	-	3.5

Table II.2-4. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass mechanically removed (%). [As no reponse was assumed, no removal occurred.]

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	-	-	-	-	-
JF-Bunk-N	-	-	-	-	-	-	-
JF-Dies-N	-	-	-	-	-	-	-
JF-Crud-N	-	-	-	-	-	-	-
SJ-Crud-N	-	-	-	-	-	-	-
CL-Bunk-N	-	-	-	-	-	-	-
CU-Bunk-N	-	-	-	-	-	-	-

Table II.2-5. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	3,359	26,550	9,255	10,391	-	30,037
JF-Bunk-N	208	473	965	533	238	57	1,010
JF-Dies-N	125	355	797	396	228	-	852
JF-Crud-N	658	1,855	3,763	1,945	897	152	3,739
SJ-Crud-N	122	852	2,904	1,201	954	-	3,110
CL-Bunk-N	33	119	540	199	171	-	541
CU-Bunk-N	1	5	11	6	3	-	12

Table II.2-6. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	2,399	22,893	7,101	8,167	-	23,436
JF-Bunk-N	207	464	975	530	237	56	1,005
JF-Dies-N	85	272	740	326	204	-	734
JF-Crud-N	543	1,434	2,966	1,529	727	76	2,983
SJ-Crud-N	97	537	2,018	771	649	-	2,070
CL-Bunk-N	33	121	540	196	166	0	527
CU-Bunk-N	1	5	11	6	3	-	11

Table II.2-7. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	1,027	5,974	2,040	2,020	-	6,079
JF-Bunk-N	160	354	822	428	217	-	863
JF-Dies-N	120	440	1,551	588	481	-	1,550
JF-Crud-N	546	2,435	5,536	2,647	1,576	-	5,799
SJ-Crud-N	1,524	4,552	9,167	4,958	2,340	278	9,638
CL-Bunk-N	-	589	1,573	635	491	-	1,617
CU-Bunk-N	143	279	506	296	115	67	525

Table II.2-8. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 100 g/m^2.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	796	3,703	1,295	1,229	-	3,752
JF-Bunk-N	160	344	813	411	212	-	835
JF-Dies-N	54	201	836	302	277	-	856
JF-Crud-N	473	1,656	3,241	1,783	905	-	3,593
SJ-Crud-N	1,006	2,492	3,805	2,528	883	761	4,294
CL-Bunk-N	-	567	1,472	607	467	-	1,541
CU-Bunk-N	140	260	485	284	108	67	500

Table II.2-9. Summary of results for all stochastic scenarios of 100 runs each: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	605,920	4,493,300	1,369,300	1,528,100	-	4,425,500
JF-Bunk-N	9,200	82,797	435,010	140,660	149,610	-	439,880
JF-Dies-N	84,487	344,140	1,374,500	465,070	422,970	-	1,311,010
JF-Crud-N	98,193	1,184,900	3,817,500	1,473,700	1,188,300	-	3,850,300
SJ-Crud-N	757,260	2,986,000	7,568,900	3,406,800	2,050,600	-	7,508,000
CL-Bunk-N	-	191,800	1,004,700	335,380	341,220	-	1,017,820
CU-Bunk-N	2,511	70,795	210,880	79,953	68,244	-	216,441

Table II.2-10. Summary of results for all stochastic scenarios of 100 runs each: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	584,800	1,651,800	670,540	545,370	-	1,761,280
JF-Bunk-N	154,330	287,070	461,300	287,120	91,302	104,516	469,724
JF-Dies-N	11,077	76,226	440,650	122,760	135,380	-	393,520
JF-Crud-N	350,340	1,155,200	2,026,200	1,173,100	487,560	197,980	2,148,220
SJ-Crud-N	868,180	1,585,700	2,263,700	1,551,200	449,320	652,560	2,449,840
CL-Bunk-N	-	280,160	626,100	300,020	187,700	-	675,420
CU-Bunk-N	123,010	204,850	365,020	216,210	68,534	79,142	353,278

Table II.2-11. Summary of results for all stochastic scenarios of 100 runs each: Cost (2003$) for shoreline cleanup (per area costs only).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	36,336,000	211,430,000	68,702,000	69,596,000	-	207,894,000
JF-Bunk-N	17,881,000	34,676,000	95,179,000	42,215,000	22,730,000	-	87,675,000
JF-Dies-N	511,050	4,408,300	24,155,000	7,300,400	7,897,000	-	23,094,400
JF-Crud-N	24,337,000	108,780,000	228,760,000	113,280,000	64,193,000	-	241,666,000
SJ-Crud-N	84,092,000	202,950,000	398,520,000	214,040,000	96,393,000	21,254,000	406,826,000
CL-Bunk-N	0	59311000	167220000	63182000	52573000	0	168328000
CU-Bunk-N	14,550,000	28,445,000	63,761,000	31,519,000	14,773,000	1,973,000	61,065,000

Table II.2-12. Summary of results for all stochastic scenarios of 100 runs each: Total number of waterfowl oiled.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	7,257	974,128	281,660	401,722	-	1,085,104
JF-Bunk-N	9,092	14,365	24,651	15,746	4,886	5,974	25,518
JF-Dies-N	13,709	20,590	37,575	22,645	7,560	7,524	37,766
JF-Crud-N	19,252	115,943	278,416	126,652	78,868	-	284,388
SJ-Crud-N	44,504	62,771	116,619	72,525	26,956	18,614	126,437
CL-Bunk-N	2,605	28,111	150,560	50,761	48,632	-	148,025
CU-Bunk-N	13	79	191	89	57	-	203

Table II.2-13. Summary of results for all stochastic scenarios of 100 runs each: Total number of seabirds oiled.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	22,349	83,938	564,703	205,770	210,912	-	627,593
JF-Bunk-N	1,925	5,152	11,449	5,998	2,991	16	11,980
JF-Dies-N	814	6,343	19,992	7,995	6,075	-	20,145
JF-Crud-N	22,347	31,791	47,661	32,832	7,713	17,407	48,257
SJ-Crud-N	13,068	13,663	15,420	13,982	879	12,223	15,740
CL-Bunk-N	917	2,755	11,582	4,380	3,514	-	11,408
CU-Bunk-N	6	17	35	18	9	-	37

Table II.2-14. Summary of results for all stochastic scenarios of 100 runs each: Total number of wading birds and shorebirds oiled.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	527	4,214	1,321	1,493	-	4,308
JF-Bunk-N	556	1,055	3,745	1,375	938	-	3,251
JF-Dies-N	9	208	1,117	370	428	-	1,225
JF-Crud-N	720	3,449	10,144	4,252	2,945	-	10,142
SJ-Crud-N	5,717	6,846	7,979	6,874	676	5,522	8,226
CL-Bunk-N	3	3,288	16,178	5,208	8,306	-	21,820
CU-Bunk-N	173	1,022	2,464	1,156	734	-	2,624

Table II.2-15. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	22,349	92,883	1,539,016	488,751	611,866	-	1,712,483
JF-Bunk-N	12,485	21,018	39,138	23,120	8,247	6,627	39,613
JF-Dies-N	14,528	27,072	58,541	31,010	13,852	3,306	58,714
JF-Crud-N	45,608	153,806	328,242	163,739	87,505	-	338,749
SJ-Crud-N	63,977	83,475	139,398	93,384	28,122	37,140	149,627
CL-Bunk-N	8,688	39,600	163,133	60,349	50,185	-	160,718
CU-Bunk-N	192	1,118	2,689	1,263	800	-	2,864

Table II.2-16. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	98.77	144.23	499.16	234.18	155.71	-	545.59
JF-Bunk-N	0.96	1.62	2.92	1.80	0.62	0.57	3.03
JF-Dies-N	0.90	2.09	5.03	2.45	1.31	-	5.07
JF-Crud-N	2.95	14.44	33.74	15.71	9.38	-	34.47
SJ-Crud-N	6.01	7.46	11.74	8.24	2.14	3.95	12.52
CL-Bunk-N	2.16	6.42	26.85	10.18	8.13	-	26.45
CU-Bunk-N	60.04	94.77	141.60	97.09	23.44	50.21	143.97

Table II.2-17. Summary of results for all stochastic scenarios of 100 runs each: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	18,189	1,585	5,696	-	12,978
JF-Bunk-N	-	-	-	-	-	-	-
JF-Dies-N	256	472	973	517	214	89	944
JF-Crud-N	-	-	-	-	-	-	-
SJ-Crud-N	-	-	-	-	-	-	-
CL-Bunk-N	-	-	-	-	-	-	-
CU-Bunk-N	-	-	-	-	-	-	-

Table II.2-18. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	0.3	1,053	4,601	1,376	1,388	-	4,152
JF-Bunk-N	52	59	82	62	10	41	82
JF-Dies-N	44	45,108	103,599	49,500	29,488	-	108,476
JF-Crud-N	5,721	11,444	34,139	14,544	8,834	-	32,212
SJ-Crud-N	1,693	3,829	17,383	6,807	9,599	-	26,005
CL-Bunk-N	0.3	4	29	6	9	-	24
CU-Bunk-N	2,948	3,299	4,015	3,382	343	2,695	4,069

Table II.2-19. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	3,243	30,746	9,026	10,561	-	30,149
JF-Bunk-N	-	16,997	108,804	33,955	35,399	-	104,752
JF-Dies-N	-	11,412	118,054	28,928	41,555	-	112,038
JF-Crud-N	12,141	159,528	403,740	174,703	117,105	-	408,913
SJ-Crud-N	117,942	287,366	528,744	305,639	130,644	44,351	566,926
CL-Bunk-N	-	1,001	2,686	1,086	860	-	2,805
CU-Bunk-N	-	-	-	-	-	-	-

Table II.2-20. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	0.35	4,295	35,347	10,403	11,949	-	34,301
JF-Bunk-N	52	17,056	108,886	34,016	35,409	41	104,834
JF-Dies-N	44	56,521	221,653	78,428	71,042	-	220,513
JF-Crud-N	17,862	170,972	437,878	189,247	125,939	-	441,125
SJ-Crud-N	119,634	291,195	546,127	312,446	140,243	44,351	592,931
CL-Bunk-N	0.26	1,005	2,716	1,092	868	-	2,829
CU-Bunk-N	2,948	3,299	4,015	3,382	343	2,695	4,069

Table II.2-21. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	193	739	8,011	2,677	3,114	-	8,905
JF-Bunk-N	50	115	266	137	68	13	273
JF-Dies-N	43	379	954	436	273	17	981
JF-Crud-N	431	888	1,729	953	396	284	1,744
SJ-Crud-N	371	483	760	527	156	283	838
CL-Bunk-N	18	127	643	221	212	0	645
CU-Bunk-N	3	6	12	7	3	2	13

Table II.2-22. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	36	139	1,501	502	584	-	1,669
JF-Bunk-N	9.3	22	50	26	13	2.4	51
JF-Dies-N	8.1	71	179	82	51	3.3	184
JF-Crud-N	81	166	324	179	74	53	327
SJ-Crud-N	70	90	142	99	29	53	157
CL-Bunk-N	3.3	24	121	41	40	0	121
CU-Bunk-N	0.6	1.2	2.3	1.3	0.6	0.4	2.4

Table II.2-23. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	120	462	5,006	1,673	1,946	-	5,565
JF-Bunk-N	31	72	166	85	43	8	171
JF-Dies-N	27	237	596	272	170	11	613
JF-Crud-N	269	555	1,080	595	247	177	1,090
SJ-Crud-N	232	302	475	329	97	177	524
CL-Bunk-N	11	79	402	138	132	0	403
CU-Bunk-N	1.9	4.0	7.8	4.4	1.9	1.3	8.2

Table II.2-24. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	14	55	598	200	232	-	664
JF-Bunk-N	3.7	9	20	10	5	1.0	20
JF-Dies-N	3.2	28	71	33	20	1.3	73
JF-Crud-N	32	66	129	71	30	21	130
SJ-Crud-N	28	36	57	39	12	21	63
CL-Bunk-N	1.3	9.5	48.0	16.5	15.8	0	48.1
CU-Bunk-N	0.2	0.5	0.9	0.5	0.2	0.2	1.0

Table II.2-25. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of $), using WA Compensation Schedule.

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	238	248	248	246	8	230	261
JF-Bunk-N	27.0	28.3	32.2	29.1	1.5	26.1	32.0
JF-Dies-N	45.0	45.0	49.1	45.8	1.9	42.1	49.5
JF-Crud-N	218	238	268	238	15	208	267
SJ-Crud-N	228	249	269	249	17	214	284
CL-Bunk-N	0.0**	27.1	29.5	19.9	12.3	0.0	44.6
CU-Bunk-N	*	*	*	*	*	*	*

* WA Compensation Schedule damages were not calculated for the Upper Columbia River
** For some runs, the oiling was entirely outside WA jurisdiction where the Compensation Schedule does not apply.

II.3. COMPARISON OF ALTERNATIVE RESPONSES: OUTER COAST AT DUNTZ ROCK OFF CAPE FLATTERY – ALASKAN NORTH SLOPE CRUDE

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume V, and discussion of the results is in Volume I. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Olympia Coast National Marine Sanctuary; and
3. the worst case run for impacts at Tatoosh Island.

Table II.3-1. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island
OC-C250K-N	13.9	11.1	22.4
OC-C250K-Fed	15.8	11.3	21.8
OC-C250K-WA	15.8	6.4	21.8
OC-C250K-3	15.9	8.1	21.4

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.3-2. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	7.8	6.2	7.1
OC-C250K-Fed	7.7	6.1	7.0
OC-C250K-WA	7.7	3.2	6.4
OC-C250K-3	7.9	4.5	6.6

*Differences between runs are, for some comparisons, less than the randomized variability in the model and are not significant.

Table II.3-3. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for Tatoosh Island
OC-C250K-N	5.9	12.6	9.0
OC-C250K-Fed	11.4	16.8	8.9
OC-C250K-WA	11.4	19.6	8.7
OC-C250K-3	12.1	17.4	8.3

** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.3-4. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
OC-C250K-N	-	-	-
OC-C250K-Fed	0.04	0.72	0.95
OC-C250K-WA	0.04	3.30	3.54
OC-C250K-3	0.48	3.95	4.31

* The Federal and Washington State responses involved the same removal amounts and timing.

Table II.3-5. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island*
OC-C250K-N	3,251	46,034	21,583
OC-C250K-Fed	4,032	40,633	21,524
OC-C250K-WA	4,032	34,931	22,100
OC-C250K-3	4,140	36,685	20,242

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-6. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island*
OC-C250K-N	2,127	33,931	16,508
OC-C250K-Fed	2,967	27,434	16,603
OC-C250K-WA	2,967	23,518	16,711
OC-C250K-3	2,854	25,896	16,757

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-7. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island**
OC-C250K-N	6,939	931	3,418
OC-C250K-Fed	7,482	900	3,446
OC-C250K-WA	7,482	558	4,085
OC-C250K-3	6,850	900	3,209

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.3-8. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	3,869	726	2,510
OC-C250K-Fed	3,050	746	2,361
OC-C250K-WA	3,050	394	2,476
OC-C250K-3	3,148	686	2,394

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.3-9. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for Tatoosh Island**
OC-C250K-N	5,318,700	463,390	2,189,100
OC-C250K-Fed	6,389,900	429,080	2,280,800
OC-C250K-WA	6,389,900	360,840	2,831,600
OC-C250K-3	5,701,700	545,590	1,964,400

** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.3-10. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	1,620,600	467,160	1,228,800
OC-C250K-Fed	1,092,300	471,310	1,165,500
OC-C250K-WA	1,092,300	197,200	1,253,300
OC-C250K-3	1,148,100	354,050	1,244,600

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.3-11. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	256.2	26.0	86.9
OC-C250K-Fed	238.1	26.3	85.7
OC-C250K-WA	238.1	12.1	103.7
OC-C250K-3	211.1	21.4	87.2

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.3-12. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	-	1,645,669	740,850
OC-C250K-Fed	37,655	1,308,244	745,836
OC-C250K-WA	37,655	1,104,813	751,445
OC-C250K-3	31,775	1,228,368	753,782

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-13. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	77,378	898,618	448,708
OC-C250K-Fed	99,053	730,838	451,187
OC-C250K-WA	99,053	629,684	453,976
OC-C250K-3	96,129	691,120	455,138

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.3-14. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island
OC-C250K-N	4,887	468	2,004
OC-C250K-Fed	3,693	485	1,998
OC-C250K-WA	3,693	182	1,974
OC-C250K-3	4,022	433	1,904

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.3-15. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	82,265	2,544,755	1,191,561
OC-C250K-Fed	140,400	2,039,567	1,199,021
OC-C250K-WA	140,400	1,734,679	1,207,395
OC-C250K-3	131,926	1,919,921	1,210,824

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.3-16. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island*
OC-C250K-N	139.38	745.68	413.53
OC-C250K-Fed	155.39	621.81	415.36
OC-C250K-WA	155.39	547.14	417.41
OC-C250K-3	153.23	592.49	418.27

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-17. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb (averaged over each grid cell and within some depth interval) at some time after the spill (An entry "-" indicates the area is less than a grid cell size of 0.14 km^2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
OC-C250K-N	-	-	-
OC-C250K-Fed	-	-	-
OC-C250K-WA	-	-	-
OC-C250K-3	-	-	-

Table II.3-18. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for Tatoosh Island
OC-C250K-N	559	3,492	1,929
OC-C250K-Fed	2,979	5,339	1,877
OC-C250K-WA	2,979	6,524	1,776
OC-C250K-3	3,277	5,586	1,616

**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.3-19. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	33,652	2,454	21,968
OC-C250K-Fed	25,006	2,980	21,091
OC-C250K-WA	25,006	1,753	22,727
OC-C250K-3	25,473	2,395	21,266

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.3-20. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for Tatoosh Island*
OC-C250K-N	34,211	5,945	23,897
OC-C250K-Fed	27,985	8,318	22,968
OC-C250K-WA	27,985	8,276	24,503
OC-C250K-3	28,750	7,982	22,882

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.3-21. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	675	13,021	6,246
OC-C250K-Fed	987	10,502	6,283
OC-C250K-WA	987	8,983	6,325
OC-C250K-3	945	9,905	6,341

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-22. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	126	2,440	1,170
OC-C250K-Fed	185	1,968	1,177
OC-C250K-WA	185	1,683	1,185
OC-C250K-3	177	1,856	1,188

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-23. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	422	8,137	3,903
OC-C250K-Fed	617	6,563	3,926
OC-C250K-WA	617	5,613	3,952
OC-C250K-3	591	6,189	3,963

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-24. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	50.3	971	466
OC-C250K-Fed	73.7	784	469
OC-C250K-WA	73.7	670	472
OC-C250K-3	70.5	739	473

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-25. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
OC-C250K-N	248	248	248
OC-C250K-Fed	248	248	248
OC-C250K-WA	248	246	246
OC-C250K-3	247	245	245

II.4. COMPARISON OF ALTERNATIVE RESPONSES: STRAIT OF JUAN DE FUCA – BUNKER C

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume VIII. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

Table II.4-1. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	62.6	68.9	60.9
JF-B25K-Fed	58.9	70.5	54.0
JF-B25K-WA	57.4	60.4	45.5
JF-B25K-3	55.9	53.7	36.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-2. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	19	22	50
JF-B25K-Fed	17	18	43
JF-B25K-WA	16	20	36
JF-B25K-3	16	19	29

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-3. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	0.6	3.5	1.4
JF-B25K-Fed	0.5	2.0	1.2
JF-B25K-WA	0.5	2.7	1.1
JF-B25K-3	0.5	2.3	0.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-B25K-N	-	-	-
JF-B25K-Fed	5.8	5.8	12.7
JF-B25K-WA	8.5	14.6	28.4
JF-B25K-3	11.6	24.1	42.1

Table II.4-5. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	790	321	183
JF-B25K-Fed	740	250	181
JF-B25K-WA	771	281	150
JF-B25K-3	707	250	146

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-6. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	789	321	183
JF-B25K-Fed	740	250	181
JF-B25K-WA	761	275	149
JF-B25K-3	701	246	146

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-7. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	904	752	342
JF-B25K-Fed	846	711	296
JF-B25K-WA	919	742	264
JF-B25K-3	816	674	270

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-8. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-B25K-N	901	751	301
JF-B25K-Fed	846	711	296
JF-B25K-WA	918	695	264
JF-B25K-3	816	634	269

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-9. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	330,060	290,630	81,483
JF-B25K-Fed	292,700	288,380	56,700
JF-B25K-WA	329,870	298,710	86,740
JF-B25K-3	295,890	208,960	134,050

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-10. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	573,760	461,300	260,220
JF-B25K-Fed	553,670	422,430	238,820
JF-B25K-WA	589,150	443,460	177,230
JF-B25K-3	519,690	464,870	135,930

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	107.8	95.3	42.8
JF-B25K-Fed	102.2	89.8	37.3
JF-B25K-WA	110.7	93.0	30.2
JF-B25K-3	96.4	90.0	28.3

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	21,075	11,436	8,586
JF-B25K-Fed	20,074	9,976	8,541
JF-B25K-WA	20,499	10,486	7,884
JF-B25K-3	19,262	9,887	7,817

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-13. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	9,260	3,360	1,615
JF-B25K-Fed	8,647	2,466	1,587
JF-B25K-WA	8,907	2,778	1,185
JF-B25K-3	8,150	2,411	1,144

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-14. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-B25K-N	2,437	2,056	915
JF-B25K-Fed	2,299	1,955	901
JF-B25K-WA	2,480	1,914	821
JF-B25K-3	2,221	1,761	833

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-15. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	32,772	16,852	11,119
JF-B25K-Fed	31,020	14,397	11,033
JF-B25K-WA	31,886	15,179	9,892
JF-B25K-3	29,633	14,059	9,796

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-16. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	2.47	1.25	0.89
JF-B25K-Fed	2.34	1.07	0.89
JF-B25K-WA	2.40	1.13	0.81
JF-B25K-3	2.24	1.06	0.80

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-17. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-B25K-N	-	-	-
JF-B25K-Fed	-	-	-
JF-B25K-WA	-	-	-
JF-B25K-3	-	-	-

Table II.4-18. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	52	86	61
JF-B25K-Fed	51	69	59
JF-B25K-WA	51	76	58
JF-B25K-3	51	72	55

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-19. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	122,377	106,837	16,997
JF-B25K-Fed	115,578	108,294	16,511
JF-B25K-WA	129,176	100,524	16,511
JF-B25K-3	110,722	94,211	21,853

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-20. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	122,429	106,923	17,058
JF-B25K-Fed	115,629	108,363	16,570
JF-B25K-WA	129,227	100,600	16,569
JF-B25K-3	110,773	94,283	21,908

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-21. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	225.7	112.5	50.3
JF-B25K-Fed	212.1	96.3	49.6
JF-B25K-WA	221.5	99.6	42.0
JF-B25K-3	201.4	90.5	42.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-22. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	42.3	21.1	9.4
JF-B25K-Fed	39.7	18.0	9.3
JF-B25K-WA	41.5	18.7	7.9
JF-B25K-3	37.7	17.0	8.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	141.1	70.3	31.4
JF-B25K-Fed	132.5	60.2	31.0
JF-B25K-WA	138.4	62.2	26.2
JF-B25K-3	125.8	56.5	26.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	16.8	8.4	3.8
JF-B25K-Fed	15.8	7.2	3.7
JF-B25K-WA	16.5	7.4	3.1
JF-B25K-3	15.0	6.8	3.2

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-25. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-B25K-N	29.6	28.3	28.4
JF-B25K-Fed	29.2	28.0	27.5
JF-B25K-WA	28.7	27.1	25.8
JF-B25K-3	28.1	25.8	24.1

II.5. COMPARISON OF ALTERNATIVE RESPONSES: STRAIT OF JUAN DE FUCA – DIESEL

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XXI. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

Table II.5-1. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit**	Worst run for Protection Island*
JF-D65K-N	13.8	17.5	6.0
JF-D65K-Fed	6.7	18.1	6.4
JF-D65K-WA	7.7	18.9	5.1
JF-D65K-3	9.1	16.9	5.2

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.5-2. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	-	-	-
JF-D65K-Fed	-	-	-
JF-D65K-WA	-	-	-
JF-D65K-3	-	-	-

Table II.5-3. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	25.5	22.3	40.7
JF-D65K-Fed	34.3	18.8	37.2
JF-D65K-WA	32.3	14.6	36.1
JF-D65K-3	31.7	14.6	33.5

**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.5-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	-	-	-
JF-D65K-Fed	2.8	4.1	3.8
JF-D65K-WA	3.9	9.2	8.4
JF-D65K-3	4.8	13.3	12.2

Table II.5-5. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	587	325	170
JF-D65K-Fed	541	303	174
JF-D65K-WA	535	267	166
JF-D65K-3	544	263	155

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-6. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	552	288	166
JF-D65K-Fed	506	273	172
JF-D65K-WA	469	238	164
JF-D65K-3	494	230	154

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-7. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	2,451	1,564	685
JF-D65K-Fed	1,057	1,521	746
JF-D65K-WA	1,051	1,638	583
JF-D65K-3	1,276	1,204	569

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-8. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	1,767	1,054	322
JF-D65K-Fed	674	941	336
JF-D65K-WA	701	1,011	286
JF-D65K-3	949	896	339

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-9. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	2,034,600	1,016,100	481,760
JF-D65K-Fed	884,670	1,046,700	551,420
JF-D65K-WA	808,820	1,142,300	428,250
JF-D65K-3	1,027,900	749,120	430,320

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-10. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-D65K-N	416,800	548,040	203,140
JF-D65K-Fed	172,350	474,440	194,130
JF-D65K-WA	242,010	495,470	154,700
JF-D65K-3	248,580	454,730	138,750

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	36.5	24.9	8.9
JF-D65K-Fed	14.8	24.8	9.7
JF-D65K-WA	14.6	27.0	6.8
JF-D65K-3	17.7	17.7	7.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	31,065	21,260	16,735
JF-D65K-Fed	29,341	20,706	16,937
JF-D65K-WA	27,970	19,398	16,639
JF-D65K-3	28,902	19,117	16,271

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-13. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	14,760	6,882	3,246
JF-D65K-Fed	13,376	6,437	3,409
JF-D65K-WA	12,274	5,386	3,169
JF-D65K-3	13,023	5,160	2,873

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-14. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	2,301	1,314	346
JF-D65K-Fed	835	1,171	365
JF-D65K-WA	869	1,259	302
JF-D65K-3	1,182	1,070	412

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-15. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	48,126	29,455	20,327
JF-D65K-Fed	43,552	28,314	20,711
JF-D65K-WA	41,113	26,043	20,111
JF-D65K-3	43,107	25,347	19,556

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-16. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	3.90	2.21	1.42
JF-D65K-Fed	3.61	2.11	1.46
JF-D65K-WA	3.37	1.88	1.41
JF-D65K-3	3.53	1.84	1.34

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-17. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit**	Worst run for Protection Island*
JF-D65K-N	509	330	256
JF-D65K-Fed	521	386	243
JF-D65K-WA	525	359	239
JF-D65K-3	562	353	248

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.5-18. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	319	29	38,643
JF-D65K-Fed	22,510	24	29,860
JF-D65K-WA	17,466	24	26,922
JF-D65K-3	15,907	24	20,567

**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.5-19. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	257,862	163,169	22,824
JF-D65K-Fed	81,099	142,773	22,824
JF-D65K-WA	87,412	156,369	16,511
JF-D65K-3	129,661	137,917	29,138

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-20. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	258,182	163,197	61,467
JF-D65K-Fed	103,608	142,797	52,684
JF-D65K-WA	104,878	156,393	43,433
JF-D65K-3	145,568	137,941	49,704

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-21. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	361.6	197.8	296.0
JF-D65K-Fed	399.5	183.8	252.0
JF-D65K-WA	356.1	170.4	230.3
JF-D65K-3	373.9	160.5	195.6

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.5-22. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	67.8	37.1	55.5
JF-D65K-Fed	74.9	34.4	47.2
JF-D65K-WA	66.7	31.9	43.2
JF-D65K-3	70.1	30.1	36.6

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.5-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	226.0	123.6	184.9
JF-D65K-Fed	249.6	114.8	157.5
JF-D65K-WA	222.5	106.5	143.9
JF-D65K-3	233.7	100.3	122.2

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.5-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	27.0	14.8	22.1
JF-D65K-Fed	29.8	13.7	18.8
JF-D65K-WA	26.6	12.7	17.2
JF-D65K-3	27.9	12.0	14.6

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.5-25. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	45.0	47.1	47.2
JF-D65K-Fed	48.9	46.5	46.8
JF-D65K-WA	48.7	45.4	44.0
JF-D65K-3	48.4	42.7	43.3

II.6. COMPARISON OF ALTERNATIVE RESPONSES: STRAIT OF JUAN DE FUCA – ALASKAN NORTH SLOPE CRUDE

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XIV. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

Table II.6-1. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-C250K-N	25.8	32.4	23.8
JF-C250K-Fed	24.3	32.2	22.8
JF-C250K-WA	25.1	33.0	22.6
JF-C250K-3	23.0	31.9	21.7

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-2. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	19.5	7.6	14.5
JF-C250K-Fed	19.2	7.5	13.6
JF-C250K-WA	18.6	6.2	13.9
JF-C250K-3	18.1	6.5	14.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-3. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	0.6	0.2	0.9
JF-C250K-Fed	1.0	0.2	0.9
JF-C250K-WA	0.7	0.2	0.8
JF-C250K-3	0.8	0.2	1.1

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-C250K-N	-	-	-
JF-C250K-Fed	2.0	0.9	1.9
JF-C250K-WA	4.5	2.3	4.2
JF-C250K-3	6.7	3.6	6.3

Table II.6-5. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	1,236	1,117	593
JF-C250K-Fed	1,299	1,065	576
JF-C250K-WA	1,255	864	584
JF-C250K-3	1,200	878	561

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-6. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	817	556	543
JF-C250K-Fed	954	578	522
JF-C250K-WA	916	493	527
JF-C250K-3	839	527	496

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-7. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island**
JF-C250K-N	7,661	1,789	2,407
JF-C250K-Fed	6,731	1,949	2,620
JF-C250K-WA	5,930	1,364	2,526
JF-C250K-3	5,991	1,440	2,521

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.6-8. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island**
JF-C250K-N	3,109	1,382	1,901
JF-C250K-Fed	3,378	1,366	2,062
JF-C250K-WA	2,944	1,158	1,928
JF-C250K-3	2,846	1,265	1,926

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.6-9. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island**
JF-C250K-N	5,936,100	575,260	975,730
JF-C250K-Fed	5,296,600	839,800	1,308,200
JF-C250K-WA	4,194,700	289,320	1,126,300
JF-C250K-3	4,458,700	326,870	1,312,200

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.6-10. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	1,725,200	1,213,600	1,431,600
JF-C250K-Fed	1,434,600	1,109,600	1,312,200
JF-C250K-WA	1,735,000	1,074,700	1,399,700
JF-C250K-3	1,532,600	1,113,000	1,208,500

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	309.1	103.6	141.4
JF-C250K-Fed	254.7	102.5	143.5
JF-C250K-WA	239.6	90.3	142.0
JF-C250K-3	234.4	92.1	134.6

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	49,403	20,855	19,452
JF-C250K-Fed	64,256	23,156	17,188
JF-C250K-WA	60,053	13,921	17,678
JF-C250K-3	51,681	17,622	14,372

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-13. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	25,292	22,503	22,366
JF-C250K-Fed	26,743	22,728	22,145
JF-C250K-WA	26,332	21,826	22,193
JF-C250K-3	25,514	22,188	21,870

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-14. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	6,613	2,752	3,990
JF-C250K-Fed	7,214	2,717	4,352
JF-C250K-WA	6,243	2,251	4,051
JF-C250K-3	6,024	2,490	3,968

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-15. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	81,310	46,112	45,837
JF-C250K-Fed	98,214	48,602	43,711
JF-C250K-WA	92,630	37,999	43,950
JF-C250K-3	83,221	42,301	40,238

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-16. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	6.54	3.15	2.98
JF-C250K-Fed	8.30	3.42	2.71
JF-C250K-WA	7.80	2.32	2.76
JF-C250K-3	6.81	2.76	2.37

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-17. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-C250K-N	-	-	-
JF-C250K-Fed	-	-	-
JF-C250K-WA	-	-	-
JF-C250K-3	-	-	-

Table II.6-18. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-C250K-N	7,947	5,119	10,547
JF-C250K-Fed	10,814	5,050	10,481
JF-C250K-WA	8,738	4,939	9,543
JF-C250K-3	9,774	4,896	11,687

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.6-19. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	362,273	178,216	213,674
JF-C250K-Fed	396,760	165,597	247,182
JF-C250K-WA	319,546	147,144	214,160
JF-C250K-3	309,835	161,711	223,385

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-20. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	370,220	183,336	224,221
JF-C250K-Fed	407,574	170,648	257,663
JF-C250K-WA	328,284	152,083	223,703
JF-C250K-3	319,609	166,607	235,072

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-21. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	684.1	490.9	528.1
JF-C250K-Fed	768.5	495.6	530.2
JF-C250K-WA	715.3	452.1	516.5
JF-C250K-3	684.4	471.4	516.9

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-22. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	128.2	92.0	98.9
JF-C250K-Fed	144.0	92.9	99.3
JF-C250K-WA	134.0	84.7	96.8
JF-C250K-3	128.2	88.3	96.9

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	427.5	306.8	330.0
JF-C250K-Fed	480.2	309.7	331.3
JF-C250K-WA	447.0	282.5	322.8
JF-C250K-3	427.7	294.6	323.0

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	51.0	36.6	39.4
JF-C250K-Fed	57.3	37.0	39.6
JF-C250K-WA	53.4	33.7	38.5
JF-C250K-3	51.1	35.2	38.6

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-25. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-C250K-N	268	248	222
JF-C250K-Fed	261	245	217
JF-C250K-WA	264	247	219
JF-C250K-3	261	245	217

II.7. COMPARISON OF ALTERNATIVE RESPONSES: SAN JUAN ISLANDS – ALASKAN NORTH SLOPE CRUDE

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XVII. For the alternate response scenarios, the following 6 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Lopez Island;
3. the worst case run for impacts at Orcas Island;
4. the worst case run for impacts at Lummi Island;
5. the worst case run for impacts at Padilla Bay; and
6. the 50th percentile run based on shoreline oiling and area-based costs for cleanup.

Table II.7-1. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	34.1	24.9	31.4	26.1	27.6	29.8
SJ-C250K-Fed	33.0	23.5	31.7	27.8	24.4	29.2
SJ-C250K-WA	31.8	23.1	30.5	24.6	26.9	29.2
SJ-C250K-3	30.5	24.0	29.1	23.9	24.2	29.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-2. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	13.8	15.1	16.5	14.4	20.5	17.0
SJ-C250K-Fed	13.1	14.6	14.7	13.4	21.4	17.2
SJ-C250K-WA	11.6	14.5	15.0	14.5	17.6	15.0
SJ-C250K-3	11.7	12.7	15.0	12.1	20.1	15.9

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-3. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island**	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	2.8	1.4	0.5	0.6	1.6	0.4
SJ-C250K-Fed	2.7	1.4	0.4	0.7	1.7	0.5
SJ-C250K-WA	2.7	1.4	0.5	1.1	1.7	0.4
SJ-C250K-3	2.7	1.4	0.4	1.1	1.7	0.5

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.7-4. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	Worst run for Lummi Island	Worst run for Padilla Bay	50th Percentile Run (based on shore cost)
SJ-C250K-N	-	-	-	-	-	-
SJ-C250K-Fed	1.8	2.0	2.0	1.6	1.8	1.3
SJ-C250K-WA	4.2	4.6	4.4	3.7	3.6	3.4
SJ-C250K-3	5.9	6.8	6.5	5.5	5.2	5.0

Table II.7-5. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	1,777	4,025	786	409	606	372
SJ-C250K-Fed	1,760	4,323	577	375	604	250
SJ-C250K-WA	1,530	2,969	606	508	796	258
SJ-C250K-3	2,272	3,981	658	316	600	231

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-6. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	1,255	3,626	577	293	535	267
SJ-C250K-Fed	1,132	3,927	445	259	528	189
SJ-C250K-WA	1,025	2,658	423	353	597	185
SJ-C250K-3	1,475	3,451	459	228	515	171

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-7. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)**
SJ-C250K-N	11,810.5	4,145.4	5,782.8	4,416.0	7,161.6	4,105.5
SJ-C250K-Fed	8,803.4	5,067.1	5,543.8	5,633.4	5,816.4	4,774.7
SJ-C250K-WA	9,596.9	4,351.1	4,375.0	3,728.1	9,385.9	6,806.8
SJ-C250K-3	9,305.3	4,107.5	4,798.4	3,964.0	5,669.2	5,438.6

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.7-8. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	4,542.45	2,802.85	3,324.41	2,543.73	3,276.26	2,763.21
SJ-C250K-Fed	5,131.01	2,701.24	3,625.27	3,176.84	2,851.36	2,635.86
SJ-C250K-WA	5,038.34	2,857.75	2,959.48	2,138.42	3,861.82	3,058.27
SJ-C250K-3	4,560.75	2,491.68	2,830.54	2,627.51	2,747.38	2,409.13

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.7-9. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island**	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)**
SJ-C250K-N	9,604,900	2,435,100	3,348,300	2,706,300	5,035,800	2,105,900
SJ-C250K-Fed	6,581,100	3,439,500	3,094,000	3,916,000	4,168,300	2,934,200
SJ-C250K-WA	7,501,500	2,854,800	2,367,400	2,397,100	6,951,400	5,038,500
SJ-C250K-3	7,149,000	2,615,800	2,748,600	2,463,700	3,732,700	3,638,000

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.7-10. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	2,205,600	1,710,300	2,434,500	1,709,700	2,125,800	1,999,600
SJ-C250K-Fed	2,222,300	1,627,600	2,449,800	1,717,400	1,648,100	1,840,500
SJ-C250K-WA	2,095,400	1,496,300	2,007,600	1,331,000	2,434,500	1,768,300
SJ-C250K-3	2,156,300	1,491,700	2,049,800	1,500,300	1,936,500	1,800,600

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-11. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)**
SJ-C250K-N	514	159	285	203	344	206
SJ-C250K-Fed	396	193	285	253	264	228
SJ-C250K-WA	430	165	227	162	419	299
SJ-C250K-3	415	154	236	184	274	254

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.7-12. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	92,659	190,946	64,502	52,685	62,750	51,609
SJ-C250K-Fed	87,615	203,445	59,035	51,295	62,436	48,380
SJ-C250K-WA	83,180	150,815	58,108	55,174	65,356	48,251
SJ-C250K-3	101,802	183,674	59,605	49,996	61,896	47,614

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-13. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	14,638	17,844	13,720	13,334	13,663	13,299
SJ-C250K-Fed	14,474	18,252	13,542	13,289	13,653	13,194
SJ-C250K-WA	14,329	16,535	13,511	13,416	13,748	13,190
SJ-C250K-3	14,937	17,607	13,560	13,247	13,635	13,169

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-14. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	8,348	7,128	7,442	6,861	7,406	7,024
SJ-C250K-Fed	8,786	7,152	7,666	7,332	7,090	6,930
SJ-C250K-WA	8,717	7,095	7,171	6,560	7,842	7,244
SJ-C250K-3	8,362	7,491	7,075	6,924	7,013	6,761

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-15. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	115,649	215,921	85,666	72,883	83,821	71,936
SJ-C250K-Fed	110,878	228,852	80,245	71,919	83,181	68,507
SJ-C250K-WA	106,229	174,448	78,793	75,152	86,948	68,688
SJ-C250K-3	125,103	208,775	80,243	70,169	82,546	67,547

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-16. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	9.84	17.65	7.60	6.66	7.46	6.57
SJ-C250K-Fed	9.44	18.64	7.16	6.55	7.43	6.32
SJ-C250K-WA	9.08	14.46	7.09	6.86	7.67	6.31
SJ-C250K-3	10.56	17.07	7.21	6.45	7.39	6.26

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-17. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	Worst run for Lummi Island	Worst run for Padilla Bay	50th Percentile Run (based on shore cost)
SJ-C250K-N	-	-	-	-	-	-
SJ-C250K-Fed	-	-	-	-	-	-
SJ-C250K-WA	-	-	-	-	-	-
SJ-C250K-3	-	-	-	-	-	-

Table II.7-18. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island**	Worst run for Padilla Bay**	50th Percentile Run (based on shore cost)*
SJ-C250K-N	17,347	8,576	2,942	3,557	9,976	2,815
SJ-C250K-Fed	16,317	8,811	2,777	4,547	10,264	3,257
SJ-C250K-WA	16,317	8,576	2,920	7,080	10,264	2,563
SJ-C250K-3	16,317	8,576	2,755	6,674	10,264	3,055

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.7-19. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	623,325	242,536	424,678	328,406	489,324	364,744
SJ-C250K-Fed	724,311	229,324	495,463	463,373	411,935	357,189
SJ-C250K-WA	718,648	268,956	399,657	260,938	575,198	444,972
SJ-C250K-3	620,032	214,233	359,083	366,636	400,140	340,207

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-20. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	640,672	251,112	427,620	331,963	499,300	367,559
SJ-C250K-Fed	740,627	238,135	498,240	467,920	422,199	360,446
SJ-C250K-WA	734,965	277,533	402,577	268,018	585,463	447,535
SJ-C250K-3	636,349	222,809	361,838	373,310	410,404	343,262

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.7-21. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	728.6	818.1	526.0	468.2	574.2	473.4
SJ-C250K-Fed	742.6	847.1	533.3	511.3	550.6	464.7
SJ-C250K-WA	729.4	724.1	501.3	470.1	609.4	488.4
SJ-C250K-3	746.0	792.6	491.8	487.8	545.4	456.1

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-22. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	136.5	153.3	98.6	87.7	107.6	88.7
SJ-C250K-Fed	139.2	158.7	99.9	95.8	103.2	87.1
SJ-C250K-WA	136.7	135.7	93.9	88.1	114.2	91.5
SJ-C250K-3	139.8	148.5	92.2	91.4	102.2	85.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-23. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	455.3	511.2	328.7	292.6	358.8	295.8
SJ-C250K-Fed	464.1	529.3	333.3	319.5	344.1	290.4
SJ-C250K-WA	455.8	452.5	313.2	293.7	380.8	305.2
SJ-C250K-3	466.2	495.3	307.3	304.8	340.8	285.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-24. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	54.4	61.0	39.2	34.9	42.8	35.3
SJ-C250K-Fed	55.4	63.2	39.8	38.1	41.1	34.7
SJ-C250K-WA	54.4	54.0	37.4	35.1	45.5	36.4
SJ-C250K-3	55.7	59.1	36.7	36.4	40.7	34.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-25. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	Worst run for Lummi Island	Worst run for Padilla Bay	50th Percentile Run (based on shore cost)
SJ-C250K-N	228	238	228	228	249	268
SJ-C250K-Fed	227	237	267	227	248	267
SJ-C250K-WA	225	264	263	265	226	246
SJ-C250K-3	224	232	261	233	224	244

II.8. COMPARISON OF ALTERNATIVE RESPONSES: LOWER COLUMBIA RIVER – BUNKER C

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XX. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Baker Bay; and
3. the worst case run for impacts at the Columbia National Wildlife Refuge.

Table II.8-1. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	73.4	68.1	72.4
CL-B25K-Fed	72.1	66.8	72.4
CL-B25K-WA	73.0	65.5	71.2
CL-B25K-3	69.2	64.1	70.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-2. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	7.3	41.7	23.4
CL-B25K-Fed	7.5	40.3	19.4
CL-B25K-WA	7.2	40.3	18.5
CL-B25K-3	7.7	41.2	17.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-3. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	1.0	5.4	3.0
CL-B25K-Fed	1.1	5.3	2.6
CL-B25K-WA	1.1	5.3	2.4
CL-B25K-3	1.1	5.5	2.3

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-4. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	-	-	-
CL-B25K-Fed	1.6	2.2	1.6
CL-B25K-WA	3.4	4.4	3.4
CL-B25K-3	6.7	8.1	6.7

Table II.8-5. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	74	96	105
CL-B25K-Fed	79	90	95
CL-B25K-WA	69	83	90
CL-B25K-3	71	76	86

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-6. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	74	95	101
CL-B25K-Fed	79	89	95
CL-B25K-WA	69	83	90
CL-B25K-3	71	76	85

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-7. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	1,506	1,284	1,738
CL-B25K-Fed	1,469	1,200	1,498
CL-B25K-WA	1,640	1,231	1,840
CL-B25K-3	1,502	1,037	1,607

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-8. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	1,470	1,176	1,665
CL-B25K-Fed	1,469	1,162	1,463
CL-B25K-WA	1,640	1,052	1,770
CL-B25K-3	1,466	967	1,607

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-9. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	671,790	929,360	1,211,500
CL-B25K-Fed	812,380	892,210	889,700
CL-B25K-WA	1,023,300	888,690	1,202,500
CL-B25K-3	787,270	751,620	1,066,400

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.8-10. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge**
CL-B25K-N	833,970	354,980	526,190
CL-B25K-Fed	656,230	307,280	608,530
CL-B25K-WA	616,560	341,920	637,650
CL-B25K-3	714,470	285,190	540,750

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.8-11. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	187.9	111.1	167.2
CL-B25K-Fed	168.8	101.2	159.6
CL-B25K-WA	179.3	107.1	188.7
CL-B25K-3	177.4	88.2	164.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-12. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	15,000	21,183	23,094
CL-B25K-Fed	16,394	19,405	21,144
CL-B25K-WA	13,433	17,599	19,816
CL-B25K-3	14,140	15,388	18,241

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-13. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	1,810	2,256	2,393
CL-B25K-Fed	1,910	2,128	2,253
CL-B25K-WA	1,697	1,997	2,157
CL-B25K-3	1,748	1,838	2,044

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-14. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	7,420	12,810	60,916
CL-B25K-Fed	7,819	8,645	64,708
CL-B25K-WA	8,790	9,474	60,609
CL-B25K-3	7,671	8,648	63,636

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-15. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	24,229	36,249	86,404
CL-B25K-Fed	26,123	30,178	88,105
CL-B25K-WA	23,920	29,070	82,582
CL-B25K-3	23,559	25,874	83,921

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-16. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	4.2	5.3	5.6
CL-B25K-Fed	4.5	5.0	5.3
CL-B25K-WA	4.0	4.7	5.0
CL-B25K-3	4.1	4.3	4.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-17. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	-	-	-
CL-B25K-Fed	-	-	-
CL-B25K-WA	-	-	-
CL-B25K-3	-	-	-

Table II.8-18. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	0	5	0
CL-B25K-Fed	0	5	0
CL-B25K-WA	0	5	0
CL-B25K-3	0	5	0

Table II.8-19. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	2,681	2,074	3,057
CL-B25K-Fed	2,691	2,050	2,681
CL-B25K-WA	3,024	1,852	3,270
CL-B25K-3	2,696	1,726	2,975

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-20. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	2,682	2,079	3,058
CL-B25K-Fed	2,691	2,054	2,682
CL-B25K-WA	3,024	1,856	3,270
CL-B25K-3	2,696	1,732	2,976

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-21. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	83.4	119.0	225.3
CL-B25K-Fed	89.8	103.3	225.1
CL-B25K-WA	80.0	97.7	211.6
CL-B25K-3	80.5	87.2	211.4

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-22. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	15.6	22.3	42.2
CL-B25K-Fed	16.8	19.4	42.2
CL-B25K-WA	15.0	18.3	39.6
CL-B25K-3	15.1	16.3	39.6

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-23. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	52.1	74.3	140.8
CL-B25K-Fed	56.1	64.6	140.7
CL-B25K-WA	50.0	61.1	132.2
CL-B25K-3	50.3	54.5	132.1

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-24. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	6.2	8.9	16.8
CL-B25K-Fed	6.7	7.7	16.8
CL-B25K-WA	6.0	7.3	15.8
CL-B25K-3	6.0	6.5	15.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-25. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	30.3	28.2	27.7
CL-B25K-Fed	27.0	28.2	27.7
CL-B25K-WA	28.1	27.9	27.5
CL-B25K-3	29.0	26.9	27.3

II.9. COMPARISON OF ALTERNATIVE RESPONSES: UPPER COLUMBIA RIVER – BUNKER C

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XXIII. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Ridgefield National Wildlife Refuge (referred to as run#1); and
3. the (second) worst case run for impacts at Ridgefield National Wildlife Refuge (referred to as run#2).

Note that the Washington Compensation Schedule is not applicable to spills in this location. Thus, NRDA costs using that method are not presented.

Table II.9-1. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	76.8	75.7	69.2
CU-B25K-Fed	75.3	75.1	67.8
CU-B25K-WA	74.0	73.6	68.1
CU-B25K-3	72.5	71.6	68.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-2. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	44.5	41.8	58.3
CU-B25K-Fed	45.0	39.2	56.7
CU-B25K-WA	44.6	40.1	56.1
CU-B25K-3	44.3	37.5	53.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-3. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	2.6	2.5	1.6
CU-B25K-Fed	2.6	2.3	2.1
CU-B25K-WA	2.6	2.4	2.1
CU-B25K-3	2.6	2.2	2.1

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.9-4. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	-	-	-
CU-B25K-Fed	1.8	2.2	2.2
CU-B25K-WA	3.3	3.3	3.8
CU-B25K-3	5.3	6.6	7.4

Table II.9-5. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	12.8	6.9	8.0
CU-B25K-Fed	12.5	6.4	8.2
CU-B25K-WA	12.7	7.1	8.1
CU-B25K-3	12.5	6.6	7.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-6. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	12.6	6.9	7.9
CU-B25K-Fed	12.4	6.3	7.9
CU-B25K-WA	12.5	7.1	7.4
CU-B25K-3	12.4	6.6	7.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-7. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	743	309	196
CU-B25K-Fed	668	289	183
CU-B25K-WA	595	294	149
CU-B25K-3	617	299	178

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-8. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	705	274	196
CU-B25K-Fed	665	254	183
CU-B25K-WA	593	257	149
CU-B25K-3	579	262	178

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-9. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	294,230	80,335	42,678
CU-B25K-Fed	261,090	50,209	40,168
CU-B25K-WA	153,640	85,356	23,096
CU-B25K-3	289,210	52,720	35,147

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-10. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	448,370	228,950	153,140
CU-B25K-Fed	406,700	239,000	143,100
CU-B25K-WA	441,840	208,870	148,120
CU-B25K-3	327,870	246,530	143,100

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-11. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	80.9	30.3	14.9
CU-B25K-Fed	71.6	31.7	14.1
CU-B25K-WA	69.1	28.9	11.6
CU-B25K-3	61.5	32.4	14.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-12. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Ridgefield National Wildlife Refuge (#1)**	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	56	54	54
CU-B25K-Fed	92	73	77
CU-B25K-WA	92	75	76
CU-B25K-3	92	74	76

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.9-13. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Ridgefield National Wildlife Refuge (#1)**	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	10	10	9
CU-B25K-Fed	31	20	23
CU-B25K-WA	31	21	22
CU-B25K-3	31	20	22

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.9-14. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	3,462	882	284
CU-B25K-Fed	3,239	769	213
CU-B25K-WA	2,832	783	18
CU-B25K-3	2,756	811	185

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-15. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	3,529	946	347
CU-B25K-Fed	3,363	862	313
CU-B25K-WA	2,956	880	116
CU-B25K-3	2,879	905	283

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-16. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	156	107	115
CU-B25K-Fed	154	103	115
CU-B25K-WA	154	109	110
CU-B25K-3	153	105	112

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-17. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	-	-	-
CU-B25K-Fed	-	-	-
CU-B25K-WA	-	-	-
CU-B25K-3	-	-	-

Table II.9-18. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	3,728	3,689	3,357
CU-B25K-Fed	3,740	3,629	3,537
CU-B25K-WA	3,728	3,652	3,544
CU-B25K-3	3,721	3,595	3,537

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.9-19. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	-	-	-
CU-B25K-Fed	-	-	-
CU-B25K-WA	-	-	-
CU-B25K-3	-	-	-

Table II.9-20. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	3,728	3,689	3,357
CU-B25K-Fed	3,740	3,629	3,537
CU-B25K-WA	3,728	3,652	3,544
CU-B25K-3	3,721	3,595	3,537

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.9-21. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	15.1	6.2	4.0
CU-B25K-Fed	14.8	6.0	4.1
CU-B25K-WA	13.4	6.1	3.4
CU-B25K-3	13.1	6.1	4.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-22. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	2.8	1.2	0.7
CU-B25K-Fed	2.8	1.1	0.8
CU-B25K-WA	2.5	1.1	0.6
CU-B25K-3	2.5	1.1	0.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-23. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	9.5	3.9	2.5
CU-B25K-Fed	9.2	3.7	2.6
CU-B25K-WA	8.4	3.8	2.1
CU-B25K-3	8.2	3.8	2.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-24. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	1.1	0.5	0.3
CU-B25K-Fed	1.1	0.4	0.3
CU-B25K-WA	1.0	0.5	0.3
CU-B25K-3	1.0	0.5	0.3

* Differences between runs are less than the randomized variability in the model and are not significant.

II.10. COMPARISON OF ALTERNATIVE RESPONSES: OUTER COAST-SEA LANES – BUNKER C

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XXVI, and discussion of the results is in Volume I. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Olympia Coast National Marine Sanctuary; and
3. the worst case run for impacts for sensitive locations identified in Geographic Response Plans (GRPs).

Table II.10-1. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs**
OL-B150K-N	54.0	28.6	62.6
OL-B150K-Fed	54.5	28.7	60.5
OL-B150K-WA	51.0	27.0	56.3
OL-B150K-3	55.2	28.5	58.0

* Differences between runs are less than the randomized variability in the model and are not significant.
** Differences between alternate response runs are less than the randomized variability in the model and are not significant.

Table II.10-2. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	39.0	34.9	31.7
OL-B150K-Fed	36.6	34.6	31.8
OL-B150K-WA	34.2	31.5	31.9
OL-B150K-3	33.5	32.3	30.9

*Differences between runs are, for some comparisons, less than the randomized variability in the model and are not significant.

Table II.10-3. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	8.7	7.2	15.6
OL-B150K-Fed	8.5	7.2	11.4
OL-B150K-WA	7.7	7.0	11.4
OL-B150K-3	8.1	6.8	11.1

Table II.10-4. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	-	-	-
OL-B150K-Fed	1.9	1.7	1.8
OL-B150K-WA	6.6	5.6	5.6
OL-B150K-3	6.8	6.1	5.7

Table II.10-5. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs**
OL-B150K-N	917	5,563	392
OL-B150K-Fed	902	5,222	369
OL-B150K-WA	876	5,654	376
OL-B150K-3	818	5,315	355

* Differences between runs are less than the randomized variability in the model and are not significant.
** Differences between alternate response runs are less than the randomized variability in the model and are not significant.

Table II.10-6. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs**
OL-B150K-N	916	5,563	390
OL-B150K-Fed	887	5,091	368
OL-B150K-WA	863	5,615	376
OL-B150K-3	808	5,222	354

* Differences between runs are less than the randomized variability in the model and are not significant.
** Differences between alternate response runs are less than the randomized variability in the model and are not significant.

Table II.10-7. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	3,134	1,312	2,355
OL-B150K-Fed	3,071	1,432	1,932
OL-B150K-WA	2,457	1,484	2,270
OL-B150K-3	3,112	1,434	2,311

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.10-8. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	3,014	1,293	2,295
OL-B150K-Fed	2,882	1,425	1,872
OL-B150K-WA	2,390	1,480	2,270
OL-B150K-3	3,084	1,414	2,252

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.10-9. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*,**
OL-B150K-N	727,270	172,790	371,730
OL-B150K-Fed	659,060	207,180	270,270
OL-B150K-WA	456,140	241,290	213,150
OL-B150K-3	721,300	324,560	507,300

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.10-10. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	2,406,600	1,138,800	1,983,100
OL-B150K-Fed	2,411,700	1,224,900	1,661,700
OL-B150K-WA	2,000,800	1,242,500	2,057,300
OL-B150K-3	2,391,000	1,109,800	1,804,100

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-11. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	363.6	104.6	273.2
OL-B150K-Fed	361.1	113.8	216.9
OL-B150K-WA	288.4	116.9	271.6
OL-B150K-3	370.1	107.0	259.3

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.10-12. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs**
OL-B150K-N	12,645	205,840	-
OL-B150K-Fed	11,457	186,197	-
OL-B150K-WA	10,429	208,011	-
OL-B150K-3	8,147	191,671	-

* Differences between runs are less than the randomized variability in the model and are not significant.
** Injuries to waterfowl were not significant for this run.

Table II.10-13. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*,**	Worst run for GRPs
OL-B150K-N	25,448	99,125	17,102
OL-B150K-Fed	24,994	91,634	16,740
OL-B150K-WA	24,602	99,953	16,868
OL-B150K-3	23,732	93,721	16,516

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.10-14. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	34,478	5,287	23,892
OL-B150K-Fed	29,524	7,040	17,229
OL-B150K-WA	23,015	7,769	21,428
OL-B150K-3	31,125	6,893	20,112

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.10-15. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*,**	Worst run for GRPs*
OL-B150K-N	72,571	310,252	40,994
OL-B150K-Fed	65,976	284,872	33,969
OL-B150K-WA	58,046	315,733	38,297
OL-B150K-3	63,004	292,285	36,628

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.10-16. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	34	108	26
OL-B150K-Fed	34	101	25
OL-B150K-WA	33	109	26
OL-B150K-3	32	103	25

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-17. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb (averaged over each grid cell and within some depth interval) at some time after the spill (An entry "-" indicates the area is less than a grid cell size of 0.08 km^2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	-	-	-
OL-B150K-Fed	-	-	-
OL-B150K-WA	-	-	-
OL-B150K-3	-	-	-

Table II.10-18. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	95	84	143
OL-B150K-Fed	93	84	114
OL-B150K-WA	88	83	113
OL-B150K-3	90	81	112

* Differences between alternative response runs are less than the randomized variability in the model and are not significant.

Table II.10-19. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	30,341	9,556	23,296
OL-B150K-Fed	28,844	10,481	18,936
OL-B150K-WA	23,868	11,538	23,119
OL-B150K-3	31,046	10,833	22,988

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact more shoreline and so more intertidal invertebrates.

Table II.10-20. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	30,435	9,640	23,438
OL-B150K-Fed	28,938	10,565	19,050
OL-B150K-WA	23,955	11,620	23,233
OL-B150K-3	31,136	10,914	23,099

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.10-21. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	302	1,448	178
OL-B150K-Fed	287	1,330	163
OL-B150K-WA	268	1,466	172
OL-B150K-3	269	1,363	167

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-22. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	56.6	271.4	33.4
OL-B150K-Fed	53.7	249.1	30.6
OL-B150K-WA	50.3	274.8	32.3
OL-B150K-3	50.4	255.5	31.4

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-23. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	189	905	111
OL-B150K-Fed	179	831	102
OL-B150K-WA	168	916	108
OL-B150K-3	168	852	105

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-24. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	22.5	108.1	13.3
OL-B150K-Fed	21.4	99.2	12.2
OL-B150K-WA	20.0	109.4	12.8
OL-B150K-3	20.1	101.7	12.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-25. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	196.3	176.8	191.8
OL-B150K-Fed	194.5	176.0	191.1
OL-B150K-WA	191.8	173.3	189.6
OL-B150K-3	190.3	172.4	189.3

II.11. COMPARISON OF ALTERNATIVE RESPONSES: GRAYS HARBOR – BUNKER C

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XXIX, and discussion of the results is in Volume I. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Willapa Bay; and
3. the worst case run for impacts for sensitive locations identified in Geographic Response Plans (GRPs).

Table II.11-1. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	77.2	73.7	75.6
GH-B25K-Fed	69.2	71.8	74.1
GH-B25K-WA	56.4	67.6	71.8
GH-B25K-3	44.8	63.2	68.9

Table II.11-2. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	14.9	28.0	27.9
GH-B25K-Fed	14.5	30.3	24.7
GH-B25K-WA	10.5	23.8	23.2
GH-B25K-3	10.4	23.5	20.3

*Differences between runs are, for some comparisons, less than the randomized variability in the model and are not significant.

Table II.11-3. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	0.8	1.3	2.9
GH-B25K-Fed	0.7	1.3	2.7
GH-B25K-WA	0.5	1.1	2.6
GH-B25K-3	0.5	1.1	2.3

Table II.11-4. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	-	-	-
GH-B25K-Fed	9.8	3.8	6.4
GH-B25K-WA	25.8	8.4	11.1
GH-B25K-3	42.5	14.2	15.5

Table II.11-5. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	59	121	46
GH-B25K-Fed	57	120	32
GH-B25K-WA	55	117	27
GH-B25K-3	51	112	27

Table II.11-6. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	59	121	46
GH-B25K-Fed	57	120	32
GH-B25K-WA	55	117	27
GH-B25K-3	51	111	27

Table II.11-7. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	2,027	1,198	1,394
GH-B25K-Fed	1,948	942	1,201
GH-B25K-WA	1,588	1,026	878
GH-B25K-3	1,070	979	868

* Differences between alternative response runs are less than the randomized variability in the model and are not significant.

Table II.11-8. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	1,988	1,156	1,276
GH-B25K-Fed	1,948	903	1,122
GH-B25K-WA	1,548	948	878
GH-B25K-3	1,070	898	868

* Differences between alternative response runs are less than the randomized variability in the model and are not significant.

Table II.11-9. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Willapa Bay*	Worst run for GRPs*
GH-B25K-N	1,101,200	712,040	795,000
GH-B25K-Fed	1,140,500	317,440	592,740
GH-B25K-WA	867,850	519,700	238,780
GH-B25K-3	511,270	483,180	278,110

*Differences between runs are, for some comparisons, less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore (unless additional cleanup removes it).

Table II.11-10. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs*
GH-B25K-N	925,720	486,180	598,550
GH-B25K-Fed	807,930	624,770	608,100
GH-B25K-WA	719,900	506,590	639,370
GH-B25K-3	559,030	496,100	589,930

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-11. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	217.9	115.5	138.8
GH-B25K-Fed	202.4	107.9	128.8
GH-B25K-WA	169.7	106.3	109.4
GH-B25K-3	120.5	102.7	105.2

Table II.11-12. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Willapa Bay	Worst run for GRPs*
GH-B25K-N	-	4,658	-
GH-B25K-Fed	-	4,543	-
GH-B25K-WA	-	4,230	-
GH-B25K-3	-	3,648	-

* Injuries to waterfowl were not significant for this run.

Table II.11-13. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	1,835	3,071	1,561
GH-B25K-Fed	1,789	3,047	1,271
GH-B25K-WA	1,745	2,981	1,169
GH-B25K-3	1,664	2,859	1,163

Table II.11-14. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	14,363	8,152	9,045
GH-B25K-Fed	14,071	6,261	7,899
GH-B25K-WA	11,082	6,595	6,076
GH-B25K-3	7,511	6,223	6,001

* Differences between alternate response runs are less than the randomized variability in the model and are not significant.

Table II.11-15. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	16,197	15,881	10,606
GH-B25K-Fed	15,859	13,851	9,170
GH-B25K-WA	12,827	13,806	7,246
GH-B25K-3	9,176	12,730	7,164

Table II.11-16. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Willapa Bay	Worst run for GRPs*
GH-B25K-N	2	4	2
GH-B25K-Fed	2	4	2
GH-B25K-WA	2	3	2
GH-B25K-3	2	3	2

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-17. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb (averaged over each grid cell and within some depth interval) at some time after the spill (An entry "-" indicates the area is less than a grid cell size of 0.04 km^2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	-	-	-
GH-B25K-Fed	-	-	-
GH-B25K-WA	-	-	-
GH-B25K-3	-	-	-

Table II.11-18. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Willapa Bay*	Worst run for GRPs*
GH-B25K-N	12	13	16
GH-B25K-Fed	12	13	15
GH-B25K-WA	11	12	15
GH-B25K-3	11	12	15

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-19. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	20,168	11,811	13,030
GH-B25K-Fed	19,762	9,228	11,462
GH-B25K-WA	15,671	9,692	8,967
GH-B25K-3	10,737	9,228	8,880

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-20. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	20,180	11,824	13,045
GH-B25K-Fed	19,774	9,241	11,478
GH-B25K-WA	15,682	9,705	8,982
GH-B25K-3	10,748	9,240	8,894

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-21. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	45.7	58.2	32.3
GH-B25K-Fed	44.7	53.6	27.5
GH-B25K-WA	38.0	52.7	22.8
GH-B25K-3	29.7	49.0	22.5

Table II.11-22. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	8.6	10.9	6.0
GH-B25K-Fed	8.4	10.0	5.1
GH-B25K-WA	7.1	9.9	4.3
GH-B25K-3	5.6	9.2	4.2

Table II.11-23. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	28.6	36.3	20.2
GH-B25K-Fed	27.9	33.5	17.2
GH-B25K-WA	23.7	32.9	14.2
GH-B25K-3	18.6	30.6	14.1

Table II.11-24. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	3.4	4.3	2.4
GH-B25K-Fed	3.3	4.0	2.0
GH-B25K-WA	2.8	3.9	1.7
GH-B25K-3	2.2	3.7	1.7

Table II.11-25. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	33.7	32.8	32.5
GH-B25K-Fed	32.6	32.7	31.1
GH-B25K-WA	31.5	32.6	30.2
GH-B25K-3	26.7	32.0	27.1

Phase II: Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XV: Model Inputs for San Juan Islands – Alaskan North Slope Crude

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XV.A. INTRODUCTION

This appendix contains model input data (in maps, figures and tables) for the modeled locations and the sources for that information. The approach and sources applicable to all modeled locations are described in Volume I, Section 3 of this technical report. Specifics to this model location are below. Thus, the reader should refer to Volume I, Section 3 for background and the context within which these data are used.

XV.B. GEOGRAPHICAL DATA

Geographic data for the modeled location are presented in this section. The sources for these data are described in Volume I, Section 3. Maps are also presented below showing areas where mechanical removal was assumed to occur in the model simulations. The assumptions for the response scenarios are in Volume I, Section 3.

XV.B.1. Maps of the Vicinity of the Modeled Spill Locations

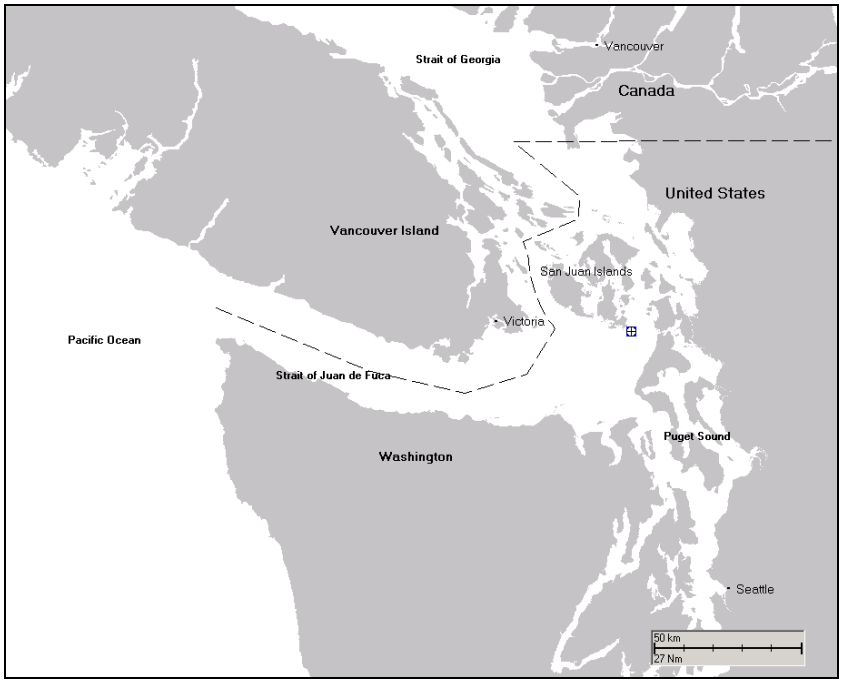

Figure XV.B.1-1 Map of the vicinity of the potential spill locations.

XV.B.2. Gridded Habitat Mapping

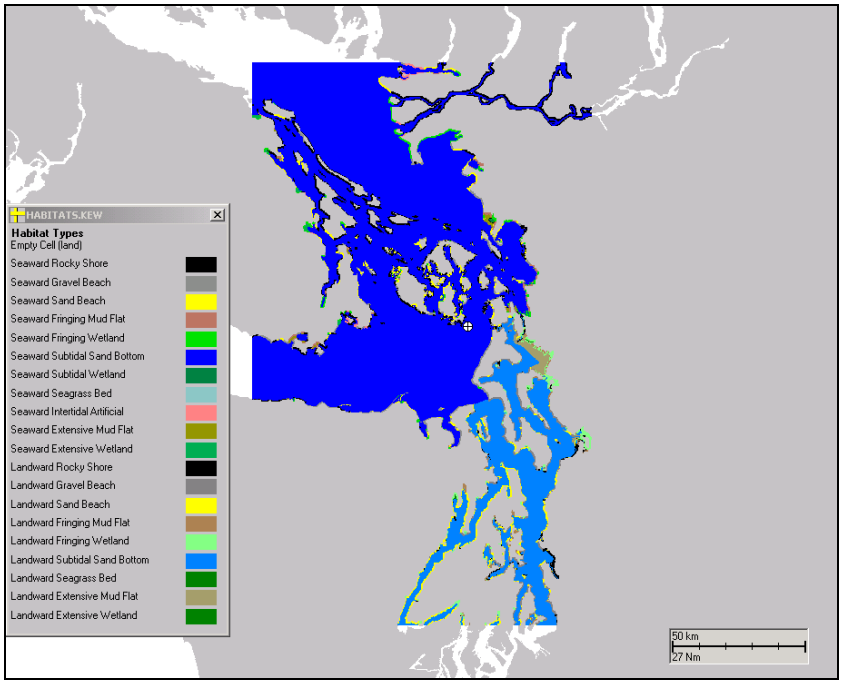

Figure XV.B.2-1 Habitat grid used for modeling the potential spills.

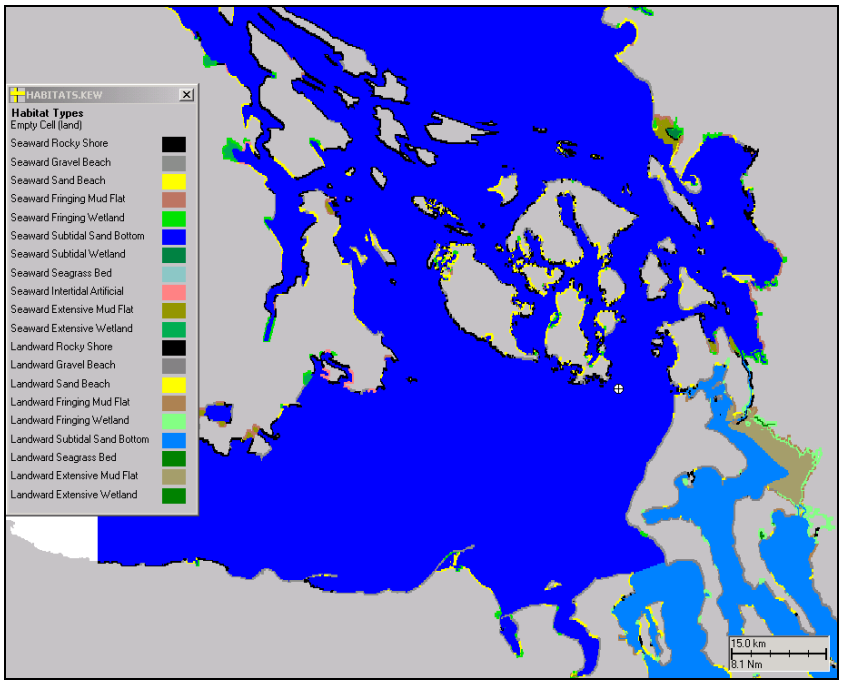

Figure XV.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XV.B-3. Gridded Depth Data

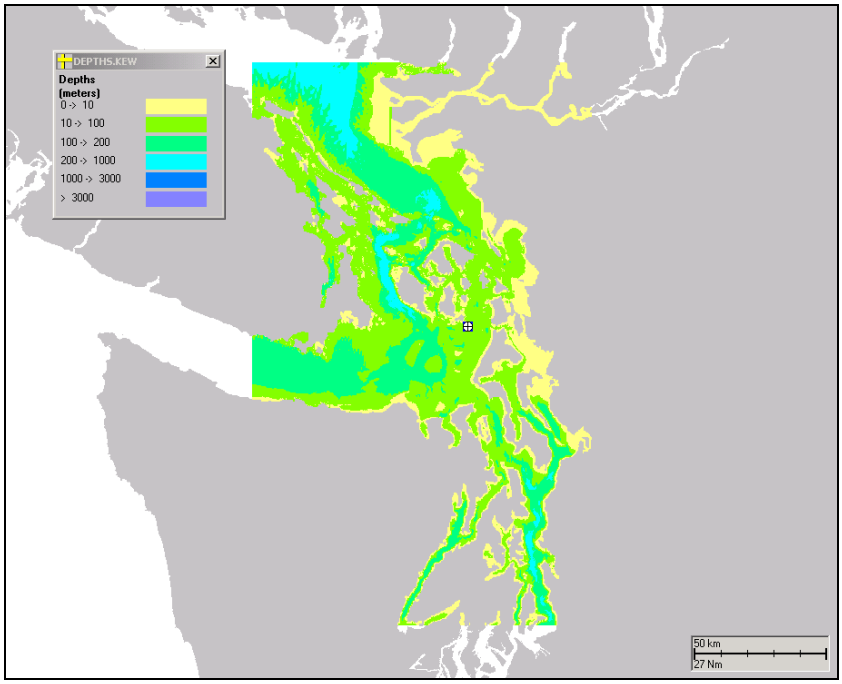

Figure XV.B.3-1 Depth grid used for modeling the potential spills.

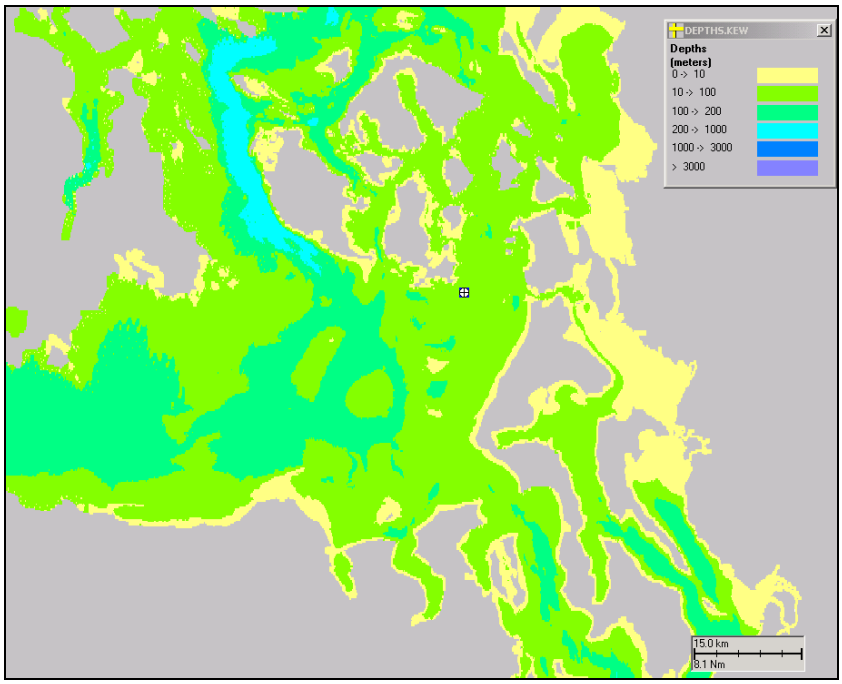

Figure XV.B.3-2 Depth grid used for modeling the potential spills (closer view).

XV.B-4. Areas Where Response Actions Assumed

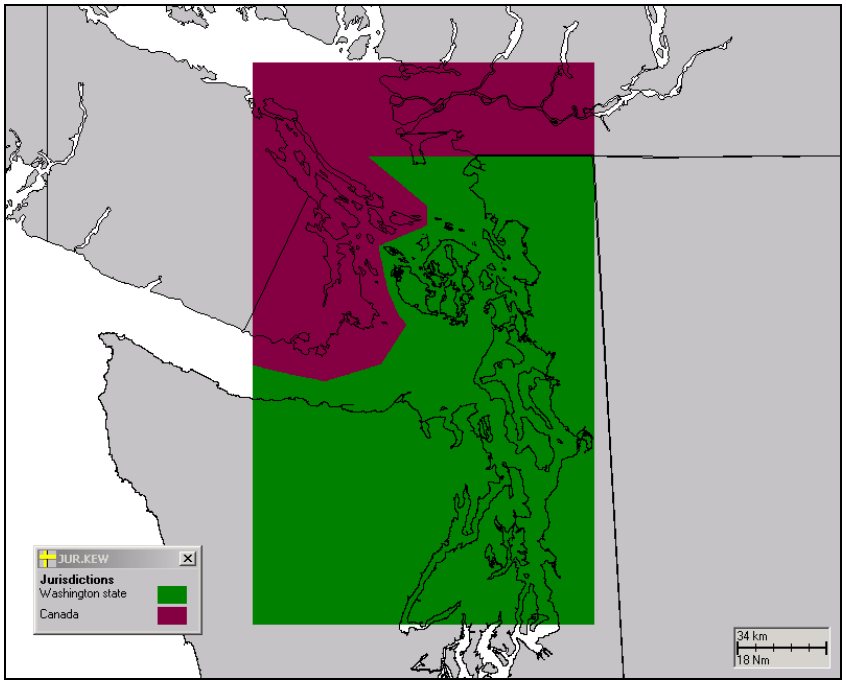

Figure XV.B.4-1 Jurisdictions in the area of the potential spills.

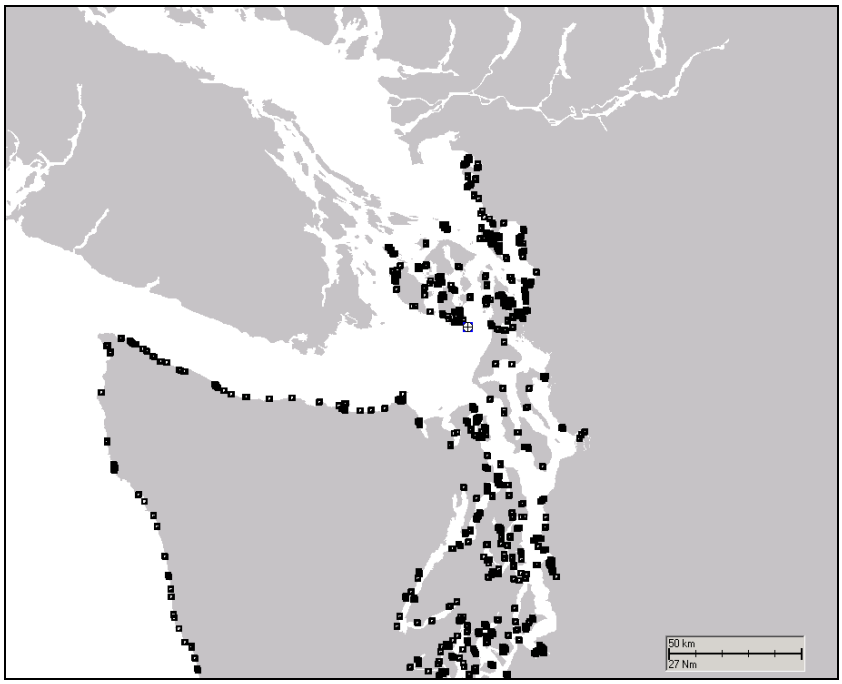

Figure XV.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

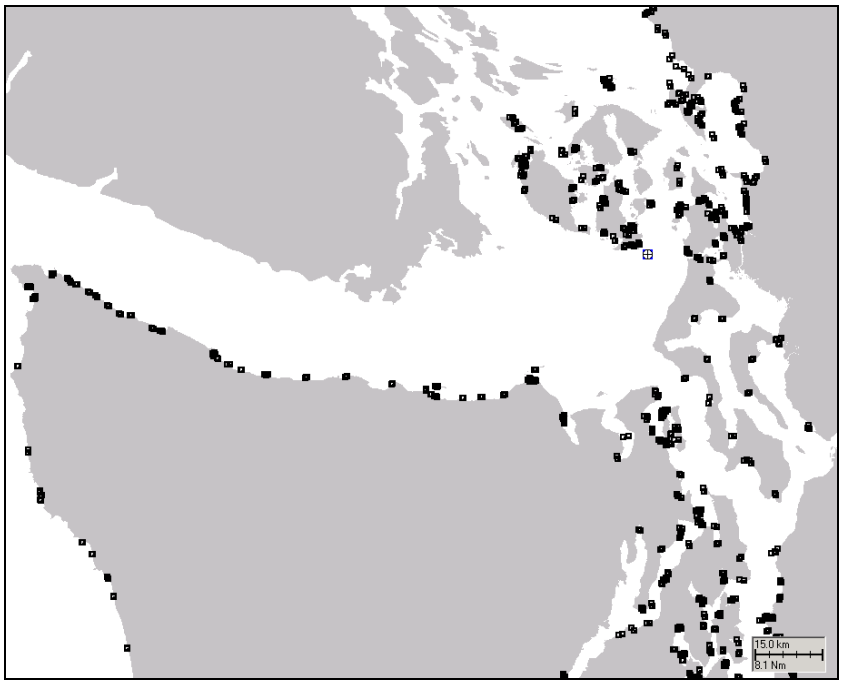

Figure XV.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

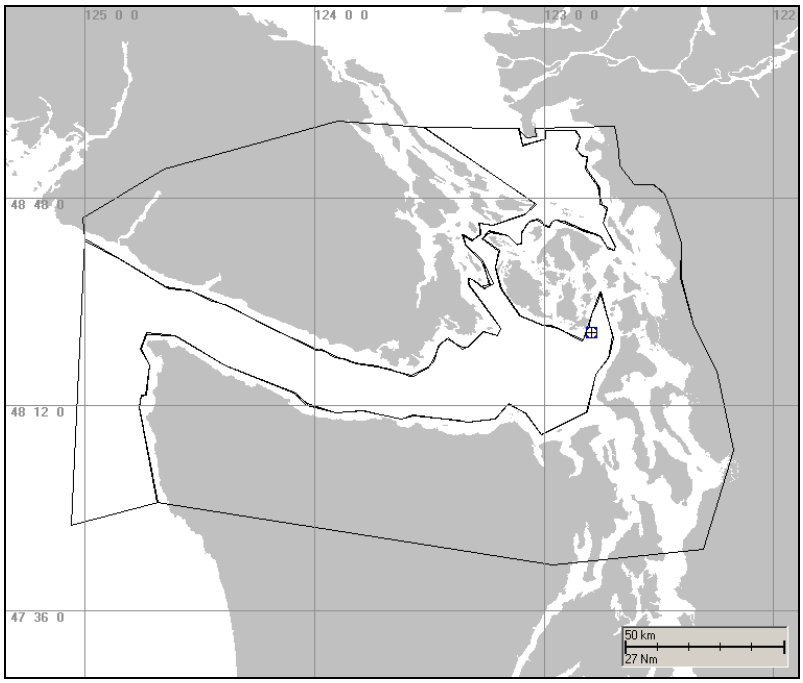

Figure XV.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

XV.C. CURRENT DATA
XV.C.1. Basis of Current Data

Currents were based on hydrodynamic model data from D.O. Hodgins (1998; Seaconsult Marine Research Ltd, 8805 Osler Street, Vancouver V6P 4G1, Canada), who simulated currents in the Strait of Georgia. The surface currents from Hodgins' three-dimensional model outputs were formatted for use in SIMAP. The tidal forcing functions applied were the 9 harmonic constituents (M_2, S_2, N_2, K_2, MF, Q_1, K_1, O_1 and P_1).

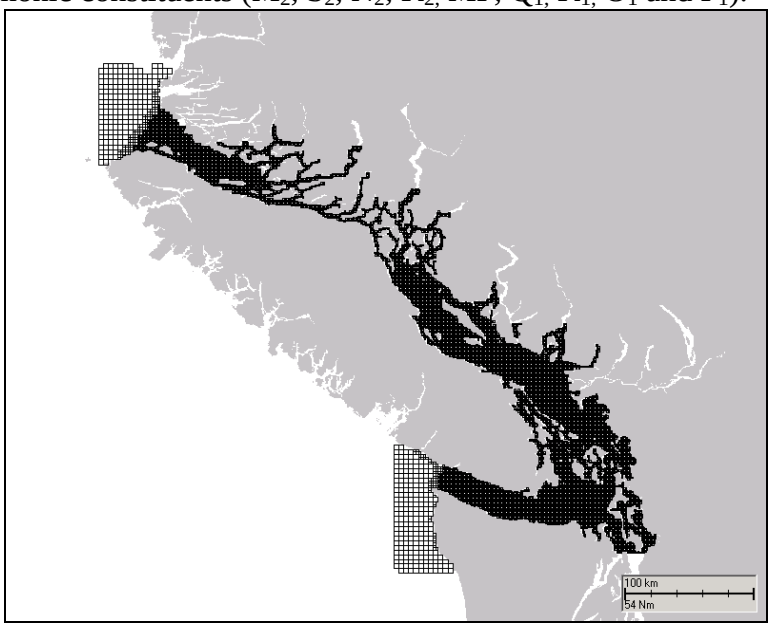

Figure XV.C.1-1 Grid used for the hydrodynamic model-generated current data.

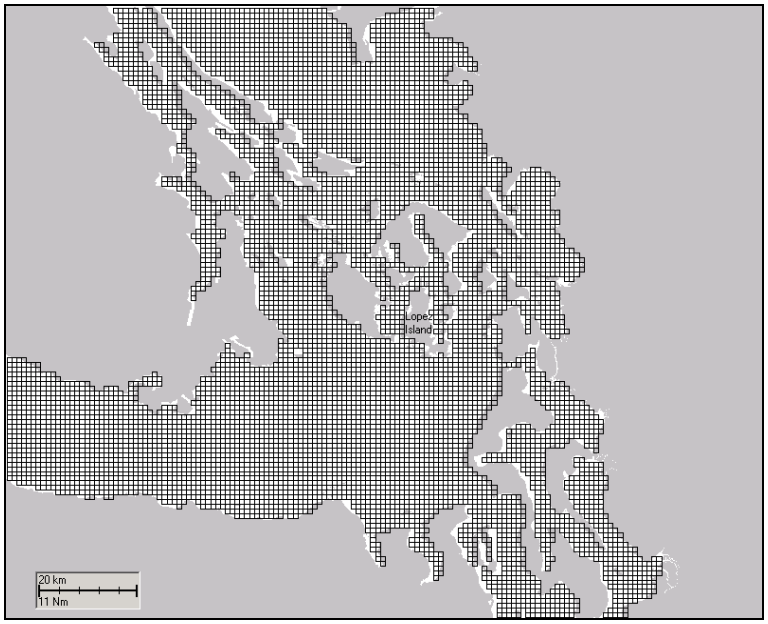

Figure XV.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island).

XV.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations

The figures below show the maximum flood and ebb of the M_2 and K_1 component. Note that 0.5 m/sec = 1 knot.

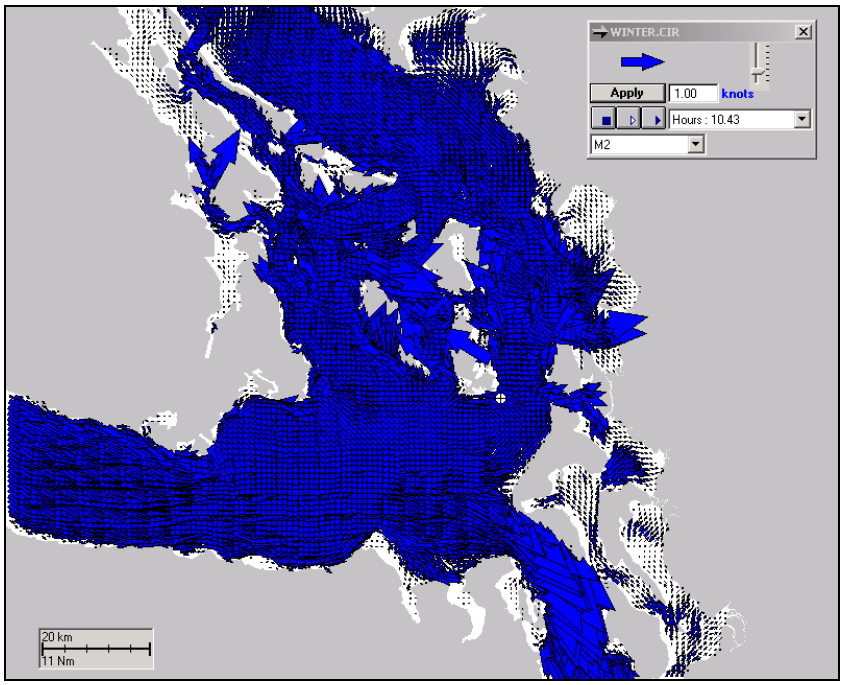

Figure XV.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Lopez Island.

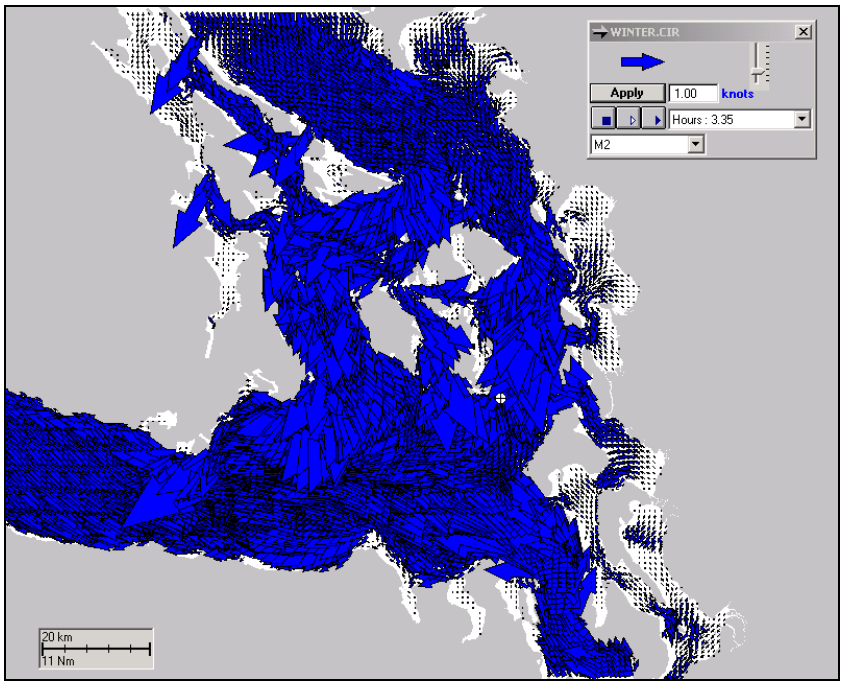

Figure XV.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Lopez Island.

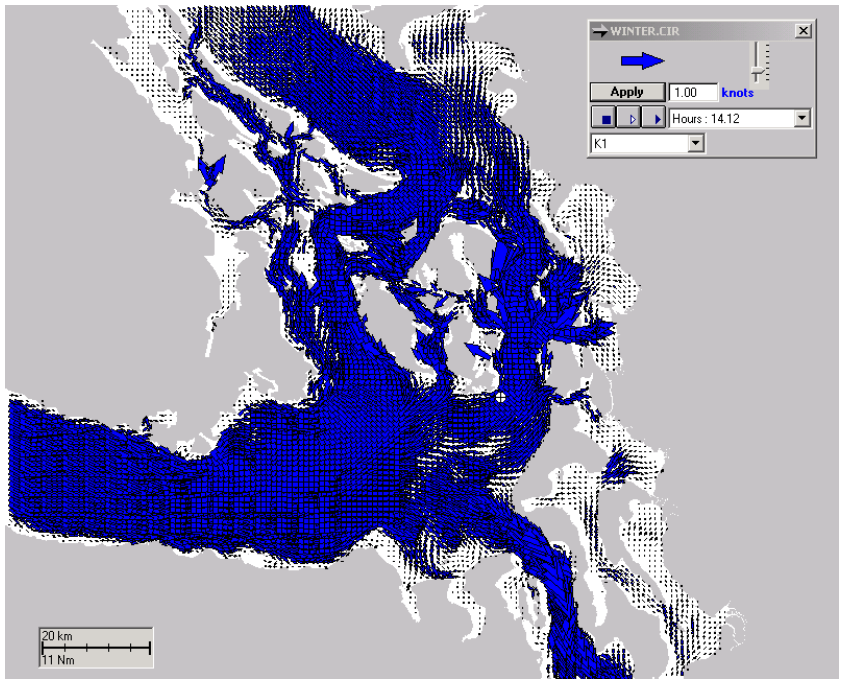

Figure XV.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Lopez Island.

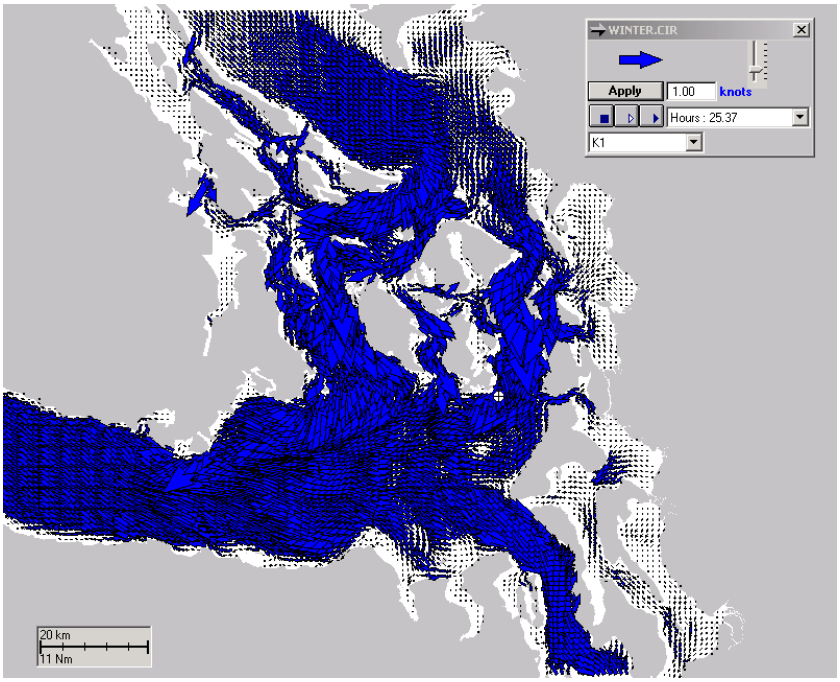

Figure XV.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Lopez Island.

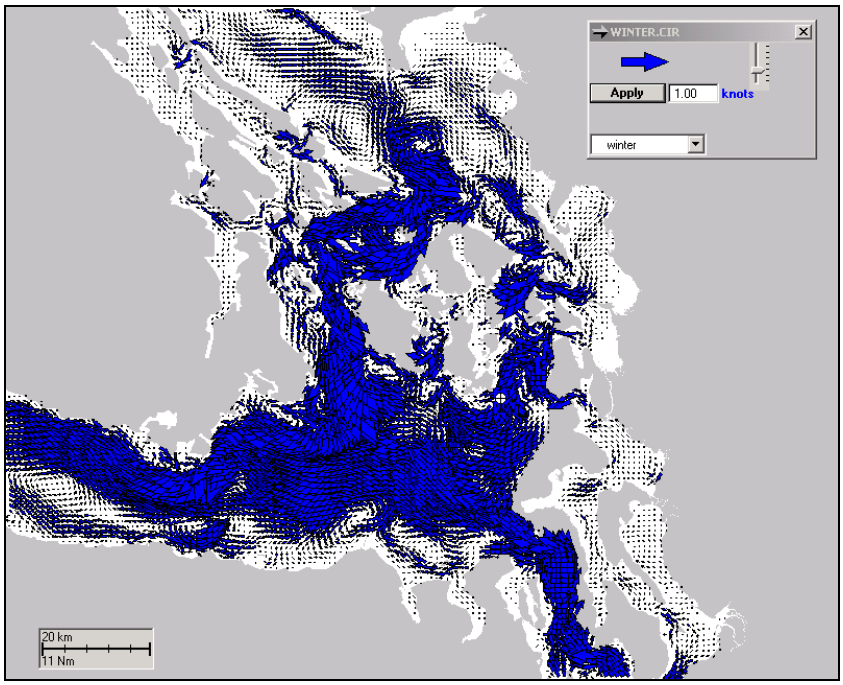

Figure XV.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction.

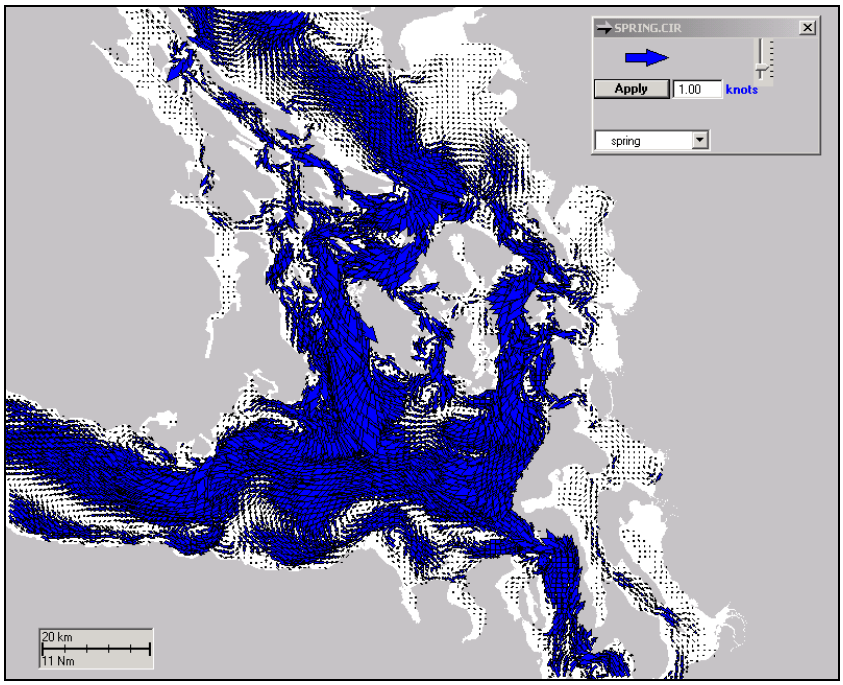

Figure XV.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction.

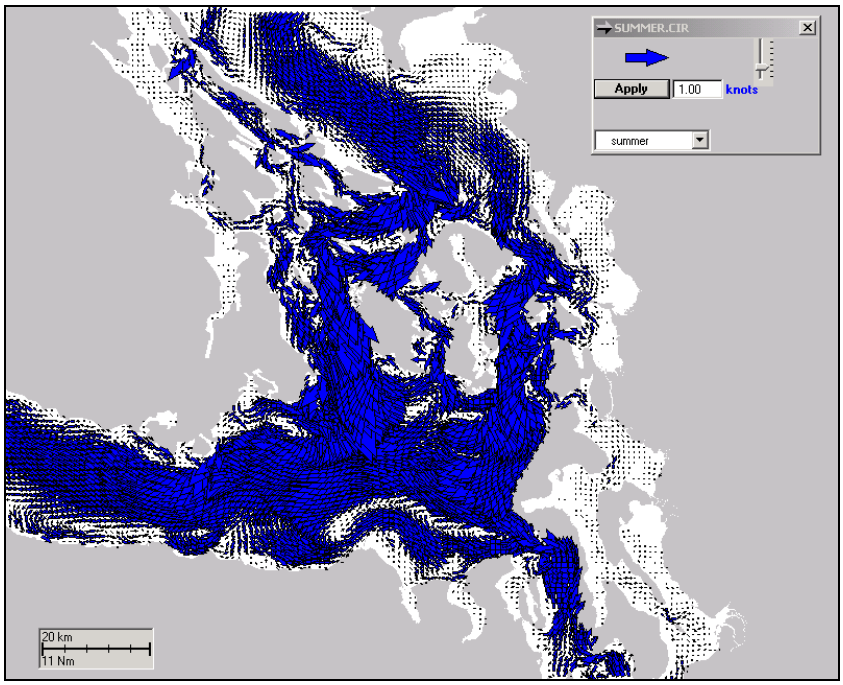

Figure XV.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.

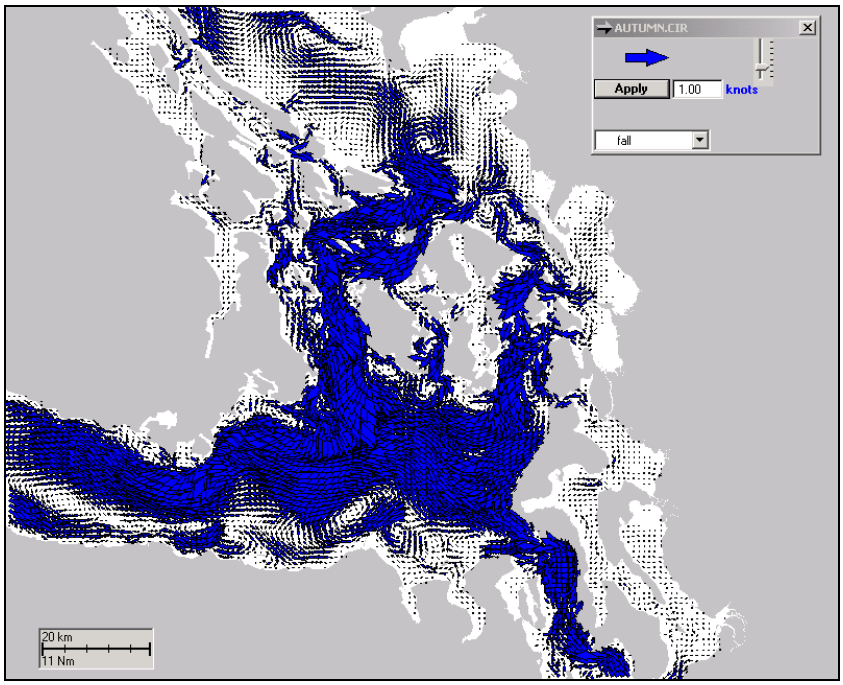

Figure XV.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction.

XV.D: OIL PROPERTIES

Table XV.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.8761	Wang et al. (1999)
Viscosity @ 25 deg. C (cp)	16	Wang et al. (1999)
Surface Tension (dyne/cm)	27	Wang et al. (1999)
Pour Point (deg. C)	-54	Wang et al. (1999)
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.030662	Wang et al. (1999)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.010372	A.D. Little (1996)
Fraction 2-ring aromatics (included in PAHs above)	0.00375	A.D. Little (1996)
Fraction 3-ring aromatics (included in PAHs above)	0.006622	A.D. Little (1996)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.189338	Wang et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.13325	Wang et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.200378	Wang et al. (1999)[1]
Minimum Oil Thickness (m)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	70	Wang et al. (1999)[2]; ADIOS (2000)[2]
Mousse Water Content as Spilled (%)	0	-
Water content of fuel (not in mousse, %)	0	-
Degradation Rate (/day), Surface & Shore	0.01	National Research Council (1985)
Degradation Rate (/day), Hydrocarbons in Water	0.01	National Research Council (1985)
Degradation Rate (/day), Oil in Sediment	0.001	Haines and Atlas (1982)
Degradation Rate (/day), Aromatics in Water	0.01	French et al. (1996b)
Degradation Rate (/day), Aromatics in Sediment	0.001	French et al. (1996b)

[1] – Wang et al. (1999) provided total hydrocarbon data. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.
[2] – Mid-value used.

Table XV.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil.

Aromatic	Log(K_{ow})*	Concentration (mg/kg)
benzene	2.13	0.0
Toluene	2.69	0.0
Ethylbenzene	3.13	0.0
o-Xylene	3.15	0.0
p-Xylene	3.18	0.0
m-Xylene	3.2	0.0
Xylenes	3.18	0.0
styrene	3.05	0.0
methylstyrenes	3.35	0.0
1,2,3-Trimethylbenzene	3.55	0.0
1,2,4-Trimethylbenzene	3.6	0.0
1,3,4-Trimethylbenzene	3.6	0.0
1,3,5-Trimethylbenzene	3.58	0.0
Trimethylbenzenes	3.58	0.0
n-propylbenzene	3.69	0.0
iso-propylbenzene	3.63	0.0
ethyl-methylbenzenes	3.63	0.0
iso-propyl-4-methylbenzene	4.10	0.0
butylbenzenes	4.12	0.0
tetramethylbenzenes	4.01	0.0
tetralin	3.83	0.0
diphenylmethane	4.14	0.0
naphthalene	3.37	650
C1-naphthalenes	3.87	1,300
C2-naphthalenes	4.37	1,800
C3-naphthalenes	5.00	1,400
C4-naphthalenes	5.55	850
biphenyls	3.9	180
acenaphthylene	4.07	0.0
acenaphthene	3.92	0.0
dibenzofuran	4.31	0.0
Fluorene	4.18	82
C1-fluorenes	4.97	220
C2-fluorenes	5.20	260
C3-fluorenes	5.50	280

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

Table XV.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	200
C1-dibenzothiophene	4.86	360
C2-dibenzothiophene	5.50	540
C3-dibenzothiophene	5.73	460
phenanthrene	4.57	230
anthracene	4.54	0.0
C1-phenanthrenes/anthracenes	5.14	430
C2-phenanthrenes/anthracenes	5.25	490
C3-phenanthrenes/anthracenes	6.00	380
C4-phenanthrenes/anthracenes	6.51	260
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total log(K_{ow})$\leq$5.6	-	9,272

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

XV.E: INPUTS TO THE SIMAP PHYSICAL FATES MODEL

This section summarizes the model input data for the scenarios run and the sources for that information. The approach and sources applicable to all modeled locations are described in Volume I, Section 3 of this technical report. Specifics to this model location are below. Thus, the reader should refer to Volume I, Section 3 for background and the context within which these data are used.

The model grid and cell size were set to provide the maximum resolution (minimum cell size) possible within the memory constraints of the model, while also providing sufficient geographic coverage to encompass the maximum extent of oiling possible for the scenario. Test runs (randomizing weather conditions) were made to estimate the maximum extent of surface oiling and the grid size was set to cover that area.

Table XV.E-1. Inputs to the Fates Model for Stochastic Scenarios

Name	Description	Units	Source(s) of Information	Value(s)
Spill Site	Location of the spill site	-	Washington DOE	Rosario Strait/Georgia Strait from the south end of Lopez Island to off Cherry Point
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure XV.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure XV.E-1)
Depth of release	Depth below the water surface of the release or 0 for surface release	m	Washington DOE	0 m
Start time and date	Randomized over selected months of the year	Date, hr,min	(randomized)	Jan-Dec
Spill duration	Hours over which the release occurs	Hours	(assumed)	4 hours
Total spill amount	Total volume (or weight) released (maximum if range)	bbl	Washington DOE	250,000 bbl
Model time step	Time step used for model calculations	Hours	-	0.25
Model duration	Length of each model simulation	Days	-	56 days

Table XV.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table XV.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Salinity	Surface water salinity	ppt	French et al. (1996b) province 51	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XV.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XV.E-4)
Air Temperature	Air water temperature at water surface	Degrees C	(assume = water temperature)	(= water temperature)
Fetch	Fetch = distance to land to N, S, E, W (if landfall not in model domain)	km	Chart	(calculated from model grid)
Wind drift speed	Speed oil moves down wind relative to wind	% of wind speed	Youssef (1993); Youssef and Spaulding (1993)	(model calculated)
Wind drift angle	Angle to right of wind (in northern hemisphere) that oil drifts	Deg. to right of down wind	Youssef (1993); Youssef and Spaulding (1993, 1994)	(model calculated)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y	m^2/sec	French et al. (1996, 1999a) based on Okubo (1971)	1 m^2/sec (estuaries and low energy coastal areas)
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z	m^2/sec	French et al. (1996, 1999) based on Okubo (1971)	0.0001 m^2/sec
Suspended sediment concentration	Average suspended sediment concentration during spill period	mg/l	French et al. (1996b)	10 mg/l
Suspended sediment settling rate	Net settling rate for suspended sediments	m/day	French et al. (1996b)	1 m/day

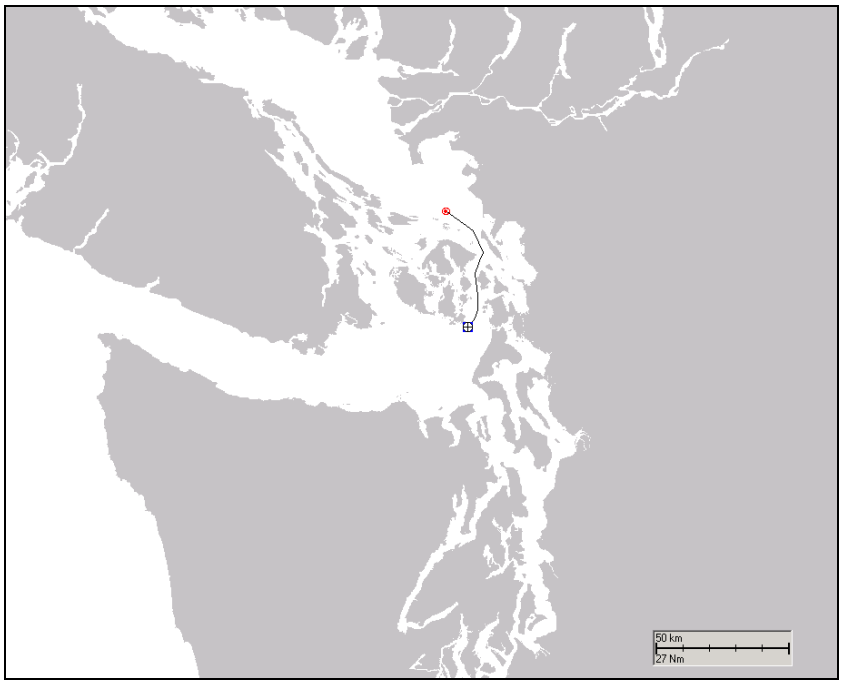

Figure XV.E-1 Varied range of spill site, Rosario Strait/Georgia Strait from the south end of Lopez Island to off Cherry Point.

Table XV.E-2. Time, date and location inputs for each of the 100 stochastic runs.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	2002	10	25	3	48.79085	122.8576
2	1992	5	12	8	48.63506	122.7353
3	1993	10	23	20	48.54226	122.7459
4	1999	3	7	5	48.61182	122.7485
5	1993	11	18	11	48.81049	122.8989
6	1998	11	21	3	48.51369	122.7412
7	1998	5	29	20	48.77623	122.8268
8	1996	6	15	9	48.80529	122.888
9	1995	5	31	18	48.41553	122.7824
10	2000	12	5	17	48.58387	122.7532
11	1999	4	23	14	48.48296	122.738
12	2003	8	3	10	48.44713	122.7527
13	2003	12	15	9	48.43967	122.759
14	1997	1	9	7	48.54966	122.7472
15	1997	1	12	14	48.54472	122.7463
16	2001	11	13	6	48.66917	122.7128
17	2002	8	28	23	48.7191	122.746
18	2002	1	21	20	48.43344	122.765
19	1996	11	4	22	48.5928	122.7548
20	1999	12	18	14	48.63166	122.7372
21	1994	6	20	10	48.5304	122.7438
22	1992	10	31	6	48.63742	122.734
23	1994	3	12	7	48.76853	122.8106
24	2001	11	5	14	48.43426	122.7642
25	2000	10	20	22	48.52842	122.7434
26	1995	11	9	1	48.77577	122.8259
27	2001	7	11	4	48.41615	122.7818
28	1993	5	26	4	48.73642	122.7575
29	1992	6	17	18	48.80195	122.881
30	1993	2	7	18	48.75351	122.779
31	2002	2	20	10	48.51136	122.7409
32	1993	5	23	17	48.72731	122.7514
33	1997	1	6	21	48.64153	122.7317
34	1995	3	28	12	48.66311	122.7169
35	1992	8	8	18	48.61361	122.7475
36	1993	8	21	16	48.50145	122.7399
37	1994	3	17	20	48.62929	122.7386
38	1995	6	3	17	48.5179	122.7416
39	1993	11	30	23	48.66429	122.7161
40	1993	3	16	5	48.59597	122.7554
41	2000	8	30	13	48.5145	122.7412
42	1995	9	5	14	48.7494	122.7704
43	2002	3	10	13	48.74996	122.7715
44	1997	4	24	5	48.77132	122.8165
45	1999	7	31	5	48.53325	122.7443
46	1998	9	4	1	48.577	122.752
47	1994	7	21	19	48.4921	122.7389
48	1996	11	9	16	48.50862	122.7406
49	2002	6	10	20	48.70258	122.735
50	1999	3	15	21	48.7546	122.7813
51	2000	8	30	18	48.65939	122.7195

52	1998	1	15	10	48.67227	122.7149
53	1996	4	19	3	48.43198	122.7664
54	2000	3	7	12	48.50174	122.7399
55	1995	7	17	21	48.72907	122.7526
56	2001	3	30	8	48.59129	122.7545
57	1994	6	15	8	48.47271	122.7395
58	1996	3	9	17	48.75243	122.7767
59	1992	12	1	17	48.75869	122.7899
60	1998	2	24	8	48.61583	122.7462
61	2003	4	30	12	48.50673	122.7404
62	1996	3	2	19	48.43837	122.7602
63	1994	11	8	17	48.53302	122.7442
64	1998	4	12	18	48.68127	122.7208
65	2000	7	9	21	48.76229	122.7975
66	1998	12	8	18	48.57396	122.7515
67	2003	1	17	18	48.6074	122.751
68	1992	12	23	2	48.80341	122.8841
69	2001	11	17	7	48.80557	122.8886
70	1998	1	12	19	48.72387	122.7491
71	1993	7	18	23	48.46932	122.7412
72	1993	5	7	6	48.51317	122.7411
73	1998	10	21	22	48.43058	122.7678
74	1994	4	11	21	48.79472	122.8658
75	1993	11	1	1	48.68985	122.7265
76	1992	4	22	6	48.75858	122.7897
77	1999	6	8	0	48.52494	122.7428
78	1998	2	27	20	48.75238	122.7766
79	2002	6	22	16	48.60842	122.7504
80	2000	4	8	6	48.5786	122.7523
81	2000	11	16	7	48.46533	122.7433
82	1992	1	28	9	48.43696	122.7616
83	2000	6	22	0	48.74442	122.7628
84	2002	12	29	3	48.74872	122.7689
85	1994	4	24	4	48.62067	122.7435
86	1995	6	19	4	48.75866	122.7899
87	2002	3	3	4	48.76675	122.8069
88	1994	2	27	2	48.64845	122.727
89	2000	11	9	13	48.41859	122.7795
90	1997	2	13	16	48.63328	122.7363
91	2003	4	30	12	48.59886	122.7558
92	1994	2	26	1	48.77412	122.8224
93	1998	7	7	18	48.58145	122.7528
94	1995	12	28	3	48.45767	122.7472
95	1996	8	8	10	48.78553	122.8464
96	2003	3	24	15	48.76492	122.803
97	2002	10	30	15	48.64107	122.7319
98	2000	10	5	10	48.54698	122.7467
99	2002	9	10	19	48.71212	122.7413
100	1992	5	5	13	48.6987	122.7324

Table XV.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	SI_HABS2.HAB
Grid W edge	123° 57.76'W
Grid S edge	47° 22.01' N
Cell size (^{o}longitude)	0.002^o W
Cell size (^{o}latitude)	0.002^o N
Cell size (m) west-east	150.14
Cell size (m) south-north	221.67
# cells west-east	890
# cells south-north	978
Water cell area (m^2)	33,279.9
Shore cell length (m)	182.43
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	3.0
Shore cell width – Gravel beach (m)	7.0
Shore cell width – Sand beach (m)	15.0
Shore cell width – Mud flat (m)	210.0
Shore cell width – Wetlands (fringing,m)	210.0

Table XV.E-4. Water temperature by month of the year (from French et al., 1996b).

Month	**Surface Water Temperature (^{o}C)**	**Bottom Water Temperature (^{o}C)**	**Pycnocline Depth (m)**
January	10	8	20
February	10	8	20
March	10	8	20
April	11	8	20
May	12	8	20
June	14	8	20
July	14	7	10
August	14	7	10
September	14	7	10
October	13	7	20
November	12	7	20
December	10	7	20

Table XV.E-5. Wind data sources and records used.

File Name	Location	Latitude Longitude	Dates	Data Source
SISW1_1992_2003_ LST.WNE	Station SISW1 - Smith Island, WA	48.32 ºN 122.84 ºW	1991-2003	National Data Buoy Center

The SISW1_1992_2003_LST.WNE wind data were downloaded from one buoy Station SISW1 - Smith Island, WA. Figure XV.E-2 displays where the buoy is located along with surrounding buoys. SISW1_1992_2003_LST.WNE data start on 31 December 1991 and end on 31 December 2003.

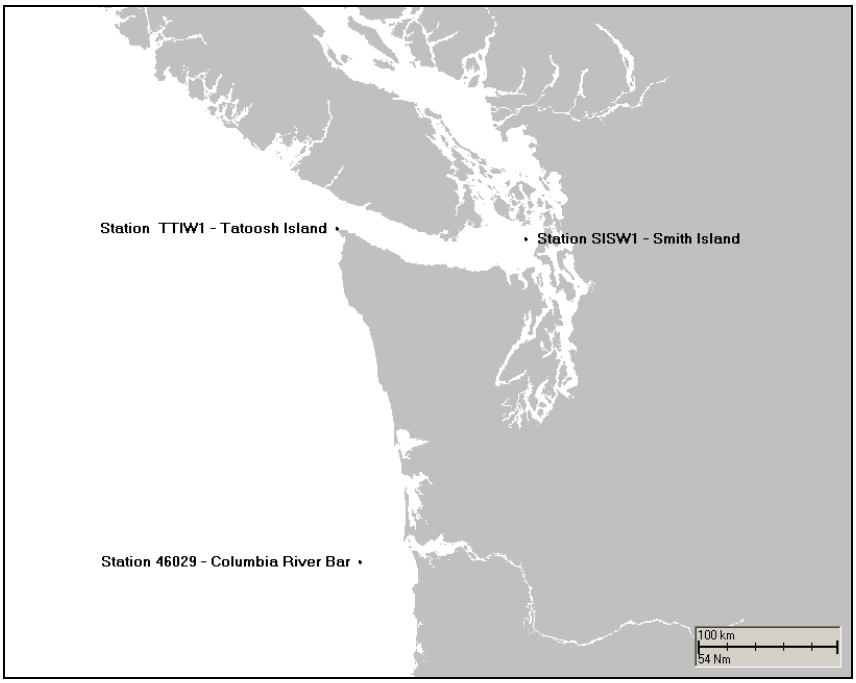

Figure XV.E-2 Wind Station Locations.

Phase II: Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XVI: Model Results for Runs Assuming No Response for San Juan Islands – Alaskan North Slope Crude

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XVI.A. INTRODUCTION

The results of the stochastic scenario for the San Juan Islands – Alaskan North Slope Crude are contained in this volume. The stochastic scenario was run with no protection booming and no mechanical removal (i.e., no response to the spill).

XVI.B. MAPS OF EXPOSURE PROBABILITY AND TIME FIRST EXPOSED

The results of multiple model runs are evaluated to develop the following statistics, for each cell in the model grid ("location") and for each exposure index. Maps of results summarizing all 100 runs of a scenario are contained in this section. The mapped results presented in this Section include:

- Probability that the minimum threshold thickness or concentration will be exceeded at each location at any time following the spill). For surface oil thickness, the model records if any oil of greater than that thickness passes through the grid cell, regardless of the aerial coverage of the oil. For dissolved aromatic concentrations, the average concentration in the grid cell is used to determine if the threshold is exceeded.
- Time (hours) to first exceedance of the minimum threshold at each location (i.e., in each cell).

Exposure indices and minimum thresholds (i.e., those less than values that might have an impact on any resource) used in the modeling were:

- Surface slick or floating oil: $\geq$ 0.01 g/m^2 (average thickness $\geq$ 0.01 micron)
- Shoreline: average mass loading over the shore segment (length of one grid cell, calculated as the cell diagonal length, times the typical width for the habitat type) $\geq$ 0.01 g/m^2
- Dissolved aromatics: average over the water cell $\geq$ 1 ppb (1 mg/m^3)

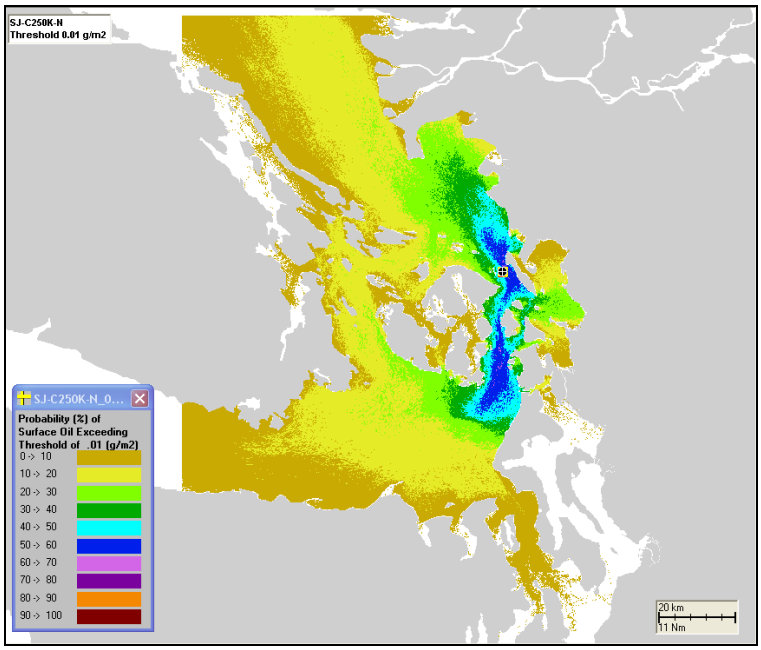

Figure XVI.B-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

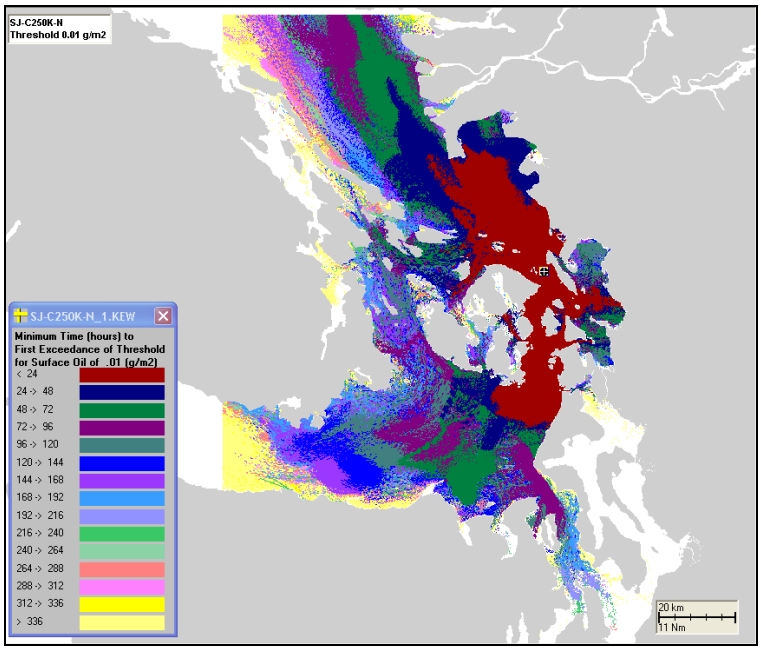

Figure XVI.B-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

For all 100 stochastic runs performed in the San Juan Islands, maximum water column exposure of dissolved aromatic concentration never exceeded 1 ppb. Consequently, maps of such exceedances are not shown here.

XVI.C. STATISTICS FOR ALL MODEL RUNS

The following impact indices are summarized below. The 50th and 95th percentile results were based on rank order distributions.

- Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 (which is sheen) and 10 g/m^2 times duration of exposure (in km^2-hrs);
- Water surface (km^2) exposed to hydrocarbons of various threshold thicknesses (>0.01, 1, 10, 100, and 1000 g/m^2);
- Water volume exposed to > 1 ppb (>1 mg/m^3) of dissolved aromatic concentration at some time after the spill;
- Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill;
- Percent of spilled hydrocarbon mass eventually going ashore;
- Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats); and
- Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill.

Table XVI.C-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Summary of on- and in-water exposure indices for 100 stochastic runs.

Exposure Index	Mean	Standard Deviation	Mean + 2(Std.Dev.)	Number of Zeros	50th Percentile	95th Percentile	Maximum
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2-hr)	324	392	1,109	0	226	987	3,108
Surface Oil Exposure Exceeding 10g/m^2 (km^2-hr)	291	379	1,048	0	197	922	2,991
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2) for all waters	28,373	28,028	84,430	0	21,304	84,249	203,932
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2) for all waters	28,363	28,025	84,412	0	21,303	84,242	203,930
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2) for all waters	28,053	27,995	84,044	0	21,133	83,883	203,869
Surface Oil Exposure Exceeding 10g/m^2 (km^2) for all waters	25,545	27,331	80,208	0	18,945	80,302	198,266
Surface Oil Exposure Exceeding 100g/m^2 (km^2) for all waters	11,388	8,010	27,408	0	9,199	30,153	48,677
Surface Oil Exposure Exceeding 1000g/m^2 (km^2) for all waters	4,872	1,831	8,535	0	4,622	7,564	12,626
Maximum Dissolved Aromatic Plume Volume Exceeding 1 ppb (m^3)	0	0	0	100	0	0	0
Average Dose of PAH's in Maximum Volume Exceeding 1 ppb (ppb-hrs)	0	0	0	100	0	0	0
Percent of Spilled Hydrocarbon Mass Coming Ashore (%)	26.01	6.64	39.28	0	26.13	38.67	41.29
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	14.8754	6.1649	27.2052	0	16.6349	23.2745	24.2881
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	1.10	1.58	4.27	0	0.61	2.96	14.70

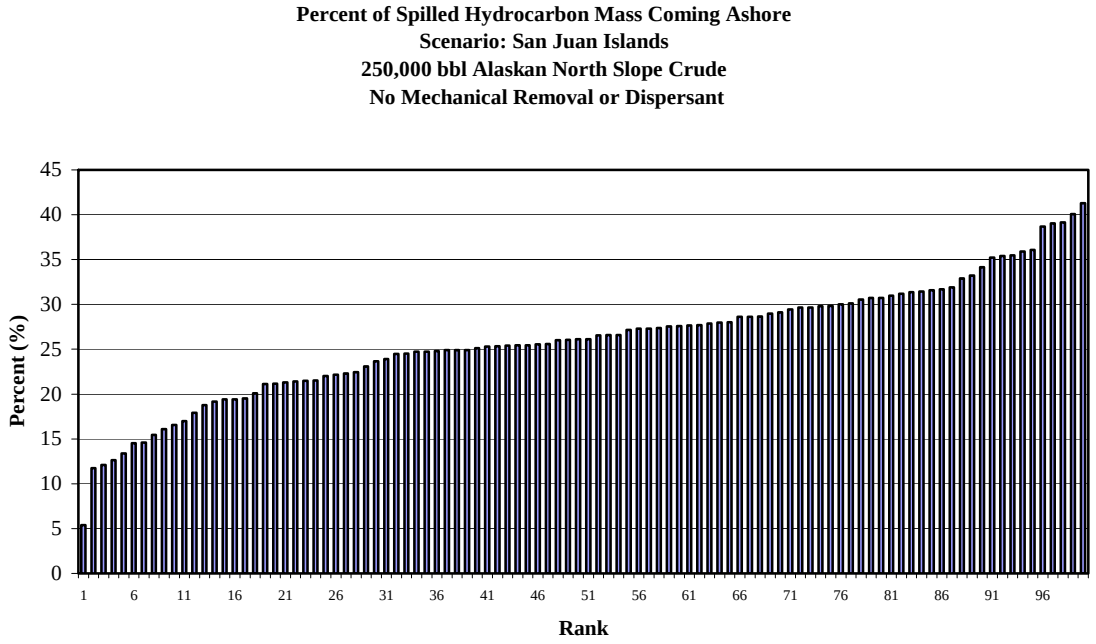

Figure XVI.C-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

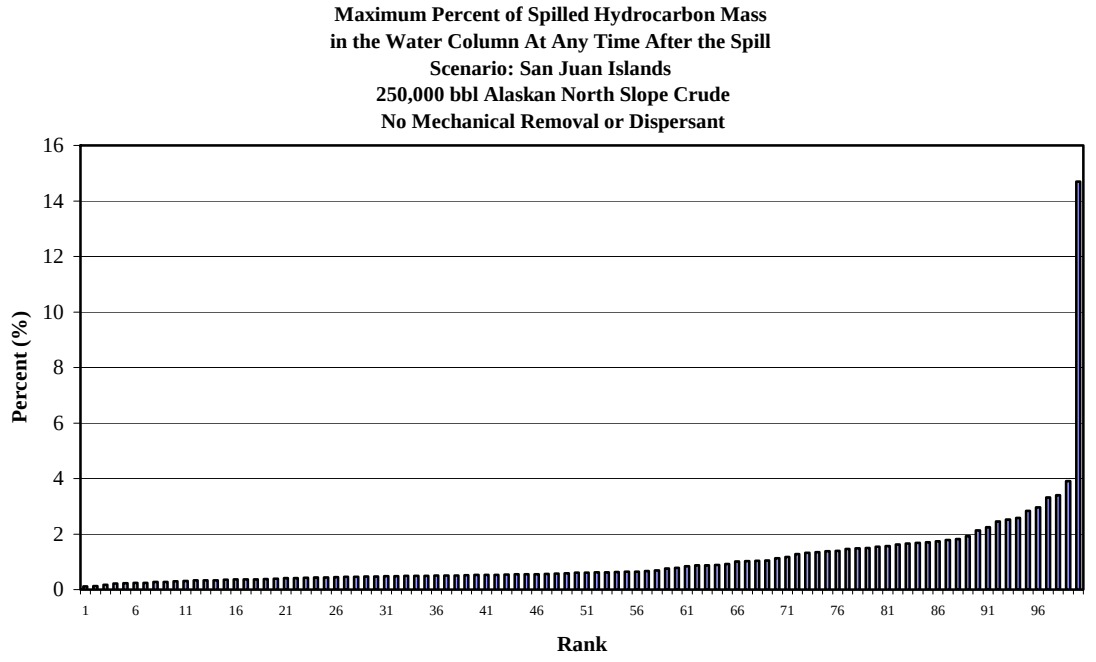

Figure XVI.C-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

XVI.D. SHORELINE AREAS EXPOSED BY SHORE TYPE

The tables in this section list the areas of shoreline oiled by shore type for the stochastic scenario involving no response. The 50th and 95th percentile results were based on rank order distributions by total shoreline oiled at the indicated threshold. Thus, the 50th and 95th percentile results shown in the tables below for each shore type correspond to the individual runs that resulted in the 50th and 95th percentile impacts in terms of *total* shoreline oiled. Inevitably, there are some events where a relatively small area of a particular type of shoreline was oiled even though the total area of shoreline oiling was large. In such cases, the area oiled by the 95th percentile run for a particular type of shoreline may be smaller than the area affected in the 50th percentile run.

Table XVI.D-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	3,937,165	280,756	164,733	120,403	0	3,371,273	0
95th	8,064,968	487,628	801,956	722,415	1,302,536	4,750,433	0
Maximum	10,176,034	1,100,063	1,454,503	1,108,251	3,332,963	8,236,643	12,040
Mean	4,177,770	368,734	511,834	481,883	984,181	1,830,831	306
Std. Dev.	1,912,175	261,742	274,660	241,570	828,442	1,676,151	1,429
Mean + 2 Std. Dev.	8,002,120	892,218	1,061,154	965,023	2,641,065	5,183,133	3,164

Table XVI.D-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	3,098,904	310,856	694,688	560,965	1,110,986	421,409	0
95th	5,899,563	911,246	481,429	484,345	0	4,022,543	0
Maximum	8,073,180	1,069,964	1,312,756	875,655	2,911,553	6,359,453	2,736
Mean	3,268,970	352,156	467,586	397,300	770,795	1,281,083	49
Std. Dev.	1,346,894	250,535	250,443	186,967	699,806	1,174,905	349
Mean + 2 Std. Dev.	5,962,758	853,226	968,472	771,234	2,170,407	3,630,893	747

Table XVI.D-3. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	2,203,378	790,290	272,001	221,650	38,310	881,127	0
95th	3,490,030	241,351	337,128	229,859	2,221,973	459,719	0
Maximum	4,316,432	1,001,005	975,628	569,174	2,221,973	3,218,033	0
Mean	2,225,535	302,183	383,624	263,627	543,617	732,485	0
Std. Dev.	750,703	215,078	195,360	117,399	540,295	602,549	0
Mean + 2 Std. Dev.	3,726,941	732,339	774,344	498,425	1,624,207	1,937,583	0

Table XVI.D-4. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick).

Statistic	Total All Shorelines (m^2)	Rocky shoreline (m^2)	Gravel beach (m^2)	Sand beach (m^2)	Mud flat (m^2)	Wetland (m^2)	Artificial shoreline (m^2)
50th	1,081,068	488,723	307,757	16,419	0	268,169	0
95th	1,559,393	360,111	123,869	2,736	0	1,072,677	0
Maximum	1,623,609	847,210	588,697	172,395	1,110,986	1,264,226	0
Mean	1,058,428	221,283	255,272	44,768	232,158	304,947	0
Std. Dev.	271,109	154,414	127,053	50,396	265,408	296,443	0
Mean + 2 Std. Dev.	1,600,646	530,111	509,378	145,560	762,974	897,833	0

XVI.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

To examine alternate response scenarios, six representative runs were selected from the 100 stochastic runs involving no response and rerun with each set of response assumptions. The geographic data, current data, and model inputs are the same for each of the alternate response scenarios as was used for the no response runs. The representative runs were selected on this basis:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Lopez Island;
3. the worst case run for impacts at Orcas Island;
4. the 50th percentile run based on shoreline oiling and area-based costs for cleanup;
5. the worst case run for impacts at Lummi Island, and
6. the worst case run for impacts at Padilla Bay.

In this section, the oil movements for the representative runs are shown, as plots of water surface exposed to floating hydrocarbons (g/m^2) at any time after the spill. Thus, these are cumulative plots of the oil trajectory and amount of exposure. For the scenarios considered here, dissolved aromatic concentrations never exceeded 1 ppb at any time after a spill. Consequently, plots of maximum water column exposure to dissolved aromatic concentrations are not displayed here.

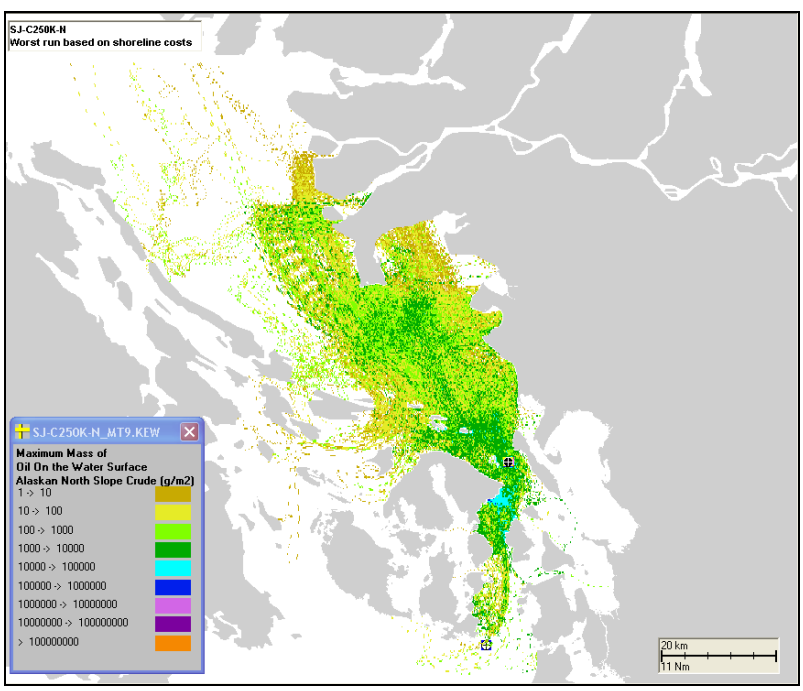

Figure XVI.E-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

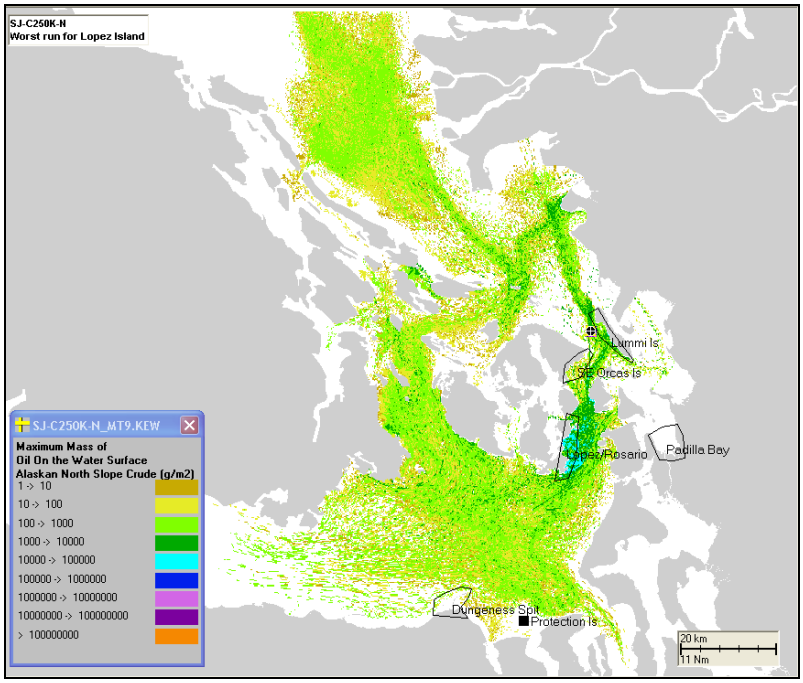

Figure XVI.E-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Lopez Island.

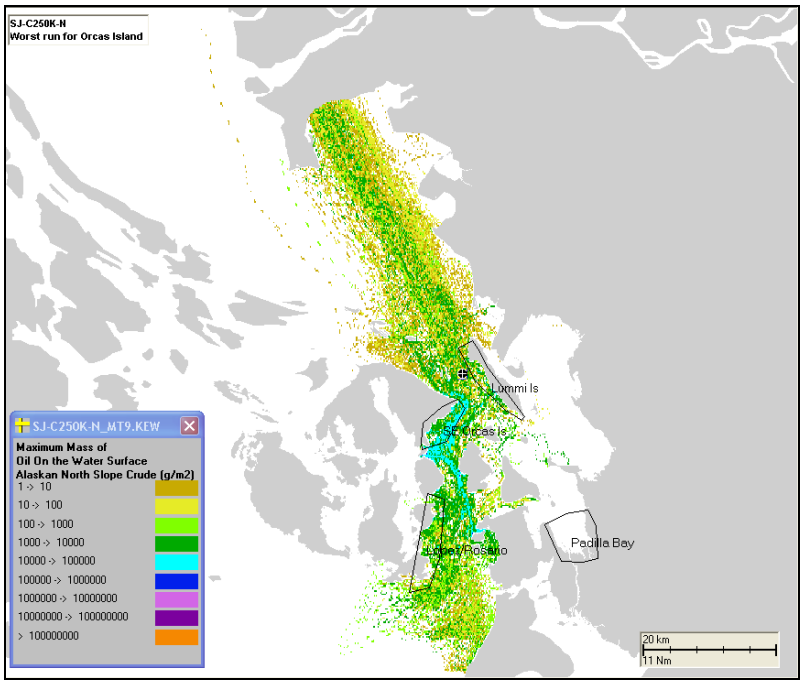

Figure XVI.E-3. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Orcas Island.

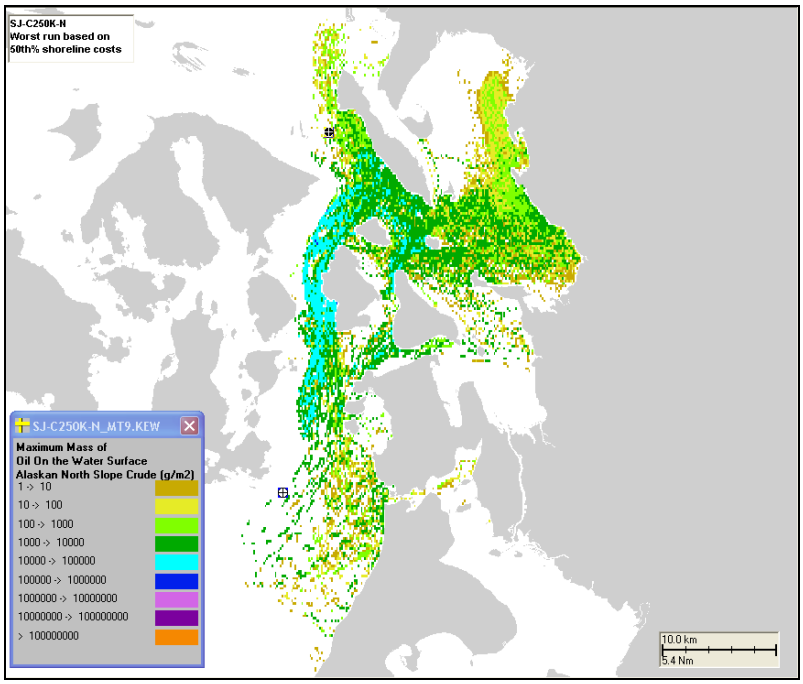

Figure XVI.E-4. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

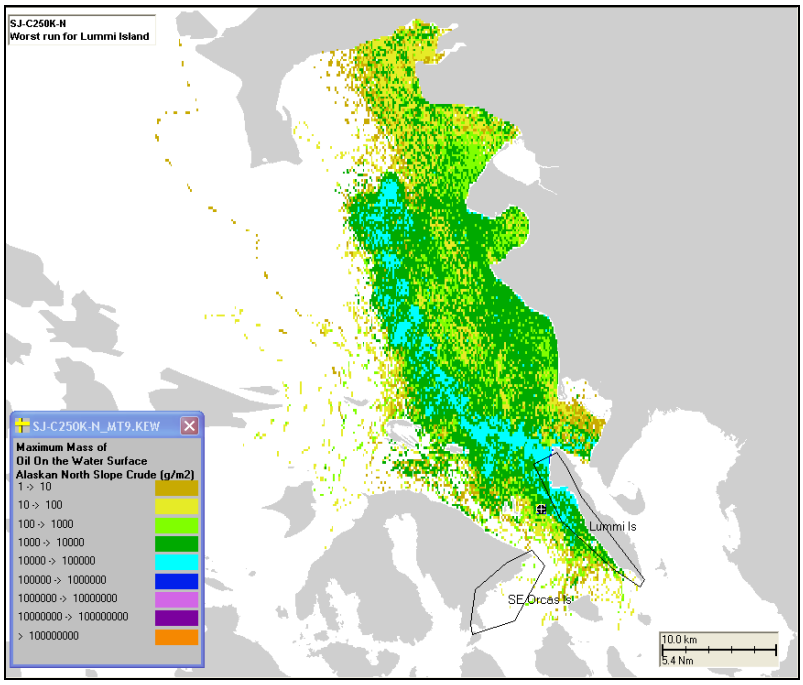

Figure XVI.E-5. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Lummi Island.

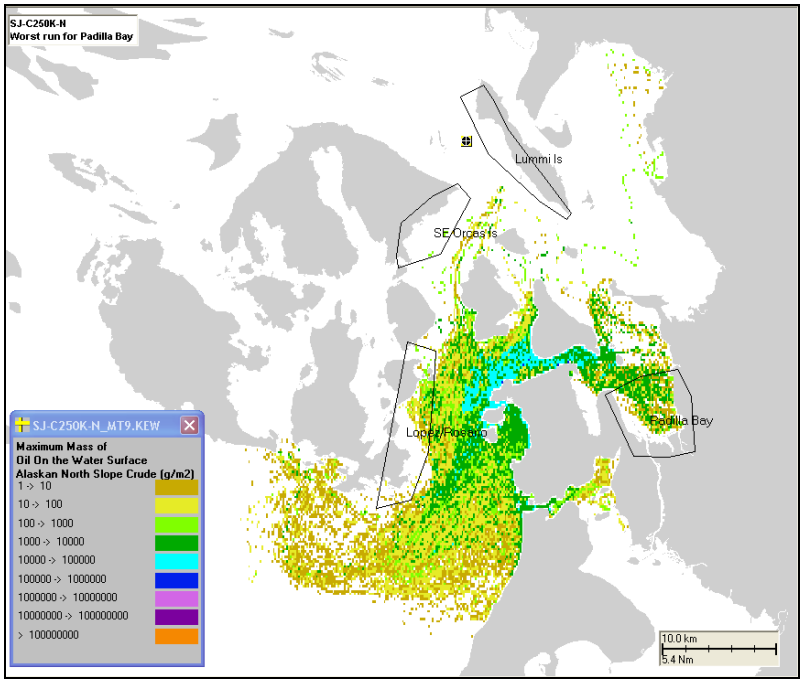

Figure XVI.E-6. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Padilla Bay.

XVI.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the biological effects model for the following 12 runs selected from the stochastic model results (assuming no response).

- 5th, 50th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions;
- 5th, 50th and 95th percentile runs based on shore cost, including only Washington state shorelines;
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (TableXVI.F-1), were used to estimate wildlife impacts for the other 88 runs in the stochastic scenario.

The wildlife impacts for all 100 runs were estimated from the habitat area occupied by the species group that was oiled, i.e., areas of water swept by oil $> 10 g/m^2$ and shoreline oiled by $>100 g/m^2$, using the methods described in Section 2.3 of Volume I. The 100 estimates of wildlife impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the wildlife group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Table XVI.F-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Results of the linear regression of wildlife killed (kg) versus the area oiled above the threshold for a lethal dose.

Wildlife Injuries (kg)	Slope[1]	Intercept	Standard Error	R^2	Correlation Coefficient (R)
Waterfowl	2.04E-05	27,455.99	22,229.16	0.2676	0.5173
Seabirds	6.22E-06	10,149.46	6,452.79	0.2878	0.5364
Wading birds	1.49E-05	100.67	104.49	0.0135	0.1164
Shorebirds	-2.05E-04	844.40	386.25	0.1600	-0.4000
Raptors	1.55E-07	12.25	5.76	0.0058	0.0761
Kingfishers[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Cetaceans	1.67E-08	24.84	22.23	0.1972	0.4441
Pinnipeds (seals)	3.74E-07	739.84	662.04	0.1219	0.3491
Other mammals[2]	0.00E+00	0.00	0.00	0.0000	0.0000

[1] For regressions in which the slope was not significantly different from zero, the mean weight of injured wildlife (i.e., the regression's intercept) was used to estimate wildlife impacts for the additional 88 stochastic runs.
[2] Results of these regressions reflect the fact that no injuries were sustained for these wildlife species.

Table XVI.F-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Cetaceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile	44,504	13,068	89	5,629	2	0	6	-	63,983	63,977	6.01
50th Percentile	62,771	13,663	106	6,740	3	0	7	-	83,483	83,475	7.46
95th Percentile	116,619	15,420	124	7,856	3	0	12	-	139,410	139,398	11.74
Mean	72,525	13,982	107	6,767	3	0	8	-	93,392	93,384	8.24
Std Dev (SD)	26,956	879	10	666	0	0	2	-	28,124	28,122	2.14
Mean - 2SD	18,614	12,223	86	5,436	2	0	4	-	37,144	37,140	3.95
Mean + 2SD	126,437	15,740	128	8,099	4	0	12	-	149,640	149,627	12.52

XVI.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table XVI.G-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Results of the linear regression of fishes and invertebrates killed (kg) versus the percentage of spilled oil in the water column.

Fish and Invertebrate Injuries (kg)	Slope[1]	Intercept	Standard Error	R^2	Correlation Coefficient (R)
Total small pelagic fish	2.07E+03	-588.04	2,035.02	0.3321	0.5763
Total large pelagic fish	3.79E+03	-928.53	3,963.09	0.3042	0.5516
Total demersal fish	6.09E+01	14.49	167.37	0.0596	0.2441
Total demersal invertebrates	1.94E+01	-1.40	46.61	0.0769	0.2773
Total mollusks	1.28E+02	1,629.14	2,114.08	0.0018	0.0419

[1] For regressions in which the slope was not significantly different from zero, the mean weight of injured fishes and invertebrates (i.e., the regression's intercept) was used to estimate injuries for the additional 88 stochastic runs.

Table XVI.G-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile	-	-	29.21	3.30	1,660.11	117,942	119,634
50th Percentile	677.34	1,382.43	51.64	10.47	1,707.31	287,366	291,195
95th Percentile	5,308.17	9,839.72	187.62	53.89	1,993.36	528,744	546,127
Mean	1,698.87	3,237.66	81.25	19.92	1,769.58	305,639	312,446
Std Dev (SD)	3,277.50	5,991.23	96.46	30.80	202.92	130,644	140,243
Mean - 2SD	-	-	-	-	1,363.75	44,351	45,715
Mean + 2SD	8,253.86	15,220.13	274.16	81.53	2,175.42	566,926	592,932

XVI.H. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All injuries used to calculate habitat restoration costs are expressed as wet weight; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

The NRDA costs for all 100 runs were estimated from the wildlife, fish and invertebrate impact estimates for each run. The 100 estimates were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Table XVI.H-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	677.3	5,308.2	1,698.9	-	8,253.9
Large pelagic fish	-	1,382.4	9,839.7	3,237.7	-	15,220.1
Demersal fish	29.2	51.6	187.6	81.2	-	274.2
Decapods	3.3	10.5	53.9	19.9	-	81.5
Molluscs	119,602	289,074	530,738	307,408	45,715	569,102
Birds:						
Waterfowl (# * kg each)	29,224	41,220	76,580	47,625	12,223	83,027
Seabirds (# * kg each)	15,191	15,884	17,926	16,254	14,209	18,298
Waders (# * kg each)	103	124	144	124	100	148
Shorebirds (# * kg each)	6,543	7,835	9,132	7,867	6,319	9,415
Raptors (# * kg each)	2.9	3.0	3.7	3.1	2.0	4.2
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	7.0	8.6	13.6	9.5	4.6	14.5
Cetaceans	0.0	0.0	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	119,634	291,195	546,127	312,446	45,715	592,932
Subtotal birds	51,065	65,065	103,785	71,873	32,853	110,892
Subtotal other wildlife	7	9	14	10	5	15
Total all species	170,706	356,269	649,926	384,328	78,573	703,838

Table XVI.H-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Percentile	50th Percentile	95th Percentile	Mean	Standard deviation (SD)	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	150.3	195.4	307.6	213.4	62.9	114.5	339.3
Saltmarsh Area (acres)	371.3	482.8	760.0	527.2	155.5	282.8	838.3
Saltmarsh Cost (millions of 2004$)	69.6	90.5	142.4	98.8	29.1	53.0	157.1
Eelgrass Area (m^2)	93.9	122.1	192.2	133.3	39.3	71.5	212.0
Eelgrass Area (acres)	232.0	301.7	474.9	329.5	97.2	176.7	523.8
Eelgrass Cost (millions of 2004$)	27.7	36.0	56.7	39.3	11.6	21.1	62.5

XVI.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table XVI.I-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	21.74	23.67	25.58	23.71	20.41	27.00
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	228	249	269	249	214	284

Phase II: Final Report

Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters

Volume XVII: Results of Alternative Response Scenarios for San Juan Islands – Alaskan North Slope Crude

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XVII.A. INTRODUCTION

The results of the alternate response scenarios for the San Juan Islands – Alaskan North Slope Crude spills are contained in this volume. There were four response scenarios for this location, oil type and spill volume:

1. No mechanical removal and no booming (i.e., no response);
2. Mechanical removal under US federal Caps standards, with booming as per the Regional Response Plan;
3. Mechanical removal under Washington state Caps standards, with booming as per the Regional Response Plan; and
4. Mechanical removal under a third alternative and higher standard, with booming as per the Regional Response Plan.

The geographic data, current data, and model inputs are the same for each of the alternate response scenarios as was used for the no response runs. For the alternate response scenarios, the following six representative runs were selected from the 100 stochastic runs and rerun with each set of response assumptions:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Lopez Island;
3. the worst case run for impacts at Orcas Island;
4. the 50th percentile run based on shoreline oiling and area-based costs for cleanup;
5. the worst case run for impacts at Lummi Island; and
6. the worst case run for impacts at Padilla Bay.

Locations of the sensitive sites are shown in Figure XVII.A-1.

The tables in this volume summarize the model results for the alternate response scenarios, as well as corresponding runs (of the same start date and time) from the no response stochastic scenario. The stochastic scenario assuming no response was used to identify the run dates and times for the representative runs. The 100 main stochastic scenario runs of the base case scenario were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are listed here) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to shoreline oiling. However, certain impacts, such as to waterfowl and seabirds, are more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) are related to water contaminated above a threshold for effects. Intertidal zone impacts to clams are related to the degree of soft (sand, mud, or wetland) shoreline oiling. The water surface oiled and water volumes contaminated are usually not correlated with shoreline oiling.

In the tables, the results as oil fate over time; wildlife, fish and invertebrate impacts; and the NRDA costs (damages) for the individual representative runs are presented. The

same representative runs were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made.

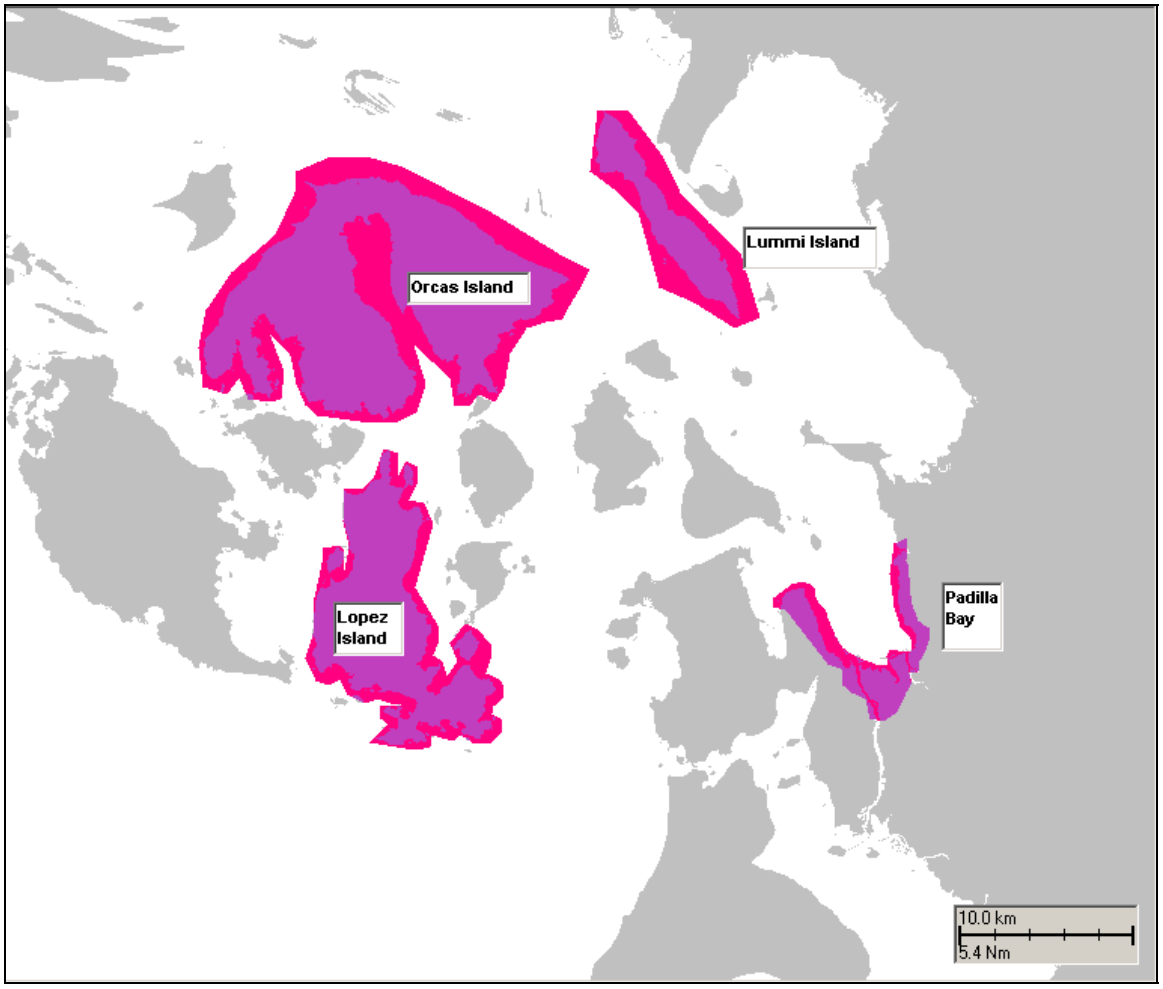
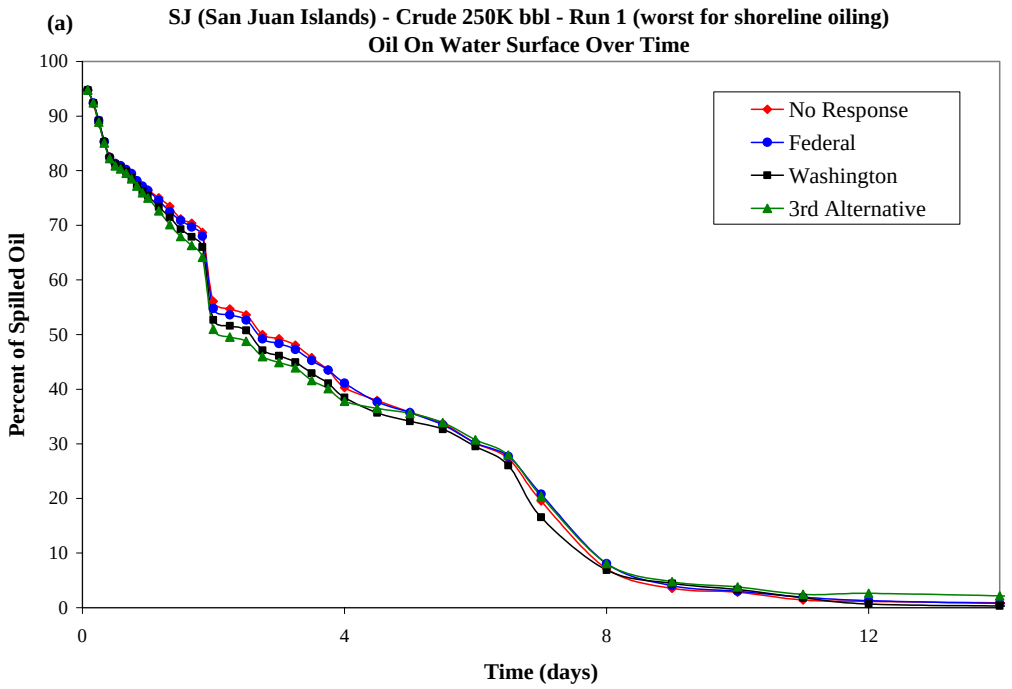


Figure XVII.A-1 Sensitive sites for location: San Juan Islands.

XVII.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables XVII.B-1 to XVII.B-24 list the mass balance of oil as a function of time. The oil on the water surface is floating oil (thick, sheen or tar balls) within the model grid. The percent "out of grid" is floating oil that has been transported out of the model grid. The sum of these (right-most column) is the total amount of oil floating at a given time. Oil in the water column is either entrained oil droplets or dissolved. Percent in the sediment represents oil in subtidal sediments, while percent on shore is oil in intertidal sediments on the shorelines. The percent decayed is by natural degradation. The percent removed is by mechanical removal during the response to the spill. Figures XVII.B-1 to XVII.B-22 summarize the results, showing comparisons of the alternative responses for each of the individual runs. Note that for the worst run to each critical site, the figures showing the *percentage* of oil on the shoreline display information on oil hitting *all* coastal areas, while the figures showing the *amount* of oil on the shoreline include only oil coming ashore within the critical site.

Tables XVII.B-25 to XVII.B-28 summarize the water surface area exposed to oil at some time after the spill (i.e., cumulative total area) and the shoreline oiled to varying degrees at any time after the spill (i.e., areas above thresholds using the maximum amount of oil on shore at any time). These tables also include the per-unit-area component of shoreline cleanup costs. The total shoreline cleanup and other response costs are described in Etkin (2005b,c) and French-McCay (2005). Note that the variability in these results is due to randomized variations (simulating natural variability and turbulence) included in the model and variations in the exact time and locations oil reaches shorelines due to differences in response timing and equipment used. The variability is greater than the signal related to response alternatives in many cases.



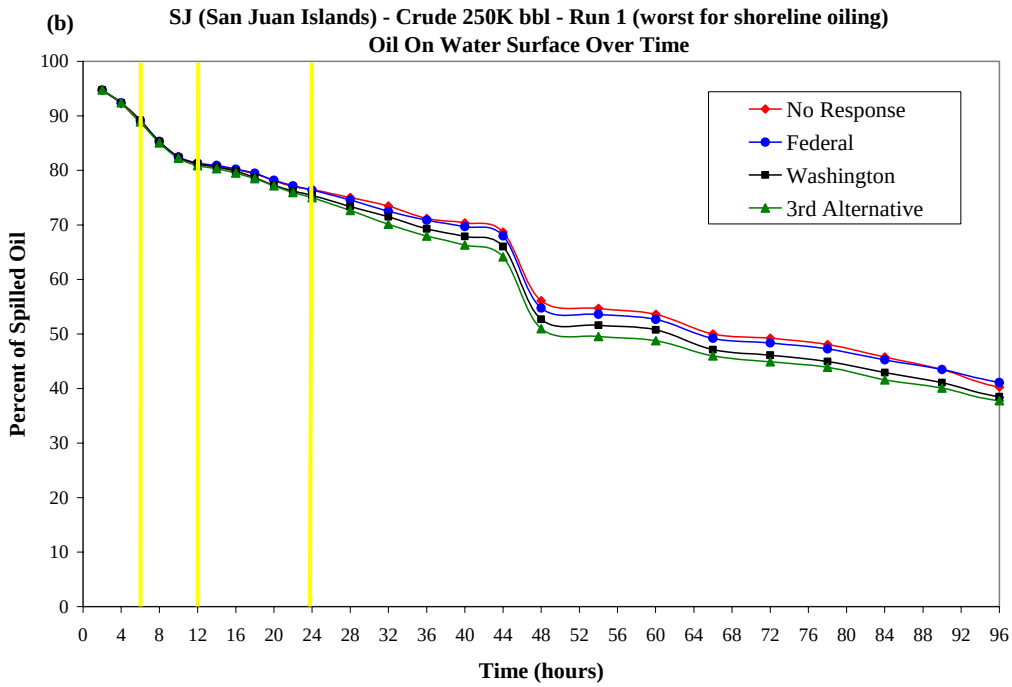
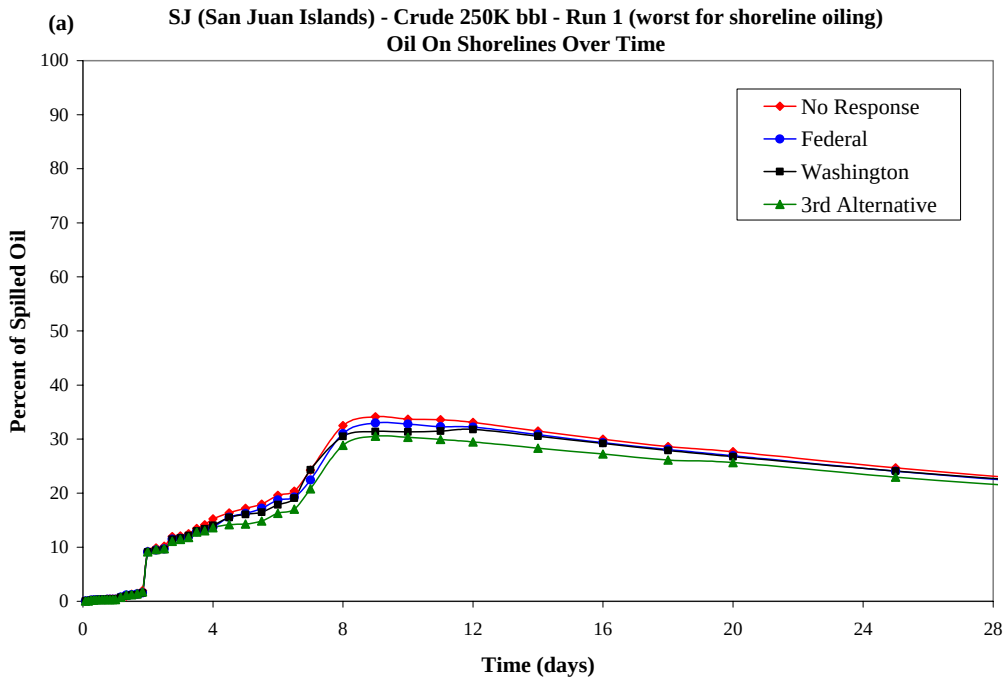


Figure XVII.B-1 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



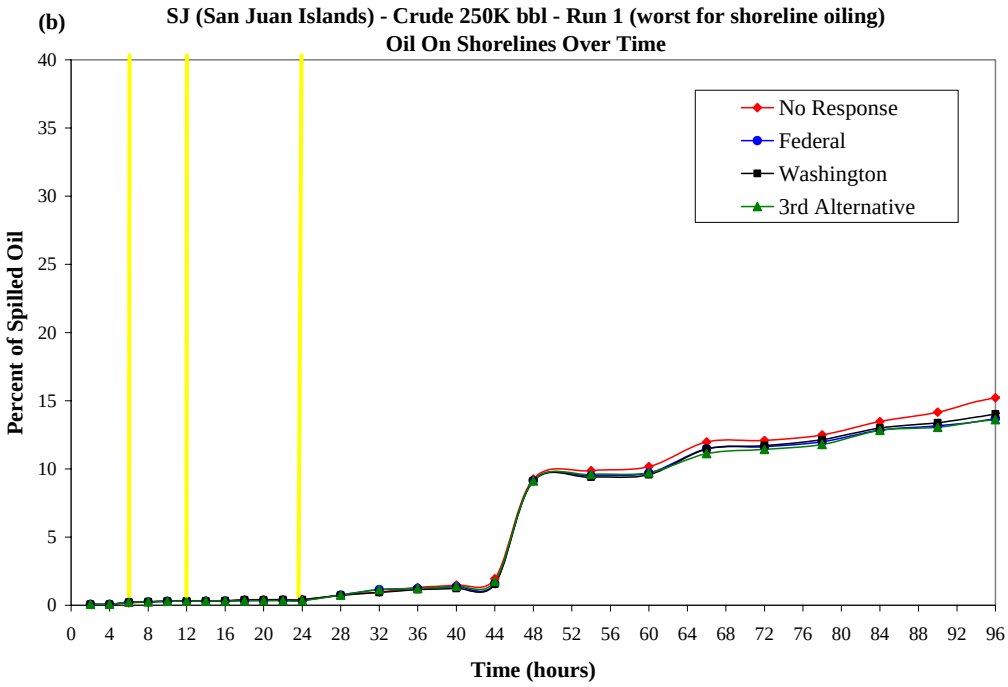


Figure XVII.B-2 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

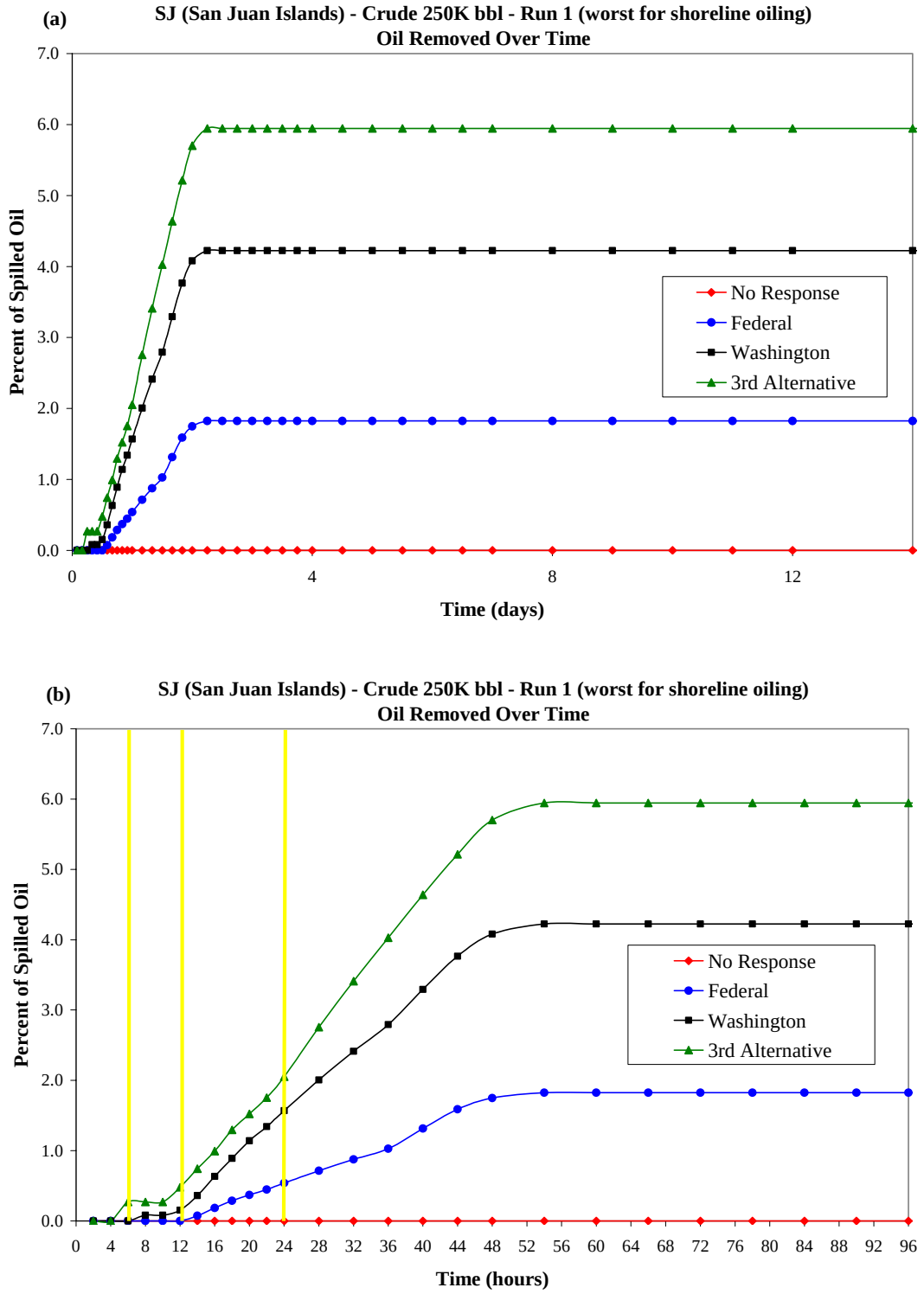
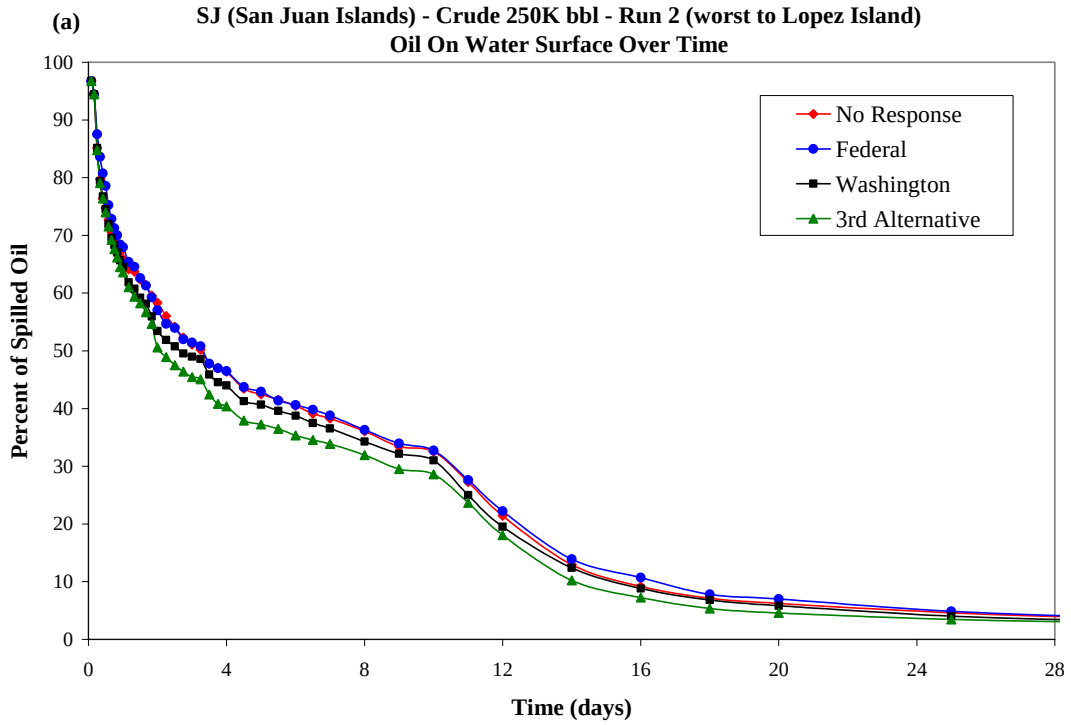


Figure XVII.B-3 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



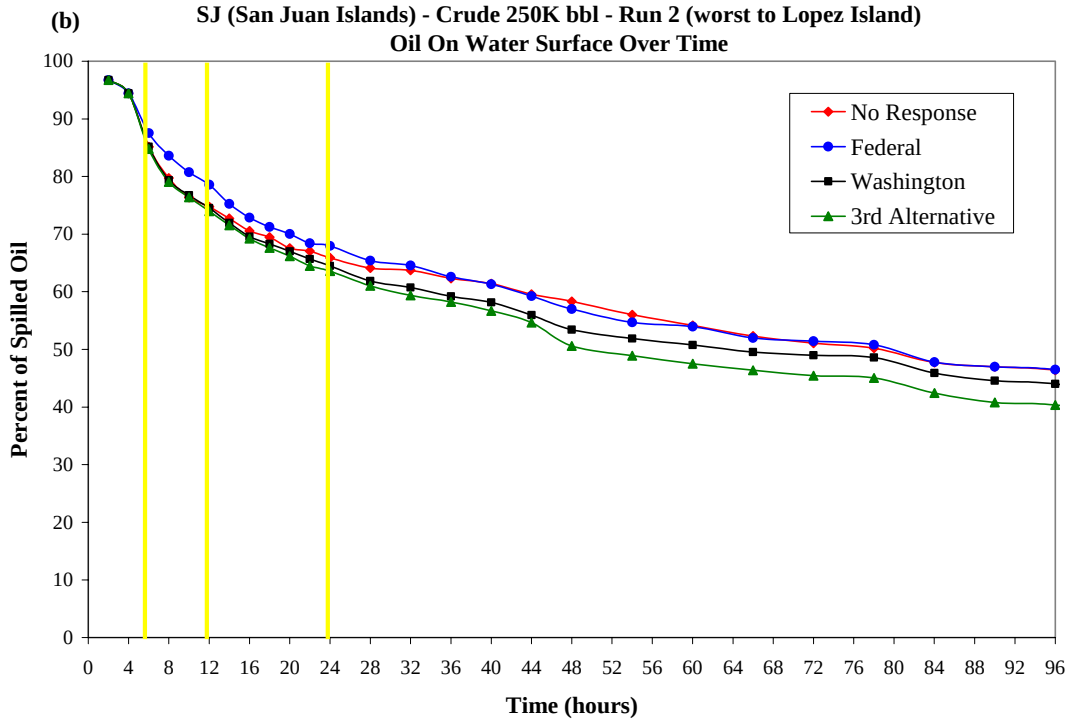
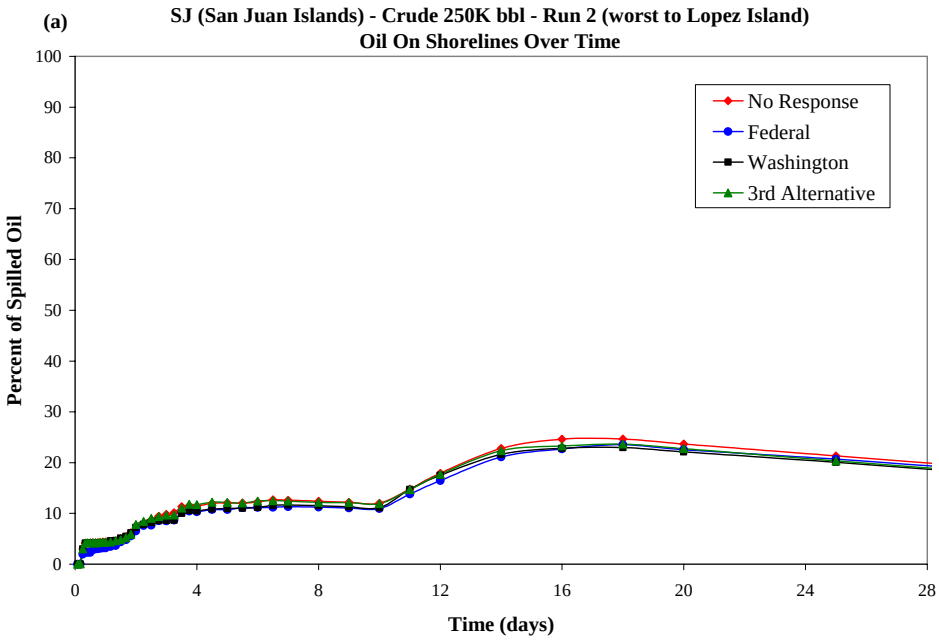


Figure XVII.B-4 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



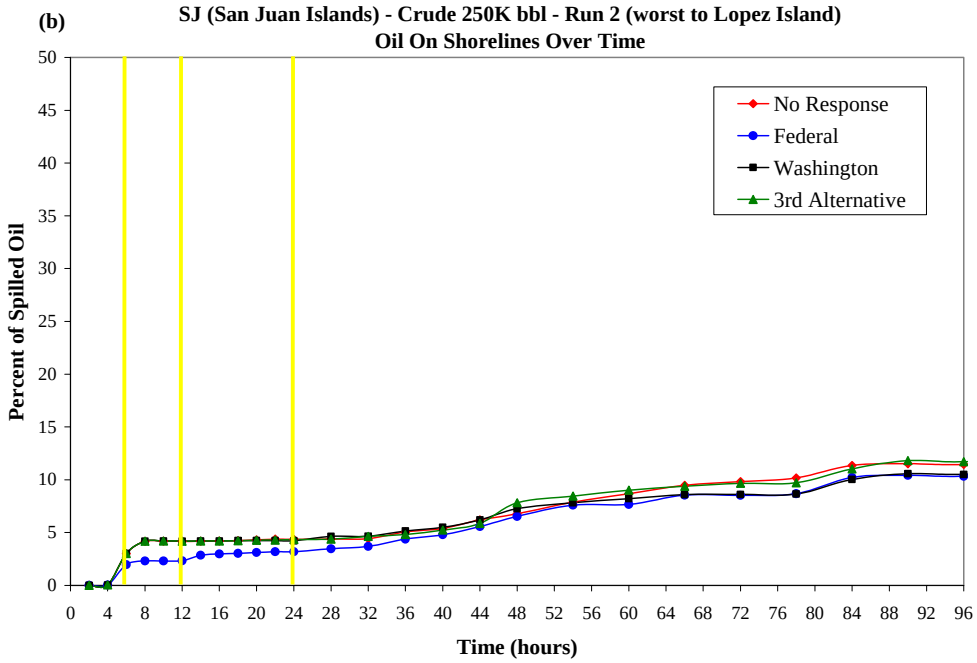
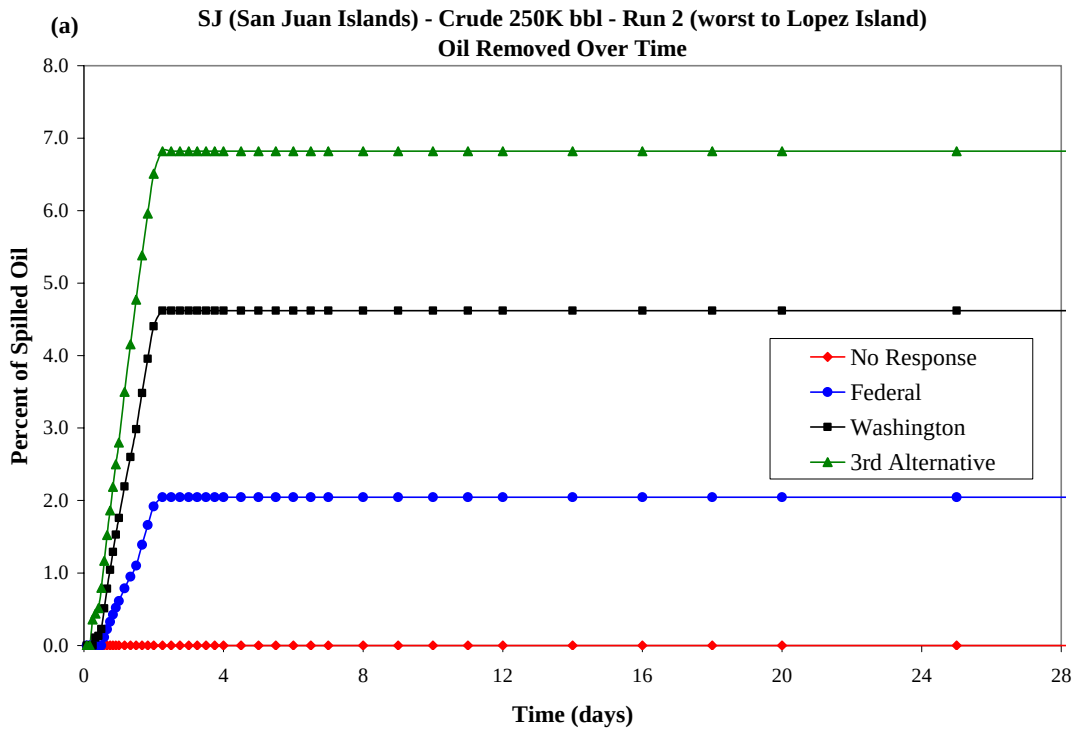


Figure XVII.B-5 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



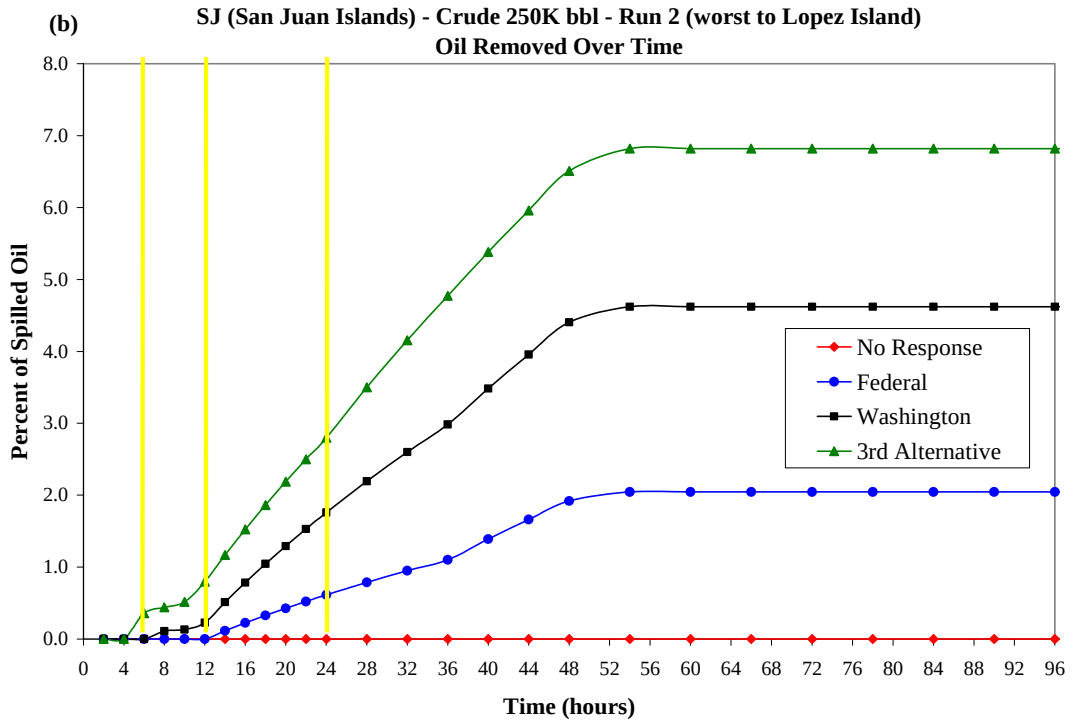
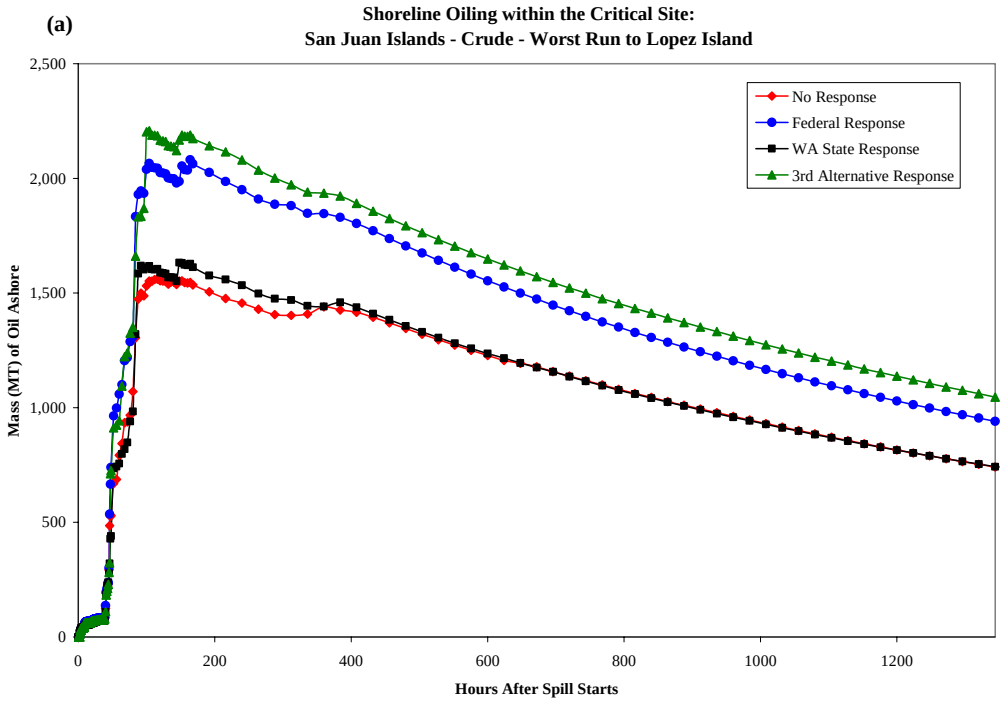


Figure XVII.B-6 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a.



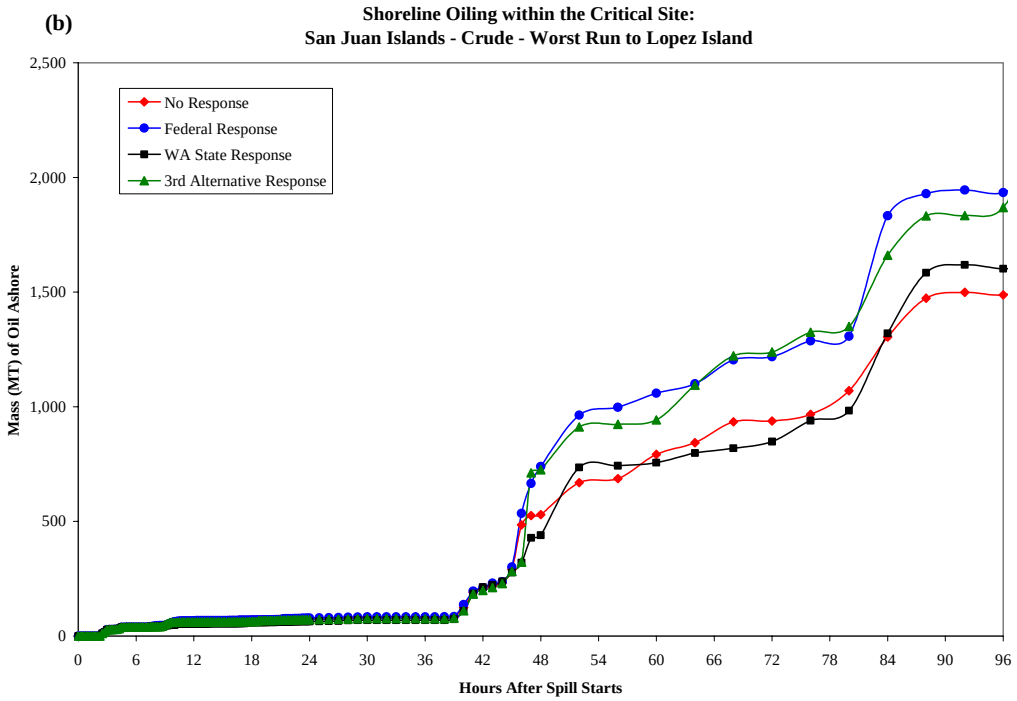
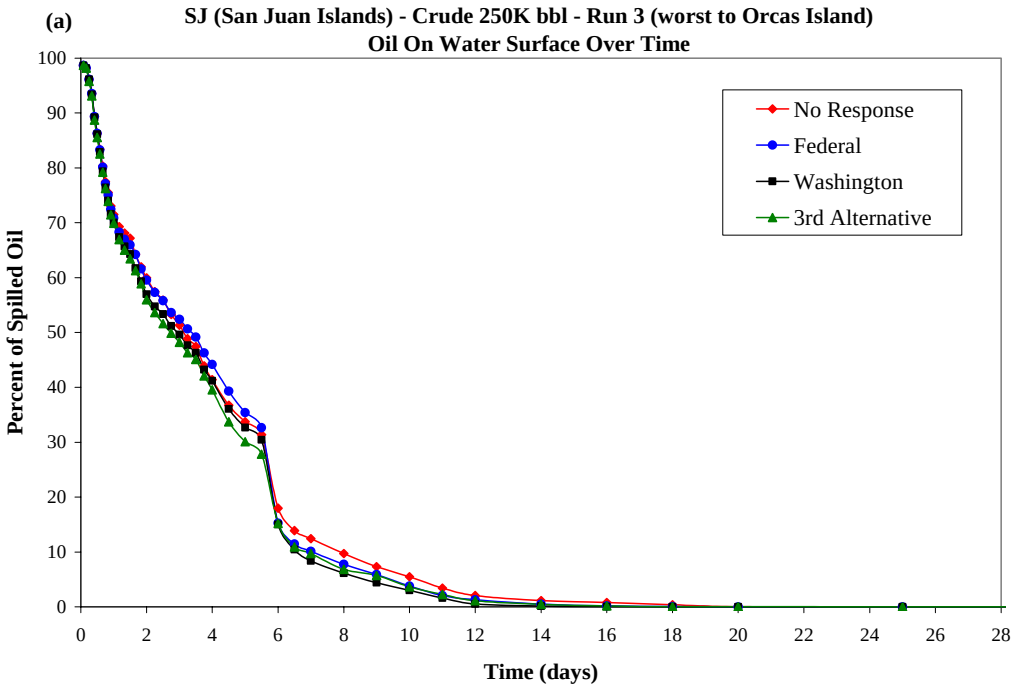


Figure XVII.B-7 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



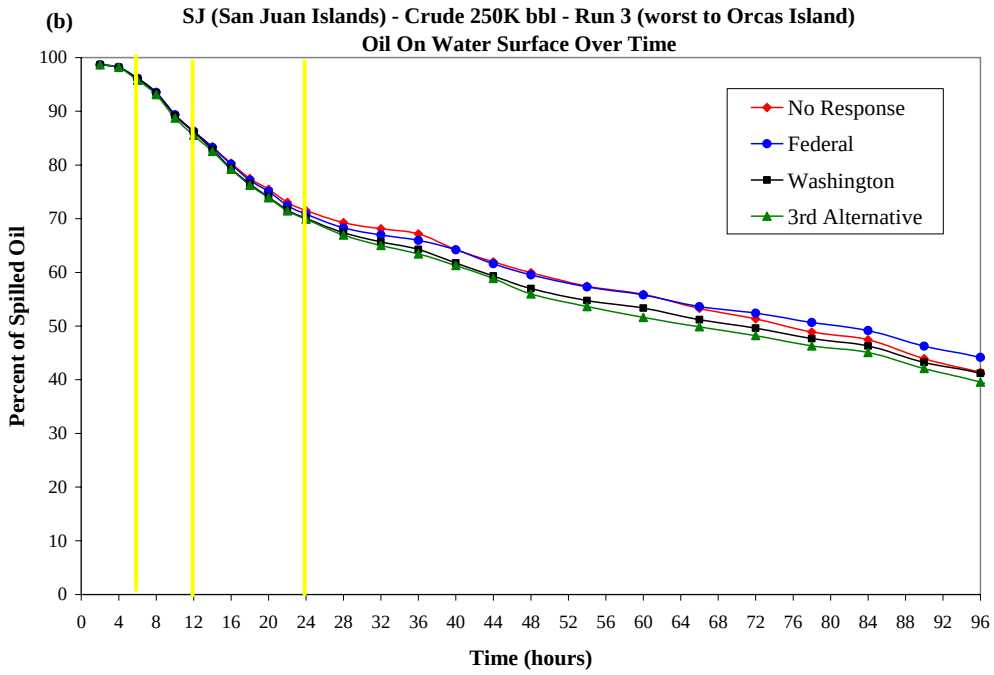
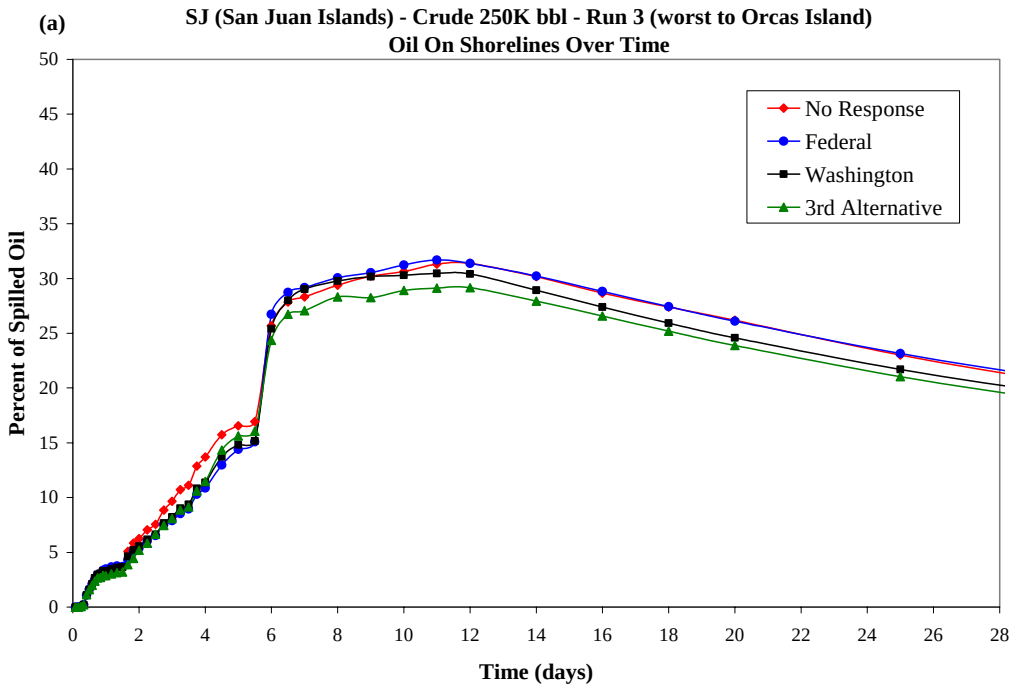


Figure XVII.B-8 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Orcas Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



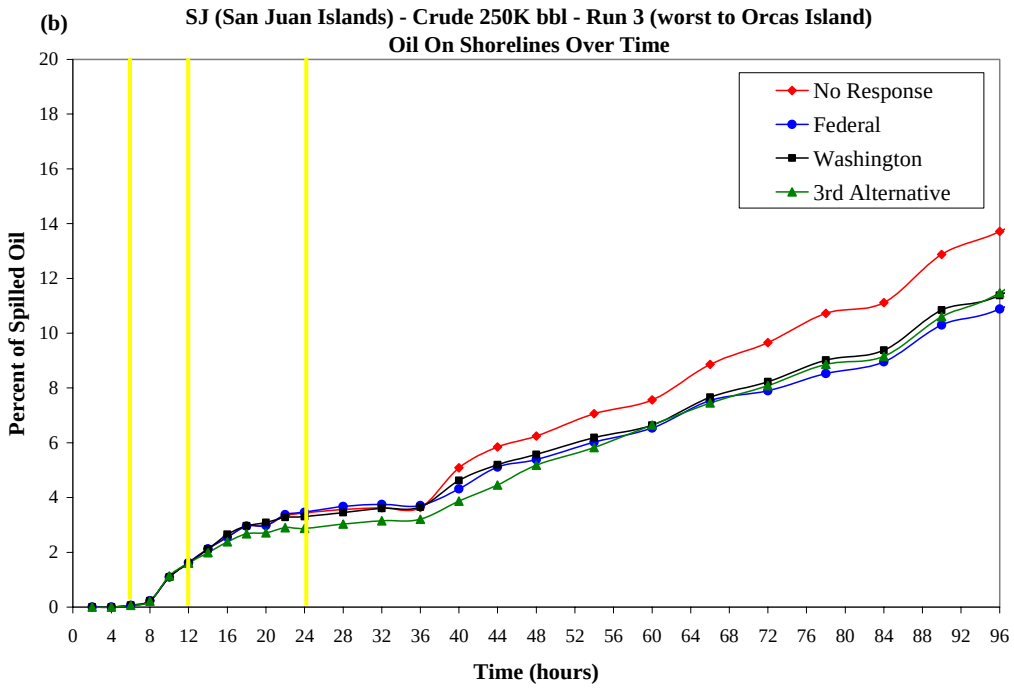


Figure XVII.B-9 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Orcas Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

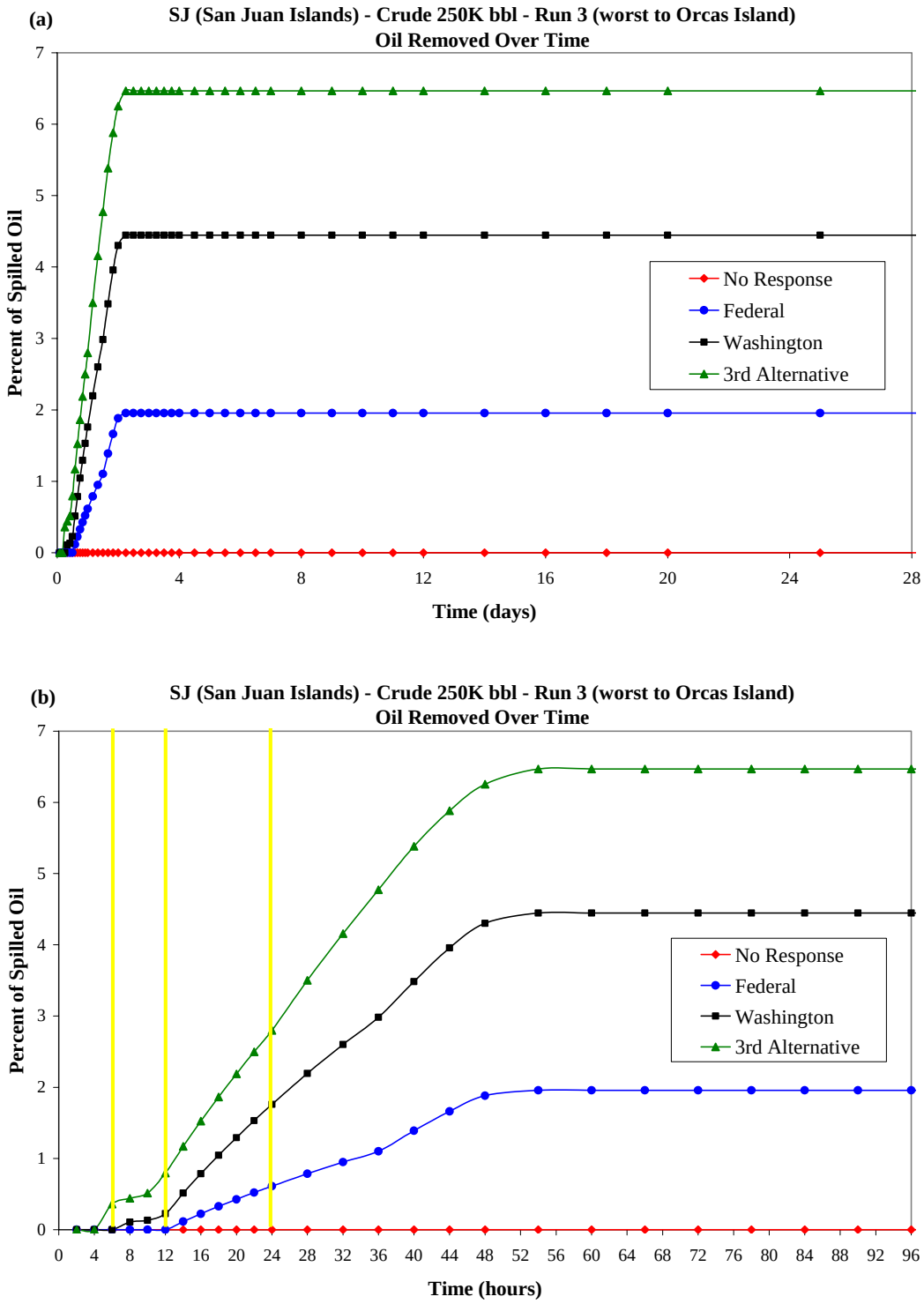
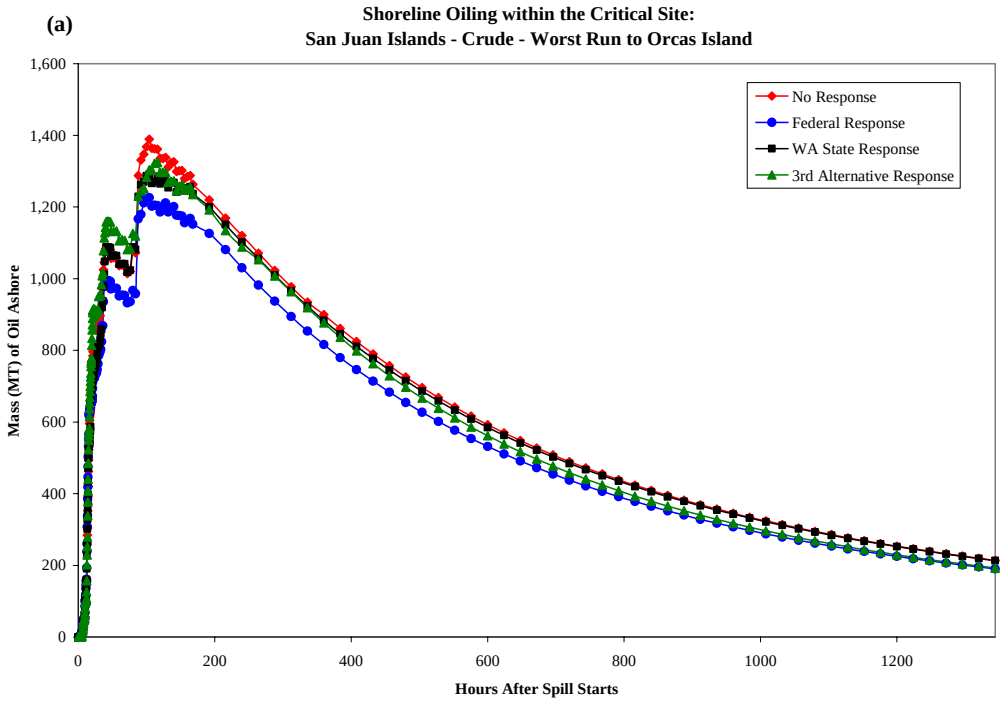


Figure XVII.B-10 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Orcas Island. Part b of this figure is a subset of Part a.



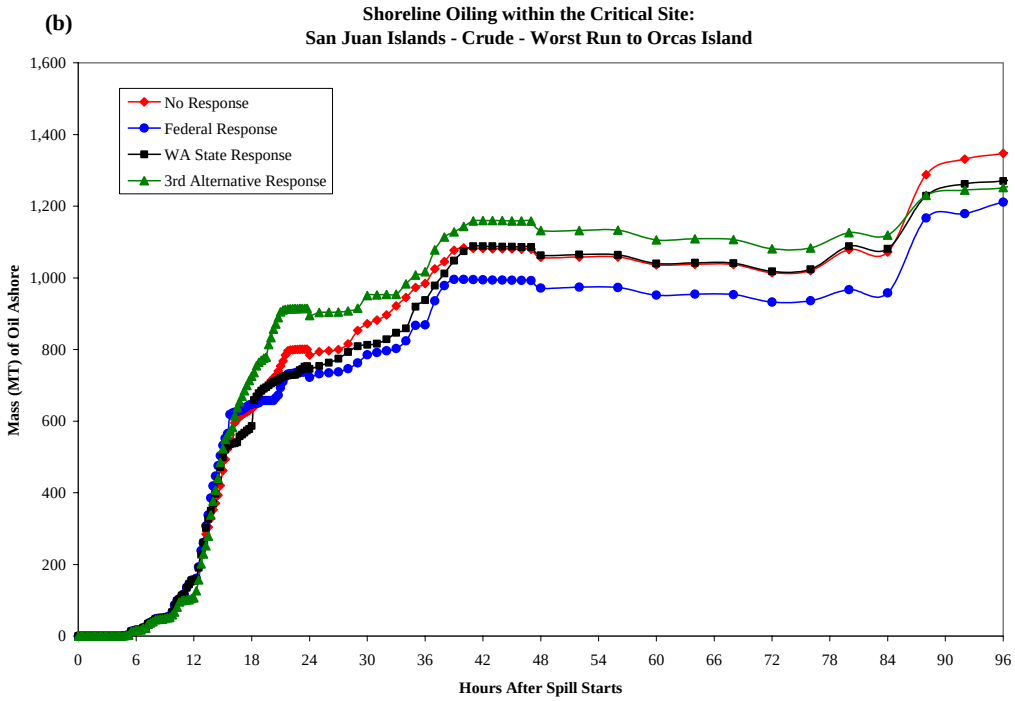
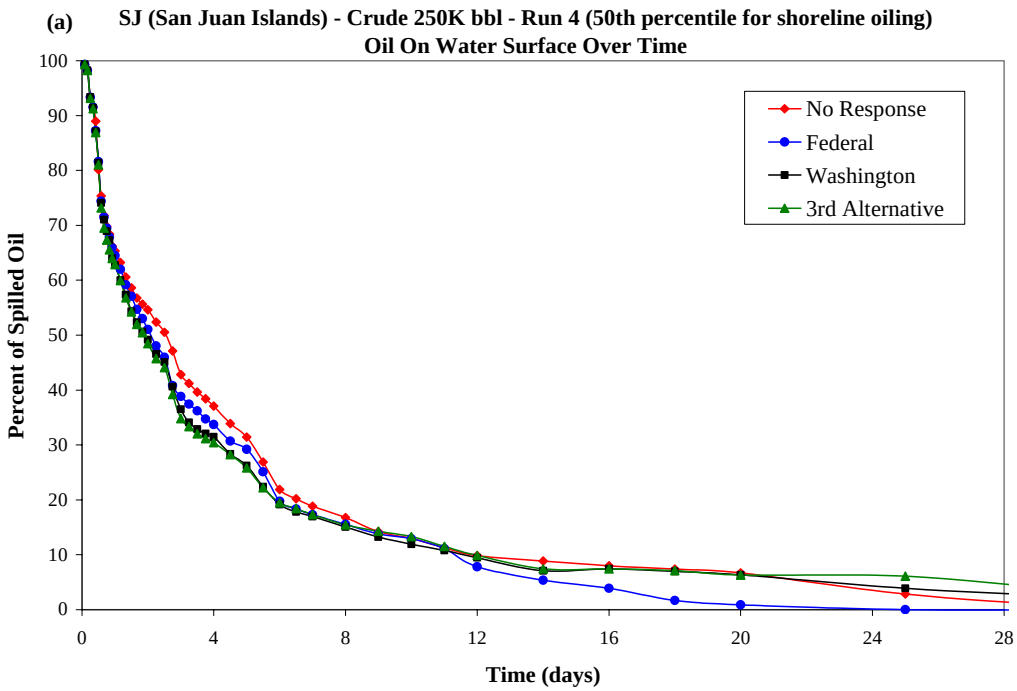


Figure XVII.B-11 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Orcas Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



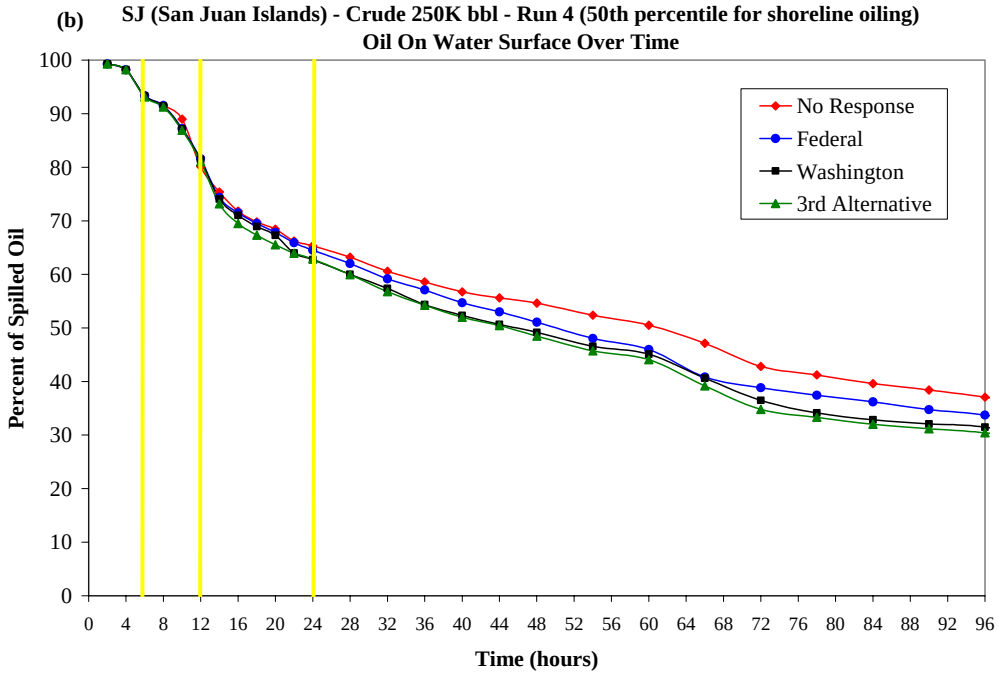


Figure XVII.B-12 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 50th percentile run (based on shore cost). Part b a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

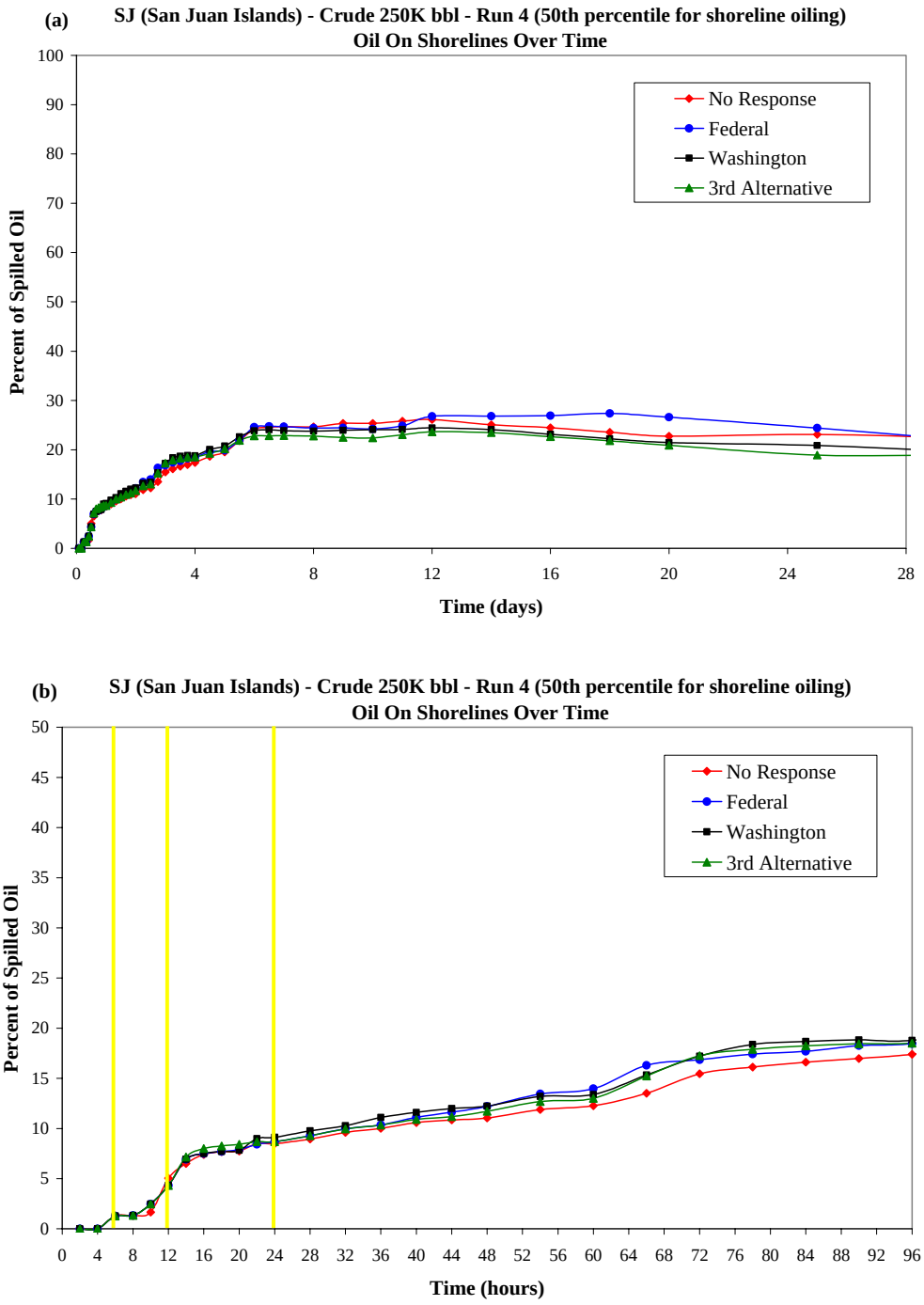


Figure XVII.B-13 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 50th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

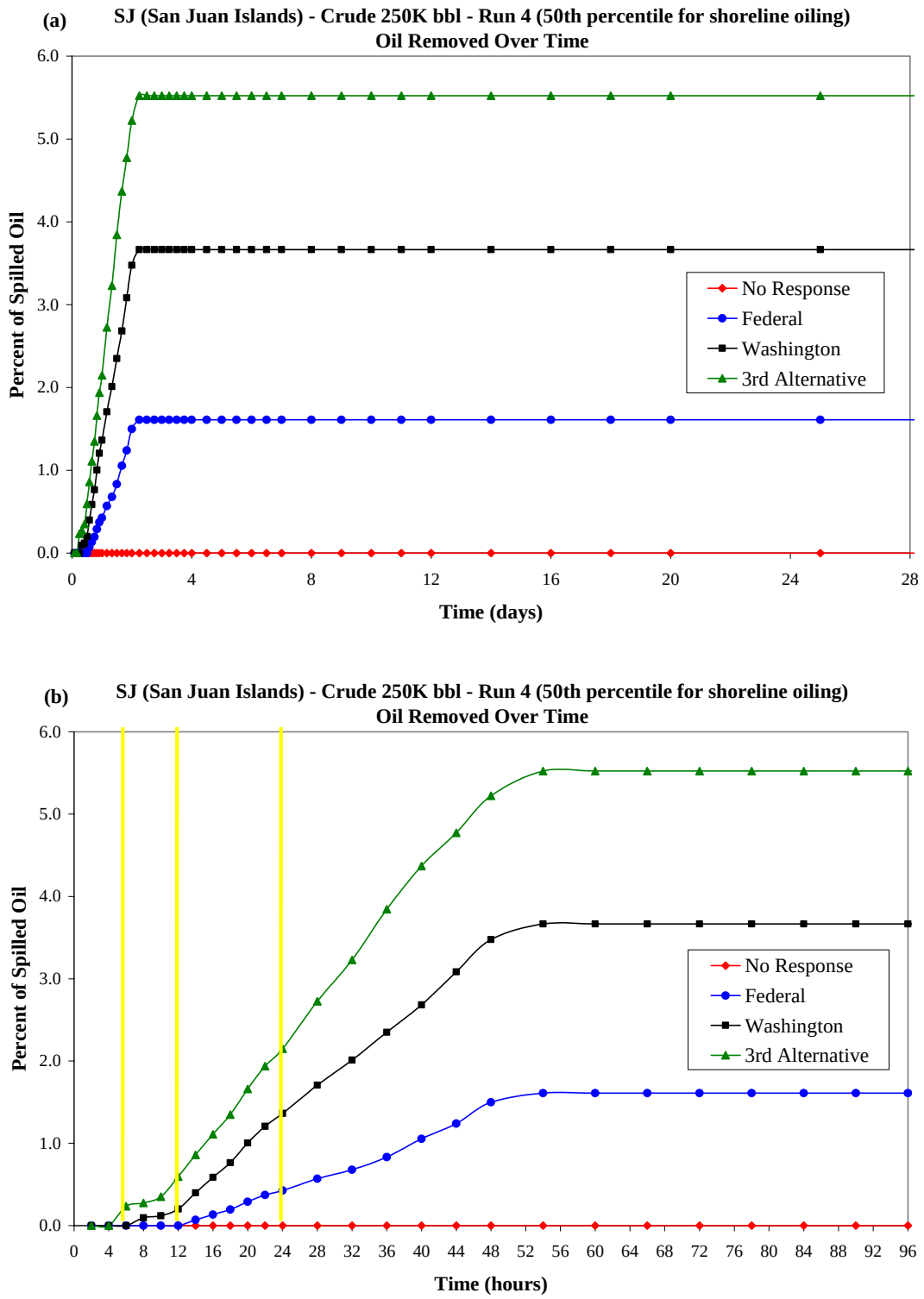
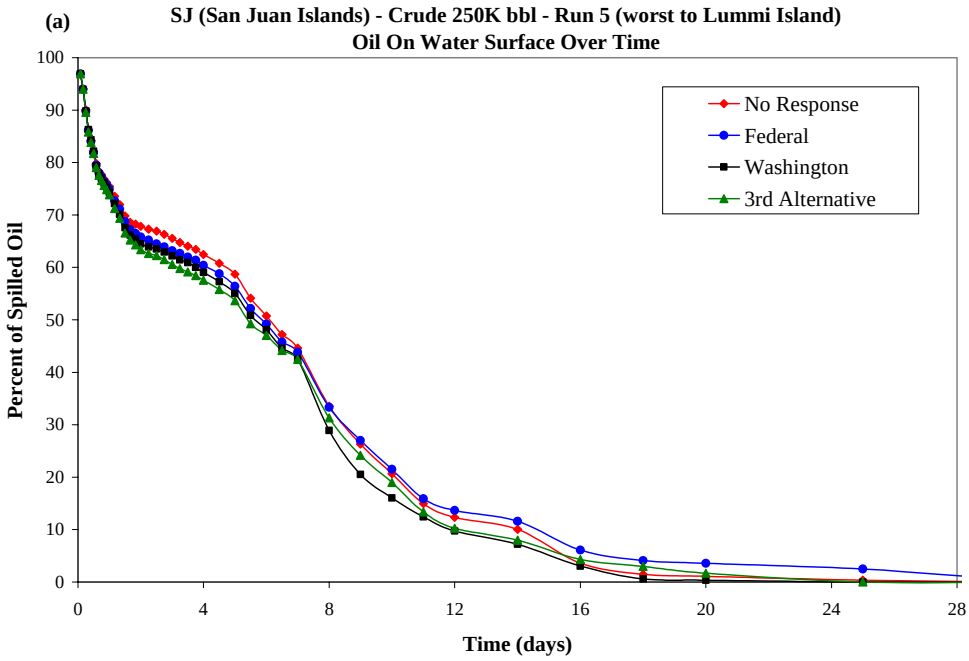


Figure XVII.B-14 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 50th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



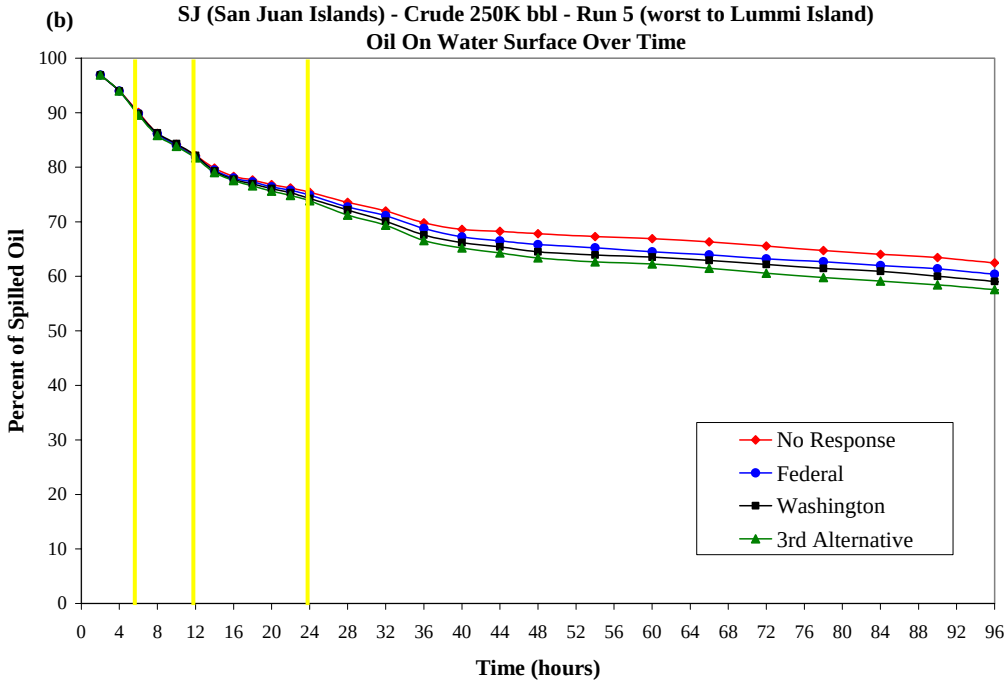


Figure XVII.B-15 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

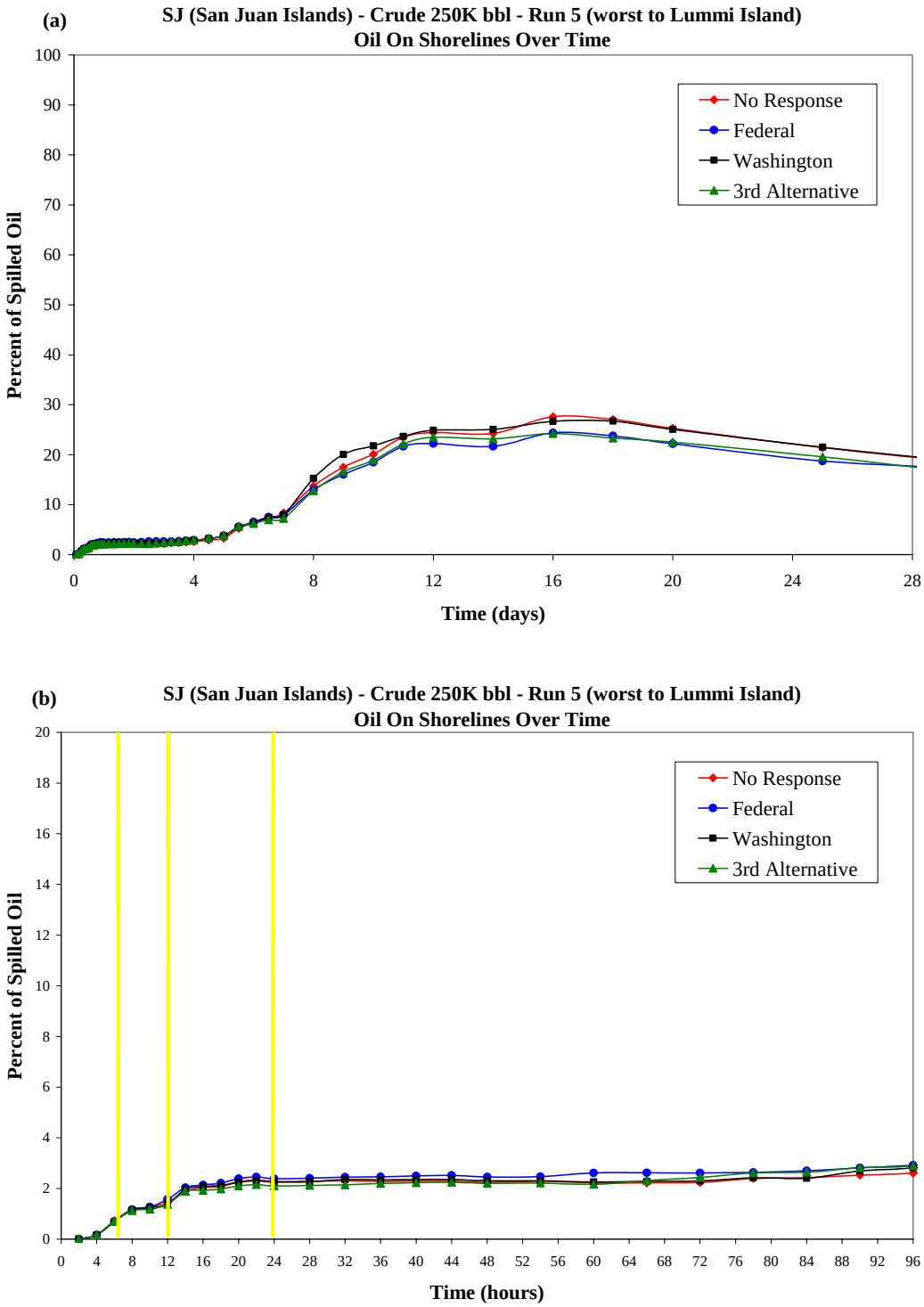


Figure XVII.B-16 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

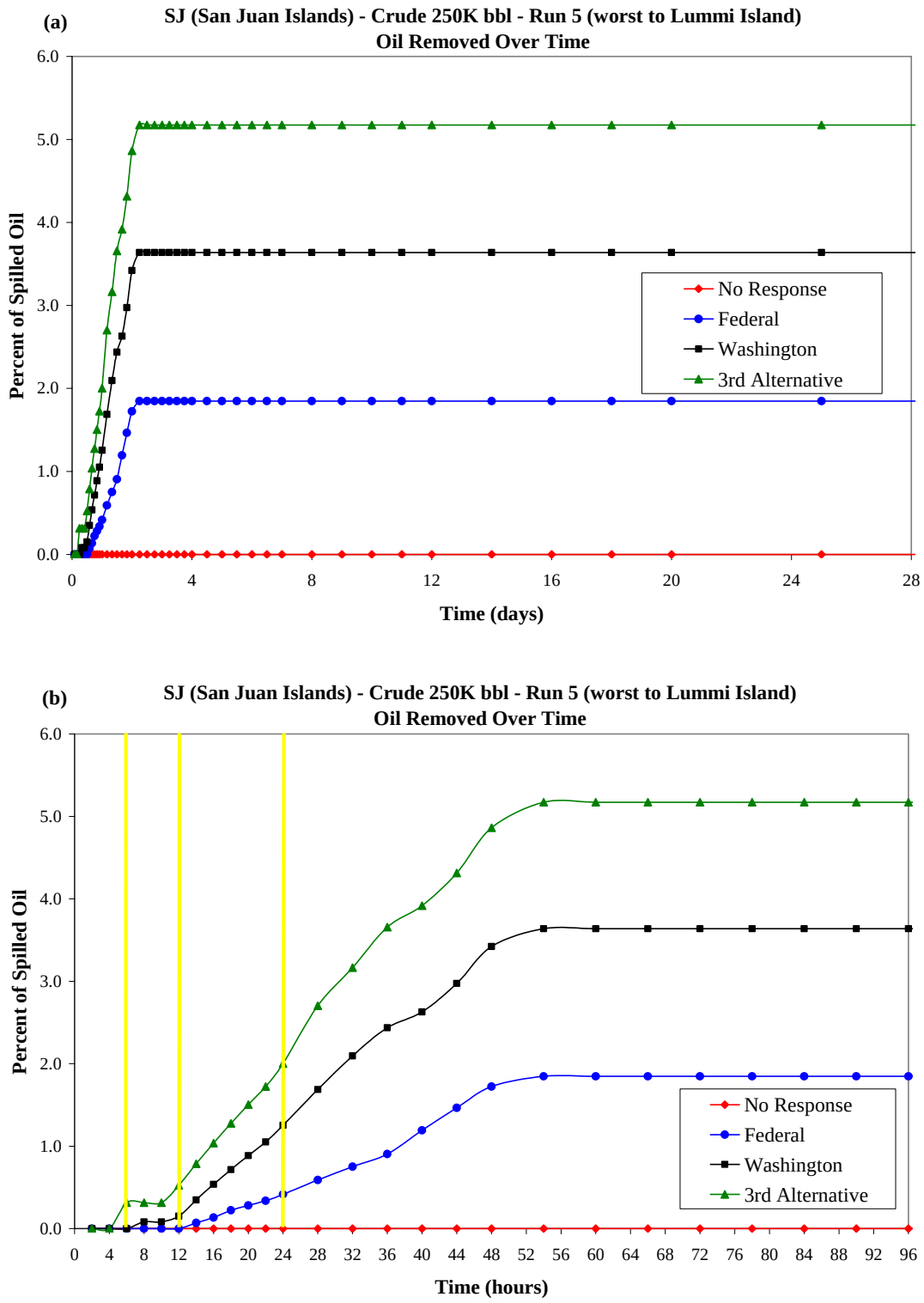
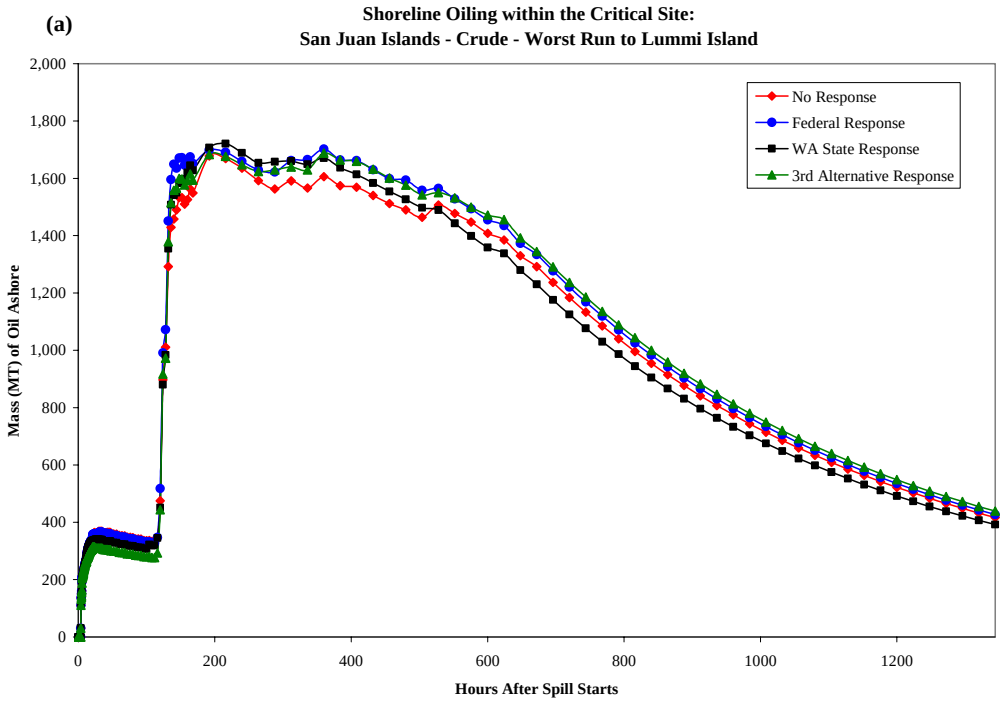


Figure XVII.B-17 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a.



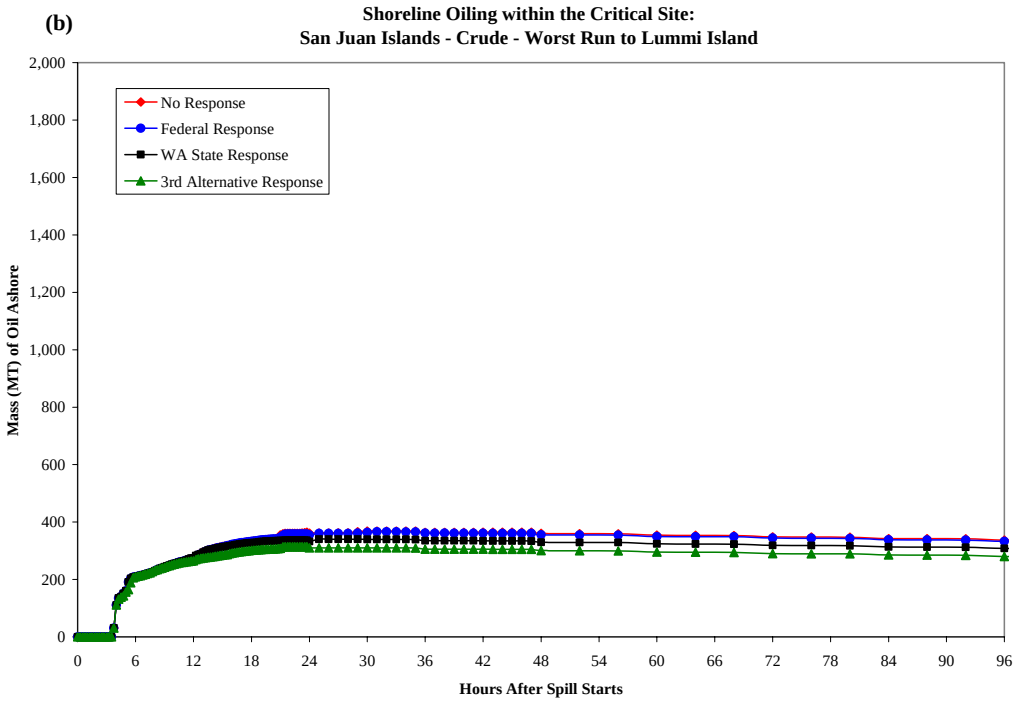


Figure XVII.B-18 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

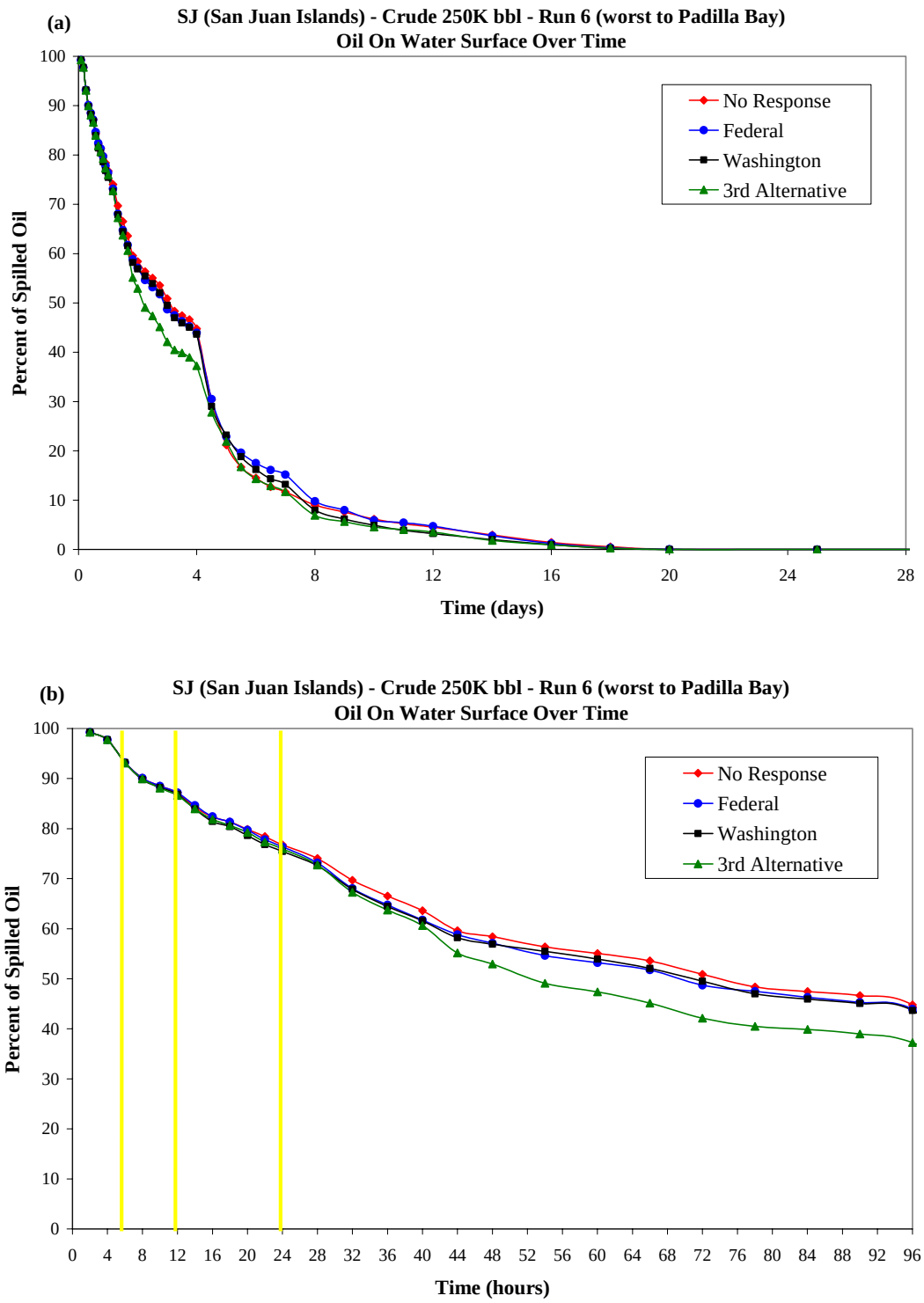


Figure XVII.B-19 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

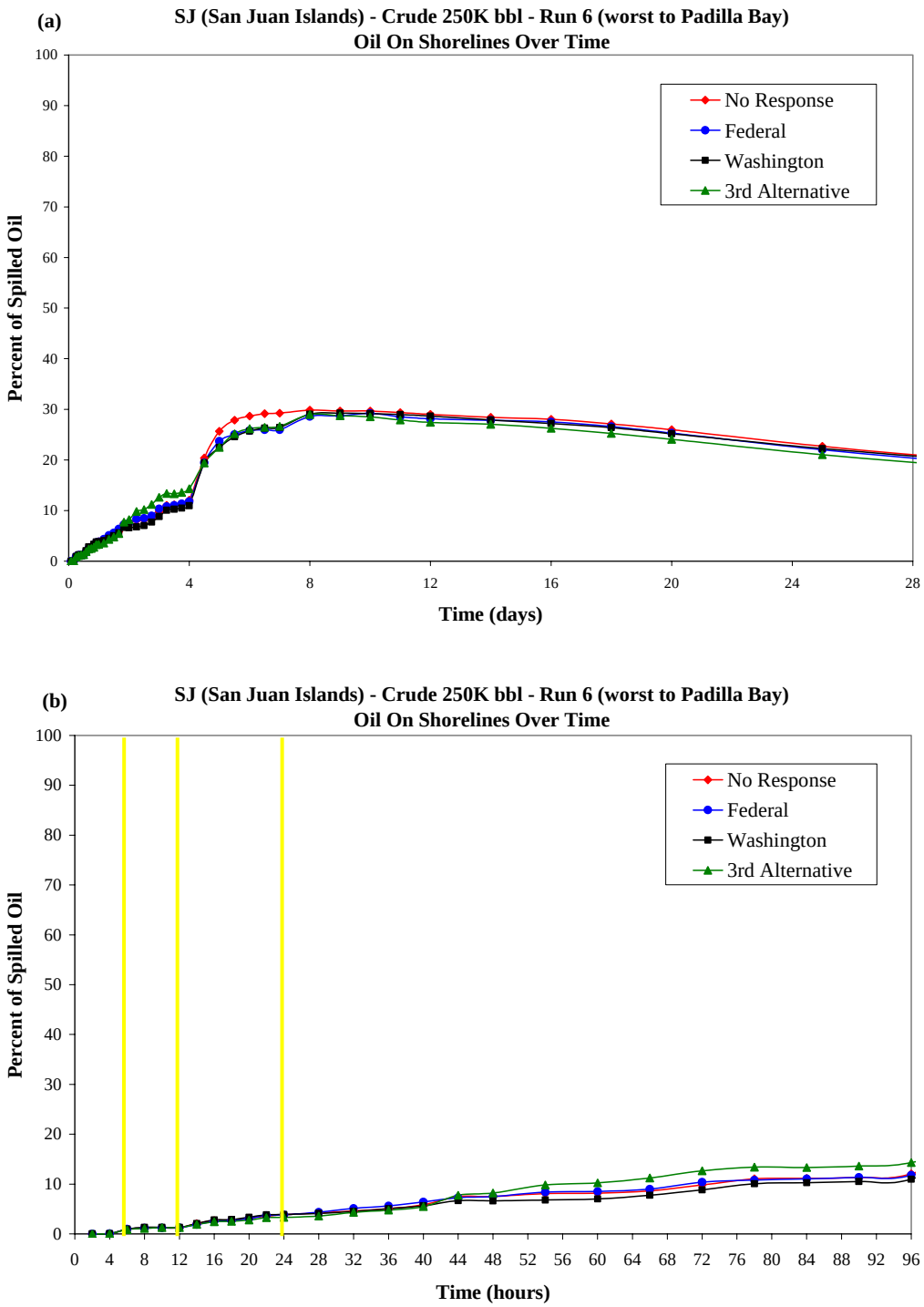


Figure XVII.B-20 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

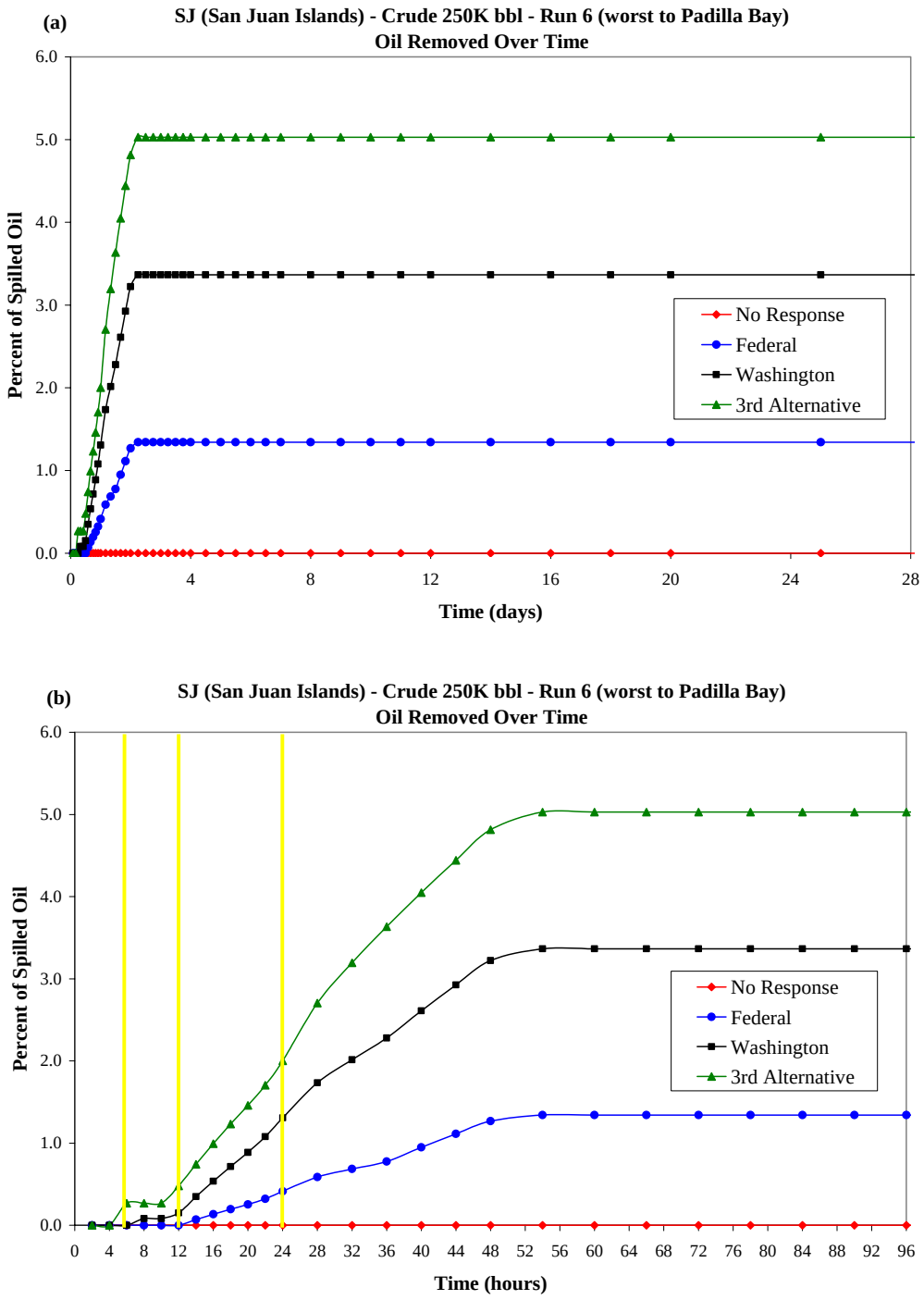
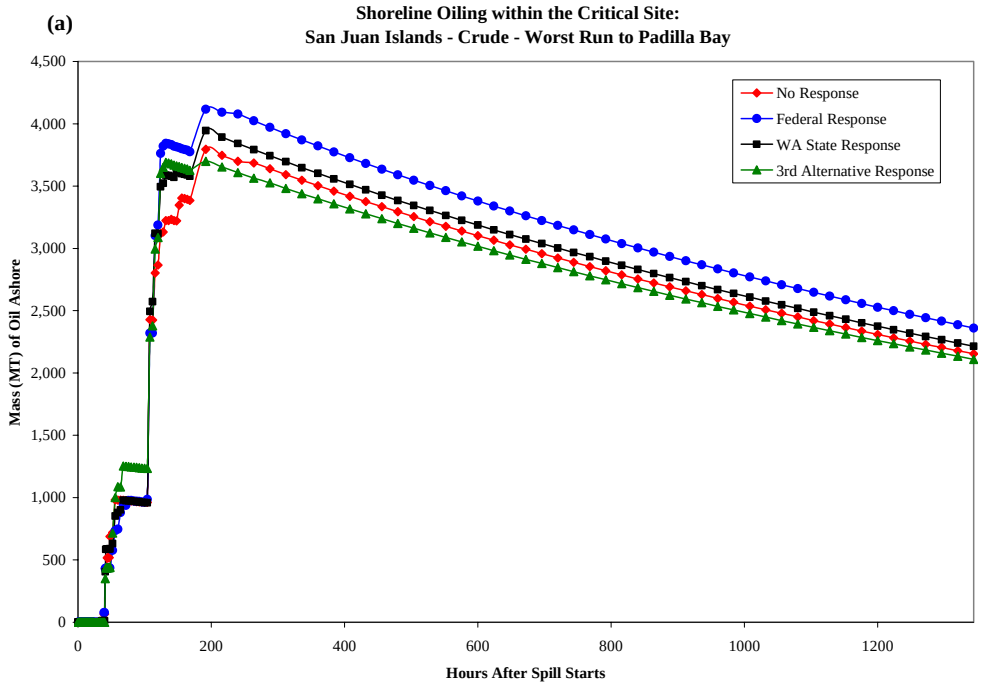


Figure XVII.B-21 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



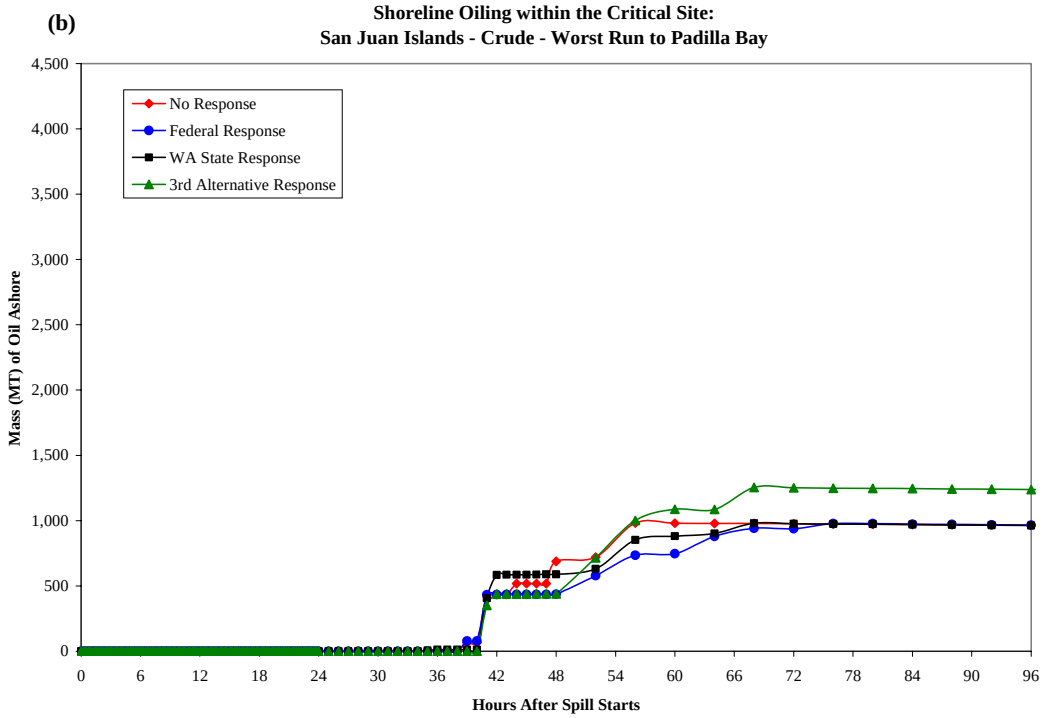


Figure XVII.B-22 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

Table XVII.B-1 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	94.71	2.99	2.19	0.00	0.08	0.05	0.00	0.00	94.71
4	0.17	92.25	4.75	2.84	0.00	0.07	0.09	0.00	0.00	92.25
6	0.25	88.71	8.62	2.33	0.00	0.18	0.16	0.00	0.00	88.71
8	0.33	85.27	12.25	2.01	0.00	0.24	0.24	0.00	0.00	85.27
10	0.42	82.55	15.05	1.79	0.00	0.30	0.31	0.00	0.00	82.55
12	0.50	81.26	16.80	1.27	0.00	0.30	0.38	0.00	0.00	81.26
14	0.58	80.74	17.53	0.97	0.00	0.31	0.45	0.00	0.00	80.74
16	0.67	80.10	18.29	0.77	0.00	0.32	0.51	0.00	0.00	80.10
18	0.75	79.37	19.04	0.61	0.00	0.40	0.58	0.00	0.00	79.37
20	0.83	78.13	20.04	0.78	0.00	0.40	0.65	0.00	0.00	78.13
22	0.92	77.04	20.90	0.94	0.00	0.41	0.71	0.00	0.00	77.04
24	1.00	76.46	21.55	0.79	0.00	0.42	0.78	0.00	0.00	76.46
28	1.17	75.04	22.73	0.60	0.00	0.72	0.91	0.00	0.00	75.04
32	1.33	73.44	23.94	0.62	0.00	0.96	1.03	0.00	0.00	73.44
36	1.50	71.17	25.18	1.19	0.00	1.30	1.16	0.00	0.00	71.17
40	1.67	70.38	26.14	0.71	0.01	1.48	1.28	0.00	0.00	70.38
44	1.83	68.70	27.21	0.72	0.02	1.95	1.40	0.00	0.00	68.70
48	2.00	56.08	32.67	0.47	0.02	9.25	1.51	0.00	0.00	56.08
54	2.25	54.70	33.45	0.26	0.04	9.88	1.68	0.00	0.00	54.70
60	2.50	53.61	34.07	0.25	0.05	10.17	1.84	0.00	0.00	53.61
66	2.75	49.99	35.70	0.23	0.09	11.98	2.00	0.00	0.00	49.99
72	3.00	49.22	36.15	0.28	0.11	12.08	2.16	0.00	0.00	49.22
78	3.25	48.06	36.76	0.22	0.16	12.49	2.32	0.00	0.00	48.06
84	3.50	45.77	37.79	0.31	0.19	13.47	2.47	0.00	0.00	45.77
90	3.75	43.47	38.89	0.58	0.28	14.16	2.62	0.00	0.00	43.47

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	40.30	40.50	0.90	0.31	15.22	2.77	0.00	0.00	40.30
108	4.50	37.93	41.91	0.33	0.41	16.37	3.05	0.00	0.00	37.93
120	5.00	35.77	42.84	0.35	0.51	17.20	3.33	0.00	0.00	35.77
132	5.50	33.70	43.70	0.38	0.63	17.98	3.60	0.00	0.00	33.70
144	6.00	30.12	45.14	0.45	0.80	19.61	3.87	0.00	0.00	30.12
156	6.50	27.30	46.45	0.77	1.00	20.36	4.12	0.00	0.00	27.30
168	7.00	19.53	49.27	1.37	1.20	24.26	4.37	0.00	0.00	19.53
192	8.00	7.14	53.25	0.66	1.64	32.50	4.82	0.00	0.00	7.14
216	9.00	3.55	54.17	0.62	2.28	34.14	5.24	0.00	0.00	3.55
240	10.00	2.84	54.33	0.56	2.93	33.70	5.65	0.00	0.00	2.84
264	11.00	1.40	54.56	0.81	3.60	33.60	6.05	0.00	0.00	1.40
288	12.00	1.15	54.65	0.54	4.14	33.09	6.43	0.00	0.00	1.15
336	14.00	0.92	54.68	0.49	5.26	31.49	7.16	0.00	0.00	0.92
384	16.00	0.77	54.70	0.43	6.29	29.96	7.86	0.00	0.00	0.77
432	18.00	0.58	54.73	0.41	7.17	28.60	8.52	0.00	0.00	0.58
480	20.00	0.04	54.80	0.34	8.01	27.66	9.14	0.00	0.02	0.05
600	25.00	0.00	54.80	0.28	9.65	24.69	10.56	0.00	0.02	0.02
720	30.00	0.00	54.80	0.23	10.88	22.24	11.82	0.00	0.02	0.02
840	35.00	0.00	54.80	0.21	11.79	20.21	12.96	0.00	0.02	0.02
1080	45.00	0.00	54.80	0.16	13.05	17.06	14.91	0.00	0.02	0.02
1200	50.00	0.00	54.80	0.14	13.47	15.80	15.76	0.00	0.02	0.02
1320	55.00	0.00	54.80	0.14	13.78	14.71	16.55	0.00	0.02	0.02
Maximum	56.00	95.68	54.80	2.84	13.85	34.14	16.70	0.00	0.02	95.68

Table XVII.B-2 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	94.74	2.99	2.15	0.00	0.08	0.05	0.00	0.00	94.74
4	0.17	92.42	4.76	2.67	0.00	0.07	0.09	0.00	0.00	92.42
6	0.25	89.17	8.64	1.81	0.00	0.22	0.16	0.00	0.00	89.17
8	0.33	85.32	12.21	1.98	0.00	0.25	0.24	0.00	0.00	85.32
10	0.42	82.47	15.00	1.94	0.00	0.29	0.31	0.00	0.00	82.47
12	0.50	81.34	16.74	1.24	0.00	0.30	0.38	0.00	0.00	81.34
14	0.58	80.92	17.48	0.78	0.00	0.31	0.45	0.07	0.00	80.92
16	0.67	80.20	18.24	0.54	0.00	0.32	0.51	0.18	0.00	80.20
18	0.75	79.47	18.93	0.38	0.00	0.35	0.58	0.29	0.00	79.47
20	0.83	78.20	19.93	0.49	0.00	0.35	0.65	0.37	0.00	78.20
22	0.92	77.16	20.80	0.52	0.00	0.36	0.71	0.45	0.00	77.16
24	1.00	76.41	21.44	0.46	0.00	0.36	0.78	0.54	0.00	76.41
28	1.17	74.59	22.71	0.33	0.00	0.76	0.91	0.71	0.00	74.59
32	1.33	72.51	24.03	0.40	0.00	1.15	1.03	0.87	0.00	72.51
36	1.50	70.86	25.07	0.66	0.00	1.23	1.15	1.03	0.00	70.86
40	1.67	69.66	25.99	0.38	0.01	1.36	1.27	1.32	0.00	69.66
44	1.83	67.99	26.86	0.57	0.01	1.58	1.39	1.59	0.00	67.99
48	2.00	54.76	32.55	0.29	0.01	9.13	1.50	1.75	0.00	54.76
54	2.25	53.59	33.15	0.23	0.03	9.50	1.66	1.82	0.00	53.59
60	2.50	52.66	33.69	0.26	0.05	9.70	1.82	1.82	0.00	52.66
66	2.75	49.20	35.27	0.18	0.08	11.47	1.98	1.82	0.00	49.20
72	3.00	48.36	35.73	0.23	0.09	11.62	2.14	1.82	0.00	48.36
78	3.25	47.27	36.30	0.18	0.14	11.99	2.29	1.82	0.00	47.27
84	3.50	45.22	37.24	0.27	0.17	12.84	2.44	1.82	0.00	45.22
90	3.75	43.50	38.10	0.56	0.27	13.17	2.59	1.82	0.00	43.50
96	4.00	41.10	39.39	0.97	0.29	13.69	2.73	1.82	0.00	41.10

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	37.67	41.16	0.41	0.39	15.54	3.01	1.82	0.00	37.67
120	5.00	35.73	42.01	0.42	0.48	16.26	3.28	1.82	0.00	35.73
132	5.50	33.47	42.91	0.44	0.60	17.20	3.55	1.82	0.00	33.47
144	6.00	30.16	44.26	0.45	0.77	18.72	3.81	1.82	0.00	30.16
156	6.50	27.71	45.44	0.74	0.97	19.26	4.06	1.82	0.00	27.71
168	7.00	20.81	48.00	1.46	1.17	22.44	4.30	1.82	0.00	20.81
192	8.00	8.11	52.18	0.55	1.59	31.01	4.75	1.82	0.00	8.11
216	9.00	4.03	53.27	0.55	2.18	32.99	5.16	1.82	0.00	4.03
240	10.00	3.02	53.51	0.53	2.78	32.77	5.56	1.82	0.00	3.02
264	11.00	1.93	53.69	0.92	3.42	32.27	5.95	1.82	0.00	1.93
288	12.00	1.28	53.87	0.54	3.94	32.22	6.32	1.82	0.00	1.28
336	14.00	0.81	53.95	0.52	5.00	30.85	7.04	1.82	0.00	0.82
384	16.00	0.71	53.96	0.45	6.00	29.33	7.72	1.82	0.01	0.71
432	18.00	0.35	54.00	0.39	6.84	28.10	8.36	1.82	0.13	0.48
480	20.00	0.00	54.04	0.32	7.64	26.94	8.97	1.82	0.28	0.28
600	25.00	0.00	54.04	0.27	9.18	24.07	10.35	1.82	0.28	0.28
720	30.00	0.00	54.04	0.22	10.34	21.72	11.59	1.82	0.28	0.28
840	35.00	0.00	54.04	0.20	11.20	19.77	12.69	1.82	0.28	0.28
1080	45.00	0.00	54.04	0.15	12.39	16.71	14.61	1.82	0.28	0.28
1200	50.00	0.00	54.04	0.20	12.78	15.29	15.59	1.82	0.28	0.28
1320	55.00	0.00	54.04	0.21	12.99	14.45	16.20	1.82	0.28	0.28
Maximum	56.00	95.68	54.04	2.67	13.11	32.99	16.50	1.82	0.28	95.68

Table XVII.B-3 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	94.74	2.99	2.15	0.00	0.08	0.05	0.00	0.00	94.74
4	0.17	92.42	4.76	2.67	0.00	0.07	0.09	0.00	0.00	92.42
6	0.25	89.17	8.64	1.81	0.00	0.22	0.16	0.00	0.00	89.17
8	0.33	85.24	12.21	1.98	0.00	0.25	0.24	0.08	0.00	85.24
10	0.42	82.39	15.00	1.94	0.00	0.29	0.31	0.08	0.00	82.39
12	0.50	81.19	16.74	1.24	0.00	0.30	0.38	0.15	0.00	81.19
14	0.58	80.63	17.48	0.78	0.00	0.31	0.45	0.36	0.00	80.63
16	0.67	79.82	18.23	0.48	0.00	0.32	0.51	0.63	0.00	79.82
18	0.75	78.68	18.96	0.49	0.00	0.39	0.58	0.89	0.00	78.68
20	0.83	77.28	19.96	0.58	0.00	0.39	0.65	1.14	0.00	77.28
22	0.92	76.23	20.83	0.48	0.00	0.40	0.71	1.34	0.00	76.23
24	1.00	75.43	21.46	0.36	0.00	0.41	0.78	1.57	0.00	75.43
28	1.17	73.40	22.64	0.31	0.00	0.74	0.90	2.00	0.00	73.40
32	1.33	71.49	23.80	0.33	0.00	0.94	1.02	2.41	0.00	71.49
36	1.50	69.28	24.92	0.71	0.00	1.15	1.14	2.79	0.00	69.28
40	1.67	67.88	25.77	0.55	0.01	1.24	1.26	3.29	0.00	67.88
44	1.83	66.03	26.69	0.57	0.02	1.55	1.38	3.77	0.00	66.03
48	2.00	52.71	32.29	0.32	0.02	9.10	1.48	4.08	0.00	52.71
54	2.25	51.62	32.83	0.25	0.03	9.40	1.64	4.22	0.00	51.62
60	2.50	50.78	33.33	0.24	0.05	9.58	1.80	4.22	0.00	50.78
66	2.75	47.13	34.97	0.20	0.08	11.45	1.95	4.22	0.00	47.13
72	3.00	46.13	35.49	0.27	0.09	11.71	2.10	4.22	0.00	46.13
78	3.25	44.95	36.10	0.20	0.14	12.15	2.24	4.22	0.00	44.95
84	3.50	42.93	37.01	0.29	0.17	12.99	2.39	4.22	0.00	42.93
90	3.75	41.07	37.87	0.64	0.27	13.39	2.53	4.22	0.00	41.07

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	38.47	39.18	1.12	0.30	14.03	2.67	4.22	0.00	38.47
108	4.50	35.67	40.75	0.48	0.41	15.52	2.94	4.22	0.00	35.67
120	5.00	34.14	41.49	0.36	0.52	16.06	3.20	4.22	0.00	34.14
132	5.50	32.66	42.15	0.35	0.65	16.50	3.46	4.22	0.00	32.66
144	6.00	29.52	43.46	0.39	0.82	17.86	3.71	4.22	0.00	29.52
156	6.50	26.05	44.94	0.71	1.03	19.09	3.96	4.22	0.00	26.05
168	7.00	16.55	48.31	1.17	1.23	24.33	4.19	4.22	0.00	16.55
192	8.00	6.91	51.57	0.56	1.64	30.49	4.61	4.22	0.00	6.91
216	9.00	4.43	52.30	0.47	2.16	31.41	5.01	4.22	0.00	4.43
240	10.00	3.34	52.56	0.46	2.68	31.35	5.39	4.22	0.00	3.34
264	11.00	1.84	52.83	0.64	3.22	31.48	5.77	4.22	0.00	1.84
288	12.00	0.66	53.05	0.48	3.66	31.80	6.13	4.22	0.00	0.66
336	14.00	0.31	53.11	0.42	4.56	30.54	6.83	4.22	0.00	0.31
384	16.00	0.18	53.12	0.37	5.41	29.19	7.49	4.22	0.00	0.18
432	18.00	0.10	53.13	0.35	6.13	27.92	8.12	4.22	0.01	0.11
480	20.00	0.00	53.14	0.30	6.82	26.74	8.72	4.22	0.05	0.05
600	25.00	0.00	53.14	0.25	8.14	24.09	10.10	4.22	0.05	0.05
720	30.00	0.00	53.14	0.21	9.15	21.89	11.34	4.22	0.05	0.05
840	35.00	0.00	53.14	0.19	9.89	20.04	12.46	4.22	0.05	0.05
1080	45.00	0.00	53.14	0.14	10.93	17.09	14.41	4.22	0.06	0.06
1200	50.00	0.00	53.14	0.13	11.28	15.90	15.27	4.22	0.06	0.06
1320	55.00	0.00	53.14	0.13	11.54	14.85	16.06	4.22	0.06	0.06
Maximum	56.00	95.68	53.14	2.67	11.60	31.80	16.21	4.22	0.06	95.68

Table XVII.B-4 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	94.74	2.99	2.15	0.00	0.08	0.05	0.00	0.00	94.74
4	0.17	92.42	4.76	2.67	0.00	0.07	0.09	0.00	0.00	92.42
6	0.25	88.90	8.64	1.81	0.00	0.22	0.16	0.27	0.00	88.90
8	0.33	85.06	12.20	1.98	0.00	0.25	0.24	0.27	0.00	85.06
10	0.42	82.21	14.99	1.94	0.00	0.29	0.31	0.27	0.00	82.21
12	0.50	80.87	16.73	1.24	0.00	0.30	0.38	0.48	0.00	80.87
14	0.58	80.32	17.46	0.73	0.00	0.31	0.45	0.74	0.00	80.32
16	0.67	79.52	18.21	0.44	0.00	0.32	0.51	0.99	0.00	79.52
18	0.75	78.50	18.88	0.41	0.00	0.33	0.58	1.29	0.00	78.50
20	0.83	77.17	19.88	0.45	0.00	0.33	0.64	1.52	0.00	77.17
22	0.92	75.93	20.73	0.54	0.00	0.33	0.71	1.75	0.00	75.93
24	1.00	74.99	21.36	0.49	0.00	0.33	0.77	2.05	0.00	74.99
28	1.17	72.66	22.62	0.33	0.00	0.74	0.90	2.75	0.00	72.66
32	1.33	70.14	23.93	0.35	0.00	1.15	1.02	3.41	0.00	70.14
36	1.50	67.95	24.94	0.70	0.00	1.24	1.14	4.03	0.00	67.95
40	1.67	66.31	25.84	0.55	0.01	1.41	1.25	4.64	0.00	66.31
44	1.83	64.16	26.75	0.74	0.02	1.75	1.37	5.22	0.00	64.16
48	2.00	51.00	32.28	0.41	0.02	9.12	1.47	5.70	0.00	51.00
54	2.25	49.54	32.94	0.31	0.04	9.60	1.62	5.95	0.00	49.54
60	2.50	48.78	33.41	0.33	0.05	9.72	1.77	5.95	0.00	48.78
66	2.75	45.96	34.72	0.25	0.08	11.12	1.92	5.95	0.00	45.96
72	3.00	44.90	35.27	0.29	0.10	11.43	2.07	5.95	0.00	44.90
78	3.25	43.89	35.81	0.21	0.15	11.79	2.21	5.95	0.00	43.89
84	3.50	41.60	36.82	0.28	0.17	12.83	2.35	5.95	0.00	41.60
90	3.75	40.08	37.55	0.62	0.26	13.05	2.49	5.95	0.00	40.08

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	37.77	38.78	0.98	0.29	13.61	2.63	5.95	0.00	37.77
108	4.50	36.48	39.78	0.36	0.37	14.17	2.89	5.95	0.00	36.48
120	5.00	35.57	40.29	0.30	0.46	14.28	3.15	5.95	0.00	35.57
132	5.50	33.90	41.02	0.32	0.55	14.86	3.41	5.95	0.00	33.90
144	6.00	30.76	42.33	0.34	0.69	16.28	3.65	5.95	0.00	30.76
156	6.50	27.93	43.63	0.69	0.85	17.06	3.89	5.95	0.00	27.93
168	7.00	20.40	46.49	1.26	1.00	20.78	4.13	5.95	0.00	20.40
192	8.00	8.10	50.51	0.69	1.36	28.85	4.54	5.95	0.00	8.10
216	9.00	4.75	51.50	0.47	1.87	30.53	4.94	5.95	0.00	4.75
240	10.00	3.83	51.73	0.46	2.40	30.32	5.32	5.95	0.00	3.83
264	11.00	2.44	51.93	1.09	2.96	29.94	5.69	5.95	0.00	2.44
288	12.00	2.63	52.01	0.47	3.40	29.50	6.04	5.95	0.00	2.63
336	14.00	2.16	52.08	0.43	4.32	28.33	6.73	5.95	0.00	2.16
384	16.00	1.73	52.14	0.38	5.20	27.22	7.38	5.95	0.00	1.73
432	18.00	1.38	52.18	0.37	5.96	26.12	8.00	5.95	0.05	1.43
480	20.00	0.00	52.32	0.39	6.68	25.66	8.58	5.95	0.43	0.43
600	25.00	0.00	52.32	0.34	8.08	22.99	9.90	5.95	0.43	0.43
720	30.00	0.00	52.32	0.29	9.14	20.79	11.09	5.95	0.43	0.43
840	35.00	0.00	52.32	0.27	9.93	18.95	12.15	5.95	0.43	0.43
1080	45.00	0.00	52.32	0.15	11.03	16.05	14.00	5.95	0.50	0.50
1200	50.00	0.00	52.32	0.13	11.41	14.89	14.80	5.95	0.50	0.50
1320	55.00	0.00	52.32	0.13	11.69	13.87	15.54	5.95	0.50	0.50
Maximum	56.00	95.68	52.32	2.67	11.75	30.53	15.68	5.95	0.50	95.68

Table XVII.B-5 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lopez Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.74	2.25	0.96	0.00	0.00	0.05	0.00	0.00	96.74
4	0.17	94.44	4.05	1.39	0.00	0.04	0.09	0.00	0.00	94.44
6	0.25	85.14	10.84	0.84	0.00	3.01	0.16	0.00	0.00	85.14
8	0.33	79.71	15.30	0.58	0.00	4.17	0.24	0.00	0.00	79.71
10	0.42	76.38	18.18	0.96	0.00	4.18	0.30	0.00	0.00	76.38
12	0.50	74.77	20.36	0.32	0.00	4.18	0.37	0.00	0.00	74.77
14	0.58	72.72	22.29	0.36	0.01	4.19	0.44	0.00	0.00	72.72
16	0.67	70.56	24.04	0.69	0.01	4.20	0.50	0.00	0.00	70.56
18	0.75	69.48	25.35	0.37	0.01	4.23	0.56	0.00	0.00	69.48
20	0.83	67.57	26.42	1.06	0.01	4.31	0.62	0.00	0.00	67.57
22	0.92	67.04	27.36	0.54	0.01	4.37	0.69	0.00	0.00	67.04
24	1.00	65.91	28.10	0.87	0.01	4.36	0.75	0.00	0.00	65.91
28	1.17	64.13	29.31	1.28	0.03	4.39	0.86	0.00	0.00	64.13
32	1.33	63.71	30.20	0.66	0.03	4.42	0.98	0.00	0.00	63.71
36	1.50	62.34	31.10	0.38	0.03	5.06	1.09	0.00	0.00	62.34
40	1.67	61.41	31.63	0.31	0.04	5.40	1.21	0.00	0.00	61.41
44	1.83	59.56	32.52	0.35	0.05	6.20	1.32	0.00	0.00	59.56
48	2.00	58.33	33.17	0.25	0.05	6.77	1.43	0.00	0.00	58.33
54	2.25	56.03	34.24	0.18	0.09	7.88	1.59	0.00	0.00	56.03
60	2.50	54.16	35.10	0.20	0.11	8.69	1.75	0.00	0.00	54.16
66	2.75	52.32	35.98	0.17	0.16	9.47	1.91	0.00	0.00	52.32
72	3.00	51.09	36.60	0.23	0.18	9.83	2.07	0.00	0.00	51.09
78	3.25	50.21	37.03	0.14	0.23	10.17	2.22	0.00	0.00	50.21
84	3.50	47.74	38.05	0.22	0.26	11.36	2.38	0.00	0.00	47.74
90	3.75	46.99	38.50	0.13	0.34	11.52	2.53	0.00	0.00	46.99
96	4.00	46.39	38.87	0.23	0.37	11.46	2.67	0.00	0.00	46.39

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	43.46	40.24	0.87	0.49	11.97	2.97	0.00	0.00	43.46
120	5.00	42.47	41.23	0.39	0.60	12.07	3.25	0.00	0.00	42.47
132	5.50	41.51	41.95	0.27	0.71	12.03	3.53	0.00	0.00	41.51
144	6.00	40.48	42.43	0.25	0.79	12.24	3.80	0.00	0.00	40.48
156	6.50	39.10	43.03	0.24	0.90	12.66	4.07	0.00	0.00	39.10
168	7.00	38.28	43.54	0.21	1.03	12.61	4.33	0.00	0.00	38.28
192	8.00	36.05	45.01	0.44	1.25	12.39	4.84	0.00	0.00	36.05
216	9.00	33.44	46.77	0.80	1.46	12.19	5.33	0.00	0.00	33.44
240	10.00	32.54	47.81	0.22	1.64	11.99	5.80	0.00	0.00	32.54
264	11.00	27.27	49.42	0.38	1.87	14.82	6.24	0.00	0.00	27.27
288	12.00	21.43	50.76	1.04	2.18	17.93	6.67	0.00	0.00	21.43
336	14.00	12.94	52.27	1.37	3.15	22.79	7.48	0.00	0.00	12.94
384	16.00	9.19	52.98	0.61	4.36	24.61	8.24	0.00	0.00	9.19
432	18.00	7.13	53.32	0.93	5.02	24.64	8.95	0.00	0.02	7.15
480	20.00	6.23	53.44	1.30	5.70	23.68	9.63	0.00	0.02	6.25
600	25.00	4.59	53.66	1.21	8.03	21.31	11.18	0.00	0.02	4.61
720	30.00	2.99	53.79	0.97	10.01	19.09	12.51	0.00	0.63	3.63
840	35.00	1.92	53.86	1.02	11.31	17.12	13.64	0.00	1.12	3.04
1080	45.00	0.90	53.95	0.70	13.54	13.96	15.49	0.00	1.46	2.36
1200	50.00	0.79	53.96	0.56	14.34	12.63	16.25	0.00	1.46	2.25
1320	55.00	0.59	53.98	0.46	14.97	11.56	16.93	0.00	1.51	2.10
Maximum	56.00	97.47	53.98	1.39	15.08	24.89	17.06	0.00	1.57	97.47

Table XVII.B-6 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lopez Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.74	2.25	0.96	0.00	0.00	0.05	0.00	0.00	96.74
4	0.17	94.44	4.05	1.39	0.00	0.04	0.09	0.00	0.00	94.44
6	0.25	87.52	9.57	0.78	0.00	1.96	0.16	0.00	0.00	87.52
8	0.33	83.62	13.15	0.69	0.00	2.30	0.24	0.00	0.00	83.62
10	0.42	80.74	16.11	0.53	0.00	2.31	0.31	0.00	0.00	80.74
12	0.50	78.57	18.39	0.34	0.00	2.32	0.38	0.00	0.00	78.57
14	0.58	75.26	20.89	0.43	0.01	2.86	0.44	0.11	0.00	75.26
16	0.67	72.86	22.81	0.61	0.01	2.98	0.51	0.22	0.00	72.86
18	0.75	71.26	24.21	0.58	0.01	3.03	0.57	0.33	0.00	71.26
20	0.83	70.03	25.33	0.44	0.01	3.12	0.63	0.43	0.00	70.03
22	0.92	68.41	26.31	0.86	0.01	3.19	0.69	0.52	0.00	68.41
24	1.00	67.96	27.07	0.40	0.01	3.19	0.75	0.61	0.00	67.96
28	1.17	65.42	28.50	0.93	0.03	3.47	0.87	0.79	0.00	65.42
32	1.33	64.56	29.52	0.26	0.03	3.69	0.99	0.95	0.00	64.56
36	1.50	62.60	30.47	0.32	0.03	4.38	1.10	1.10	0.00	62.60
40	1.67	61.31	31.05	0.19	0.05	4.80	1.21	1.39	0.00	61.31
44	1.83	59.23	31.92	0.24	0.06	5.57	1.32	1.66	0.00	59.23
48	2.00	57.02	32.82	0.20	0.07	6.54	1.43	1.92	0.00	57.02
54	2.25	54.68	33.85	0.13	0.11	7.59	1.59	2.04	0.00	54.68
60	2.50	53.95	34.26	0.19	0.13	7.68	1.75	2.04	0.00	53.95
66	2.75	52.00	35.18	0.15	0.18	8.54	1.90	2.04	0.00	52.00
72	3.00	51.43	35.57	0.17	0.20	8.52	2.06	2.04	0.00	51.43
78	3.25	50.81	35.89	0.13	0.24	8.68	2.21	2.04	0.00	50.81
84	3.50	47.80	37.11	0.19	0.27	10.23	2.36	2.04	0.00	47.80
90	3.75	47.00	37.58	0.12	0.33	10.42	2.51	2.04	0.00	47.00
96	4.00	46.50	37.93	0.20	0.35	10.32	2.65	2.04	0.00	46.50

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	43.75	39.26	0.83	0.45	10.74	2.94	2.04	0.00	43.75
120	5.00	42.93	40.20	0.33	0.53	10.75	3.22	2.04	0.00	42.93
132	5.50	41.40	41.09	0.23	0.62	11.13	3.49	2.04	0.00	41.40
144	6.00	40.61	41.48	0.24	0.69	11.17	3.75	2.04	0.00	40.61
156	6.50	39.81	41.91	0.24	0.79	11.20	4.02	2.04	0.00	39.81
168	7.00	38.80	42.48	0.19	0.89	11.31	4.28	2.04	0.00	38.80
192	8.00	36.32	43.99	0.54	1.10	11.23	4.78	2.04	0.00	36.32
216	9.00	33.95	45.79	0.60	1.27	11.08	5.26	2.04	0.00	33.95
240	10.00	32.72	46.88	0.26	1.43	10.95	5.72	2.04	0.00	32.72
264	11.00	27.61	48.39	0.36	1.64	13.81	6.15	2.04	0.00	27.61
288	12.00	22.24	49.80	0.96	1.92	16.47	6.57	2.04	0.00	22.24
336	14.00	13.91	51.34	1.43	2.80	21.12	7.37	2.04	0.00	13.91
384	16.00	10.72	51.97	0.58	3.90	22.67	8.11	2.04	0.00	10.72
432	18.00	7.67	52.44	0.88	4.50	23.52	8.81	2.04	0.15	7.81
480	20.00	6.84	52.54	1.24	5.15	22.56	9.48	2.04	0.15	6.99
600	25.00	4.71	52.84	1.19	7.39	20.68	11.00	2.04	0.15	4.86
720	30.00	3.27	52.98	0.97	9.36	18.56	12.31	2.04	0.51	3.78
840	35.00	2.14	53.08	1.04	10.67	16.72	13.43	2.04	0.88	3.02
1080	45.00	0.99	53.18	0.72	12.97	13.57	15.26	2.04	1.27	2.27
1200	50.00	0.81	53.20	0.58	13.80	12.28	16.00	2.04	1.27	2.09
1320	55.00	0.44	53.23	0.48	14.46	11.22	16.66	2.04	1.47	1.90
Maximum	56.00	97.47	53.23	1.43	14.57	23.52	16.79	2.04	1.48	97.47

Table XVII.B-7 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lopez Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.74	2.25	0.96	0.00	0.00	0.05	0.00	0.00	96.74
4	0.17	94.44	4.05	1.39	0.00	0.04	0.09	0.00	0.00	94.44
6	0.25	85.14	10.84	0.84	0.00	3.01	0.16	0.00	0.00	85.14
8	0.33	79.38	15.30	0.80	0.00	4.18	0.24	0.11	0.00	79.38
10	0.42	76.76	18.21	0.39	0.00	4.20	0.30	0.13	0.00	76.76
12	0.50	74.53	20.37	0.31	0.00	4.19	0.37	0.23	0.00	74.53
14	0.58	71.96	22.29	0.59	0.01	4.20	0.44	0.51	0.00	71.96
16	0.67	69.58	24.01	0.91	0.01	4.21	0.50	0.78	0.00	69.58
18	0.75	68.33	25.33	0.49	0.01	4.24	0.56	1.04	0.00	68.33
20	0.83	67.01	26.32	0.51	0.01	4.24	0.62	1.29	0.00	67.01
22	0.92	65.69	27.20	0.65	0.01	4.23	0.68	1.53	0.00	65.69
24	1.00	64.50	27.92	0.84	0.01	4.23	0.74	1.76	0.00	64.50
28	1.17	61.85	29.36	1.07	0.02	4.64	0.85	2.19	0.00	61.85
32	1.33	60.74	30.18	0.83	0.03	4.65	0.97	2.60	0.00	60.74
36	1.50	59.21	30.95	0.61	0.02	5.14	1.08	2.98	0.00	59.21
40	1.67	58.16	31.46	0.19	0.04	5.49	1.19	3.48	0.00	58.16
44	1.83	55.94	32.25	0.33	0.05	6.20	1.29	3.96	0.00	55.94
48	2.00	53.45	33.18	0.27	0.05	7.26	1.40	4.41	0.00	53.45
54	2.25	51.90	33.88	0.15	0.08	7.83	1.55	4.62	0.00	51.90
60	2.50	50.76	34.44	0.17	0.10	8.21	1.70	4.62	0.00	50.76
66	2.75	49.56	35.05	0.19	0.14	8.59	1.85	4.62	0.00	49.56
72	3.00	49.00	35.43	0.18	0.16	8.61	2.00	4.62	0.00	49.00
78	3.25	48.59	35.66	0.13	0.20	8.65	2.14	4.62	0.00	48.59
84	3.50	45.89	36.73	0.22	0.23	10.02	2.29	4.62	0.00	45.89
90	3.75	44.59	37.37	0.13	0.29	10.58	2.43	4.62	0.00	44.59

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	44.00	37.71	0.28	0.32	10.51	2.57	4.62	0.00	44.00
108	4.50	41.27	38.90	1.10	0.42	10.85	2.84	4.62	0.00	41.27
120	5.00	40.70	39.81	0.31	0.51	10.95	3.11	4.62	0.00	40.70
132	5.50	39.60	40.50	0.28	0.60	11.04	3.37	4.62	0.00	39.60
144	6.00	38.77	40.90	0.25	0.67	11.16	3.63	4.62	0.00	38.77
156	6.50	37.50	41.45	0.21	0.76	11.57	3.88	4.62	0.00	37.50
168	7.00	36.56	41.97	0.19	0.86	11.66	4.13	4.62	0.00	36.56
192	8.00	34.29	43.33	0.58	1.05	11.50	4.62	4.62	0.00	34.29
216	9.00	32.19	45.01	0.56	1.22	11.31	5.08	4.62	0.00	32.19
240	10.00	31.01	46.09	0.25	1.37	11.13	5.52	4.62	0.00	31.01
264	11.00	25.00	47.80	0.35	1.58	14.70	5.95	4.62	0.00	25.00
288	12.00	19.54	49.15	0.93	1.91	17.50	6.35	4.62	0.00	19.54
336	14.00	12.39	50.63	0.76	2.85	21.63	7.11	4.62	0.00	12.39
384	16.00	8.84	51.23	0.65	4.00	22.84	7.82	4.62	0.00	8.84
432	18.00	6.84	51.59	0.89	4.62	22.95	8.49	4.62	0.00	6.84
480	20.00	5.85	51.72	1.25	5.28	22.14	9.13	4.62	0.00	5.85
600	25.00	4.03	51.98	1.18	7.53	20.08	10.58	4.62	0.00	4.03
720	30.00	3.03	52.09	0.94	9.46	17.91	11.83	4.62	0.12	3.15
840	35.00	1.63	52.25	1.01	10.73	16.43	12.90	4.62	0.43	2.06
1080	45.00	0.84	52.34	0.69	12.96	13.34	14.67	4.62	0.54	1.38
1200	50.00	0.68	52.36	0.56	13.75	12.09	15.39	4.62	0.54	1.22
1320	55.00	0.44	52.39	0.47	14.38	11.12	16.04	4.62	0.54	0.97
Maximum	56.00	97.47	52.40	1.39	14.50	23.13	16.16	4.62	0.54	97.47

Table XVII.B-8 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lopez Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.74	2.25	0.96	0.00	0.00	0.05	0.00	0.00	96.74
4	0.17	94.44	4.05	1.39	0.00	0.04	0.09	0.00	0.00	94.44
6	0.25	84.79	10.84	0.84	0.00	3.01	0.16	0.36	0.00	84.79
8	0.33	79.06	15.29	0.80	0.00	4.18	0.23	0.44	0.00	79.06
10	0.42	76.40	18.18	0.39	0.00	4.20	0.30	0.51	0.00	76.40
12	0.50	73.99	20.34	0.31	0.00	4.19	0.37	0.79	0.00	73.99
14	0.58	71.53	22.25	0.41	0.01	4.20	0.43	1.17	0.00	71.53
16	0.67	69.23	23.97	0.57	0.01	4.20	0.50	1.52	0.00	69.23
18	0.75	67.61	25.26	0.48	0.01	4.22	0.56	1.86	0.00	67.61
20	0.83	66.18	26.28	0.45	0.01	4.27	0.62	2.19	0.00	66.18
22	0.92	64.51	27.17	0.84	0.01	4.29	0.68	2.50	0.00	64.51
24	1.00	63.57	27.92	0.62	0.01	4.35	0.74	2.80	0.00	63.57
28	1.17	61.01	29.06	1.18	0.03	4.38	0.85	3.50	0.00	61.01
32	1.33	59.40	30.01	0.81	0.03	4.64	0.96	4.16	0.00	59.40
36	1.50	58.21	30.55	0.56	0.03	4.81	1.07	4.77	0.00	58.21
40	1.67	56.69	31.10	0.38	0.04	5.23	1.17	5.38	0.00	56.69
44	1.83	54.65	31.84	0.36	0.04	5.87	1.28	5.96	0.00	54.65
48	2.00	50.61	33.34	0.30	0.04	7.83	1.38	6.51	0.00	50.61
54	2.25	48.91	34.05	0.16	0.08	8.45	1.52	6.82	0.00	48.91
60	2.50	47.53	34.70	0.17	0.09	9.02	1.67	6.82	0.00	47.53
66	2.75	46.39	35.28	0.18	0.13	9.39	1.81	6.82	0.00	46.39
72	3.00	45.44	35.79	0.18	0.15	9.67	1.95	6.82	0.00	45.44
78	3.25	45.06	36.01	0.12	0.18	9.71	2.09	6.82	0.00	45.06
84	3.50	42.45	37.08	0.19	0.20	11.03	2.23	6.82	0.00	42.45
90	3.75	40.80	37.82	0.12	0.25	11.81	2.37	6.82	0.00	40.80

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	40.37	38.11	0.22	0.27	11.71	2.50	6.82	0.00	40.37
108	4.50	37.94	39.30	0.61	0.35	12.21	2.76	6.82	0.00	37.94
120	5.00	37.27	40.07	0.24	0.43	12.15	3.02	6.82	0.00	37.27
132	5.50	36.48	40.67	0.20	0.50	12.06	3.27	6.82	0.00	36.48
144	6.00	35.33	41.17	0.19	0.56	12.42	3.52	6.82	0.00	35.33
156	6.50	34.56	41.56	0.18	0.63	12.49	3.76	6.82	0.00	34.56
168	7.00	33.86	42.01	0.17	0.72	12.43	4.00	6.82	0.00	33.86
192	8.00	31.92	43.33	0.40	0.86	12.20	4.47	6.82	0.00	31.92
216	9.00	29.51	44.99	0.62	1.00	12.15	4.92	6.82	0.00	29.51
240	10.00	28.59	45.97	0.20	1.12	11.96	5.34	6.82	0.00	28.59
264	11.00	23.68	47.48	0.33	1.28	14.66	5.75	6.82	0.00	23.68
288	12.00	18.07	48.75	0.98	1.53	17.72	6.14	6.82	0.00	18.07
336	14.00	10.24	50.26	1.06	2.39	22.36	6.88	6.82	0.00	10.24
384	16.00	7.26	50.78	0.80	3.47	23.30	7.57	6.82	0.00	7.26
432	18.00	5.35	51.11	0.82	4.04	23.62	8.22	6.82	0.01	5.36
480	20.00	4.58	51.21	1.14	4.64	22.75	8.84	6.82	0.01	4.58
600	25.00	3.47	51.35	1.07	6.67	20.35	10.26	6.82	0.01	3.48
720	30.00	2.50	51.41	0.85	8.39	18.10	11.50	6.82	0.44	2.94
840	35.00	1.75	51.45	0.89	9.51	16.24	12.55	6.82	0.79	2.53
1080	45.00	0.88	51.51	0.60	11.40	13.36	14.30	6.82	1.12	2.00
1200	50.00	0.72	51.53	0.49	12.07	12.21	15.03	6.82	1.12	1.84
1320	55.00	0.53	51.55	0.40	12.61	11.23	15.68	6.82	1.18	1.71
Maximum	56.00	97.47	51.55	1.39	12.70	24.05	15.81	6.82	1.20	97.47

Table XVII.B-9 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Orcas Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	98.66	1.26	0.03	0.00	0.00	0.05	0.00	0.00	98.66
4	0.17	98.18	1.72	0.01	0.00	0.00	0.09	0.00	0.00	98.18
6	0.25	96.12	3.64	0.01	0.00	0.06	0.17	0.00	0.00	96.12
8	0.33	93.52	5.98	0.02	0.00	0.23	0.25	0.00	0.00	93.52
10	0.42	89.33	9.22	0.02	0.00	1.10	0.32	0.00	0.00	89.33
12	0.50	86.29	11.64	0.05	0.00	1.62	0.40	0.00	0.00	86.29
14	0.58	83.38	13.97	0.04	0.01	2.13	0.47	0.00	0.00	83.38
16	0.67	80.35	16.50	0.04	0.02	2.55	0.54	0.00	0.00	80.35
18	0.75	77.46	18.90	0.04	0.03	2.96	0.61	0.00	0.00	77.46
20	0.83	75.49	20.78	0.05	0.03	2.98	0.68	0.00	0.00	75.49
22	0.92	73.04	22.80	0.07	0.03	3.33	0.74	0.00	0.00	73.04
24	1.00	71.50	24.10	0.13	0.03	3.44	0.80	0.00	0.00	71.50
28	1.17	69.28	26.06	0.09	0.08	3.56	0.93	0.00	0.00	69.28
32	1.33	68.12	27.05	0.06	0.10	3.62	1.05	0.00	0.00	68.12
36	1.50	67.17	27.80	0.12	0.11	3.63	1.17	0.00	0.00	67.17
40	1.67	64.26	29.16	0.08	0.13	5.08	1.29	0.00	0.00	64.26
44	1.83	61.99	30.49	0.10	0.18	5.85	1.40	0.00	0.00	61.99
48	2.00	59.95	31.85	0.25	0.19	6.25	1.51	0.00	0.00	59.95
54	2.25	57.43	33.41	0.14	0.28	7.06	1.68	0.00	0.00	57.43
60	2.50	55.90	34.22	0.19	0.29	7.56	1.84	0.00	0.00	55.90
66	2.75	53.30	35.39	0.10	0.36	8.86	2.00	0.00	0.00	53.30
72	3.00	51.32	36.26	0.21	0.39	9.66	2.16	0.00	0.00	51.32
78	3.25	48.88	37.47	0.10	0.52	10.72	2.31	0.00	0.00	48.88
84	3.50	47.44	38.22	0.21	0.56	11.12	2.46	0.00	0.00	47.44
90	3.75	43.91	39.81	0.10	0.70	12.87	2.61	0.00	0.00	43.91
96	4.00	41.41	41.10	0.28	0.74	13.71	2.75	0.00	0.00	41.41

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	36.73	43.28	0.29	0.95	15.72	3.03	0.00	0.00	36.73
120	5.00	33.72	44.84	0.40	1.19	16.55	3.30	0.00	0.00	33.72
132	5.50	31.40	46.33	0.33	1.46	16.93	3.55	0.00	0.00	31.40
144	6.00	17.99	50.43	0.39	1.72	25.68	3.80	0.00	0.00	17.99
156	6.50	13.88	51.94	0.32	1.99	27.85	4.02	0.00	0.00	13.88
168	7.00	12.43	52.44	0.33	2.23	28.32	4.24	0.00	0.00	12.43
192	8.00	9.71	53.14	0.38	2.72	29.38	4.67	0.00	0.00	9.71
216	9.00	7.33	53.67	0.46	3.24	30.21	5.09	0.00	0.00	7.33
240	10.00	5.48	54.08	0.39	3.93	30.64	5.49	0.00	0.00	5.48
264	11.00	3.41	54.46	0.46	4.49	31.30	5.88	0.00	0.00	3.41
288	12.00	2.07	54.70	0.43	5.18	31.37	6.25	0.00	0.00	2.07
336	14.00	1.16	54.86	0.36	6.49	30.16	6.96	0.00	0.00	1.16
384	16.00	0.82	54.91	0.36	7.61	28.67	7.63	0.00	0.00	0.82
432	18.00	0.40	54.97	0.29	8.70	27.39	8.25	0.00	0.00	0.40
480	20.00	0.05	55.02	0.28	9.62	26.19	8.84	0.00	0.00	0.05
600	25.00	0.00	55.02	0.20	11.59	23.01	10.18	0.00	0.00	0.00
720	30.00	0.00	55.02	0.15	13.05	20.44	11.34	0.00	0.00	0.00
840	35.00	0.00	55.02	0.15	14.11	18.35	12.37	0.00	0.00	0.00
1080	45.00	0.00	55.02	0.07	15.60	15.18	14.12	0.00	0.00	0.00
1200	50.00	0.00	55.02	0.08	16.07	13.96	14.87	0.00	0.00	0.00
1320	55.00	0.00	55.02	0.06	16.45	12.92	15.55	0.00	0.00	0.00
Maximum	56.00	99.18	55.02	0.46	16.52	31.37	15.68	0.00	0.00	99.18

Table XVII.B-10 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Orcas Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	98.66	1.26	0.03	0.00	0.00	0.05	0.00	0.00	98.66
4	0.17	98.18	1.72	0.01	0.00	0.00	0.09	0.00	0.00	98.18
6	0.25	96.12	3.64	0.01	0.00	0.06	0.17	0.00	0.00	96.12
8	0.33	93.52	5.98	0.02	0.00	0.23	0.25	0.00	0.00	93.52
10	0.42	89.33	9.22	0.02	0.00	1.10	0.32	0.00	0.00	89.33
12	0.50	86.29	11.64	0.05	0.00	1.62	0.40	0.00	0.00	86.29
14	0.58	83.27	13.96	0.04	0.01	2.13	0.47	0.11	0.00	83.27
16	0.67	80.14	16.49	0.04	0.02	2.55	0.54	0.22	0.00	80.14
18	0.75	77.14	18.89	0.05	0.03	2.95	0.61	0.33	0.00	77.14
20	0.83	75.06	20.77	0.07	0.03	2.98	0.67	0.43	0.00	75.06
22	0.92	72.45	22.82	0.07	0.03	3.37	0.74	0.52	0.00	72.45
24	1.00	70.84	24.10	0.14	0.03	3.47	0.80	0.61	0.00	70.84
28	1.17	68.28	26.12	0.13	0.08	3.67	0.92	0.79	0.00	68.28
32	1.33	66.96	27.12	0.07	0.10	3.75	1.04	0.95	0.00	66.96
36	1.50	65.95	27.83	0.14	0.11	3.71	1.16	1.10	0.00	65.95
40	1.67	64.21	28.59	0.09	0.14	4.32	1.28	1.39	0.00	64.21
44	1.83	61.61	29.94	0.11	0.18	5.11	1.39	1.66	0.00	61.61
48	2.00	59.52	31.22	0.30	0.20	5.38	1.50	1.88	0.00	59.52
54	2.25	57.30	32.66	0.12	0.28	6.02	1.66	1.96	0.00	57.30
60	2.50	55.78	33.46	0.15	0.29	6.54	1.82	1.96	0.00	55.78
66	2.75	53.63	34.46	0.08	0.35	7.54	1.98	1.96	0.00	53.63
72	3.00	52.41	35.04	0.18	0.38	7.90	2.13	1.96	0.00	52.41
78	3.25	50.65	36.02	0.07	0.49	8.53	2.28	1.96	0.00	50.65
84	3.50	49.18	36.77	0.18	0.52	8.96	2.43	1.96	0.00	49.18
90	3.75	46.28	38.16	0.09	0.64	10.30	2.58	1.96	0.00	46.28
96	4.00	44.17	39.34	0.25	0.68	10.88	2.72	1.96	0.00	44.17

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	39.32	41.61	0.30	0.86	12.96	3.00	1.96	0.00	39.32
120	5.00	35.40	43.52	0.38	1.08	14.40	3.26	1.96	0.00	35.40
132	5.50	32.66	45.17	0.30	1.32	15.08	3.51	1.96	0.00	32.66
144	6.00	15.26	50.35	0.39	1.56	26.74	3.75	1.96	0.00	15.26
156	6.50	11.46	51.69	0.36	1.82	28.74	3.97	1.96	0.00	11.46
168	7.00	10.14	52.14	0.35	2.06	29.17	4.19	1.96	0.00	10.14
192	8.00	7.74	52.75	0.36	2.53	30.07	4.60	1.96	0.00	7.74
216	9.00	5.91	53.16	0.42	3.01	30.53	5.01	1.96	0.00	5.91
240	10.00	3.82	53.58	0.36	3.64	31.23	5.40	1.96	0.00	3.82
264	11.00	2.06	53.90	0.44	4.17	31.69	5.78	1.96	0.00	2.06
288	12.00	1.30	54.04	0.39	4.81	31.37	6.14	1.96	0.00	1.30
336	14.00	0.49	54.17	0.33	5.99	30.23	6.84	1.96	0.00	0.49
384	16.00	0.19	54.21	0.33	7.00	28.83	7.49	1.96	0.00	0.19
432	18.00	0.07	54.23	0.26	7.96	27.42	8.11	1.96	0.00	0.07
480	20.00	0.00	54.24	0.25	8.77	26.10	8.69	1.96	0.00	0.00
600	25.00	0.00	54.24	0.18	10.46	23.14	10.03	1.96	0.00	0.00
720	30.00	0.00	54.24	0.13	11.72	20.75	11.20	1.96	0.00	0.00
840	35.00	0.00	54.24	0.13	12.63	18.79	12.25	1.96	0.00	0.00
1080	45.00	0.00	54.24	0.06	13.90	15.78	14.06	1.96	0.00	0.00
1200	50.00	0.00	54.24	0.07	14.30	14.60	14.84	1.96	0.00	0.00
1320	55.00	0.00	54.24	0.05	14.62	13.58	15.56	1.96	0.00	0.00
Maximum	56.00	99.18	54.24	0.44	14.68	31.69	15.70	1.96	0.00	99.18

Table XVII.B-11 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Orcas Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	98.66	1.26	0.03	0.00	0.00	0.05	0.00	0.00	98.66
4	0.17	98.18	1.72	0.01	0.00	0.00	0.09	0.00	0.00	98.18
6	0.25	96.12	3.64	0.01	0.00	0.06	0.17	0.00	0.00	96.12
8	0.33	93.42	5.98	0.02	0.00	0.23	0.25	0.11	0.00	93.42
10	0.42	89.20	9.22	0.02	0.00	1.10	0.32	0.13	0.00	89.20
12	0.50	86.12	11.61	0.05	0.00	1.59	0.40	0.23	0.00	86.12
14	0.58	82.89	13.95	0.05	0.01	2.12	0.47	0.51	0.00	82.89
16	0.67	79.37	16.59	0.04	0.02	2.66	0.54	0.78	0.00	79.37
18	0.75	76.43	18.89	0.04	0.03	2.96	0.61	1.04	0.00	76.43
20	0.83	74.03	20.84	0.06	0.03	3.08	0.67	1.29	0.00	74.03
22	0.92	71.61	22.71	0.10	0.03	3.28	0.74	1.53	0.00	71.61
24	1.00	70.04	23.93	0.14	0.03	3.31	0.80	1.76	0.00	70.04
28	1.17	67.37	25.89	0.10	0.08	3.45	0.92	2.19	0.00	67.37
32	1.33	65.67	26.93	0.05	0.10	3.61	1.04	2.60	0.00	65.67
36	1.50	64.30	27.70	0.11	0.10	3.66	1.15	2.98	0.00	64.30
40	1.67	61.72	28.70	0.08	0.13	4.62	1.26	3.48	0.00	61.72
44	1.83	59.34	29.88	0.09	0.17	5.20	1.37	3.96	0.00	59.34
48	2.00	56.99	31.20	0.27	0.19	5.58	1.48	4.30	0.00	56.99
54	2.25	54.75	32.59	0.12	0.27	6.19	1.64	4.45	0.00	54.75
60	2.50	53.35	33.34	0.15	0.28	6.64	1.79	4.45	0.00	53.35
66	2.75	51.19	34.33	0.08	0.34	7.66	1.94	4.45	0.00	51.19
72	3.00	49.63	35.04	0.19	0.38	8.22	2.09	4.45	0.00	49.63
78	3.25	47.65	36.08	0.08	0.49	9.02	2.23	4.45	0.00	47.65
84	3.50	46.29	36.78	0.20	0.53	9.38	2.38	4.45	0.00	46.29
90	3.75	43.23	38.20	0.11	0.66	10.84	2.52	4.45	0.00	43.23

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	41.21	39.32	0.28	0.70	11.38	2.65	4.45	0.00	41.21
108	4.50	36.08	41.65	0.29	0.89	13.73	2.92	4.45	0.00	36.08
120	5.00	32.69	43.33	0.42	1.13	14.82	3.17	4.45	0.00	32.69
132	5.50	30.46	44.77	0.33	1.41	15.17	3.41	4.45	0.00	30.46
144	6.00	15.02	49.38	0.42	1.66	25.43	3.64	4.45	0.00	15.02
156	6.50	10.46	50.93	0.38	1.94	27.99	3.85	4.45	0.00	10.46
168	7.00	8.39	51.52	0.35	2.20	29.04	4.05	4.45	0.00	8.39
192	8.00	6.15	52.07	0.40	2.71	29.77	4.45	4.45	0.00	6.15
216	9.00	4.39	52.45	0.46	3.25	30.16	4.84	4.45	0.00	4.39
240	10.00	3.01	52.74	0.38	3.94	30.29	5.21	4.45	0.00	3.01
264	11.00	1.60	52.98	0.45	4.48	30.47	5.57	4.45	0.00	1.60
288	12.00	0.51	53.16	0.40	5.14	30.42	5.92	4.45	0.00	0.51
336	14.00	0.14	53.22	0.33	6.36	28.92	6.58	4.45	0.00	0.14
384	16.00	0.03	53.24	0.33	7.37	27.39	7.20	4.45	0.00	0.03
432	18.00	0.01	53.24	0.26	8.35	25.92	7.78	4.45	0.00	0.01
480	20.00	0.00	53.24	0.25	9.15	24.58	8.33	4.45	0.00	0.00
600	25.00	0.00	53.24	0.17	10.85	21.70	9.58	4.45	0.00	0.00
720	30.00	0.00	53.24	0.13	12.10	19.39	10.68	4.45	0.00	0.00
840	35.00	0.00	53.24	0.13	13.01	17.51	11.66	4.45	0.00	0.00
1080	45.00	0.00	53.24	0.06	14.27	14.64	13.34	4.45	0.00	0.00
1200	50.00	0.00	53.24	0.06	14.66	13.52	14.07	4.45	0.00	0.00
1320	55.00	0.00	53.24	0.05	14.98	12.55	14.73	4.45	0.00	0.00
Maximum	56.00	99.18	53.24	0.46	15.04	30.47	14.86	4.45	0.00	99.18

Table XVII.B-12 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Orcas Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	98.66	1.26	0.03	0.00	0.00	0.05	0.00	0.00	98.66
4	0.17	98.18	1.72	0.01	0.00	0.00	0.09	0.00	0.00	98.18
6	0.25	95.76	3.64	0.01	0.00	0.06	0.17	0.36	0.00	95.76
8	0.33	93.12	5.96	0.02	0.00	0.21	0.25	0.44	0.00	93.12
10	0.42	88.74	9.26	0.02	0.00	1.14	0.32	0.51	0.00	88.74
12	0.50	85.55	11.61	0.05	0.00	1.61	0.40	0.79	0.00	85.55
14	0.58	82.54	13.78	0.05	0.01	1.99	0.47	1.17	0.00	82.54
16	0.67	79.20	16.29	0.05	0.02	2.38	0.54	1.52	0.00	79.20
18	0.75	76.22	18.57	0.04	0.03	2.67	0.60	1.86	0.00	76.22
20	0.83	73.89	20.44	0.07	0.03	2.71	0.67	2.19	0.00	73.89
22	0.92	71.45	22.32	0.07	0.03	2.90	0.73	2.50	0.00	71.45
24	1.00	69.92	23.48	0.11	0.03	2.87	0.79	2.80	0.00	69.92
28	1.17	66.93	25.45	0.11	0.07	3.03	0.91	3.50	0.00	66.93
32	1.33	65.03	26.47	0.07	0.09	3.15	1.03	4.16	0.00	65.03
36	1.50	63.45	27.23	0.11	0.09	3.20	1.14	4.77	0.00	63.45
40	1.67	61.29	28.01	0.08	0.12	3.87	1.25	5.38	0.00	61.29
44	1.83	58.88	29.19	0.08	0.15	4.45	1.36	5.88	0.00	58.88
48	2.00	55.98	30.71	0.24	0.17	5.18	1.47	6.25	0.00	55.98
54	2.25	53.64	32.10	0.11	0.24	5.83	1.62	6.47	0.00	53.64
60	2.50	51.62	33.07	0.18	0.25	6.65	1.77	6.47	0.00	51.62
66	2.75	49.88	33.92	0.07	0.30	7.45	1.91	6.47	0.00	49.88
72	3.00	48.23	34.66	0.17	0.33	8.09	2.06	6.47	0.00	48.23
78	3.25	46.29	35.68	0.07	0.44	8.86	2.20	6.47	0.00	46.29
84	3.50	45.06	36.33	0.18	0.47	9.16	2.34	6.47	0.00	45.06
90	3.75	42.07	37.72	0.08	0.59	10.60	2.47	6.47	0.00	42.07

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	39.57	39.00	0.25	0.62	11.48	2.61	6.47	0.00	39.57
108	4.50	33.71	41.53	0.29	0.81	14.33	2.86	6.47	0.00	33.71
120	5.00	30.11	43.25	0.39	1.05	15.62	3.11	6.47	0.00	30.11
132	5.50	27.84	44.64	0.34	1.31	16.06	3.34	6.47	0.00	27.84
144	6.00	15.20	48.47	0.39	1.57	24.35	3.56	6.47	0.00	15.20
156	6.50	10.91	49.94	0.34	1.85	26.73	3.77	6.47	0.00	10.91
168	7.00	9.71	50.35	0.35	2.09	27.07	3.97	6.47	0.00	9.71
192	8.00	6.86	51.03	0.38	2.59	28.32	4.36	6.47	0.00	6.86
216	9.00	5.71	51.31	0.43	3.10	28.25	4.73	6.47	0.00	5.71
240	10.00	3.68	51.72	0.37	3.75	28.92	5.10	6.47	0.00	3.68
264	11.00	2.27	51.98	0.43	4.28	29.13	5.45	6.47	0.00	2.27
288	12.00	1.12	52.17	0.39	4.92	29.15	5.79	6.47	0.00	1.12
336	14.00	0.44	52.28	0.32	6.11	27.94	6.43	6.47	0.00	0.44
384	16.00	0.16	52.33	0.33	7.12	26.57	7.04	6.47	0.00	0.16
432	18.00	0.05	52.34	0.26	8.09	25.19	7.61	6.47	0.00	0.05
480	20.00	0.02	52.34	0.25	8.90	23.88	8.14	6.47	0.00	0.02
600	25.00	0.00	52.35	0.18	10.62	21.03	9.36	6.47	0.00	0.00
720	30.00	0.00	52.35	0.13	11.90	18.73	10.42	6.47	0.00	0.00
840	35.00	0.00	52.35	0.13	12.83	16.85	11.37	6.47	0.00	0.00
1080	45.00	0.00	52.35	0.07	14.15	13.99	12.98	6.47	0.00	0.00
1200	50.00	0.00	52.35	0.07	14.57	12.88	13.67	6.47	0.00	0.00
1320	55.00	0.00	52.35	0.05	14.91	11.93	14.30	6.47	0.00	0.00
Maximum	56.00	99.18	52.35	0.43	14.97	29.15	14.42	6.47	0.00	99.18

Table XVII.B-13 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.31	0.65	0.00	0.00	0.00	0.05	0.00	0.00	99.31
4	0.17	98.22	1.69	0.00	0.00	0.00	0.09	0.00	0.00	98.22
6	0.25	93.34	5.20	0.00	0.00	1.29	0.17	0.00	0.00	93.34
8	0.33	91.55	6.89	0.00	0.00	1.31	0.25	0.00	0.00	91.55
10	0.42	88.99	9.03	0.00	0.00	1.67	0.32	0.00	0.00	88.99
12	0.50	80.14	14.41	0.01	0.00	5.05	0.39	0.00	0.00	80.14
14	0.58	75.36	17.65	0.01	0.00	6.51	0.46	0.00	0.00	75.36
16	0.67	71.81	20.24	0.01	0.00	7.41	0.53	0.00	0.00	71.81
18	0.75	69.77	21.93	0.01	0.00	7.69	0.60	0.00	0.00	69.77
20	0.83	68.43	23.13	0.01	0.00	7.76	0.66	0.00	0.00	68.43
22	0.92	66.23	24.55	0.00	0.00	8.49	0.73	0.00	0.00	66.23
24	1.00	65.32	25.33	0.06	0.00	8.49	0.79	0.00	0.00	65.32
28	1.17	63.22	26.85	0.04	0.02	8.95	0.91	0.00	0.00	63.22
32	1.33	60.57	28.73	0.02	0.04	9.61	1.03	0.00	0.00	60.57
36	1.50	58.60	30.10	0.09	0.05	10.01	1.15	0.00	0.00	58.60
40	1.67	56.74	31.26	0.07	0.07	10.59	1.26	0.00	0.00	56.74
44	1.83	55.62	32.01	0.04	0.10	10.86	1.38	0.00	0.00	55.62
48	2.00	54.61	32.61	0.13	0.11	11.05	1.49	0.00	0.00	54.61
54	2.25	52.37	33.86	0.07	0.17	11.88	1.65	0.00	0.00	52.37
60	2.50	50.51	35.04	0.16	0.21	12.27	1.82	0.00	0.00	50.51
66	2.75	47.13	36.98	0.08	0.32	13.51	1.97	0.00	0.00	47.13
72	3.00	42.81	39.09	0.17	0.34	15.46	2.13	0.00	0.00	42.81
78	3.25	41.21	39.89	0.09	0.42	16.12	2.27	0.00	0.00	41.21
84	3.50	39.62	40.68	0.20	0.46	16.61	2.42	0.00	0.00	39.62
90	3.75	38.43	41.38	0.08	0.57	16.98	2.56	0.00	0.00	38.43
96	4.00	37.07	42.00	0.22	0.61	17.40	2.71	0.00	0.00	37.07
108	4.50	33.90	43.44	0.24	0.76	18.67	2.98	0.00	0.00	33.90

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
120	5.00	31.43	44.57	0.27	0.93	19.54	3.25	0.00	0.00	31.43
132	5.50	26.91	46.37	0.29	1.13	21.80	3.51	0.00	0.00	26.91
144	6.00	21.88	48.53	0.26	1.38	24.19	3.76	0.00	0.00	21.88
156	6.50	20.21	49.36	0.28	1.58	24.56	4.00	0.00	0.00	20.21
168	7.00	18.84	50.15	0.26	1.81	24.70	4.24	0.00	0.00	18.84
192	8.00	16.78	51.35	0.26	2.27	24.64	4.69	0.00	0.00	16.78
216	9.00	14.20	52.37	0.27	2.70	25.34	5.12	0.00	0.00	14.20
240	10.00	12.94	52.78	0.30	3.09	25.36	5.53	0.00	0.00	12.94
264	11.00	11.29	53.17	0.28	3.53	25.80	5.94	0.00	0.00	11.29
288	12.00	9.85	53.45	0.33	3.92	26.12	6.33	0.00	0.00	9.85
336	14.00	8.87	53.69	0.44	4.86	25.06	7.08	0.00	0.00	8.87
384	16.00	8.00	53.84	0.30	5.58	24.49	7.79	0.00	0.00	8.00
432	18.00	7.40	53.90	0.26	6.40	23.56	8.47	0.00	0.00	7.40
480	20.00	6.68	53.97	0.36	7.10	22.77	9.12	0.00	0.00	6.68
600	25.00	2.85	54.48	0.25	8.71	23.11	10.61	0.00	0.00	2.85
720	30.00	0.73	54.76	0.19	10.14	22.25	11.92	0.00	0.00	0.73
840	35.00	0.17	54.83	0.15	11.46	20.32	13.08	0.00	0.00	0.17
1080	45.00	0.04	54.85	0.09	13.23	16.74	15.04	0.00	0.00	0.04
1200	50.00	0.01	54.85	0.08	13.83	15.35	15.87	0.00	0.00	0.01
1320	55.00	0.00	54.86	0.06	14.30	14.15	16.63	0.00	0.00	0.00
Maximum	56.00	99.57	54.86	0.57	14.39	26.12	16.77	0.00	0.00	99.57

Table XVII.B-14 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.31	0.65	0.00	0.00	0.00	0.05	0.00	0.00	99.31
4	0.17	98.22	1.69	0.00	0.00	0.00	0.09	0.00	0.00	98.22
6	0.25	93.36	5.19	0.00	0.00	1.28	0.17	0.00	0.00	93.36
8	0.33	91.53	6.90	0.00	0.00	1.32	0.25	0.00	0.00	91.53
10	0.42	87.24	9.97	0.00	0.00	2.47	0.32	0.00	0.00	87.24
12	0.50	81.62	13.64	0.01	0.00	4.33	0.39	0.00	0.00	81.62
14	0.58	74.40	18.12	0.01	0.00	6.93	0.46	0.07	0.00	74.40
16	0.67	71.47	20.36	0.01	0.00	7.49	0.53	0.13	0.00	71.47
18	0.75	69.50	21.99	0.01	0.01	7.71	0.60	0.20	0.00	69.50
20	0.83	67.86	23.29	0.00	0.01	7.90	0.66	0.29	0.00	67.86
22	0.92	65.93	24.54	0.00	0.01	8.42	0.72	0.37	0.00	65.93
24	1.00	64.51	25.54	0.07	0.01	8.67	0.79	0.43	0.00	64.51
28	1.17	62.01	27.17	0.05	0.02	9.27	0.91	0.57	0.00	62.01
32	1.33	59.17	29.08	0.02	0.04	9.98	1.03	0.68	0.00	59.17
36	1.50	57.09	30.42	0.11	0.05	10.36	1.14	0.83	0.00	57.09
40	1.67	54.71	31.70	0.07	0.08	11.12	1.26	1.06	0.00	54.71
44	1.83	53.02	32.61	0.04	0.11	11.62	1.37	1.24	0.00	53.02
48	2.00	51.06	33.49	0.15	0.12	12.20	1.47	1.50	0.00	51.06
54	2.25	48.04	35.01	0.08	0.19	13.44	1.63	1.61	0.00	48.04
60	2.50	45.96	36.24	0.19	0.24	13.96	1.79	1.61	0.00	45.96
66	2.75	40.83	38.83	0.12	0.38	16.30	1.94	1.61	0.00	40.83
72	3.00	38.83	39.99	0.22	0.40	16.86	2.09	1.61	0.00	38.83
78	3.25	37.44	40.72	0.10	0.49	17.42	2.23	1.61	0.00	37.44
84	3.50	36.19	41.36	0.22	0.54	17.71	2.37	1.61	0.00	36.19
90	3.75	34.75	42.14	0.09	0.66	18.25	2.51	1.61	0.00	34.75
96	4.00	33.72	42.63	0.24	0.70	18.46	2.64	1.61	0.00	33.72

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	30.69	43.99	0.27	0.87	19.66	2.91	1.61	0.00	30.69
120	5.00	29.22	44.76	0.29	1.06	19.90	3.17	1.61	0.00	29.22
132	5.50	25.12	46.38	0.30	1.27	21.91	3.42	1.61	0.00	25.12
144	6.00	19.74	48.61	0.27	1.53	24.57	3.66	1.61	0.00	19.74
156	6.50	18.35	49.33	0.30	1.75	24.76	3.89	1.61	0.00	18.35
168	7.00	17.30	50.00	0.29	2.00	24.69	4.12	1.61	0.00	17.30
192	8.00	15.56	51.08	0.31	2.48	24.41	4.56	1.61	0.00	15.56
216	9.00	13.81	51.92	0.32	2.92	24.45	4.97	1.61	0.00	13.81
240	10.00	12.94	52.24	0.29	3.32	24.22	5.37	1.61	0.00	12.94
264	11.00	11.11	52.64	0.27	3.76	24.85	5.76	1.61	0.00	11.11
288	12.00	7.81	53.19	0.32	4.15	26.77	6.14	1.61	0.00	7.81
336	14.00	5.35	53.56	0.73	5.08	26.81	6.87	1.61	0.00	5.35
384	16.00	3.90	53.83	0.33	5.85	26.94	7.55	1.61	0.00	3.90
432	18.00	1.69	54.12	0.25	6.76	27.38	8.20	1.61	0.00	1.69
480	20.00	0.89	54.22	0.30	7.56	26.60	8.82	1.61	0.00	0.89
600	25.00	0.00	54.34	0.17	9.25	24.41	10.22	1.61	0.00	0.00
720	30.00	0.00	54.34	0.15	10.49	21.94	11.47	1.61	0.00	0.00
840	35.00	0.00	54.34	0.10	11.44	19.92	12.58	1.61	0.00	0.00
1080	45.00	0.00	54.34	0.07	12.67	16.81	14.51	1.61	0.00	0.00
1200	50.00	0.00	54.34	0.05	13.07	15.58	15.34	1.61	0.00	0.00
1320	55.00	0.00	54.34	0.05	13.37	14.52	16.11	1.61	0.00	0.00
Maximum	56.00	99.57	54.34	0.73	13.42	27.80	16.26	1.61	0.00	99.57

Table XVII.B-15 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.31	0.65	0.00	0.00	0.00	0.05	0.00	0.00	99.31
4	0.17	98.22	1.69	0.00	0.00	0.00	0.09	0.00	0.00	98.22
6	0.25	93.36	5.19	0.00	0.00	1.28	0.17	0.00	0.00	93.36
8	0.33	91.43	6.90	0.00	0.00	1.32	0.25	0.09	0.00	91.43
10	0.42	87.13	9.97	0.00	0.00	2.47	0.32	0.12	0.00	87.13
12	0.50	81.42	13.64	0.01	0.00	4.33	0.39	0.20	0.00	81.42
14	0.58	74.07	18.12	0.01	0.00	6.93	0.46	0.40	0.00	74.07
16	0.67	71.03	20.35	0.01	0.00	7.49	0.53	0.59	0.00	71.03
18	0.75	68.94	21.97	0.01	0.01	7.71	0.60	0.77	0.00	68.94
20	0.83	67.30	23.20	0.00	0.01	7.83	0.66	1.00	0.00	67.30
22	0.92	64.00	25.06	0.00	0.01	9.01	0.72	1.21	0.00	64.00
24	1.00	62.75	25.92	0.06	0.01	9.12	0.78	1.36	0.00	62.75
28	1.17	60.00	27.56	0.04	0.02	9.76	0.90	1.71	0.00	60.00
32	1.33	57.35	29.27	0.02	0.04	10.28	1.02	2.01	0.00	57.35
36	1.50	54.36	30.92	0.10	0.05	11.09	1.13	2.35	0.00	54.36
40	1.67	52.33	31.99	0.07	0.08	11.61	1.24	2.68	0.00	52.33
44	1.83	50.64	32.79	0.04	0.11	11.99	1.35	3.08	0.00	50.64
48	2.00	49.16	33.41	0.14	0.12	12.24	1.45	3.48	0.00	49.16
54	2.25	46.56	34.71	0.07	0.18	13.20	1.61	3.66	0.00	46.56
60	2.50	45.10	35.68	0.17	0.23	13.39	1.76	3.66	0.00	45.10
66	2.75	40.63	38.00	0.11	0.35	15.34	1.91	3.66	0.00	40.63
72	3.00	36.49	40.00	0.21	0.37	17.21	2.05	3.66	0.00	36.49
78	3.25	34.12	41.08	0.11	0.46	18.39	2.19	3.66	0.00	34.12
84	3.50	32.86	41.72	0.24	0.51	18.68	2.32	3.66	0.00	32.86
90	3.75	32.07	42.23	0.10	0.64	18.83	2.45	3.66	0.00	32.07

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	31.49	42.56	0.24	0.68	18.78	2.59	3.66	0.00	31.49
108	4.50	28.35	43.95	0.27	0.85	20.07	2.84	3.66	0.00	28.35
120	5.00	26.21	44.93	0.30	1.04	20.76	3.09	3.66	0.00	26.21
132	5.50	22.36	46.45	0.30	1.26	22.63	3.34	3.66	0.00	22.36
144	6.00	19.17	47.95	0.27	1.52	23.86	3.57	3.66	0.00	19.17
156	6.50	17.79	48.67	0.30	1.73	24.06	3.79	3.66	0.00	17.79
168	7.00	16.93	49.27	0.27	1.97	23.89	4.01	3.66	0.00	16.93
192	8.00	15.05	50.37	0.29	2.41	23.77	4.44	3.66	0.00	15.05
216	9.00	13.23	51.20	0.28	2.84	23.95	4.84	3.66	0.00	13.23
240	10.00	11.92	51.58	0.30	3.23	24.08	5.23	3.66	0.00	11.92
264	11.00	10.79	51.85	0.28	3.67	24.14	5.61	3.66	0.00	10.79
288	12.00	9.45	52.10	0.31	4.05	24.45	5.98	3.66	0.00	9.45
336	14.00	7.08	52.40	1.15	4.93	24.09	6.69	3.66	0.00	7.08
384	16.00	7.42	52.47	0.32	5.61	23.16	7.36	3.66	0.00	7.42
432	18.00	6.97	52.51	0.28	6.35	22.23	8.00	3.66	0.00	6.97
480	20.00	6.33	52.56	0.37	6.99	21.47	8.61	3.66	0.00	6.33
600	25.00	3.89	52.88	0.24	8.45	20.86	10.02	3.66	0.00	3.89
720	30.00	2.37	53.07	0.18	9.87	19.58	11.26	3.66	0.00	2.37
840	35.00	0.94	53.22	0.34	11.12	18.34	12.36	3.66	0.00	0.94
1080	45.00	0.17	53.34	0.12	13.11	15.39	14.20	3.66	0.00	0.17
1200	50.00	0.00	53.36	0.09	13.83	14.07	14.97	3.66	0.00	0.00
1320	55.00	0.00	53.36	0.08	14.40	12.84	15.66	3.66	0.00	0.00
Maximum	56.00	99.57	53.36	1.15	14.50	24.61	15.79	3.66	0.00	99.57

Table XVII.B-16 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.31	0.65	0.00	0.00	0.00	0.05	0.00	0.00	99.31
4	0.17	98.22	1.69	0.00	0.00	0.00	0.09	0.00	0.00	98.22
6	0.25	93.13	5.19	0.00	0.00	1.28	0.17	0.24	0.00	93.13
8	0.33	91.25	6.90	0.00	0.00	1.32	0.25	0.28	0.00	91.25
10	0.42	86.90	9.96	0.00	0.00	2.47	0.32	0.35	0.00	86.90
12	0.50	81.03	13.64	0.01	0.00	4.33	0.39	0.60	0.00	81.03
14	0.58	73.18	18.33	0.01	0.00	7.15	0.46	0.86	0.00	73.18
16	0.67	69.49	20.85	0.01	0.00	8.01	0.53	1.11	0.00	69.49
18	0.75	67.32	22.47	0.01	0.00	8.26	0.59	1.35	0.00	67.32
20	0.83	65.54	23.71	0.00	0.01	8.42	0.66	1.66	0.00	65.54
22	0.92	63.96	24.69	0.00	0.01	8.68	0.72	1.94	0.00	63.96
24	1.00	62.86	25.46	0.07	0.01	8.68	0.78	2.15	0.00	62.86
28	1.17	59.95	27.08	0.05	0.02	9.28	0.90	2.73	0.00	59.95
32	1.33	56.78	28.94	0.03	0.04	9.96	1.01	3.23	0.00	56.78
36	1.50	54.25	30.27	0.11	0.05	10.36	1.12	3.84	0.00	54.25
40	1.67	51.98	31.36	0.07	0.08	10.90	1.23	4.37	0.00	51.98
44	1.83	50.44	32.10	0.04	0.11	11.20	1.34	4.77	0.00	50.44
48	2.00	48.46	32.91	0.14	0.12	11.71	1.44	5.22	0.00	48.46
54	2.25	45.73	34.21	0.07	0.18	12.69	1.59	5.52	0.00	45.73
60	2.50	44.07	35.26	0.17	0.23	13.01	1.74	5.52	0.00	44.07
66	2.75	39.17	37.74	0.11	0.35	15.23	1.88	5.52	0.00	39.17
72	3.00	34.80	39.81	0.22	0.37	17.26	2.02	5.52	0.00	34.80
78	3.25	33.32	40.54	0.12	0.45	17.90	2.15	5.52	0.00	33.32
84	3.50	32.03	41.19	0.23	0.50	18.25	2.29	5.52	0.00	32.03
90	3.75	31.15	41.73	0.11	0.62	18.46	2.41	5.52	0.00	31.15

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	30.44	42.10	0.23	0.66	18.51	2.54	5.52	0.00	30.44
108	4.50	28.22	43.15	0.25	0.82	19.24	2.79	5.52	0.00	28.22
120	5.00	25.80	44.22	0.27	0.99	20.16	3.04	5.52	0.00	25.80
132	5.50	22.18	45.66	0.27	1.19	21.90	3.28	5.52	0.00	22.18
144	6.00	19.47	47.01	0.26	1.43	22.81	3.50	5.52	0.00	19.47
156	6.50	18.42	47.64	0.27	1.61	22.82	3.72	5.52	0.00	18.42
168	7.00	17.31	48.32	0.24	1.82	22.85	3.94	5.52	0.00	17.31
192	8.00	15.44	49.43	0.29	2.22	22.74	4.36	5.52	0.00	15.44
216	9.00	14.28	50.16	0.24	2.58	22.46	4.75	5.52	0.00	14.28
240	10.00	13.29	50.50	0.25	2.91	22.39	5.14	5.52	0.00	13.29
264	11.00	11.51	50.89	0.24	3.28	23.05	5.51	5.52	0.00	11.51
288	12.00	9.89	51.19	0.28	3.61	23.64	5.88	5.52	0.00	9.89
336	14.00	7.43	51.50	1.08	4.42	23.47	6.57	5.52	0.00	7.43
384	16.00	7.43	51.57	0.53	5.06	22.65	7.24	5.52	0.00	7.43
432	18.00	7.12	51.62	0.31	5.76	21.80	7.87	5.52	0.00	7.12
480	20.00	6.30	51.66	0.77	6.36	20.91	8.48	5.52	0.00	6.30
600	25.00	6.10	51.74	0.21	7.63	18.92	9.88	5.52	0.00	6.10
720	30.00	3.63	52.05	0.14	8.63	18.88	11.14	5.52	0.00	3.63
840	35.00	2.26	52.19	0.36	9.58	17.81	12.28	5.52	0.00	2.26
1080	45.00	1.32	52.31	0.11	11.01	15.50	14.22	5.52	0.00	1.32
1200	50.00	0.72	52.39	0.11	11.54	14.66	15.06	5.52	0.00	0.72
1320	55.00	0.56	52.41	0.08	12.01	13.60	15.82	5.52	0.00	0.56
Maximum	56.00	99.57	52.42	1.08	12.10	23.87	15.96	5.52	0.00	99.57

Table XVII.B-17 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lummi Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.91	1.89	1.14	0.00	0.00	0.05	0.00	0.00	96.91
4	0.17	94.00	4.13	1.62	0.00	0.17	0.09	0.00	0.00	94.00
6	0.25	90.05	8.29	0.76	0.00	0.73	0.16	0.00	0.00	90.05
8	0.33	86.22	11.72	0.66	0.00	1.16	0.24	0.00	0.00	86.22
10	0.42	84.16	13.80	0.45	0.00	1.27	0.31	0.00	0.00	84.16
12	0.50	82.16	15.62	0.39	0.00	1.45	0.38	0.00	0.00	82.16
14	0.58	79.82	17.49	0.35	0.01	1.88	0.45	0.00	0.00	79.82
16	0.67	78.32	18.77	0.33	0.02	2.04	0.52	0.00	0.00	78.32
18	0.75	77.67	19.45	0.20	0.03	2.07	0.59	0.00	0.00	77.67
20	0.83	76.84	20.04	0.19	0.03	2.26	0.65	0.00	0.00	76.84
22	0.92	76.21	20.54	0.17	0.03	2.33	0.72	0.00	0.00	76.21
24	1.00	75.42	21.28	0.20	0.03	2.28	0.78	0.00	0.00	75.42
28	1.17	73.56	22.91	0.27	0.07	2.28	0.91	0.00	0.00	73.56
32	1.33	71.99	24.26	0.33	0.09	2.30	1.04	0.00	0.00	71.99
36	1.50	69.83	25.90	0.74	0.09	2.28	1.16	0.00	0.00	69.83
40	1.67	68.58	27.09	0.63	0.14	2.29	1.28	0.00	0.00	68.58
44	1.83	68.25	27.62	0.29	0.15	2.29	1.40	0.00	0.00	68.25
48	2.00	67.82	28.00	0.27	0.15	2.24	1.52	0.00	0.00	67.82
54	2.25	67.29	28.35	0.21	0.17	2.28	1.69	0.00	0.00	67.29
60	2.50	66.90	28.60	0.22	0.19	2.22	1.87	0.00	0.00	66.90
66	2.75	66.33	29.02	0.16	0.23	2.22	2.04	0.00	0.00	66.33
72	3.00	65.53	29.58	0.18	0.25	2.23	2.21	0.00	0.00	65.53
78	3.25	64.73	30.07	0.13	0.29	2.39	2.38	0.00	0.00	64.73
84	3.50	64.05	30.50	0.16	0.30	2.43	2.55	0.00	0.00	64.05
90	3.75	63.45	30.85	0.13	0.33	2.52	2.72	0.00	0.00	63.45
96	4.00	62.48	31.51	0.16	0.36	2.60	2.88	0.00	0.00	62.48

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	60.79	32.54	0.16	0.41	2.89	3.21	0.00	0.00	60.79
120	5.00	58.71	33.82	0.16	0.47	3.31	3.52	0.00	0.00	58.71
132	5.50	54.13	36.06	0.20	0.54	5.24	3.83	0.00	0.00	54.13
144	6.00	50.72	37.82	0.25	0.64	6.45	4.12	0.00	0.00	50.72
156	6.50	47.20	39.83	0.31	0.77	7.49	4.41	0.00	0.00	47.20
168	7.00	44.60	41.18	0.31	0.91	8.32	4.68	0.00	0.00	44.60
192	8.00	33.54	45.73	0.51	1.28	13.74	5.20	0.00	0.00	33.54
216	9.00	26.29	48.44	0.40	1.68	17.51	5.67	0.00	0.00	26.29
240	10.00	20.66	50.35	0.64	2.15	20.08	6.12	0.00	0.00	20.66
264	11.00	14.96	51.78	0.55	2.68	23.49	6.54	0.00	0.00	14.96
288	12.00	12.31	52.41	0.56	3.32	24.45	6.94	0.00	0.00	12.31
336	14.00	10.06	52.80	0.49	4.68	24.25	7.71	0.00	0.00	10.06
384	16.00	3.61	53.70	0.69	6.01	27.58	8.42	0.00	0.00	3.61
432	18.00	1.48	53.99	0.57	7.80	27.08	9.08	0.00	0.00	1.48
480	20.00	1.09	54.05	0.51	9.37	25.28	9.69	0.00	0.00	1.09
600	25.00	0.35	54.15	0.43	12.65	21.42	11.00	0.00	0.00	0.35
720	30.00	0.01	54.20	0.34	15.03	18.33	12.09	0.00	0.00	0.01
840	35.00	0.00	54.20	0.25	16.84	15.70	13.01	0.00	0.00	0.00
1080	45.00	0.00	54.20	0.16	19.13	12.04	14.46	0.00	0.00	0.00
1200	50.00	0.00	54.20	0.12	19.86	10.76	15.05	0.00	0.00	0.00
1320	55.00	0.00	54.20	0.11	20.39	9.72	15.58	0.00	0.00	0.00
Maximum	56.00	97.75	54.20	1.62	20.47	27.58	15.67	0.00	0.00	97.75

Table XVII.B-18 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lummi Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.92	1.89	1.15	0.00	0.00	0.05	0.00	0.00	96.92
4	0.17	93.99	4.09	1.67	0.00	0.16	0.09	0.00	0.00	93.99
6	0.25	89.81	8.19	1.15	0.00	0.69	0.16	0.00	0.00	89.81
8	0.33	86.12	11.64	0.84	0.00	1.16	0.24	0.00	0.00	86.12
10	0.42	84.05	13.72	0.65	0.00	1.27	0.31	0.00	0.00	84.05
12	0.50	81.85	15.64	0.56	0.00	1.57	0.38	0.00	0.00	81.85
14	0.58	79.50	17.53	0.40	0.01	2.03	0.45	0.07	0.00	79.50
16	0.67	78.01	18.77	0.41	0.02	2.14	0.52	0.13	0.00	78.01
18	0.75	77.29	19.48	0.18	0.03	2.21	0.59	0.22	0.00	77.29
20	0.83	76.42	20.06	0.17	0.03	2.38	0.65	0.28	0.00	76.42
22	0.92	75.77	20.57	0.12	0.03	2.45	0.72	0.34	0.00	75.77
24	1.00	74.88	21.30	0.20	0.04	2.39	0.78	0.42	0.00	74.88
28	1.17	72.74	22.94	0.34	0.07	2.41	0.91	0.59	0.00	72.74
32	1.33	71.12	24.30	0.25	0.09	2.45	1.04	0.75	0.00	71.12
36	1.50	68.77	25.97	0.64	0.10	2.46	1.16	0.91	0.00	68.77
40	1.67	67.24	27.16	0.50	0.15	2.50	1.28	1.19	0.00	67.24
44	1.83	66.48	27.69	0.29	0.16	2.52	1.39	1.47	0.00	66.48
48	2.00	65.84	28.05	0.26	0.16	2.46	1.51	1.72	0.00	65.84
54	2.25	65.24	28.37	0.21	0.19	2.47	1.68	1.85	0.00	65.24
60	2.50	64.51	28.75	0.23	0.20	2.61	1.85	1.85	0.00	64.51
66	2.75	63.94	29.16	0.17	0.25	2.62	2.02	1.85	0.00	63.94
72	3.00	63.22	29.68	0.19	0.27	2.61	2.18	1.85	0.00	63.22
78	3.25	62.68	30.05	0.13	0.30	2.64	2.35	1.85	0.00	62.68
84	3.50	61.98	30.48	0.16	0.32	2.69	2.51	1.85	0.00	61.98
90	3.75	61.36	30.83	0.12	0.35	2.81	2.67	1.85	0.00	61.36
96	4.00	60.40	31.48	0.15	0.38	2.92	2.83	1.85	0.00	60.40

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	58.78	32.45	0.15	0.44	3.18	3.15	1.85	0.00	58.78
120	5.00	56.40	33.83	0.17	0.50	3.80	3.46	1.85	0.00	56.40
132	5.50	52.16	35.92	0.20	0.57	5.55	3.76	1.85	0.00	52.16
144	6.00	49.18	37.48	0.24	0.67	6.54	4.04	1.85	0.00	49.18
156	6.50	45.77	39.40	0.34	0.80	7.53	4.32	1.85	0.00	45.77
168	7.00	43.84	40.54	0.31	0.93	7.95	4.59	1.85	0.00	43.84
192	8.00	33.33	44.97	0.51	1.29	12.96	5.09	1.85	0.00	33.33
216	9.00	27.01	47.48	0.39	1.68	16.03	5.56	1.85	0.00	27.01
240	10.00	21.51	49.41	0.57	2.17	18.50	5.99	1.85	0.00	21.51
264	11.00	15.89	50.87	0.57	2.75	21.67	6.41	1.85	0.00	15.89
288	12.00	13.64	51.47	0.60	3.43	22.22	6.80	1.85	0.00	13.64
336	14.00	11.57	51.81	0.69	4.85	21.68	7.54	1.85	0.00	11.57
384	16.00	6.08	52.61	0.67	6.19	24.37	8.23	1.85	0.00	6.08
432	18.00	4.10	52.88	0.60	7.94	23.76	8.87	1.85	0.00	4.10
480	20.00	3.57	52.96	0.53	9.46	22.19	9.46	1.85	0.00	3.57
600	25.00	2.49	53.10	0.45	12.65	18.73	10.73	1.85	0.00	2.49
720	30.00	0.47	53.37	0.37	15.09	17.08	11.78	1.85	0.00	0.47
840	35.00	0.00	53.42	0.28	17.17	14.63	12.65	1.85	0.00	0.00
1080	45.00	0.00	53.42	0.18	19.83	10.73	13.98	1.85	0.00	0.00
1200	50.00	0.00	53.42	0.13	20.69	9.40	14.51	1.85	0.00	0.00
1320	55.00	0.00	53.42	0.12	21.30	8.35	14.96	1.85	0.00	0.00
Maximum	56.00	97.75	53.42	1.67	21.39	24.37	15.04	1.85	0.00	97.75

Table XVII.B-19 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lummi Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.92	1.89	1.15	0.00	0.00	0.05	0.00	0.00	96.92
4	0.17	93.99	4.09	1.67	0.00	0.16	0.09	0.00	0.00	93.99
6	0.25	89.81	8.19	1.15	0.00	0.69	0.16	0.00	0.00	89.81
8	0.33	86.27	11.61	0.66	0.00	1.15	0.24	0.08	0.00	86.27
10	0.42	84.33	13.66	0.38	0.00	1.24	0.31	0.08	0.00	84.33
12	0.50	82.14	15.43	0.52	0.00	1.38	0.38	0.15	0.00	82.14
14	0.58	79.31	17.45	0.46	0.01	1.97	0.45	0.35	0.00	79.31
16	0.67	77.76	18.67	0.43	0.02	2.07	0.52	0.54	0.00	77.76
18	0.75	76.96	19.36	0.23	0.02	2.13	0.59	0.72	0.00	76.96
20	0.83	76.07	19.90	0.22	0.03	2.25	0.65	0.89	0.00	76.07
22	0.92	75.31	20.39	0.20	0.03	2.30	0.72	1.05	0.00	75.31
24	1.00	74.28	21.12	0.29	0.03	2.25	0.78	1.25	0.00	74.28
28	1.17	72.16	22.74	0.17	0.07	2.26	0.91	1.69	0.00	72.16
32	1.33	70.08	24.14	0.21	0.08	2.35	1.03	2.10	0.00	70.08
36	1.50	67.58	25.77	0.63	0.09	2.34	1.15	2.44	0.00	67.58
40	1.67	66.19	26.92	0.51	0.13	2.35	1.27	2.63	0.00	66.19
44	1.83	65.41	27.44	0.29	0.14	2.35	1.38	2.97	0.00	65.41
48	2.00	64.51	27.79	0.33	0.15	2.30	1.49	3.42	0.00	64.51
54	2.25	63.89	28.09	0.24	0.17	2.30	1.66	3.64	0.00	63.89
60	2.50	63.52	28.34	0.24	0.19	2.25	1.83	3.64	0.00	63.52
66	2.75	62.91	28.75	0.20	0.23	2.28	1.99	3.64	0.00	62.91
72	3.00	62.20	29.28	0.19	0.25	2.29	2.16	3.64	0.00	62.20
78	3.25	61.47	29.72	0.16	0.28	2.42	2.32	3.64	0.00	61.47
84	3.50	60.91	30.09	0.18	0.30	2.41	2.48	3.64	0.00	60.91
90	3.75	60.03	30.53	0.15	0.33	2.69	2.64	3.64	0.00	60.03

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	59.06	31.18	0.16	0.35	2.81	2.79	3.64	0.00	59.06
108	4.50	57.28	32.21	0.16	0.41	3.20	3.10	3.64	0.00	57.28
120	5.00	55.05	33.52	0.18	0.48	3.73	3.40	3.64	0.00	55.05
132	5.50	50.84	35.60	0.21	0.56	5.46	3.69	3.64	0.00	50.84
144	6.00	48.13	37.06	0.24	0.66	6.31	3.97	3.64	0.00	48.13
156	6.50	44.56	39.02	0.31	0.79	7.44	4.24	3.64	0.00	44.56
168	7.00	42.52	40.16	0.31	0.93	7.94	4.50	3.64	0.00	42.52
192	8.00	28.91	45.33	0.56	1.31	15.25	4.99	3.64	0.00	28.91
216	9.00	20.52	48.24	0.37	1.72	20.07	5.44	3.64	0.00	20.52
240	10.00	16.05	49.72	0.75	2.20	21.79	5.86	3.64	0.00	16.05
264	11.00	12.44	50.71	0.59	2.71	23.67	6.25	3.64	0.00	12.44
288	12.00	9.73	51.36	0.48	3.28	24.88	6.63	3.64	0.00	9.73
336	14.00	7.21	51.78	0.45	4.51	25.06	7.36	3.64	0.00	7.21
384	16.00	3.04	52.37	0.58	5.67	26.67	8.04	3.64	0.00	3.04
432	18.00	0.60	52.71	0.48	7.18	26.73	8.66	3.64	0.00	0.60
480	20.00	0.36	52.75	0.44	8.50	25.08	9.24	3.64	0.00	0.36
600	25.00	0.00	52.79	0.32	11.22	21.50	10.52	3.64	0.00	0.00
720	30.00	0.00	52.79	0.29	13.18	18.50	11.61	3.64	0.00	0.00
840	35.00	0.00	52.79	0.22	14.65	16.16	12.54	3.64	0.00	0.00
1080	45.00	0.00	52.79	0.15	16.52	12.84	14.06	3.64	0.00	0.00
1200	50.00	0.00	52.79	0.11	17.12	11.63	14.70	3.64	0.00	0.00
1320	55.00	0.00	52.79	0.10	17.56	10.64	15.27	3.64	0.00	0.00
Maximum	56.00	97.75	52.79	1.67	17.62	26.94	15.37	3.64	0.00	97.75

Table XVII.B-20 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lummi Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.92	1.89	1.15	0.00	0.00	0.05	0.00	0.00	96.92
4	0.17	93.99	4.09	1.67	0.00	0.16	0.09	0.00	0.00	93.99
6	0.25	89.56	8.22	1.04	0.00	0.70	0.16	0.31	0.00	89.56
8	0.33	85.82	11.65	0.85	0.00	1.13	0.24	0.31	0.00	85.82
10	0.42	83.83	13.69	0.67	0.00	1.18	0.31	0.31	0.00	83.83
12	0.50	81.71	15.51	0.50	0.00	1.37	0.38	0.52	0.00	81.71
14	0.58	79.02	17.45	0.39	0.01	1.89	0.45	0.79	0.00	79.02
16	0.67	77.55	18.62	0.33	0.02	1.92	0.52	1.04	0.00	77.55
18	0.75	76.58	19.31	0.25	0.02	1.98	0.58	1.28	0.00	76.58
20	0.83	75.63	19.85	0.24	0.03	2.10	0.65	1.51	0.00	75.63
22	0.92	74.82	20.33	0.24	0.03	2.15	0.71	1.72	0.00	74.82
24	1.00	73.85	21.06	0.19	0.03	2.10	0.78	2.00	0.00	73.85
28	1.17	71.22	22.68	0.31	0.06	2.12	0.90	2.70	0.00	71.22
32	1.33	69.37	24.01	0.21	0.08	2.14	1.02	3.17	0.00	69.37
36	1.50	66.56	25.67	0.68	0.09	2.20	1.14	3.66	0.00	66.56
40	1.67	65.18	26.82	0.47	0.13	2.23	1.26	3.92	0.00	65.18
44	1.83	64.29	27.35	0.30	0.14	2.24	1.37	4.31	0.00	64.29
48	2.00	63.38	27.70	0.23	0.14	2.21	1.48	4.86	0.00	63.38
54	2.25	62.64	28.00	0.16	0.16	2.21	1.64	5.17	0.00	62.64
60	2.50	62.26	28.24	0.18	0.18	2.16	1.81	5.17	0.00	62.26
66	2.75	61.47	28.73	0.13	0.21	2.31	1.97	5.17	0.00	61.47
72	3.00	60.56	29.32	0.15	0.23	2.43	2.13	5.17	0.00	60.56
78	3.25	59.76	29.79	0.12	0.26	2.61	2.28	5.17	0.00	59.76
84	3.50	59.12	30.18	0.15	0.28	2.64	2.44	5.17	0.00	59.12
90	3.75	58.43	30.54	0.13	0.31	2.82	2.60	5.17	0.00	58.43

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	57.56	31.14	0.15	0.34	2.89	2.75	5.17	0.00	57.56
108	4.50	55.77	32.16	0.16	0.39	3.30	3.05	5.17	0.00	55.77
120	5.00	53.65	33.39	0.19	0.46	3.79	3.34	5.17	0.00	53.65
132	5.50	49.28	35.50	0.21	0.53	5.67	3.63	5.17	0.00	49.28
144	6.00	47.03	36.78	0.24	0.64	6.23	3.90	5.17	0.00	47.03
156	6.50	44.15	38.52	0.27	0.77	6.96	4.17	5.17	0.00	44.15
168	7.00	42.42	39.53	0.31	0.90	7.24	4.42	5.17	0.00	42.42
192	8.00	31.29	44.05	0.57	1.23	12.77	4.91	5.17	0.00	31.29
216	9.00	24.17	46.68	0.45	1.62	16.56	5.35	5.17	0.00	24.17
240	10.00	18.97	48.48	0.58	2.12	18.90	5.77	5.17	0.00	18.97
264	11.00	13.37	49.88	0.58	2.70	22.14	6.16	5.17	0.00	13.37
288	12.00	10.24	50.60	0.55	3.39	23.51	6.53	5.17	0.00	10.24
336	14.00	7.99	50.99	0.54	4.88	23.19	7.23	5.17	0.00	7.99
384	16.00	4.31	51.54	0.63	6.23	24.24	7.88	5.17	0.00	4.31
432	18.00	2.97	51.71	0.50	7.86	23.31	8.48	5.17	0.00	2.97
480	20.00	1.67	51.89	0.48	9.23	22.52	9.04	5.17	0.00	1.67
600	25.00	0.00	52.12	0.37	12.51	19.59	10.23	5.17	0.00	0.00
720	30.00	0.00	52.12	0.33	14.89	16.28	11.21	5.17	0.00	0.00
840	35.00	0.00	52.12	0.24	16.65	13.80	12.02	5.17	0.00	0.00
1080	45.00	0.00	52.12	0.16	18.83	10.43	13.28	5.17	0.00	0.00
1200	50.00	0.00	52.12	0.12	19.51	9.28	13.79	5.17	0.00	0.00
1320	55.00	0.00	52.12	0.11	20.00	8.36	14.24	5.17	0.00	0.00
Maximum	56.00	97.75	52.12	1.67	20.07	24.24	14.32	5.17	0.00	97.75

Table XVII.B-21 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Padilla Bay.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.27	0.68	0.00	0.00	0.00	0.05	0.00	0.00	99.27
4	0.17	97.76	1.97	0.14	0.00	0.04	0.09	0.00	0.00	97.76
6	0.25	93.21	5.59	0.10	0.00	0.93	0.17	0.00	0.00	93.21
8	0.33	90.12	8.37	0.09	0.00	1.17	0.24	0.00	0.00	90.12
10	0.42	88.49	9.92	0.06	0.00	1.20	0.32	0.00	0.00	88.49
12	0.50	87.18	11.14	0.08	0.00	1.21	0.39	0.00	0.00	87.18
14	0.58	84.29	13.10	0.07	0.00	2.07	0.47	0.00	0.00	84.29
16	0.67	82.31	14.44	0.04	0.01	2.66	0.54	0.00	0.00	82.31
18	0.75	81.35	15.23	0.04	0.01	2.77	0.61	0.00	0.00	81.35
20	0.83	79.86	16.26	0.04	0.01	3.16	0.68	0.00	0.00	79.86
22	0.92	78.42	17.24	0.04	0.01	3.54	0.75	0.00	0.00	78.42
24	1.00	76.78	18.42	0.12	0.01	3.85	0.82	0.00	0.00	76.78
28	1.17	74.04	20.65	0.11	0.04	4.21	0.95	0.00	0.00	74.04
32	1.33	69.71	24.43	0.11	0.09	4.59	1.08	0.00	0.00	69.71
36	1.50	66.54	26.92	0.18	0.10	5.06	1.20	0.00	0.00	66.54
40	1.67	63.61	28.89	0.17	0.16	5.85	1.32	0.00	0.00	63.61
44	1.83	59.59	31.18	0.16	0.19	7.45	1.43	0.00	0.00	59.59
48	2.00	58.41	32.09	0.27	0.20	7.50	1.54	0.00	0.00	58.41
54	2.25	56.37	33.41	0.14	0.28	8.08	1.71	0.00	0.00	56.37
60	2.50	55.05	34.40	0.20	0.30	8.18	1.87	0.00	0.00	55.05
66	2.75	53.57	35.32	0.08	0.38	8.63	2.03	0.00	0.00	53.57
72	3.00	50.89	36.55	0.18	0.40	9.80	2.19	0.00	0.00	50.89
78	3.25	48.34	37.71	0.09	0.48	11.04	2.34	0.00	0.00	48.34
84	3.50	47.45	38.20	0.21	0.52	11.13	2.49	0.00	0.00	47.45
90	3.75	46.65	38.68	0.11	0.62	11.30	2.64	0.00	0.00	46.65
96	4.00	44.79	39.46	0.24	0.67	12.07	2.79	0.00	0.00	44.79

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	30.33	45.04	0.30	0.87	20.39	3.07	0.00	0.00	30.33
120	5.00	21.18	48.42	0.35	1.08	25.65	3.32	0.00	0.00	21.18
132	5.50	16.70	50.14	0.36	1.37	27.86	3.57	0.00	0.00	16.70
144	6.00	14.52	50.97	0.40	1.64	28.67	3.80	0.00	0.00	14.52
156	6.50	12.71	51.73	0.39	1.98	29.16	4.03	0.00	0.00	12.71
168	7.00	11.67	52.16	0.40	2.27	29.24	4.25	0.00	0.00	11.67
192	8.00	9.03	53.10	0.40	2.94	29.85	4.68	0.00	0.00	9.03
216	9.00	7.61	53.65	0.38	3.59	29.67	5.10	0.00	0.00	7.61
240	10.00	6.18	54.04	0.38	4.23	29.68	5.49	0.00	0.00	6.18
264	11.00	5.21	54.28	0.41	4.86	29.36	5.88	0.00	0.00	5.21
288	12.00	4.52	54.41	0.37	5.46	29.00	6.25	0.00	0.00	4.52
336	14.00	2.95	54.60	0.44	6.63	28.42	6.95	0.00	0.00	2.95
384	16.00	1.44	54.82	0.35	7.74	28.04	7.62	0.00	0.00	1.44
432	18.00	0.55	54.93	0.33	8.83	27.12	8.24	0.00	0.00	0.55
480	20.00	0.05	55.00	0.30	9.84	25.98	8.83	0.00	0.00	0.05
600	25.00	0.00	55.01	0.23	11.93	22.68	10.15	0.00	0.00	0.00
720	30.00	0.00	55.01	0.18	13.47	20.05	11.29	0.00	0.00	0.00
840	35.00	0.00	55.01	0.14	14.61	17.93	12.30	0.00	0.00	0.00
1080	45.00	0.00	55.01	0.10	16.09	14.79	14.01	0.00	0.00	0.00
1200	50.00	0.00	55.01	0.08	16.57	13.60	14.74	0.00	0.00	0.00
1320	55.00	0.00	55.01	0.06	16.95	12.59	15.40	0.00	0.00	0.00
Maximum	56.00	99.57	55.01	0.44	17.01	29.85	15.53	0.00	0.00	99.57

Table XVII.B-22 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Padilla Bay.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.27	0.68	0.00	0.00	0.00	0.05	0.00	0.00	99.27
4	0.17	97.76	1.97	0.14	0.00	0.04	0.09	0.00	0.00	97.76
6	0.25	93.21	5.59	0.10	0.00	0.93	0.17	0.00	0.00	93.21
8	0.33	90.12	8.37	0.09	0.00	1.17	0.24	0.00	0.00	90.12
10	0.42	88.49	9.92	0.06	0.00	1.20	0.32	0.00	0.00	88.49
12	0.50	87.18	11.14	0.08	0.00	1.21	0.39	0.00	0.00	87.18
14	0.58	84.65	12.88	0.07	0.00	1.86	0.47	0.07	0.00	84.65
16	0.67	82.39	14.32	0.07	0.01	2.54	0.54	0.13	0.00	82.39
18	0.75	81.33	15.13	0.07	0.01	2.66	0.61	0.20	0.00	81.33
20	0.83	79.70	16.20	0.06	0.01	3.09	0.68	0.26	0.00	79.70
22	0.92	77.81	17.37	0.06	0.01	3.68	0.75	0.32	0.00	77.81
24	1.00	76.37	18.41	0.15	0.01	3.83	0.82	0.41	0.00	76.37
28	1.17	73.15	20.79	0.13	0.04	4.36	0.95	0.59	0.00	73.15
32	1.33	68.04	24.86	0.15	0.09	5.11	1.07	0.68	0.00	68.04
36	1.50	64.76	27.33	0.25	0.10	5.59	1.19	0.78	0.00	64.76
40	1.67	61.73	29.27	0.18	0.17	6.40	1.31	0.95	0.00	61.73
44	1.83	58.84	31.00	0.17	0.21	7.25	1.42	1.11	0.00	58.84
48	2.00	57.11	32.06	0.31	0.21	7.51	1.53	1.27	0.00	57.11
54	2.25	54.63	33.53	0.13	0.31	8.36	1.70	1.34	0.00	54.63
60	2.50	53.19	34.52	0.25	0.33	8.50	1.85	1.34	0.00	53.19
66	2.75	51.76	35.41	0.09	0.42	8.96	2.01	1.34	0.00	51.76
72	3.00	48.70	36.78	0.21	0.45	10.36	2.16	1.34	0.00	48.70
78	3.25	47.46	37.44	0.10	0.55	10.79	2.31	1.34	0.00	47.46
84	3.50	46.30	38.03	0.23	0.60	11.03	2.46	1.34	0.00	46.30
90	3.75	45.29	38.58	0.12	0.70	11.37	2.61	1.34	0.00	45.29
96	4.00	43.95	39.16	0.26	0.76	11.78	2.75	1.34	0.00	43.95

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	30.53	44.36	0.31	0.98	19.45	3.03	1.34	0.00	30.53
120	5.00	22.90	47.26	0.33	1.19	23.70	3.28	1.34	0.00	22.90
132	5.50	19.62	48.66	0.34	1.46	25.05	3.52	1.34	0.00	19.62
144	6.00	17.53	49.50	0.37	1.72	25.79	3.76	1.34	0.00	17.53
156	6.50	16.11	50.20	0.36	2.04	25.97	3.98	1.34	0.00	16.11
168	7.00	15.17	50.64	0.38	2.31	25.96	4.21	1.34	0.00	15.17
192	8.00	9.79	52.31	0.40	2.94	28.59	4.63	1.34	0.00	9.79
216	9.00	8.00	52.96	0.40	3.58	28.69	5.04	1.34	0.00	8.00
240	10.00	5.91	53.48	0.39	4.22	29.23	5.43	1.34	0.00	5.91
264	11.00	5.41	53.66	0.40	4.86	28.52	5.80	1.34	0.00	5.41
288	12.00	4.73	53.80	0.36	5.45	28.16	6.17	1.34	0.00	4.73
336	14.00	2.76	54.04	0.52	6.63	27.85	6.86	1.34	0.00	2.76
384	16.00	1.22	54.27	0.37	7.76	27.54	7.51	1.34	0.00	1.22
432	18.00	0.35	54.38	0.34	8.88	26.60	8.12	1.34	0.00	0.35
480	20.00	0.02	54.43	0.30	9.91	25.31	8.69	1.34	0.00	0.02
600	25.00	0.00	54.43	0.23	12.01	22.01	9.97	1.34	0.00	0.00
720	30.00	0.00	54.43	0.18	13.57	19.40	11.08	1.34	0.00	0.00
840	35.00	0.00	54.43	0.14	14.72	17.31	12.06	1.34	0.00	0.00
1080	45.00	0.00	54.43	0.10	16.22	14.21	13.70	1.34	0.00	0.00
1200	50.00	0.00	54.43	0.08	16.71	13.04	14.40	1.34	0.00	0.00
1320	55.00	0.00	54.43	0.06	17.09	12.05	15.04	1.34	0.00	0.00
Maximum	56.00	99.57	54.43	0.52	17.15	29.23	15.16	1.34	0.00	99.57

Table XVII.B-23 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Padilla Bay.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.27	0.68	0.00	0.00	0.00	0.05	0.00	0.00	99.27
4	0.17	97.76	1.97	0.14	0.00	0.04	0.09	0.00	0.00	97.76
6	0.25	93.21	5.59	0.10	0.00	0.93	0.17	0.00	0.00	93.21
8	0.33	89.81	8.49	0.10	0.00	1.28	0.24	0.08	0.00	89.81
10	0.42	88.22	10.02	0.08	0.00	1.29	0.32	0.08	0.00	88.22
12	0.50	86.85	11.22	0.09	0.00	1.29	0.39	0.15	0.00	86.85
14	0.58	83.93	13.10	0.08	0.00	2.07	0.47	0.35	0.00	83.93
16	0.67	81.43	14.61	0.07	0.01	2.82	0.54	0.54	0.00	81.43
18	0.75	80.43	15.32	0.06	0.01	2.86	0.61	0.72	0.00	80.43
20	0.83	78.61	16.43	0.04	0.01	3.34	0.68	0.89	0.00	78.61
22	0.92	76.85	17.48	0.03	0.01	3.80	0.74	1.08	0.00	76.85
24	1.00	75.44	18.43	0.12	0.02	3.88	0.81	1.31	0.00	75.44
28	1.17	72.62	20.48	0.10	0.05	4.08	0.94	1.73	0.00	72.62
32	1.33	67.88	24.28	0.14	0.09	4.53	1.07	2.02	0.00	67.88
36	1.50	64.44	26.77	0.18	0.10	5.04	1.19	2.28	0.00	64.44
40	1.67	61.56	28.56	0.17	0.17	5.64	1.30	2.61	0.00	61.56
44	1.83	58.20	30.43	0.16	0.20	6.67	1.41	2.92	0.00	58.20
48	2.00	56.89	31.26	0.26	0.21	6.63	1.52	3.22	0.00	56.89
54	2.25	55.46	32.27	0.13	0.30	6.79	1.68	3.37	0.00	55.46
60	2.50	53.92	33.32	0.21	0.32	7.02	1.84	3.37	0.00	53.92
66	2.75	52.07	34.36	0.09	0.40	7.73	1.99	3.37	0.00	52.07
72	3.00	49.50	35.54	0.19	0.43	8.84	2.14	3.37	0.00	49.50
78	3.25	47.00	36.66	0.09	0.52	10.07	2.29	3.37	0.00	47.00
84	3.50	45.92	37.22	0.23	0.56	10.27	2.43	3.37	0.00	45.92
90	3.75	45.07	37.70	0.12	0.67	10.50	2.57	3.37	0.00	45.07

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	43.65	38.31	0.26	0.73	10.97	2.71	3.37	0.00	43.65
108	4.50	29.01	43.93	0.33	0.95	19.42	2.99	3.37	0.00	29.01
120	5.00	23.21	46.24	0.33	1.18	22.45	3.23	3.37	0.00	23.21
132	5.50	18.82	47.97	0.34	1.45	24.58	3.47	3.37	0.00	18.82
144	6.00	16.22	48.96	0.36	1.70	25.71	3.69	3.37	0.00	16.22
156	6.50	14.33	49.76	0.35	2.00	26.28	3.91	3.37	0.00	14.33
168	7.00	13.21	50.23	0.37	2.27	26.43	4.13	3.37	0.00	13.21
192	8.00	7.98	51.81	0.38	2.89	29.03	4.54	3.37	0.00	7.98
216	9.00	6.15	52.42	0.37	3.51	29.24	4.93	3.37	0.00	6.15
240	10.00	4.91	52.77	0.38	4.12	29.15	5.31	3.37	0.00	4.91
264	11.00	3.88	53.02	0.36	4.72	28.99	5.68	3.37	0.00	3.88
288	12.00	3.22	53.13	0.34	5.27	28.65	6.03	3.37	0.00	3.22
336	14.00	1.99	53.28	0.40	6.36	27.90	6.70	3.37	0.00	1.99
384	16.00	1.00	53.43	0.30	7.35	27.22	7.34	3.37	0.00	1.00
432	18.00	0.21	53.53	0.29	8.29	26.38	7.94	3.37	0.00	0.21
480	20.00	0.01	53.56	0.24	9.14	25.18	8.50	3.37	0.00	0.01
600	25.00	0.00	53.56	0.19	10.85	22.24	9.79	3.37	0.00	0.00
720	30.00	0.00	53.56	0.15	12.11	19.90	10.92	3.37	0.00	0.00
840	35.00	0.00	53.56	0.12	13.04	17.99	11.92	3.37	0.00	0.00
1080	45.00	0.00	53.56	0.08	14.24	15.09	13.65	3.37	0.00	0.00
1200	50.00	0.00	53.56	0.07	14.63	13.97	14.40	3.37	0.00	0.00
1320	55.00	0.00	53.56	0.05	14.94	13.00	15.09	3.37	0.00	0.00
Maximum	56.00	99.57	53.56	0.40	14.98	29.24	15.22	3.37	0.00	99.57

Table XVII.B-24 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Padilla Bay.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.27	0.68	0.00	0.00	0.00	0.05	0.00	0.00	99.27
4	0.17	97.76	1.97	0.14	0.00	0.04	0.09	0.00	0.00	97.76
6	0.25	93.09	5.50	0.12	0.00	0.86	0.17	0.27	0.00	93.09
8	0.33	89.96	8.28	0.14	0.00	1.10	0.24	0.27	0.00	89.96
10	0.42	88.09	9.98	0.07	0.00	1.27	0.32	0.27	0.00	88.09
12	0.50	86.61	11.18	0.07	0.00	1.27	0.39	0.48	0.00	86.61
14	0.58	83.96	12.88	0.06	0.00	1.88	0.47	0.74	0.00	83.96
16	0.67	81.84	14.15	0.06	0.01	2.42	0.54	0.99	0.00	81.84
18	0.75	80.67	14.92	0.05	0.01	2.51	0.61	1.23	0.00	80.67
20	0.83	79.24	15.80	0.04	0.01	2.76	0.68	1.46	0.00	79.24
22	0.92	77.35	16.89	0.04	0.01	3.27	0.74	1.70	0.00	77.35
24	1.00	75.97	17.79	0.11	0.02	3.30	0.81	2.00	0.00	75.97
28	1.17	72.73	19.91	0.10	0.04	3.58	0.94	2.70	0.00	72.73
32	1.33	67.28	23.95	0.13	0.08	4.30	1.07	3.20	0.00	67.28
36	1.50	63.75	26.39	0.19	0.09	4.76	1.18	3.63	0.00	63.75
40	1.67	60.62	28.24	0.17	0.15	5.47	1.30	4.05	0.00	60.62
44	1.83	55.15	30.93	0.16	0.18	7.73	1.40	4.44	0.00	55.15
48	2.00	52.94	32.08	0.25	0.19	8.21	1.51	4.81	0.00	52.94
54	2.25	49.10	33.99	0.13	0.27	9.83	1.66	5.03	0.00	49.10
60	2.50	47.38	35.05	0.21	0.29	10.23	1.81	5.03	0.00	47.38
66	2.75	45.14	36.19	0.09	0.38	11.22	1.96	5.03	0.00	45.14
72	3.00	42.12	37.51	0.21	0.40	12.64	2.10	5.03	0.00	42.12
78	3.25	40.46	38.30	0.10	0.49	13.38	2.24	5.03	0.00	40.46
84	3.50	39.88	38.65	0.22	0.54	13.31	2.37	5.03	0.00	39.88
90	3.75	38.98	39.13	0.11	0.64	13.60	2.51	5.03	0.00	38.98

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	37.26	39.83	0.25	0.69	14.30	2.64	5.03	0.00	37.26
108	4.50	27.83	43.63	0.31	0.90	19.39	2.90	5.03	0.00	27.83
120	5.00	21.92	45.96	0.35	1.11	22.49	3.14	5.03	0.00	21.92
132	5.50	16.76	47.91	0.34	1.39	25.20	3.37	5.03	0.00	16.76
144	6.00	14.34	48.82	0.38	1.64	26.20	3.59	5.03	0.00	14.34
156	6.50	12.91	49.47	0.37	1.97	26.44	3.81	5.03	0.00	12.91
168	7.00	11.70	49.94	0.39	2.25	26.67	4.02	5.03	0.00	11.70
192	8.00	6.89	51.39	0.39	2.91	28.97	4.42	5.03	0.00	6.89
216	9.00	5.65	51.85	0.38	3.56	28.74	4.80	5.03	0.00	5.65
240	10.00	4.56	52.15	0.38	4.19	28.52	5.17	5.03	0.00	4.56
264	11.00	4.02	52.31	0.39	4.81	27.92	5.52	5.03	0.00	4.02
288	12.00	3.54	52.40	0.36	5.37	27.44	5.86	5.03	0.00	3.54
336	14.00	1.83	52.62	0.48	6.49	27.03	6.52	5.03	0.00	1.83
384	16.00	0.95	52.75	0.35	7.55	26.24	7.13	5.03	0.00	0.95
432	18.00	0.28	52.84	0.31	8.57	25.27	7.71	5.03	0.00	0.28
480	20.00	0.00	52.88	0.27	9.50	24.07	8.25	5.03	0.00	0.00
600	25.00	0.00	52.88	0.21	11.39	21.03	9.47	5.03	0.00	0.00
720	30.00	0.00	52.88	0.16	12.76	18.63	10.53	5.03	0.00	0.00
840	35.00	0.00	52.88	0.13	13.78	16.71	11.47	5.03	0.00	0.00
1080	45.00	0.00	52.88	0.09	15.08	13.86	13.06	5.03	0.00	0.00
1200	50.00	0.00	52.88	0.07	15.50	12.77	13.75	5.03	0.00	0.00
1320	55.00	0.00	52.88	0.05	15.82	11.85	14.37	5.03	0.00	0.00
Maximum	56.00	99.57	52.88	0.48	15.87	28.97	14.49	5.03	0.00	99.57

Table XVII.B-25 San Juan Islands - Alaskan North Slope Crude, no removal: Water surface area exposed to oil at some time after the spill (i.e., cumulative total area), shoreline oiled to varying degrees, and the per-unit-area component of shoreline cleanup costs.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,777	4,025	786	409	606	372
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	1,255	3,626	577	293	535	267
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	11,811	4,145	5,783	4,416	7,162	4,106
Shoreline length (km) oiled by > 100 g/m^2	4,542	2,803	3,324	2,544	3,276	2,763
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	9,604,900	2,435,100	3,348,300	2,706,300	5,035,800	2,105,900
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,205,600	1,710,300	2,434,500	1,709,700	2,125,800	1,999,600
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	514	159	285	203	344	206

Table XVII.B-26 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Water surface area exposed to oil at some time after the spill (i.e., cumulative total area), shoreline oiled to varying degrees, and the per-unit-area component of shoreline cleanup costs.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,760	4,323	577	375	604	250
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	1,132	3,927	445	259	528	189
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	8,803	5,067	5,544	5,633	5,816	4,775
Shoreline length (km) oiled by > 100 g/m^2	5,131	2,701	3,625	3,177	2,851	2,636
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	6,581,100	3,439,500	3,094,000	3,916,000	4,168,300	2,934,200
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,222,300	1,627,600	2,449,800	1,717,400	1,648,100	1,840,500
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	396	193	285	253	264	228

Table XVII.B-27 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Water surface area exposed to oil at some time after the spill (i.e., cumulative total area), shoreline oiled to varying degrees, and the per-unit-area component of shoreline cleanup costs.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,530	2,969	606	508	796	258
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	1,025	2,658	423	353	597	185
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	9,597	4,351	4,375	3,728	9,386	6,807
Shoreline length (km) oiled by > 100 g/m^2	5,038	2,858	2,959	2,138	3,862	3,058
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	7,501,500	2,854,800	2,367,400	2,397,100	6,951,400	5,038,500
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,095,400	1,496,300	2,007,600	1,331,000	2,434,500	1,768,300
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	430	165	227	162	419	299

Table XVII.B-28 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Water surface area exposed to oil at some time after the spill (i.e., cumulative total area), shoreline oiled to varying degrees, and the per-unit-area component of shoreline cleanup costs.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	2,272	3,981	658	316	600	231
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	1,475	3,451	459	228	515	171
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	9,305	4,108	4,798	3,964	5,669	5,439
Shoreline length (km) oiled by > 100 g/m^2	4,561	2,492	2,831	2,628	2,747	2,409
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	7,149,000	2,615,800	2,748,600	2,463,700	3,732,700	3,638,000
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,156,300	1,491,700	2,049,800	1,500,300	1,936,500	1,800,600
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	415	154	236	184	274	254

XVII.C. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the appropriate seasonal abundance for each of the representative run dates. Impacts are proportional to pre-spill abundance. To allow for comparisons between runs from different seasons, the results were corrected such that annual mean abundances bird and mammals species are presented in the tables below.

Table XVII.C-1 San Juan Islands - Alaskan North Slope Crude, no removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
99th Percentile Run (based on shore cost)	92,659	14,638	129	8,219	3	0	10	-	115,658	115,649	10
Worst run for Lopez Island	190,946	17,844	111	7,018	3	0	18	-	215,939	215,921	18
Worst run for Orcas Island	64,502	13,720	115	7,327	3	0	8	-	85,674	85,666	8
50th Percentile Run (based on shore cost)	52,685	13,334	107	6,755	3	0	7	-	72,890	72,883	7
Worst run for Lummi Island	62,750	13,663	115	7,291	3	0	7	-	83,829	83,821	7
Worst run for Padilla Bay	51,609	13,299	109	6,915	3	0	7	-	71,942	71,936	7

Table XVII.C-2 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
99th Percentile Run (based on shore cost)	87,615	14,474	136	8,650	3	0	9	-	110,887	110,878	9
Worst run for Lopez Island	203,445	18,252	111	7,041	4	0	19	-	228,871	228,852	19
Worst run for Orcas Island	59,035	13,542	119	7,547	3	0	7	-	80,252	80,245	7
50th Percentile Run (based on shore cost)	51,295	13,289	114	7,218	3	0	7	-	71,925	71,919	7
Worst run for Lummi Island	62,436	13,653	110	6,980	3	0	7	-	83,189	83,181	7
Worst run for Padilla Bay	48,380	13,194	108	6,822	3	0	6	-	68,513	68,507	6

Table XVII.C-3 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
99th Percentile Run (based on shore cost)	83,180	14,329	135	8,582	3	0	9	-	106,239	106,229	9
Worst run for Lopez Island	150,815	16,535	110	6,985	3	0	14	-	174,462	174,448	14
Worst run for Orcas Island	58,108	13,511	111	7,059	3	0	7	-	78,800	78,793	7
50th Percentile Run (based on shore cost)	55,174	13,416	102	6,458	3	0	7	-	75,159	75,152	7
Worst run for Lummi Island	65,356	13,748	122	7,720	3	0	8	-	86,955	86,948	8
Worst run for Padilla Bay	48,251	13,190	112	7,132	3	0	6	-	68,694	68,688	6

Table XVII.C-4 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
99th Percentile Run (based on shore cost)	101,802	14,937	130	8,232	3	0	11	-	125,114	125,103	11
Worst run for Lopez Island	183,674	17,607	116	7,375	4	0	17	-	208,792	208,775	17
Worst run for Orcas Island	59,605	13,560	110	6,965	3	0	7	-	80,250	80,243	7
50th Percentile Run (based on shore cost)	49,996	13,247	108	6,816	3	0	6	-	70,176	70,169	6
Worst run for Lummi Island	61,896	13,635	109	6,904	3	0	7	-	82,554	82,546	7
Worst run for Padilla Bay	47,614	13,169	105	6,656	3	0	6	-	67,553	67,547	6

XVII.D. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates were calculated using the seasonal abundance for each of the spill dates included in the 3 runs (i.e., the data were not corrected to be seasonal means).

Table XVII.D-1. San Juan Islands - Alaskan North Slope Crude, no removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
99th Percentile Run (based on shore cost)	5,296	9,817	187	54	1,993	623,325	640,672
Worst run for Lopez Island	2,299	4,344	99	26	1,807	242,536	251,112
Worst run for Orcas Island	374	829	43	8	1,689	424,678	427,620
50th Percentile Run (based on shore cost)	584	1,212	49	9.6	1,702	328,406	331,963
Worst run for Lummi Island	2,777	5,218	113	30	1,837	489,324	499,300
Worst run for Padilla Bay	331	750	41	7.2	1,686	364,744	367,559

Table XVII.D-2. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
99th Percentile Run (based on shore cost)	4,944	9,175	177	50	1,971	724,311	740,627
Worst run for Lopez Island	2,379	4,491	102	26	1,812	229,324	238,135
Worst run for Orcas Island	318	726	41	7.1	1,685	495,463	498,240
50th Percentile Run (based on shore cost)	923	1,830	59	13	1,722	463,373	467,920
Worst run for Lummi Island	2,876	5,398	116	31	1,843	411,935	422,199
Worst run for Padilla Bay	482	1,025	46	8.6	1,695	357,189	360,446

Table XVII.D-3. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
99th Percentile Run (based on shore cost)	4,944	9,175	177	50	1,971	718,648	734,965
Worst run for Lopez Island	2,299	4,344	99	26	1,807	268,956	277,533
Worst run for Orcas Island	367	815	43	7.6	1,688	399,657	402,577
50th Percentile Run (based on shore cost)	1,788	3,411	84	21	1,776	260,938	268,018
Worst run for Lummi Island	2,876	5,398	116	31	1,843	575,198	585,463
Worst run for Padilla Bay	245	592	39	6.4	1,681	444,972	447,535

Table XVII.D-4. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
99th Percentile Run (based on shore cost)	4,944	9,175	177	50	1,971	620,032	636,349
Worst run for Lopez Island	2,299	4,344	99	26	1,807	214,233	222,809
Worst run for Orcas Island	310	712	41	7.0	1,685	359,083	361,838
50th Percentile Run (based on shore cost)	1,649	3,158	80	20	1,767	366,636	373,310
Worst run for Lummi Island	2,876	5,398	116	31	1,843	400,140	410,404
Worst run for Padilla Bay	413	899	44	8.0	1,691	340,207	343,262

XVII.E. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All injuries used to calculate habitat restoration costs are expressed as wet weights; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

Table XVII.E-1. San Juan Islands - Alaskan North Slope Crude, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Fish and Invertebrates:						
Small pelagic fish	5,296	2,299	374	584	2,777	331
Large pelagic fish	9,817	4,345	829	1,213	5,218	750
Demersal fish	187	99	43	49	113	42
Decapods	54	26	7.6	9.6	30	7.2
Molluscs	625,318	244,343	426,366	330,108	491,162	366,430
Birds:						
Waterfowl (# * kg each)	60,846	125,388	42,356	34,596	41,206	33,890
Seabirds (# * kg each)	17,017	20,744	15,949	15,501	15,883	15,461
Waders (# * kg each)	150	129	134	124	134	127
Shorebirds (# * kg each)	9,554	8,158	8,517	7,852	8,476	8,039
Raptors (# * kg each)	3.0	3.5	3.0	3.0	3.0	3.2
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	11	20	8.8	7.7	8.6	7.6
Cetaceans	0.0	0.1	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	640,672	251,112	427,620	331,963	499,300	367,559
Subtotal birds	87,571	154,422	66,960	58,077	65,701	57,520
Subtotal other wildlife	11	21	9	8	9	8
Total all species	728,255	405,554	494,588	390,048	565,010	425,087

Table XVII.E-2. San Juan Islands - Alaskan North Slope Crude, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Saltmarsh Area (ha)	295	331	213	190	232	192
Saltmarsh Area (acres)	729	818	526	468	574	473
Saltmarsh Cost (millions of 2004$)	136.5	153.3	98.6	87.7	107.6	88.7
Eelgrass Area (m2)	184	207	133	118	145	120
Eelgrass Area (acres)	455	511	329	293	359	296
Eelgrass Cost (millions of 2004$)	54.4	61.0	39.2	34.9	42.8	35.3

Table XVII.E-3. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Fish and Invertebrates:						
Small pelagic fish	4,944	2,379	318	923	2,876	482
Large pelagic fish	9,175	4,491	726	1,830	5,398	1,025
Demersal fish	177	102	41	59	116	46
Decapods	51	26	7	13	31	8.6
Molluscs	726,282	231,137	497,148	465,095	413,778	358,885
Birds:						
Waterfowl (# * kg each)	57,534	133,595	38,766	33,684	41,000	31,770
Seabirds (# * kg each)	16,826	21,218	15,742	15,449	15,871	15,338
Waders (# * kg each)	158	129	138	132	128	125
Shorebirds (# * kg each)	10,056	8,185	8,773	8,391	8,114	7,931
Raptors (# * kg each)	3.0	4.2	3.0	3.0	3.0	3.3
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	10.9	22	8.3	7.6	8.6	7.3
Cetaceans	0.0	0.1	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	740,627	238,135	498,240	467,920	422,199	360,446
Subtotal birds	84,577	163,131	63,423	57,659	65,116	55,167
Subtotal other wildlife	11	22	8	8	9	7
Total all species	825,215	401,288	561,671	525,586	487,324	415,620

Table XVII.E-4. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Saltmarsh Area (ha)	301	343	216	207	223	188
Saltmarsh Area (acres)	743	847	533	511	551	465
Saltmarsh Cost (millions of 2004$)	139.2	158.7	99.9	95.8	103.2	87.1
Eelgrass Area (m2)	188	214	135	129	139	118
Eelgrass Area (acres)	464	529	333	320	344	290
Eelgrass Cost (millions of 2004$)	55.4	63.2	39.8	38.1	41.1	34.7

Table XVII.E-5. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Fish and Invertebrates:						
Small pelagic fish	4,944	2,299	367	1,788	2,876	245
Large pelagic fish	9,175	4,345	815	3,411	5,398	592
Demersal fish	177	99	43	84	116	39
Decapods	51	26	7.6	21	31	6.4
Molluscs	720,619	270,764	401,345	262,714	577,041	446,653
Birds:						
Waterfowl (# * kg each)	54,622	99,035	38,158	36,231	42,917	31,685
Seabirds (# * kg each)	16,658	19,222	15,707	15,596	15,982	15,333
Waders (# * kg each)	157	128	129	118	141	131
Shorebirds (# * kg each)	9,977	8,120	8,206	7,507	8,975	8,290
Raptors (# * kg each)	3.0	3.6	3.0	2.9	3.0	3.2
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	10.5	17	8.2	7.9	8.9	7.3
Cetaceans	0.0	0.1	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	734,965	277,533	402,577	268,018	585,463	447,535
Subtotal birds	81,416	126,509	62,204	59,455	68,018	55,442
Subtotal other wildlife	11	17	8	8	9	7
Total all species	816,392	404,058	464,789	327,481	653,489	502,985

Table XVII.E-6. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Saltmarsh Area (ha)	295	293	203	190	247	198
Saltmarsh Area (acres)	729	724	501	470	609	488
Saltmarsh Cost (millions of 2004$)	136.7	135.7	93.9	88.1	114.2	91.5
Eelgrass Area (m2)	185	183	127	119	154	124
Eelgrass Area (acres)	456	453	313	294	381	305
Eelgrass Cost (millions of 2004$)	54.4	54.0	37.4	35.1	45.5	36.4

Table XVII.E-7. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Fish and Invertebrates:						
Small pelagic fish	4,944	2,299	311	1,649	2,876	413
Large pelagic fish	9,175	4,345	712	3,158	5,398	899
Demersal fish	177	99	41	80	116	44
Decapods	51	26	7.0	20	31	8.0
Molluscs	622,003	216,040	360,767	368,403	401,983	341,898
Birds:						
Waterfowl (# * kg each)	66,850	120,612	39,141	32,831	40,645	31,267
Seabirds (# * kg each)	17,364	20,468	15,764	15,399	15,851	15,309
Waders (# * kg each)	151	135	128	125	127	122
Shorebirds (# * kg each)	9,570	8,573	8,097	7,924	8,026	7,738
Raptors (# * kg each)	3.0	4.1	3.0	2.9	2.9	3.1
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	12	20	8.4	7.5	8.6	7.3
Cetaceans	0.0	0.1	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	636,349	222,809	361,838	373,310	410,404	343,262
Subtotal birds	93,938	149,793	63,132	56,282	64,651	54,439
Subtotal other wildlife	12	20	8	7	9	7
Total all species	730,298	372,622	424,978	429,599	475,064	397,708

Table XVII.E-8. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Saltmarsh Area (ha)	302	321	199	197	221	185
Saltmarsh Area (acres)	746	793	492	488	545	456
Saltmarsh Cost (millions of 2004$)	139.8	148.5	92.2	91.4	102.2	85.5
Eelgrass Area (m2)	189	200	124	123	138	115
Eelgrass Area (acres)	466	495	307	305	341	285
Eelgrass Cost (millions of 2004$)	55.7	59.1	36.7	36.4	40.7	34.0

XVII.F. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

The Washington Compensation Schedule was applied to the model results for the hypothetical spills simulated. The methods are described in Section 6.2 of Volume I. Note that the Compensation Schedule is designed to be a simplified procedure for small spills. Thus, for spills the size of those considered here, the OPA procedures using restoration costs (listed in Section XVII.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table XVII.F-1. San Juan Islands - Alaskan North Slope Crude, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Vulnerability Score ($/gal.)	21.74	22.70	21.74	25.57	21.75	23.69
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	228	238	228	268	228	249

Table XVII.F-2. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Vulnerability Score ($/gal.)	21.74	22.71	25.54	25.58	21.75	23.71
% Removed by 24 hours	0.54	0.61	0.61	0.43	0.42	0.41
Compensation (millions $)	227	237	267	267	227	248

Table XVII.F-3. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Vulnerability Score ($/gal.)	21.74	25.55	25.54	25.56	21.76	23.71
% Removed by 24 hours	1.57	1.76	1.76	1.36	1.25	1.31
Compensation (millions $)	225	264	263	265	226	246

Table XVII.F-4. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Vulnerability Score ($/gal.)	21.74	22.71	25.54	22.72	21.75	23.70
% Removed by 24 hours	2.05	2.80	2.80	2.15	2.00	2.00
Compensation (millions $)	224	232	261	233	224	244

Appendix F

Descriptions and Life History Requirements of Nearshore and Marine Species

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List of Acronyms

BRT	Biological Review Team
cm	centimeter(s)
CPS	coastal pelagic species
DPS	distinct population segment
ESA	federal Endangered Species Act
ESU	evolutionary significant unit
FMP	Fisheries Management Plan
km	kilometer(s)
MBTA	Migratory Bird Treaty Act
mi	mile(s)
mm	millimeter(s)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
ppt	parts per trillion
WDFW	Washington Department of Fish and Wildlife

1. INTRODUCTION

Appendix F provides general descriptions, life history requirements, and potential for occurrence in the study area for common and federally and state-listed nearshore and marine species. Summaries of species occurrence and life histories are based on available literature, consultations and coordination with federal and state agencies, and public and agency websites. Federally listed species with the potential to occur in the study area were identified through a review of the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) lists of fish and wildlife species protected under the federal Endangered Species Act (ESA). Species receiving protection under the ESA are designated as endangered or threatened. Candidate or proposed species could be included on the ESA list in the future. Areas designated as critical habitat for listed species also receive protection under the ESA. At the state level, the Washington Department of Fish and Wildlife (WDFW) maintains lists of species considered threatened, endangered, or candidates for listing.

The study area encompasses the Cooperative Vessel Traffic Service system marked north-south boundary 8 miles west of the “J” Buoy at the entrance to the Strait of Juan de Fuca to the BP Cherry Point dock, as well as vessel routes from the BP Cherry Point dock to distribution points in Puget Sound. The scope also includes the tidal zone (200 feet inland) within the defined study area.

2. MARINE MAMMALS

2.1 Protected Species

This section identifies federally and state-listed marine mammals with the potential to occur in the study area. More detailed discussions of the life histories and listing status of federally listed species are provided in the draft Biological Evaluation (Appendix G).

2.1.1 Federally Listed Species

2.1.1.1 Humpback Whale (Endangered)

Humpback whales were common in Puget Sound and the Georgia Strait in the early 1900s, but there have been few sightings of humpback whales in Puget Sound in the last 20 years (Calambokidis 2008). Although humpback whales have been recovering from commercial whaling (Carretta et al. 2011), they still are rare visitors to Puget Sound and Georgia Strait. Some sightings have been reported in recent years. A study by Calambokidis et al. (2004) found that humpback whale sightings were concentrated between the Juan de Fuca Canyon and the outer edge of the continental shelf, in an area known as *the Prairie*. The highest density of sightings all year was in a small area east of the mouth of Barkley Canyon and north of Nitnat Canyon, where water depth was from 125 to 145 meters (410 to 476 feet) (Calambokidis et al. 2004). These areas are outside of the study area for the project; therefore, although they may occur in the study area, humpback whale occurrences are not expected to be common in the study area.

2.1.1.2 Blue Whale (Endangered)

The Eastern North Pacific population of blue whales is the population occurring closest to the study area. They feed in California waters in summer/fall (from June to November) and migrate south to productive areas off Mexico in winter (Carretta et al. 2007). More recently, sightings have occurred off the coasts of Oregon, Washington, and British Columbia (Calambokidis et al. 2009). Historically, blue whales were not common along the coast of Washington; however, they did occasionally occur (Calambokidis et al. 2004). Vessel surveys conducted in Washington waters in 1996 and 2001 did not detect the presence of blue whales (Carretta et al. 2013). Consequently, although they may occur in the study area, blue whale occurrences are not expected to be common in the study area (Calambokidis et al. 2009).

2.1.1.3 Fin Whale (Endangered)

Fin whales are year-round residents off the coast of California, are summer residents off the coast of Oregon, and possibly pass through Washington waters. Aerial surveys conducted by Brueggeman et al. (1992) off the Oregon and Washington coasts observed 13 groups of 27 fin whales between June and January. All of the fin whales were observed in Oregon waters, with all but five whales in waters on the continental slope in depths from 200 to 2,000 meters (656 to 6,562 feet). The whales not observed in continental slope waters included two whales approximately 200 kilometers (km) (124 miles [mi]) offshore in November and three whales on the continental shelf just south of the Columbia River in January. The former group was traveling south, suggesting that they were migrating back to wintering grounds. Except for these two groups, all of the other whales were observed during June and July. No calves were observed with any of the whales. Green et al. (1993) reported sighting two fin whales during aerial surveys off the Oregon and Washington coasts between March and May in 1992 but did not report the location. An estimated 2,636 fin whales occur off the coasts of California, Oregon, and Washington during summer/fall based on shipboard surveys in 2001 and 2005 (NMFS 2010a). These areas are outside

the study area. Therefore, although they may occur in the study area, fin whale occurrences are not expected to be common in the study area.

2.1.1.4 Southern Resident Killer Whale (Endangered)

The southern resident killer whale population is a trans-boundary population comprised of 89 animals split among three pods (J, K, and L) that are considered one stock under the Marine Mammal Protection Act and a distinct population segment (DPS) under the ESA. Southern resident killer whales reside for part of the year in the protected inshore waters of the Strait of Georgia and Puget Sound (especially in the vicinity of Haro Strait, west of San Juan Island, and off the southern tip of Vancouver Island). Southern resident killer whales occur in the area principally during late spring, summer, and fall (May through October) (NMFS 2006). Winter movements and range are poorly known for this stock; however, the J pod is more commonly sighted in inland waters, while pods K and L spend more time offshore during winter (Ford et al. 2000). The southern resident stock is differentiated from the northern and southern Alaska resident stocks, which do not inhabit waters off the Washington coast. The distribution of southern resident DPS killer whales in Puget Sound is shown in Figure 1.

Based on the natural history and habitat needs of southern resident killer whales, the following primary constituent elements of critical habitat were identified as essential to their conservation: (1) water quality to support growth and development; (2) prey species of sufficient quantity, quality, and availability to support individual growth, reproduction, and development, as well as overall population growth; and (3) passage conditions to allow for migration, resting, and foraging.

Two critical habitat areas have been designated in the study area for southern resident killer whales: Area 1 – Summer Core Area and Area 3 – Strait of Juan de Fuca Area (Figure 2). The Summer Core Area is bordered to the north and west by the U.S./Canadian border and includes waters surrounding the San Juan Islands, the U.S. portion of the southern Strait of Georgia, and areas directly offshore of Skagit and Whatcom Counties. This area is important for all pods (J, K, and L) (NMFS 2006). The Strait of Juan de Fuca Area is bordered on the southeast by the entrance to Admiralty Inlet, Deception Pass Bridge, San Juan and Skagit Counties to the northeast, the U.S./Canadian border to the north, and Bonilla Point/Tatoosh line to the west. All pods regularly use the Strait of Juan de Fuca as a passage from the Summer Core Area and Puget Sound to access oceanic waters; however, the whales are not known to spend long periods of time in localized areas in the Strait, and sightings of southern residents in the strait are limited (NMFS 2006). Southern resident killer whales are expected to occur in the study area.

2.1.1.5 Dall's Porpoise (Monitored)

Dall's porpoises apparently feed at night and depend to some degree on the *deep scattering layer*, the fauna that travels upward each night from the deeper parts of the ocean's water column. Prey species, as determined from stomach contents, include squid and schooling fishes (Walker 1996; Reeves and Leatherwood 1994). Killer whales and sharks are believed to be the primary natural predators of Dall's porpoises. Dall's porpoises occur only rarely in groups of mixed species, although they are sometimes seen in the company of harbor porpoises and gray whales (Reeves and Leatherwood 1994). Within the inland waters of Washington, Dall's porpoises primarily occur in the Strait of Juan de Fuca and the San Juan Islands (Chandler and Calambokidis 2003a, 2003b). Consequently, Dall's porpoises are expected to occur in the study area.

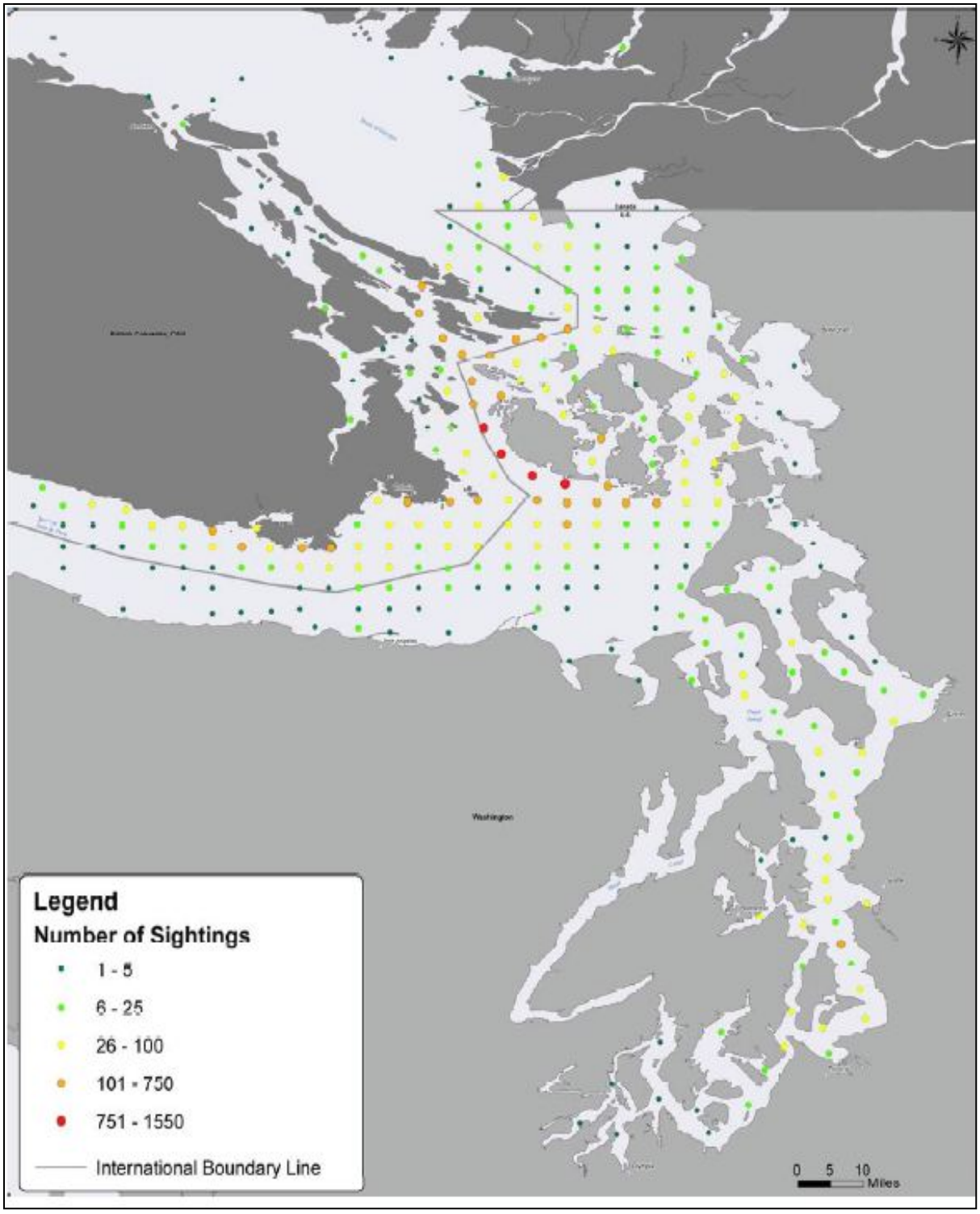

Figure 1. Distribution of Southern Resident Killer Whale Sightings from 1990 to 2005

Source: The Whale Museum 2005, as cited in NMFS 2008b.

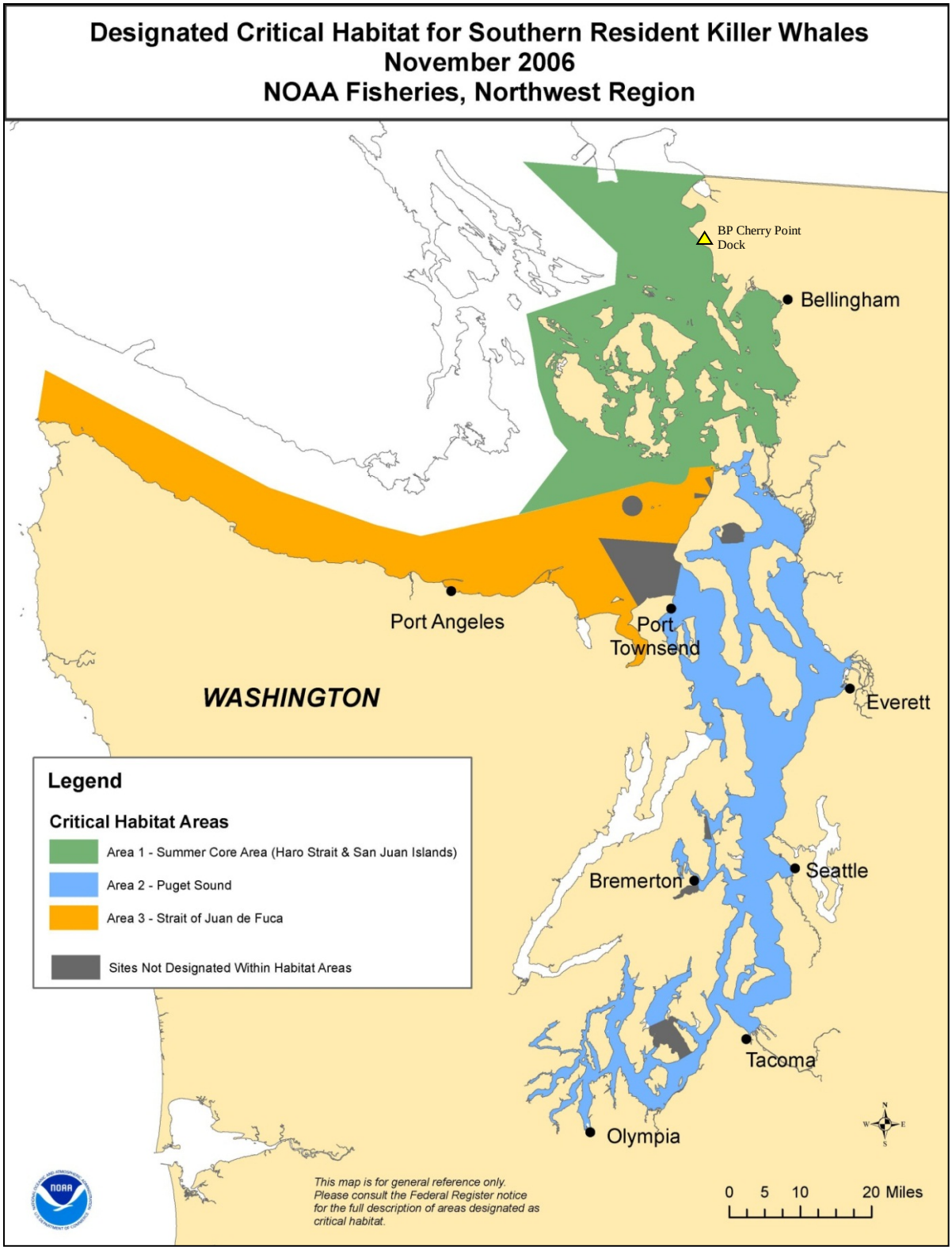

Figure 2. Designated Critical Habitat for Southern Resident Killer Whales

Source: NMFS 2006.

2.1.1.6 Gray Whale (Sensitive)

Gray whales are one of the most studied whales, resulting in an extensive understanding of their migration and general ecology. The estimated carrying capacity for the North Pacific gray whale is 22,000 and the current population is 19,126 animals; therefore, the population is currently at or near carrying capacity (Rugh et al. 2005; Wade and Perryman 2002; Carretta et al. 2013).

Gray whales seasonally migrate between summer feeding grounds in the Bering and Chukchi Seas and winter breeding grounds in the lagoons in Baja, California (Rugh et al. 1999, 2001). The southward migration can occur off the Washington coast beginning as early as November; however, recent studies indicate that gray whales begin their southward migration in early December, peaking on or about January 5 and ending in the first week of February (Rugh et al. 2001). During their migration, gray whales move past Washington in a wide corridor that extends from nearshore to over 47 km (29 mi) offshore, with a mean distance of approximately 24 km (15 mi) from shore (Green et al. 1995; Shelden et al. 2000). The southbound migration is segregated by age, sex, and reproductive status (Rice and Wolman 1971); near-term pregnant females lead the migration, followed by oestrus (sexually receptive) females and mature males, and then immature animals of both sexes.

The northward migration off the coast of Washington occurs from February through June, with females and calves dominating the migration in June. The northward migration corridor is narrower than the southward and extends from nearshore to over 19 km (12 mi) offshore, with a mean distance of approximately 11 km (7 mi), indicating that most northbound whales migrate closer to shore and in a narrower band than southbound whales (Braham 1984; Darling 1984; Brueggeman et al. 1992; Green et al. 1995). The northward migration occurs in two distinct phases segregated according to age, sex, and reproductive condition (Poole 1984; Swartz 1986). The first phase includes newly pregnant females, followed by adult males, anestrous (sexually inactive) females, and immature whales of both sexes.

Gray whales are predominantly bottom feeders, preying on small invertebrates and crustaceans (Nerini 1984); they feed primarily on large aggregations or patches of benthic amphipods (Nerini 1984). Gray whales have been observed feeding off Vancouver Island on amphipod and mysid crustaceans, and feeding on ghost shrimps off Washington coasts (Murison et al.1984; Weitkamp et al. 1992).

Most eastern North Pacific gray whales summer in the Bering Sea and in the adjacent waters of the Arctic Ocean, but some remain in Washington waters to feed from late spring into fall (Calambokidis et al. 2002). Most whales occur off the coast, but a few also occur in the inland waters. Small numbers of gray whales occasionally have been recorded throughout the inland waters in the Strait of Juan de Fuca and San Juan Islands, and off of Vancouver Island. Cow-calf pairs have not been recorded outside of the migration periods in Washington, indicating that most whales summering in the region are non-breeding. Gray whales are expected to occur in the study area.

2.1.1.7 Harbor Seal (Monitored)

The harbor seal is the most common marine mammal in Washington (NMFS 1992), with a stable population that numbers 10,430 seals off the Washington coast and 14,612 in inland waters (Carretta et al. 2004, 2007). The species occurs year-round in Washington. Harbor seals give birth on shore and nurse their pups for 4 to 5 weeks. After the pups are weaned, they disperse widely in search of food. Pupping seasons vary geographically, with pups born along the Olympic Peninsula from May through July, in the San Juan Islands and eastern Bays of Puget Sound from June through August, and in Hood Canal from August through January (Jeffries et al. 2000). Breeding occurs in the water shortly after the pups are weaned. Females produce one pup per year, beginning at age 4 or 5. Common prey includes sole,

flounder, sculpin, hake, cod, herring, squid, octopus, and to a much lesser degree salmon (Newby in Haley 1978).

The study area contains hundreds of harbor seal haul-out sites (Jeffries et al. 2000). Numerous haul-out sites occur on intertidal areas around islands, rocks, and reefs along the Washington coast—particularly in the vicinity of Cape Johnson, Cape Alava, Bodelteh Island, and Ozette Island. Scattered harbor seal haul outs are found along rocks, reefs, and ledges along the Strait of Juan de Fuca and Vancouver Island; large numbers haul out at Dungeness Spit, Protection Island, and the Smith/Minor Islands. Numerous haul-out sites occur throughout the San Juan Islands, such as Rosario and Haro Straits and the San Juan Channel including Vendovi, Clark, Battleship, and Goose Islands, to name a few. Peak numbers of harbor seals use haul-out sites during the pupping and molting seasons (mid-June to October). Harbor seals are expected to occur in the study area.

2.2 Non-Listed Common Marine Mammal Species off the Washington Coast

2.2.1 Toothed Whales

2.2.1.1 Harbor Porpoise

Harbor porpoises are common year-round residents off the coast and within the inland waters of Washington. An estimated 10,682 harbor porpoises occur in Washington inland waters, and 37,745 occur off the coasts of Oregon and Washington (Carretta et al. 2007). Harbor porpoise abundance is particularly high in fall and winter, low in summer, and intermediate in spring (Brueggeman et al.1992; Carretta et al. 2004). While abundances vary seasonally, harbor porpoises do not appear to be migratory (NMFS 1992). They are widespread throughout the inland and coastal waters of Washington, with the exception of southern Puget Sound (NMFS 1992). High concentrations have been recorded in the central Strait of Juan de Fuca and northern San Juan Islands, and low numbers in the central and northern Strait of Georgia (Chandler and Calambokidis 2003 a, 2003b).

Scheffer and Slipp (1948) provide a historical account of this species in Washington. Harbor porpoises are known to calf and breed in Washington, and generally give birth in summer from May through July. Calves remain dependent on their mothers for at least 6 months (ADFG 2008a). Their primary prey is small fish and squid, including herring (Leatherwood and Reeves in Haley 1978). Because harbor porpoises are usually shy and avoid vessels, they are difficult to approach. The species frequents inshore areas, shallow bays, estuaries, and harbors. They are found almost exclusively shoreward of the 100-fathom (600-foot) contour line along the Pacific coast, with the vast majority found inside the 25-fathom (150-foot) curve (Green et al. 1992). Harbor porpoises are expected to occur in the study area.

2.2.1.2 Pacific White-Sided Dolphin

The Pacific white-sided dolphin population is estimated at 25,233 animals for the California, Oregon, and Washington stock and is one of the most abundant dolphins occurring year-round off the coast of Washington (Brueggeman et al. 1992; Green et al. 1993; Carretta et al. 2007). Seasonal habitat shifts occur off Oregon and Washington, where dolphins are more common in offshore waters during spring and shift to slope waters during summer and fall, in rough synchrony with the movements of prey (Van Waerebeek 2002). There also may be seasonal north-south movements of Pacific white-sided dolphins (Forney and Barlow 1998). Peak abundance of the Pacific white-sided dolphin off the Oregon and Washington coasts has been reported during May (Buckland et al. 1993; Brueggeman et al. 1992). Pacific white-sided dolphins consume a wide variety of fishes and cephalopods. Off the coast of British Columbia, Canada, herring was the most commonly occurring prey species, followed by salmon, cod, shrimp, and capelin (Heise 1997). Pacific white-sided dolphins have been known to occur in association

with other marine mammals, including Dall's porpoise, Risso's dolphin, northern right-whale dolphin, humpback whale, and gray whale (Brueggeman et al. 1992). Pacific white-sided dolphins are expected to occur in the study area.

2.2.1.3 Risso's Dolphin

The Risso's dolphin population for the California, Oregon, and Washington stock is estimated at 12,093 animals (Carretta et al. 2007). Risso's dolphins are common off the coast of Washington, where they are present year-round (Brueggeman et al. 1992). They are most common during spring and summer, lowest in winter, and intermediate in fall (Brueggeman et al. 1992). Calves have been observed off the Oregon and Washington coasts during May, July, and November. Risso's dolphins primarily inhabit slope waters, but they also occur in lower numbers near the edge of the continental shelf. Risso's dolphins consistently are found in the continental slope and shelf edge waters throughout the year, suggesting that there is no inshore-offshore movement pattern. However, some seasonal north-south movement of Risso's dolphins may occur between Oregon/Washington and California based on the shifts in abundance between the two regions, possibly related to prey movements. Their prey mainly includes cephalopods and fish (NMFS 2012a). Risso's dolphins have been known to occur in association with other marine mammals, including Pacific white-sided and northern right whale dolphins (Brueggeman et al. 1992). Risso's dolphins are expected to occur in the study area.

2.2.1.4 Northern Right Whale Dolphin

The California, Oregon, and Washington stock of the northern right whale dolphin is estimated at 20,362 animals (Carretta et al. 2004). It is relatively common off the coast of Washington, which is toward the northern end of its range in the eastern North Pacific Ocean (Brueggeman et al. 1992), and has been reported in Washington waters during all seasons except winter (Brueggeman et al. 1992). Abundance of northern right whale dolphins is highest in fall and lowest during spring and summer. Northern right whale dolphin's use of the slope waters is considerably higher than the offshore water, and few dolphins occur in shelf waters. While northern right whale dolphins show a seasonal abundance pattern off Washington that is somewhat opposite that in California, it is not clear if they move between the two areas. The primary prey for this species is fish and squid. The northern right whale dolphin has been frequently reported in association with Pacific white-sided dolphins (Brueggeman et al. 1992; Leatherwood and Walker 1979). Northern right whale dolphins are expected to occur in the study area.

2.2.2 Baleen Whales

2.2.2.1 Minke Whale

Minke whale surveys (2001 and 2005) off the coast of California, Oregon, and Washington have estimated the population at 898 whales (Carretta et al. 2007). Minke whales reside off the Washington coast year-round (Carretta et al. 2007). They typically occur as single animals rather than in groups. Brueggeman et al. (1992) encountered four single minke whales, including three off the Oregon coast and one off the Washington coast. Most were on the continental shelf. Minke whales are also known to enter shallow bays and estuaries (NMFS 2012b). Green et al. (1993) reported 10 groups of 12 minke whales off the Oregon and Washington coasts between March and May but did not give their locations or distributions between the two states. Minke whales typically prey on small fish and squid (NMFS 2012b). Minke whales are expected to occur in the study area.

2.2.3 Pinnipeds

2.2.3.1 Steller Sea Lion

The Steller sea lion occurs year-round in Washington, with peak numbers (approximately 1,000 animals) in late summer, fall, and winter (Jeffries et al. 2000). The species does not breed in Washington; the closest rookeries are in northern British Columbia and central Oregon, where pupping occurs in May and June. Within Washington waters, Steller sea lions occur primarily along the outer coast, with smaller numbers in the inside waters of the Strait of Juan de Fuca and Puget Sound. Occurrence of the Steller sea lion in inland water is primarily limited to male and sub-adults in fall, winter, and spring months (NMFS 2008a).

Steller sea lion haul-out sites tend to be located on exposed rocky shorelines and wave-cut platforms (NMFS 2008a). There are several commonly used haul-out sites in the study area; these sites occur along the coast and a few near the entrance to the Straits of Juan de Fuca (Jefferies et al. 2000). (Maps of haul-out sites are available at the WDFW website [http://wdfw.wa.gov/publications/00427/wdfw00427.pdf].) These include sites around Neah Bay that are occupied during all months of the year but are more commonly used during late August through April. The west end of Tatoosh Island is a year-round haul-out site, with numbers peaking during fall and winter. South of Cape Alava, large numbers (more than 1,000) of Steller sea lions have been observed hauled out on the Bodelteh Islands and on Guano Rock. Farther south, large numbers also haul out on Carroll Island along with California sea lions, and at the Split Rock complex north of Taholah. Steller sea lions also occur on Vancouver Island near Carmanah and Sombrio Point, and off Victoria at Race Rocks and Trial Island. Small numbers of sea lions also use haul-out sites in the Gulf Islands at the Belle Chain and Sand Heads. Sea lion occasionally may use navigation buoys in the San Juan Islands and elsewhere in Puget Sound. Breeding habitat does not occur in the study area; however, haul-out sites are near the study area. Therefore, Steller sea lions may be swimming or feeding in the study area.

2.2.3.2 California Sea Lion

The California sea lion occurs seasonally in Washington waters (NMFS 1992). The total population is estimated at 296,750 sea lions and growing at 5.4 percent per year (Carretta et al. 2013). Of this total, an estimated 3,000 to 5,000 occur in Washington State and British Columbia (Jeffries et al. 2000). Males migrate northward along the coast following the summer breeding season in California. Beginning in August, California sea lions appear along the outer Washington coast, and some move into Puget Sound and into British Columbia. California sea lions remain in Washington waters through winter and early spring before returning to California in May and June. The migration can be characterized as a feeding migration, consisting primarily of adult and sub-adult males. California sea lion females and younger animals less than 4 to 5 years old tend to remain near their home rookeries throughout the year, or move only as far north as central California. Their main diet includes anchovies, sardine, whiting, mackerel, rockfish, and market squid (NMML 2013a).

Within the study area, California sea lions are most common off the coast and in the western extreme of the Strait of Juan de Fuca (Jeffries et al. 2000). The main haul-out sites off the coast are Carroll Island, Bodelteh Island, Cape Alava, and Tatoosh Island. As many as 4,000 to 5,000 California sea lions have been observed on the Bodelteh Islands during fall. Farther south on Carroll Island, 200 to 300 sea lions may haul out during the migration peak. Along the western Strait of Juan de Fuca, sea lions haul out at Waadah Island and Sombrio Point. There are no known sea lion haul-out sites in the eastern Strait of Juan de Fuca. Small numbers of sea lions haul out on navigation buoys in the San Juan Islands and adjoining San Juan Channel and Haro and Rosario Straits. The primary haul-out sites in British Columbia are at

Race Rock and Trial Island off Victoria, and during spring at the Belle Chain off Saturna Island and at Sand Head off the Frazer River. Male California sea lions are expected to occur in the study area.

2.2.3.3 Northern Elephant Seal

Northern elephant seals, estimated to number 124,000 animals, breed off Mexico and California during winter, and move northward to feed from Baja California to northern Vancouver Island and far offshore of the Gulf of Alaska and Aleutian Islands (Carretta et al. 2013). Solitary seals are occasionally recorded in the inland waters of Washington. A few individuals, some with pups, occasionally have been seen on the beaches at Destruction, Protection, and Smith/Minor Islands. Brueggeman et al. (1992) encountered elephant seals off the Washington coast primarily during summer and early fall, but none in spring. Most of the elephant seals they encountered were over the continental shelf and slope, at a mean distance of almost 64 km (40 mi) from the coast. Elephant seals prey on deep water and bottom-dwelling organisms, including fish, squid, crab, and octopus (NMML 2013b). No haul-out sites occur along the Washington coast or in the Strait of Juan de Fuca (Jeffries et al. 2000); however, northern elephant seals occasionally have been sited and may occur in the study area.

2.2.3.4 Northern Fur Seal

The Eastern Pacific stock of the northern fur seal, estimated to number 611,617,935 animals, is a seasonal migrant off the Washington coast (Angliss and Outlaw 2008; Carretta et al. 2013). The species does not breed in Washington; the closest rookeries are in the Bering Sea and the Channel Islands of California. During the breeding season in summer months, most of the population is found on the Pribilof Islands in the southern Bering Sea. Females and juveniles of both sexes migrate south into waters over the continental shelf and slope of the eastern North Pacific Ocean, while adult males stay in Alaska waters. The migration ranges as far south as 30 to 32 degrees north latitude off southern California and northern Baja, Mexico. Fur seals begin their return migration northward in mid-spring; by early summer, most have returned to their breeding islands. They feed on pollock, herring, capelin, squid, and small schooling fishes (ADFG 2008b).

In Washington, Brueggeman et al. (1992) reported that northern fur seals primarily inhabited the deep offshore waters, but they also use shelf and slope waters. They have been observed off the Washington coast year-round, but most (more than 90 percent) have been encountered from January through May. Sightings of northern fur seals in the Strait of Juan de Fuca or Puget Sound are rare but do occasionally occur (Gearin and Scordino 1995). Northern fur seals may occur in the study area.

3. MARINE TURTLES

Sea turtles are highly adapted for life in the marine environment with the aid of powerful, modified forelimbs that allow continuous swimming for extended periods of time. Sea turtles are among the longest and deepest diving of the air-breathing marine vertebrates, with some species spending as little as 3 to 6 percent of their time at the water's surface. Sea turtles often travel thousands of miles between their nesting beaches and feeding grounds. The only species of marine turtle with the potential to occur in the study area is the leatherback. A general overview of leatherbacks in the study area is provided below; a more thorough discussion of their life history and listing status is provided in the draft Biological Evaluation (Appendix G).

3.1 Leatherback Turtle (Endangered)

The leatherback turtle is the only extant member of the taxonomic family Dermochelyidae, distinguishable by their unique slightly flexible, leathery, barrel-shaped carapace (top shell). Other sea turtle species have bony, plated carapaces and belong to the Cheloniidae family. Leatherbacks subsist almost entirely on jellyfish but also have been known to opportunistically forage on other gelatinous organisms and small invertebrates. They generally consume from 20 to 30 percent of their body weight daily to gain their required nutritional value (Eckert et al. 2012).

Leatherback turtles regularly occur off the coast of Washington, especially off the mouth of the Columbia River during summer and fall, when large aggregations of jellyfish form (WDFW 2012). Observations, telemetry data, and gillnet captures of leatherbacks off the Washington coast identified turtles south of Cape Flattery and in deeper offshore water (WDFW 2012). Leatherback turtles could occur in the study area; however, occurrences are not expected to be common. Critical habitat for leatherback turtle has been designated at the western extent of the study area in the vicinity of "J" Buoy (77 FR 4170) and does not extend into the Strait of Juan de Fuca or Puget Sound.

4. BIRDS

4.1 Protected Species

This section identifies federally and state-listed bird species with the potential to occur in the study area. A more through discussion of the life history and listing status of the federally listed marbled murrelet is provided in the draft Biological Evaluation (Appendix G).

4.1.1 Federally Listed Species

4.1.1.1 Marbled Murrelet (Threatened)

There are six marbled murrelet conservation zones (WDFW 2014), one of which occurs in the study area. Zone 1 includes the Strait of Juan de Fuca, Hood Canal, and the San Juan Islands; it is monitored by the Pacific Northwest Research Station and the U.S. Department of Agriculture Forest Service. The most recent murrelet population estimate for Zone 1 is 4,393 birds, with the majority occurring around the southern end of the San Juan Islands and along the northern coast of the Olympic Peninsula (WDFW 2014). Primary fish prey of marbled murrelets includes Pacific sand lance, Pacific herring, northern anchovy, and smelts. Documented smelt and sand lance spawning locations occur throughout the Strait of Juan de Fuca and in the vicinity of the BP Cherry Point dock. Herring and smelt spawning occurs along the shoreline from Blaine, Washington south to Bellingham, and the BP Cherry Point dock falls within this area (WDFW 2014). Sand lance spawning occurs within the study area but has not been documented near the dock (WDFW 2014). While the presence of forage fish suggests that marbled murrelets may feed within the study area, nesting habitat is limited by a lack of the required old-growth forests. It is possible that marbled murrelets could be present within the study area, but only for foraging.

4.1.2 State-Listed Species

4.1.2.1 Brown Pelican (Endangered)

The brown pelican is a coastal bird that is rarely found away from the sea. Brown pelicans occur in substantial numbers (7,000 to 10,000) in Washington's outer coastal waters from late April through October (Wahl 2005 as cited in WDFW 2012), with small numbers occurring in the Strait of Juan de Fuca and Puget Sound (WDFW 2012). Brown pelicans feed primarily on schooling marine forage fish that can be found in the study area. The Puget Sound Seabird Survey indicates that this species has been sighted at Cape Flattery; no other occurrences within the study area have been recorded (BirdWeb 2014). Brown pelicans could occur at the western extent of the study area from April through October. Additional information on the distribution and habitat use of seabirds is provided in Section 4.3.

4.1.2.2 Streaked Horned Lark (Endangered)

The streaked horned lark historically bred in prairie and open coastal habitats in the Puget trough and Willamette Valley; recent surveys indicate that larks no longer breed in the northern Puget trough (San Juan Islands and coastal areas north of Tacoma), nor do they winter in the area (Pearson and Altman 2005; BirdWeb 2014). Therefore, it is highly unlikely that streaked horned lark would occur in the study area.

4.1.2.3 Common Loon (Sensitive)

Historical and current population levels of the common loon in Washington are not well known. It is a rare breeder and a common migrant and wintering species in the state (Richardson et al. 2000). Common

loons typically breed on forest lakes with deep inlets or bays and on numerous islands. Historical breeding records (pre-1950) indicate that common loons had previously used habitat in the San Juan Islands, while more recent surveys (1979–1999) indicate that loons are no longer present (Richardson et al. 2000). Common loons use protected marine waters in Washington during migration and for winter habitat. Christmas bird counts report their highest numbers for protected marine waters, such as Sequim-Dungeness, Port Townsend, San Juan Islands, and Padilla Bay (Richardson et al. 2000). The Puget Sound Seabird Survey indicates that the species occurs along the Olympic Peninsula and north though Rosario Strait to Anacortes (BirdWeb 2014). Wintering common loons are expected to occur in the study area. Additional information on the distribution and habitat use of seabirds is provided in Section 4.3.

4.1.2.4 Bald Eagle (Sensitive)

Bald eagles can be found in the forested parts of Washington year-round but are most abundant in the cooler, maritime region west of the Cascade Mountains; their nests are most numerous near marine shorelines (Stinson et al. 2007). Their winter distribution is similar to the breeding distribution but is more concentrated at salmon spawning streams and waterfowl wintering areas. Bald eagle surveys (2005) indicate that the species nest along the Washington shoreline and in the San Juan Islands. Bald eagles are expected to occur in the study area. Additional information on the distribution and habitat use of raptors is provided in Section 4.4.

4.1.2.5 Peregrine Falcon (Sensitive)

In Washington, peregrine falcons can be found nesting from the cooler, maritime region west of the Cascade Mountains to the more arid, dry climate of eastern Washington. The greatest number of breeding sites occurs in the San Juan Islands and lowlands of northern Puget Sound, within approximately 61 meters (200 feet) of freshwater (Hayes and Buchanan 2002). In these regions, peregrines nest on islands, “sea stacks,” or shoreline cliffs. Western Washington is noted for its high density of wintering peregrines due to the mild maritime climate and high prey density. Habitats used by peregrines during the non-breeding season include beaches, tidal flats, islands, and marshes that support high densities of shorebirds, waterfowl, and other small- to medium-sized birds. Wintering areas in the study area include Puget Sound estuaries and Willapa Bay (Hayes and Buchanan 2002). Peregrine falcons are expected to occur in the study area. Additional information on the distribution and habitat use of raptors is provided in Section 4.4.

4.1.2.6 Tufted Puffin (Candidate)

Tufted puffin populations have declined significantly in Washington waters during the 1980s and 1990s, including the Strait of Juan de Fuca, Puget Sound, and Strait of Georgia (WDFW 2012). Surveys conducted during the 2007–2008 breeding season indicate that approximately 50 percent of historically occupied breeding sites in Washington were active (WDFW 2012). Colony occupation within the study area has been recorded on Smith and Protection Islands (WDFW 2012); therefore, it is possible that tufted puffins could occur in the study area. Additional information on the distribution and habitat use of seabirds is provided in Section 4.3.

4.1.2.7 Western Grebe (Candidate)

In summer, the western grebe is found on inland freshwater lakes and marshes in eastern Washington, which is outside the study area. During fall (October), the western grebe moves to the Pacific coast and occupies nearshore marine waters during winter months (WDFW 2012). The Puget Sound Seabird Survey indicates that this species occurs along the Olympic Peninsula and north though Rosario Strait to Anacortes (BirdWeb 2014). The western grebe is expected to use habitat in the study area for wintering

and foraging; it would not be present in the study area during the breeding season. Additional information on the distribution and habitat use of seabirds is provided in Section 4.3.

4.1.2.8 Brandt's Cormorant (Candidate)

The Brandt's cormorant inhabits marine environments along the Pacific coast and can be found along rocky shorelines and the open ocean. They are mostly permanent residents, with some local movement (BirdWeb 2014). The Puget Sound Seabird Survey indicates that Brandt's cormorants occur west of Port Angeles along the Olympic Peninsula, with the highest concentrations recorded at the mouth of the Strait of Juan de Fuca (BirdWeb 2014). Brandt's cormorant are expected to occur in the study area. Additional information on the distribution and habitat use of seabirds is provided in Section 4.3.

4.1.2.9 Common Murre (Candidate)

Common murre typically nest on wide, open ledges on rocky cliffs. Most colonies are located on sea stacks and flat-topped islands that are partially vegetated or bare. They spend most of their time in the open ocean and large bays; they are found closer to rocky shorelines during the breeding season and farther offshore during the non-breeding season (BirdWeb 2014). The Puget Sound Seabird Survey indicates that the species occurs along the Olympic Peninsula and north though Rosario Strait to Anacortes, with the highest concentration occurring at the mouth of the Strait of Juan de Fuca (BirdWeb 2014). Common murre are expected to occur in the study area. Additional information on the distribution and habitat use of seabirds is provided in Section 4.3.

4.1.2.10 Cassin's Auklet (Candidate)

Cassin's auklet is a non-migratory bird that comes inland during the breeding season and nests on islands with shrubby habitat and cliffs. A breeding pair builds a burrow and uses it year after year (BirdWeb 2014). During the non-breeding season, auklets are found in the open ocean, at the outer edge of the continental shelf. The Puget Sound Seabird Survey indicates the species occurs in southern Puget Sound during the breeding season. No birds have been observed in the study area. Therefore, this species is not expected to occur in the study area. Additional information on the distribution and habitat use of seabirds is provided in Section 4.3.

4.1.2.11 Purple Martin (Candidate)

The purple martin is a long-distance migrant that can be found from mid-April to late-August in localized areas of open land near water in Washington. Purple martins have been observed in Island, King, and Kitsap Counties (BirdWeb 2014); therefore, the species could occur within the study area from April through August. Additional information on the distribution and habitat use and distribution of "other coastal birds" is provided in Section 4.6.

4.2 Waterfowl

Waterfowl are medium to large plump-bodied birds with long necks and short wings commonly found on or near water. Waterfowl feed while on the water by diving or tilting their bodies so that their heads and necks are submerged to search for fish, plants, and invertebrates. Waterfowl typically have large clutches with precocial young that can swim and eat on their own almost immediately after hatching. Twenty-eight species of waterfowl, four goose species, two swan species, six dabbling duck species, and sixteen diving duck species frequent the study area (Table 1).

Table 1. Occurrence by Month in the Puget Trough Ecoregion for Waterfowl That Commonly Use Coastal Habitats in the Study Area

	Occurrence by Month[a]											
Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Geese												
Snow goose	C	C	C	C	U				R	C	C	C
Brant	C	F	F	C	U	R	R	R	R	F	C	C
Canada goose	C	C	C	C	C	C	C	C	C	C	C	C
Swans												
Trumpeter swan	C	C	F	U						R	C	C
Tundra swan	C	C	C	U						U	C	C
Dabbling Ducks												
Gadwall	C	C	C	C	C	C	C	C	C	C	C	C
American wigeon	C	C	C	C	U	R	R	U	C	C	C	C
Mallard	C	C	C	C	C	C	C	C	C	C	C	C
Northern pintail	C	C	C	C	U	R	R	U	C	C	C	C
Green-winged teal	C	C	C	C	F	R	R	F	C	C	C	C
Diving Ducks												
Pochards												
Canvasback	F	F	U	U	R				R	U	C	F
Greater scaup	C	C	C	F	F	-	-	-	U	F	C	C
Lesser scaup	C	C	C	C	U	U	U	U	U	F	C	C
Sea Ducks												
Harlequin duck	F	F	F	U	U	U	F	F	F	F	F	F
Surf scoter	C	C	C	C	C	F	F	F	F	C	C	C
White-winged scoter	C	C	C	C	C	F	U	U	F	F	C	C
Long-tailed duck	C	C	C	U	U	-	-	-	-	F	C	C
Bufflehead	C	C	C	C	C	R	R	R	U	C	C	C
Common goldeneye	C	C	C	F	U	-	-	R	R	U	C	C
Barrow's goldeneye	C	C	C	C	R	R	R	R	R	U	C	C
Mergansers												
Common merganser	C	C	C	C	C	C	C	C	C	C	C	C
Red-breasted merganser	C	C	C	C	U	R	R	R	U	F	C	C
Ruddy duck	C	C	C	C	F	U	U	U	U	F	C	C

[a] Occurrence:
C = Common; F = Fairly Common; U = Uncommon; R = Rare; I = Irregular (Seattle Audubon Society 2008).

Sources: Seattle Audubon Society 2008; Wahl et al. 2005.

4.2.1 Geographic Distribution

Most waterfowl are migrants or winter visitors. Non-breeding individuals, including sub-adult birds, may remain in the study area year-round; and some waterfowl may breed in the study area.

4.2.2 Seasonal Distribution in Study Area

The most commonly occurring waterfowl, their group associations, and seasonal occurrence in the study area are listed in Table 1.

Four waterfowl species are common year-round: Canada goose, gadwall, mallard, and common merganser.

4.2.3 Uses, Status and Trends, and Regulatory Issues

All waterfowl are protected by the Migratory Bird Treaty Act (MBTA), and all waterfowl species occurring in the study area are harvested by sportsmen in Washington (USFWS 2007a). The most commonly harvested species (more than 10,000/year) include Canada goose, snow goose, mallard, wigeon, green-winged teal, and northern pintail (USFWS 2007a).

Breeding waterfowl population status and trends are reported from USFWS (2007b) and Wilkins et al. (2007). Snow geese occurring within the Pacific Flyway nest in the western and central Arctic and on Wrangel Island. These populations have increased 10 percent per year over the last 10 years; the U.S. population in 2007 was 734,000 birds. Brant geese occurring within the Pacific Flyway nest in the western and central Arctic United States and in the western high arctic in the Canadian Northwest Territories. These populations have shown no annual trend over the past 10 years; the total population estimate was 140,000 in 2007.

Four populations of Canada geese migrate through or winter in the study area, and resident Canada geese also occur in the study area. Ten-year population trends and 2007 estimated populations for the four migratory populations are: dusky Canada geese – no trend, 10,000 birds; cackling Canada geese – no trend, 173,000 birds; lesser and Taverner's Canada geese – 4 percent annual decline, 74,000 birds; Aleutian Canada geese – 10 percent annual increase, 119,000 birds. Western tundra swans have increased an average of 2 percent per year over the past 10 years; the estimated population in 2007 was 109,000 birds.

Most dabbling and diving ducks that migrate through or winter in the study area originate from nesting areas along the Pacific Flyway in Alaska, British Columbia, Yukon Territory, and western Alberta; breeding population estimates and trends from these regions are reported in Table 2 (USFWS 2007b; Wilkins et al. 2007).

Dabbling ducks generally feed on or near the water's surface in bays and estuaries, although the American wigeon, mallard, and northern pintail also use nearshore habitats. Dabbling ducks are considered to be primarily herbivorous, but they consume a greater variety of foods than geese and swans, including gastropods, bivalves, and other invertebrates from coastal marshes and shallow waters along shorelines (Verbeck and Butler 1989). Ruddy ducks are considered diving ducks, but they are more similar to dabbling ducks in their diet than most diving ducks. In addition to the food sources described for dabbling ducks, ruddy ducks include bivalves in their winter diets (NatureServe 2013).

Table 2. Breeding Population Estimates and Trends for Ducks That Migrate Through or Winter in the Study Area

	Regional Population Estimate and Long-Term Average (in thousands)			
	Alaska-Yukon Territory – Old Crow Flats		Alberta – Northeast British Columbia – Northwest Territories	
Species (Status)	2007 Estimate	Ten-Year Average	2007 Estimate	Ten-Year Average
Dabbling Ducks				
Gadwall	3	2	100	49
American wigeon	1,113	517	843	906
Mallard	581	360	887	1,075
Northern pintail	1,135	915	234	374
Green-winged teal	823	366	862	752
Diving Ducks				
Pochards				
Canvasback	92	91	139	73
Scaup	1,191	914	1,261	2,599
Sea Ducks				
Harlequin duck (unknown/stable)	--	--	--	--
Scoters (declining)	396	333	516	518
Long-tailed duck (declining/stable)	128	86	29	81
Bufflehead (stable/increasing)	61	45	359	338
Goldeneyes (stable/declining)	38	79	182	50
Mergansers (variable/declining)	36	25	92	78
Ruddy duck	0	0	4	28

Sources: USFWS 2007b; Mallek and Groves 2007; Ferguson and Benning 2007; Sea Duck Joint Venture 2003.

Harlequin ducks wintering in the study area also are known to nest along headwater streams in the Rocky Mountains. Summer and winter waterfowl distribution and abundance were monitored during 1992–1999 on marine waters in the study area and compared to previous results from surveys during the late 1970s (Table 3). In general, diving duck abundance has been in decline during the last decade.

4.2.4 Habitat Use by Life History Stages

Specific shoreline habitats used by waterfowl that commonly occur in the study area are indicated in Table 4. Geese and swans are primarily herbivorous and use bays and estuaries for feeding, especially during migration. Snow geese obtain most of their food by grubbing for rhizomes of bulrushes in tidal marshes, while swans feed on eelgrass leaves and rhizomes of bulrush along with grasses and sedges (Verbeck and Butler 1989).

Table 3. Summer and Winter Waterfowl Counts, Density, and Winter Trends in Puget Sound, Washington

Species	Abundance by Season					
	Summer Count (1992–1999)	Summer Density[a] (1992–1999)	Winter Count (1992–1999)	Winter Density[a] (1992–1999)	Historical Winter Density[a] (1978–1979)	Winter Trend
Geese	-	-	2,000	-	-	-
Snow goose	-	-	-	-	-	-
Brant	-	-	-	2.0	5.9	-66%
Canada goose	800	0.9	-	-	-	+ 9,000%
Swans (2 spp.)	-	-	160	-	-	-
Dabbling Ducks	600	0.7	80,000	60.7	-	-
Gadwall	-	-	160	0.1	-	-
American wigeon	-	-	43,000	32.2	-	-
Mallard	-	-	31,000	23.8	-	-
Northern pintail	-	-	4,000	3.3	-	+ 95%
Green-winged teal	-	-	1,400	1.1	-	-
Diving Ducks	-	-	72,000	45.0	-	-
Pochards	-	-	-	-	-	-
Canvasback	-	-	375	-	-	-
Greater scaup (2 spp.)	60	<0.1	5,700	7.6	27.3	-72%
Sea ducks	-	-	-	-	-	-
Harlequin duck	600	0.7	860	12.5	4.3	189%
Scoter (3 spp.)	3,300	3.8	26,500	32.0	74.6	-57%
Long-tailed duck	-	-	761	1.2	13.8	-91%
Bufflehead	-	-	16,800	59.8	49.8	20%
Goldeneye (2 spp.)	60	<0.1	11,900	14.1	18.3	-23%
Mergansers	-	-	4,500	12.4	8.0	55%
Common merganser	260	0.3	480	-	-	-
Red-breasted merganser	-	-	950	-	-	-
Ruddy duck	-	-	1,800	-	-	-

spp = species

[a] Density: Number of birds per square kilometer.

Source: Nysewander et al. 2005.

Table 4. Shoreline Habitats and Their Use by Waterfowl That Commonly Occur in the Study Area

Species	Habitats[a]											
	Eelgrass Beds	Kelp Beds	Rocky Shores	Unconsolidated Shores	Mudflats and Sandflats	Rocky Subtidal	Unconsolidated Subtidal	Estuaries	Salt Marsh	Nearshore Riparian	Backshore Spray	Cherry Point[b]
Geese												
Snow goose	F	-	-	-	F	-	-	F/O	F/O	F	-	-
Brant	F	F	F	F	F	F	F	F	F	F	-	-
Canada goose	F	-	-	-	F	-	-	F	F	F	-	-
Swans												
Trumpeter swan	F	-	-	-	F	-	-	F	F	F	-	-
Tundra swan	F	-	-	-	F	-	-	F	F	F	-	-
Dabbling Ducks												
Gadwall	F	-	-	-	F	-	-	F	F	F	-	-
American wigeon	F	F	F	F	F	F	F	F	F	F	-	-
Mallard	F	F	F	F	F	F	F	F	F	F	-	-
Northern pintail	F	F	F	F	F	F	F	F	F	F	-	-
Green-winged teal	F	-	-	-	F	-	-	F	F	F	-	-
Diving Ducks												
Pochards												
Canvasback	F	F	F	F	F	F	F	F	F	F	-	-
Greater scaup	F	F	F	F	F	F	F	F	F	F	-	-
Lesser scaup	F	F	F	F	F	F	F	F	F	F	-	W
Sea Ducks												
Harlequin duck	F	-	-	-	F	-	-	F	F	F	-	R
Surf scoter	F	F	F	F	F	F	F	F	F	F	-	W
White-winged scoter	F	F	F	F	F	F	F	F	F	F	-	W
Long-tailed duck	-	F	F	F		F	F	-	-	-	-	W
Bufflehead	F	F	F	F	F	F	F	F	F	F	-	-
Common goldeneye	F	F	F	F	F	F	F	F	F	F	-	W
Barrow's goldeneye	F	F	F	F	F	F	F	F	F	F	-	-
Mergansers												
Common merganser	F	-	-	-	F	-	-	F	F	F	-	-
Red-breasted merganser	F	F	F	F	F	F	F	F	F	F	-	W
Ruddy duck	F	-	-		F	-	-	F	F	F	-	-

[a] Habitat use: B = Feeds and Reproduces; F = Feeds; R = Reproduces; O = Other (Wahl et al. 2005). For cross reference between the listed specific habitats, those described in the text, and those listed in Wahl et al. (2005); eelgrass beds, mudflats and sandflats, estuaries, salt marsh and nearshore riparian are considered primarily bay and estuary habitats (light gray headings in table); kelp beds, rocky shores, unconsolidated shores, rocky subtidal, unconsolidated subtidal, and backshore spray are considered primarily marine nearshore (dark gray headings in table) but also occur in coastal dune and beaches habitats or headland and islet habitats.

[b] Cherry Point habitat use: W = winter, R = Resident, S = summer.

Sources: Wahl et al. 2005; Bower et al. 2008.

Diving ducks are a diverse group that includes pochards, sea ducks, and mergansers. Diving ducks generally dive completely beneath the water's surface during feeding. Diving ducks are diverse in their foraging habits. All diving ducks that occur in the study area, except the long-tailed duck, use bays and estuaries; 11 of 16 species use nearshore habitats; and 6 of 16 species also use inland marine deep water habitats for feeding (Wahl et al. 2005). The bufflehead, goldeneye, and scaup are found primarily in bays

where they feed on bivalves, crabs, barnacles, shrimp and other invertebrates, herring eggs, and some fish, in addition to algae and vascular plants. Scoters feed primarily on bivalves; black and surf scoters feed more on blue mussels while white-winged scoters feed more on clams. All scoters also feed on snails, crabs, shrimp and other invertebrates, and herring spawn (Vermeer and Ydenberg 1989). Surf scoters feed opportunistically on herring spawn during March, gathering in the tens of thousands at spawning areas (Vermeer and Ydenberg 1989). Long-tailed ducks feed on bivalves and snails during summer; bivalves, shrimp, isopods, amphipods, and crabs during winter; and herring eggs in spring (Vermeer and Ydenberg 1989). Harlequin ducks have a very diverse diet dominated by snails, limpets, fish and fish eggs, crabs, chiton, algae, bivalves, and crustaceans. Blue mussels are the only bivalve known to be consumed by harlequin ducks (Vermeer and Ydenberg 1989). Mergansers are primarily fish-eating ducks that consume sculpins, herring, rockfish, shiner perch, pipefish, blennies, and salmon, in addition to some shrimp and crabs (Vermeer and Ydenberg 1989).

4.3 Seabirds

Seabirds include a diverse assemblage of birds that are tied to marine habitats for at least a portion of their life cycle. Loons, grebes, cormorants, auks, and puffins feed by diving deeply for fish or invertebrates, while gulls and terns feed near the water surface or shoreline. Albatrosses, shearwaters, and petrels spend much of their life at sea; feeding from the water's surface and coming to land only to nest.

4.3.1 Geographic Distribution

Seabirds occurring in the study area generally belong to species that are widely distributed throughout the Pacific coast from Alaska to California. Loons and grebes are generally migrants or winter visitors, as are some of the arctic breeding gull and tern species. Cormorant, ring-billed gull, glaucous-winged gull, common murre, and pigeon guillemot are common year-round resident seabirds. Caspian tern and rhinoceros auklet move into the study area during spring and summer to nest and to rear their young.

4.3.2 Seasonal Distribution in Study Area

Of the 41 species of seabirds potentially occurring in the study area, 18 are commonly found during 3 or more months of the year (Table 5). Seabirds dominate the birds occurring in the study area during summer months while they account for less than a quarter of all birds recorded during winter (Nysewander et al. 2005). Table 5 shows occurrence by month in the Puget Trough ecoregion for seabirds that commonly use coastal habitats in the study area.

Major seabird nesting colonies in the study area occur at Protection Island, at islets within the San Juan Islands, and off Cape Flattery (Figure 3).

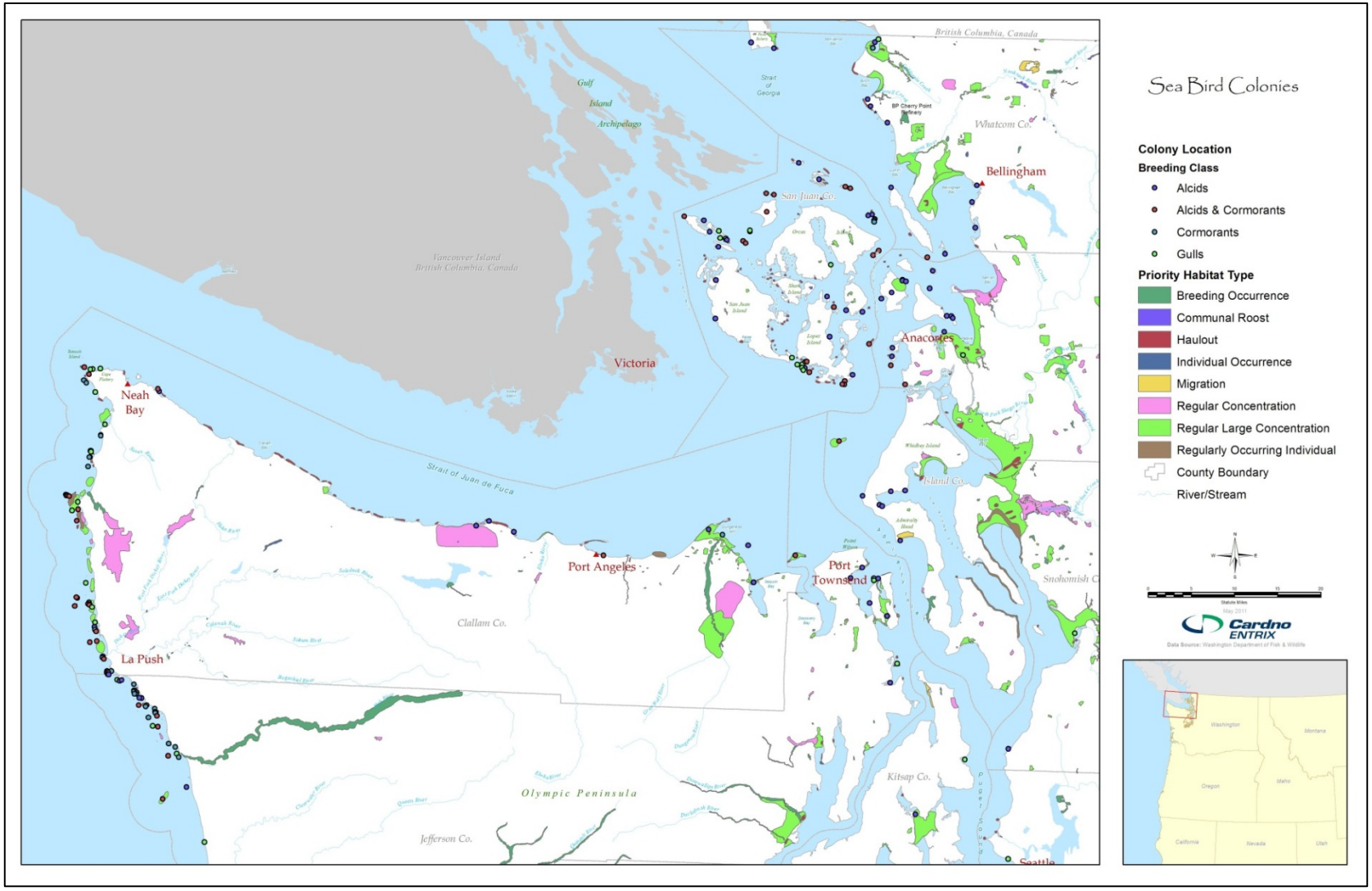

Figure 3. Species and Recent Relative Abundance of Seabird Nesting Colonies in the Study Area

Table 5. Occurrence by Month in the Puget Trough Ecoregion for Seabirds That Commonly Use Coastal Habitats in the Study Area

	Occurrence by Month[a]											
Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Loons												
Red-throated loon	C	C	C	C	F	R	R	R	C	C	C	C
Pacific loon	C	C	C	C	C	R	R	R	F	C	C	C
Common loon	C	C	C	C	C	F	F	F	C	C	C	C
Grebes												
Horned grebe	C	C	C	C	R	-	-	R	F	C	C	C
Red-necked grebe	C	C	C	F	U	-	R	F	F	C	C	C
Western grebe	C	C	C	C	U	R	U	U	F	C	C	C
Cormorants												
Brandt's cormorant	C	C	C	C	C	C	C	C	C	C	C	C
Double-crested cormorant	C	C	C	C	C	C	C	C	C	C	C	C
Pelagic cormorant	C	C	C	C	C	C	C	C	C	C	C	C
Gulls and Terns												
Bonaparte's gull	C	C	C	C	F	-	R	F	C	C	C	C
Heermann's gull	R	-	-	-	-	-	U	F	F	F	U	R
Mew gull	C	C	C	C	U	-	R	U	C	C	C	C
Ring-billed gull	C	C	C	C	C	C	C	C	C	C	C	C
California gull	R	R	R	U	U	F	C	C	C	C	F	R
Glaucous-winged gull	C	C	C	C	C	C	C	C	C	C	C	C
Caspian tern	-	-	R	C	C	C	C	C	F	R	-	-
Auks and Puffins												
Common murre	C	C	C	C	C	C	C	C	C	C	C	C
Pigeon guillemot	C	C	C	C	C	C	C	C	C	C	C	C
Rhinoceros auklet	F	F	F	C	C	C	C	C	F	F	F	F

[a] Occurrence:
C = Common; F = Fairly Common; U = Uncommon; R = Rare; I = Irregular (Seattle Audubon Society 2008)

Sources: Seattle Audubon Society 2008; Wahl et al. 2005.

4.3.3 Uses, Status and Trends, and Regulatory Issues

All seabirds are protected by the MBTA. Few seabirds are harvested for food, although historically seabird nesting colonies provided a subsistence food source for humans. Some seabirds such as pelicans, gulls, cormorants, and loons may be considered nuisance species as they are attracted to aquaculture facilities, fisheries processing plants, fishing vessels, and solid waste facilities where they opportunistically forage on wastes. Caspian terns and brown pelicans in particular have been identified as a major threat to the recovery of Pacific salmon stocks, as they forage heavily on salmon smolts emigrating to estuaries where these birds nest or aggregate. In general, loon and grebe populations may be declining, while most gull, tern, and pelican populations are considered to be increasing. Cormorant populations may have variable trends depending on the species; and murre, guillemot, and auklet populations are considered to be declining. Table 6 includes summer and winter seabird counts, density, and trends in Puget Sound. Figure 3 shows species and recent relative abundance of seabird nesting colonies in the study area.

Table 6. Summer and Winter Seabird Counts, Density, and Trends in Puget Sound, Washington

Species	Abundance by Season[a]					
	Summer Count (1992–1999)	Summer Density[a] (1992–1999)	Winter Count (1992–1999)	Winter Density[a] (1992–1999)	Historical Winter Density[a] (1978–1979)	Winter Trend
Loons	-	-	2,300	1.7	8.0	-79%
Red-throated loon	√	-	620	-	-	-72%
Pacific loon	√	-	700	-	-	-55%
Common loon	√	Most abundant	370	0.8	2.3	-64%
Grebes	-	-	24,900	-	-	-
Horned grebe	-	-	660	1.8	10.1	-82%
Red-necked grebe	-	-	500	0.5	4.3	-89%
Western grebe	-	-	21,300	1.1	22.2	-95%
Cormorants	2,000	2.7	-	8.3	17.6	-53%
Brandt's cormorant	350	0.5	-			
Double-crested cormorant	1,100	1.5	-	1.9	5.0	-62%
Pelagic cormorant	500	0.7	-			+95%
Gulls and terns	41,600	59.4	-	75.7	133.9	-43%
Bonaparte's gull	2,300	3.3	-	-	-	-
Heermann's gull	1,500	2.1	-	-	-	-
Mew gull			-	-	-	-
Ring-billed/California gull	1,000	1.4	-	-	-	-
Glaucous-winged gull	9,800	13.9	-	-	-	-
Caspian tern	1,000		-	-	-	+40,000%
Auks and puffins	4,200	5.9	-	-	-	-
Common murre	1,300	1.8	-	-	-	-93%
Pigeon guillemot	1,200	1.7	-	0.7	1.5	-55%
Rhinoceros auklet	1,500	2.1	-	-	-	-

[a] Density: Number of birds per square kilometer

Source: Nysewander et al. 2005.

4.3.4 Habitat Use by Life History Stages

Shoreline habitats used by commonly occurring seabirds in the study area are indicated in Table 7. Loons and grebes occur in bays and estuaries (8 of 9 species), nearshore marine (7 of 9 species), and inland marine habitats (6 of 9 species) (Wahl et al. 2005). They feed on fish and aquatic insects; both loons and grebes primarily nest on freshwaters and winter on saltwater. Wintering loon diets are probably dominated by fish including herring shiner perch, smelt, and sand lance, although common loons also forage on invertebrates (Vermeer and Ydenberg 1989). Wintering grebes forage on herring and herring eggs, shrimp, and other invertebrates (Vermeer and Ydenberg 1989).

Cormorants occur in bays and estuaries (3 of 3 species), nearshore marine (3 of 3 species), and headlands and islets (3 of 3 species) (Wahl et al. 2005). Cormorants feed on herring, shiner perch, gobies, rockfish, anchovy, plainfin midshipman, saury, sanddab, sole, shrimp, and squid (Vermeer and Ydenberg 1989).

Table 7. Shoreline Habitats and Their Use by Seabirds That Commonly Occur in the Study Area

Species	Habitats[a]											
	Eelgrass Beds	Kelp Beds	Rocky Shores	Unconsolidated Shores	Mudflats and Sandflats	Rocky Subtidal	Unconsolidated Subtidal	Estuaries	Salt Marsh	Nearshore Riparian	Backshore Spray	Cherry Point[b]
Loons												
Red-throated loon	F	F	F	F	F	F	F	F	F	F	-	-
Pacific loon	F	F	F	F	F	F	F	F	F	F	-	W
Common loon	F	F	F	F	F	F	F	F	F	F	-	-
Grebes												
Horned grebe	F	F	F	F	F	F	F	F	F	F	-	-
Red-necked grebe	F	F	F	F	F	F	F	F	F	F	-	-
Western grebe	F	F	F	F	F	F	F	F	F	F	-	W
Cormorants												
Brandt's cormorant	F	F	R	F	F	R	F	F	F	F	-	R
Double-crested cormorant	F	F	R	F	F	R	F	F	F	F	-	R
Pelagic cormorant	F	F	R	F	F	R	F	F	F	F	-	R
Gulls and Terns												
Bonaparte's gull	F	F	F	F	F	F	F	F	F	F	F	S
Heermann's gull	F	F	F	F	F	F	F	F	F	F	F	-
Mew gull	F	F	F	F	F	F	F	F	F	F	F	W
Ring-billed gull	F	F	F	F	F	F	F	B	B	B	F	W
California gull	F	F	F	F	F	F	F	F	F	F	F	-
Glaucous-winged gull	F	F	B	F	F	B	B	F	F	F	B	R
Caspian tern	F	F	F	F	F	F	F	F	F	F	F	S
Auks and Puffins												
Common murre	F	F	B	F	F	B	F	F	F	F	-	-
Pigeon guillemot	F	F	B	F	F	B	F	F	F	F	-	-
Rhinoceros auklet	F	F	B	F	F	B	F	F	F	F	-	-

[a] Habitat use: B = Feeds and Reproduces; F = Feeds; R = Reproduces; O = Other (Wahl et al. 2005). For cross reference between the listed specific habitats, those described in the text and those listed in Wahl et al. (2005); eelgrass beds, mudflats and sandflats, estuaries, salt marsh and nearshore riparian are considered primarily bay and estuary habitats (light gray headings); kelp beds, rocky shores, unconsolidated shores, rocky subtidal, unconsolidated subtidal, and backshore spray are considered primarily marine nearshore (dark gray headings) but also occur in coastal dune and beaches habitats or headland and islet habitats.

[b] Cherry Point Habitat Use: W = winter, R = Resident, S = summer.

Sources: Wahl et al. 2005; Bower et al. 2008.

Gulls and terns occur in nearshore marine (18 of 18 species), dunes and beaches (17 of 18 species), bays and estuaries (16 of 18 species), headlands and islets (13 of 18 species), and inland marine habitats (12 of 18 species) (Wahl et al. 2005). The diets of gulls and terns vary with the species but include bivalves, barnacles, mussels, sea urchins, limpets, shrimp, crabs, herring and herring spawn, salmon, blennies, lampreys, and sculpins (Vermeer and Ydenberg 1989).

Auks and puffins are diving birds that spend most of their time at sea, coming to land primarily for nesting. Auks and puffins occur in nearshore marine (7 of 7 species), inland marine (7 of 7 species), headlands and islets (5 of 7 species), and bays and estuary habitats (4 of 7 species) (Wahl et al. 2005). Auks forage primarily on fish and invertebrates including herring, sand lance, shiner perch, smelt, rockfish, sculpins, flatfish, squid, shrimp, and crab; but they may feed their chicks primarily fish and probably feed more on invertebrates during winter (Vermeer and Ydenberg 1989).

4.4 Raptors

For the purposes of this discussion, raptors include vultures, osprey, eagles, harriers, kites, hawks, merlins, falcons, and owls. Hawks, eagles, harriers, and falcons are medium to large birds with upright posture and strong, short, hooked beaks and acute vision that they use to catch live vertebrate prey. Vultures share these characteristics but feed primarily on carcasses of large animals. Ospreys are large diving hawks that subsist on a diet of live fish. Six species of raptors that use shoreline habitats are common or fairly common in the study area. Kites, merlins, and owls do not commonly occur in the study area.

4.4.1 Geographic Distribution

All raptors present in the study area occur throughout North America. Common species are most abundant in the study area either during winter (i.e., northern harrier and rough-legged hawk), nesting (i.e., turkey vulture and osprey), migration (i.e., peregrine falcon), or year-round (i.e., bald eagle). Peregrine falcons also nest in the study area.

4.4.2 Seasonal Distribution in Study Area

The six species of raptors occurring in the study area are common or fairly common during two or more months of the year (Table 8). The bald eagle is the most common raptor and occurs throughout the study area. Bald eagles and osprey nest in large shoreline trees during early spring and summer. The density of wintering bald eagles recorded in the study area during December to February from 1993 to 1999 was 0.6 bald eagle per km^2 (Nysewander et al. 2005). Turkey vultures are most common during spring and fall migrations, when they account for 3 percent of spring migrant raptors (Wahl et al. 2005). Northern harriers are ground-nesting birds and are a fairly common migrant and resident bird within portions of the study area (Wahl et al. 2005). The rough-legged hawk is a fairly common migrant and winter resident within portions of the study area (Wahl et al. 2005). Peregrine falcons may occur year-round in the study area but are most common during fall migrations (Wahl et al. 2005). This species nests on cliffs, bridges, and buildings (Wahl et al. 2005).

4.4.3 Uses, Status and Trends, and Regulatory Issues

All raptors are protected by the MBTA, and the bald eagle also is protected by the Bald and Golden Eagle Protection Act. The bald eagle and peregrine falcon formerly were protected under the ESA. Nearly all species of raptors declined in the 1950s and 1960s due to the use of pesticides that accumulated in predatory birds and resulted in lost or reduced productivity and survival. Since widespread bans on the use of pesticides, nearly all previously reduced raptor populations have increased. Within the study area, commonly occurring raptors, with the possible exception of the rough-legged hawk, are considered to have increased in abundance since the 1950s (Wahl et al. 2005).

Table 8. Occurrence by Month in the Puget Trough Ecoregion for Raptors That Commonly Use Coastal Habitats in the Study Area

Species	Occurrence by Month[a]											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vultures												
Turkey vulture	-	R	U	F	F	F	F	F	C	F	R	-
Accipiters												
Osprey	-	-	R	F	F	F	F	F	F	U	R	-
Bald eagle	C	C	C	C	C	C	C	F	F	F	C	C
Northern harrier	F	F	F	F	U	U	U	U	F	F	F	F
Buteos												
Rough-legged hawk	F	F	F	U	-	-	-	-	R	U	F	F
Falcons												
Peregrine falcon	U	U	U	U	U	U	U	U	F	F	U	U

[a] Occurrence:
C = Common; F = Fairly Common; U = Uncommon; R = Rare; I = Irregular (Seattle Audubon Society 2008).

Sources: Seattle Audubon Society 2008; Wahl et al. 2005.

4.4.4 Habitat Use by Life History Stages

Shoreline habitats used by raptors in the study area are indicated in Table 9. The six commonly occurring raptors are included because they commonly use marine resources such as fish, marine mammal carcasses, marine waterfowl, and shorebirds using intertidal areas. Raptors occur in coastal dunes and beaches (8 of 10 species), bays and estuary (7 of 10 species), nearshore marine (4 of 10 species), headlands and islets (4 of 10 species), and inland marine habitats (1 of 10 species) (Wahl et al. 2005). Osprey, bald eagle, northern harrier, and peregrine falcon nest in the study area. Osprey nest along shorelines, generally in tall emergent trees, and forage for fish in marine and freshwater habitats. Bald eagles nest near water in large conifers and forage in coastal areas, shifting from marine shorelines to inland rivers when salmon carcasses are abundant (Wahl et al. 2005). Bald eagle forage fishes include rockfish, lingcod, cabezon, arrowtooth flounder, and red Irish lord; forage birds include buffleheads, gulls, scoters, and murres (Verbeck and Butler 1989). Northern harriers nest in marshes and forage in wetlands and tidal flats in the study area (Wahl et al. 2005). The rough-legged hawk forages in estuarine habitats. Peregrine falcons forage and winter on large river deltas, estuaries, and coastal beaches where they feed on shorebirds and waterfowl (Wahl et al. 2005).Turkey vultures forage along shorelines scavenging for dead fish, seals, and other animals (Wahl et al. 2005).

Table 9. Shoreline Habitats and Their Use by Raptors That Commonly Occur in the Study Area

Species	Habitats[a]											
	Eelgrass	Kelp Beds	Rocky Shores	Unconsolidated Shores	Mudflats and Sandflats	Rocky Subtidal	Unconsolidated Subtidal	Estuaries	Salt Marsh	Nearshore Riparian	Backshore Spray	Cherry Point[b]
Vultures												
Turkey vulture	F	-	F	F	F	-	-	F	F	F	-	S
Accipiters												
Osprey	B	F	R	R	B	F	F	B	B	B	B	S
Bald eagle	B	F	B	B	B	F	F	B	B	B	B	R
Northern harrier	F	-	-	B	F	-	-	F	F	F	-	R
Buteos												
Rough-legged hawk	-	-	-	F	-	-	F	-	F	-	-	W
Falcons												
Peregrine falcon	F	-	B	B	F	-	-	F	F	F	-	W

[a] Habitat use: B = Feeds and Reproduces; F = Feeds; R = Reproduces; O = Other (Wahl et al. 2005). For cross reference between the listed specific habitats, those described in the text and those listed in Wahl et al. (2005); eelgrass beds, mudflats and sandflats, estuaries, salt marsh and nearshore riparian are considered primarily bay and estuary habitats (light gray headings); kelp beds, rocky shores, unconsolidated shores, rocky subtidal, unconsolidated subtidal, and backshore spray are considered primarily marine nearshore (dark gray headings) but also occur in coastal dune and beaches habitats or headland and islet habitats.

[b] Cherry Point habitat use: W = winter, R = Resident, S = summer.

Sources: Wahl et al. 2005; Woodcock and Irving 2008.

4.5 Shorebirds

For the purposes of this discussion, shorebirds include plovers, oystercatchers, sandpipers, and phalaropes. Shorebirds are a diverse group of birds associated with shorelines that feed primarily on invertebrates or small aquatic creatures. They generally have longish legs and short to long beaks that they use to probe sand or mud substrates or to pick intertidal invertebrates from rocks. Most species migrate long distances. All but the phalaropes do not generally swim, but walk along shorelines and beaches. Shorebirds are generally long-lived, nest on the ground or on small shrubs, and have precocial young. Fifteen species of shorebirds are common to fairly common in the study area (Table 10). Even though the black oystercatcher is generally considered uncommon throughout its entire range, it is included here because it is considered to be a locally common resident on exposed rocky shorelines of the San Juan Islands and the Strait of Juan de Fuca (Wahl et al. 2005).

4.5.1 Geographic Distribution

Most shorebirds occurring in the study area nest outside of the study area and occur in the study area only during migration between nesting and wintering areas. However, some of the more common shorebird species winter in the study area and the killdeer, black oystercatcher, and spotted sandpiper nest in the study area.

Table 10. Occurrence by Month in the Puget Trough Ecoregion for Shorebirds That Commonly Use Coastal Habitats in the Study Area

	Occurrence by Month[a]											
Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Plovers												
Black-bellied plover	F	F	F	F	U	R	R	C	C	F	F	F
Semipalmated plover	-	-	-	U	F	-	F	F	F	R	-	-
Killdeer	C	C	C	C	C	C	C	C	C	C	C	C
Oystercatchers												
Black oystercatcher	U	U	U	U	U	U	U	U	U	U	U	U
Sandpipers												
Spotted sandpiper	R	R	U	U	F	F	F	F	F	U	U	R
Greater yellowlegs	U	U	U	C	F	R	U	C	C	F	F	U
Black turnstone	C	C	C	C	U	-	U	U	F	C	C	C
Surfbird	F	F	F	F	R	-	R	U	U	F	F	F
Sanderling	C	C	C	F	U	-	R	U	C	C	C	C
Western sandpiper	U	U	U	C	C	R	C	C	C	F	U	U
Least sandpiper	U	U	U	C	C	R	C	C	C	U	U	U
Dunlin	C	C	C	C	F	-	R	R	R	C	C	C
Short-billed dowitcher	-	-	-	F	F	R	F	F	U	R	-	-
Long-billed dowitcher	U	U	U	F	F	-	F	F	F	F	F	U
Common snipe	U	U	F	F	U	U	U	U	F	F	F	U
Phalaropes												
Red-necked phalarope	-	-	-	R	F	-	R	C	F	R	-	-

[a] Occurrence: C = Common; F = Fairly Common; U = Uncommon; R = Rare; I = Irregular (Seattle Audubon Society 2008).

Sources: Seattle Audubon Society 2008; Wahl et al. 2005.

4.5.2 Seasonal Distribution in Study Area

The shorebirds present in the study area are common or fairly common during 2 or more months of the year (Table 10). Important shorebird areas in the study area identified in the *Northern Pacific Coast Regional Shorebird Management Plan* (Drut and Buchanan 2000) are listed in Table 11.

Table 11. Important Shorebird Sites in the Study Area That Support at Least 1,000 Shorebirds during Winter, Spring, or Autumn

Site	Estimated Foraging and Roosting Shorebirds Supported
Estuaries	
Baker Bay	~ 1,000
Bellingham Bay	≥ 4,000
Birch Bay	≥ 1,000
Boz Lake	~ 1,000
Chuckanut Bay	≥ 4,000
Crockett Lake	~ 2,000
Cultus Bay	~ 2,000
Deer Lagoon	~ 2,000
Drayton Harbor	≥ 4,000
Dungeness Bay	≥ 4,000
Fidalgo Bay	≥ 4,000
Lummi Bay	≥ 4,000
Padilla Bay	> 20,000
Port Angeles Harbor	~ 2,500
Port Susan	> 20,000
Samish Bay	> 20,000
Sequim Bay	≥ 4,000
Skagit Bay	> 20,000
Rocky Shorelines	
San Juan Islands National Wildlife Refuge	~ 4,000
Strait of Juan de Fuca	~ 4,000
Washington Maritime National Wildlife Refuge	~ 2,000

Source: Drut and Buchanan 2000.

4.5.3 Uses, Status and Trends, and Regulatory Issues

All shorebirds are protected by the MBTA. Except; for the common snipe, shorebirds are not currently harvested in the Pacific Northwest. Historically, shorebirds were harvested, and several species have yet to recover from population declines caused by over exploitation from market hunting. In general, many shorebird populations are in decline due to significant losses and degradation of wetland and estuarine habitats on which these birds rely. Shorebirds commonly occurring in the study area that are considered of high concern due to their regional importance include the black oystercatcher, common snipe, dunlin, greater yellowlegs, and sanderling (Drut and Buchanan 2000). North American population estimates, and population trends for shorebirds that commonly occur in the study area are listed in Table 12.

Table 12. North American Population Estimates, Current Population Trends, and State Natural History Rankings for Shorebirds That Commonly Occur in the Study Area

Species	Population Estimate (Accuracy Rating[a])	Current Population Trend Estimate	State Natural History Rankings[b]
Plovers			
Black-bellied plover	200,000 (Low)	Decline	S4N
Semipalmated plover	150,000 (Low)	Stable	S4N
Killdeer	1,000,000 (Low)	Decline	S4S5B, S4S5N
Oystercatchers			
Black oystercatcher	10,000 (Moderate)	Stable	S4
Sandpipers			
Spotted sandpiper	150,000 (Poor)	Decline	S4B , S3N
Greater yellowlegs	100,000 (Low)	Stable	S4S5N
Black turnstone	95,000 (Good)	Stable	S4S5N
Surfbird	70,000 (Moderate)	Decline	S4N
Sanderling	300,000 (Low)	Decline	S4N
Western sandpiper	3,500,000 (Good)	Decline	S4S5N
Least sandpiper	700,000 (Low)	Decline	S4N
Dunlin	1,525,000 (Low)	Decline	S4S5N
Short-billed dowitcher	153,000 (Low)	Decline	S4N
Long-billed dowitcher	400,000 (Poor)	Unknown	S4S5N
Common snipe	1-3 million (Poor)	Decline	S4B, S5N
Phalaropes			
Red-necked phalarope	2,500,000 (Poor)	Decline	S4N

[a] Accuracy rating: Poor: A population estimate based on an educated guess. Low: A population estimate based on broad-scale surveys where estimated population size is likely to be in the right order of magnitude. Moderate: A population estimate based on a special survey or on broad-scale surveys of a narrowly distributed species whose populations tend to concentrate to a high degree. Good: A calculated estimate based on broad-scale mark-recapture ratios or other systematic estimating effort resulting in estimates on which confidence limits can be placed.

[b] State rankings (S = State); 4 = Apparently Secure; 5 = Secure; B = Breeding; N = Non-breeding.

Sources: Morrison et al. 2006; NatureServe 2013.

4.5.4 Habitat Use by Life History Stages

Shoreline habitats used by the commonly occurring shorebirds in the study area are indicated in Table 13. Shorebirds primarily occur in bays and estuaries (27 of 31 species), coastal dunes and beaches (23 of 31 species), and headlands and islets (8 of 31 species) (Wahl et al. 2005). Phalaropes are the only shorebirds in the study area that use inland marine and marine nearshore waters (Wahl et al. 2005). Sandpipers and plovers forage primarily on benthic invertebrates such as worms, snails, bivalves, crustaceans, and insects. However, one study has shown that western sandpipers also graze and consume large quantities of surficial intertidal biofilm (a thin layer of microbes, detritus, sediment, and polymeric substances secreted by microphytobenthos and benthic bacteria), which can provide up to 50 percent of their daily energy budget (Kuwae et al. 2008). Dunlin have a similar bill and tongue shape as western sandpipers, indicating that they may be capable of consuming biofilm, and previous unexplained observations of large volumes of sediment in the alimentary tract of shorebirds may also indicate consumption of biofilm (Kuwae et al. 2008). Biofilm develops over muddy low-energy intertidal and estuarine areas that do not experience extensive sediment re-suspension (Kuwae et al. 2008).

Table 13. Shoreline Habitats and Their Use by Shorebirds that Commonly Occur in the Study Area

Species	Habitats[a]											
	Eelgrass	Kelp Beds	Rocky Shores	Unconsolidated Shores	Mudflats and Sandflats	Rocky Subtidal	Unconsolidated Subtidal	Estuaries	Salt Marsh	Nearshore Riparian	Backshore Spray	Cherry Point[b]
Plovers												
Black-bellied plover	F	-	F	F	F	-	-	F	F	-	-	-
Semipalmated plover	F	-	F	F	F	-	-	F	F	-	-	-
Killdeer	F	-	B	B	B	-	-	B	B	B	B	R
Oystercatchers												
Black oystercatcher	-	-	B	B	-	B	B	-	-	-	B	-
Sandpipers												
Spotted sandpiper	B	-	-	F	B	-	F	B	B	B	-	S
Greater yellowlegs	F	-	-	F	F	-	F	F	F	F	-	W
Black turnstone	-	-	F	F	F	F	F	-	-	-	F	W
Surfbird	-	-	F	F	F	F	F	-	-	-	F	-
Sanderling	-	-	-	F	F	-	F	F	-	-	F	W
Western sandpiper	-	-	-	F	F	-	F	F	F	-	-	-
Least sandpiper	-	-	-	F	F	-	F	F	F	-	-	-
Dunlin	-	-	-	F	F	-	F	F	F	-	-	W
Short-billed dowitcher	-	-	-	F	F	-	F	F	F	-	-	-
Long-billed dowitcher	-	-	-	-	F	-	-	F	F	-	-	-
Common snipe	-	-	-	-	F	-	-	F	F	F	-	-
Phalaropes												
Red-necked phalarope	-	F	F	F	-	F	F	F	-	-	-	-

[a] Habitat use: B = Feeds and Reproduces; F = Feeds; R = Reproduces; O = Other (Wahl et al. 2005). For cross reference between the listed specific habitats, those described in the text and those listed in Wahl et al. (2005); eelgrass beds, mudflats and sandflats, estuaries, salt marsh and nearshore riparian are considered primarily bay and estuary habitats (light gray headings); kelp beds, rocky shores, unconsolidated shores, rocky subtidal, unconsolidated subtidal, and backshore spray are considered primarily marine nearshore (dark gray headings) but also occur in coastal dune and beaches habitats or headland and islet habitats.

[b] Cherry Point habitat use: W = Winter, R = Resident, S = Summer.

Sources: Wahl et al. 2005; Drut and Buchanan 2000.

4.6 Other Coastal Birds

The "other coastal birds" group is a general grouping for shoreline-associated birds that do not fall within the previous groups. For the purposes of this discussion, "other coastal birds" includes herons, coots, and land birds that use coastal habitats, in addition to dippers, jays, crows, ravens, swallows, and wrens.

4.6.1 Geographic Distribution

Twenty-seven species of other coastal birds occur commonly in the study area during 3 or more months of the year (Table 14). Most other coastal birds are widespread in distribution throughout the Pacific Northwest.

Table 14. Occurrence by Month in the Puget Trough Ecoregion for Other Coastal Birds That Commonly Use Shoreline Habitats in the Study Area

Species	Occurrence by Month[a]											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Herons												
Great blue heron	C	C	C	C	C	C	C	C	C	C	C	C
Coots												
American coot	C	C	C	C	F	F	F	F	C	C	C	C
Land Birds												
Anna's hummingbird	C	C	C	C	C	C	C	C	C	C	C	C
Rufus hummingbird	-	R	U	C	C	C	C	F	F	-	-	-
Northern flicker	C	C	C	C	C	C	C	C	C	C	C	C
Steller's jay	C	C	C	C	C	C	C	C	C	C	C	C
American/northwestern crow	C	C	C	C	C	C	C	C	C	C	C	C
Cliff swallow	-	-	R	U	C	C	C	C	R	-	-	-
Barn swallow	R	R	R	U	C	C	C	C	F	U	R	-
Bushtit	C	C	C	C	C	C	C	C	C	C	C	C
Winter wren	C	C	C	C	C	C	C	C	C	C	C	C
Marsh wren	F	F	F	C	C	C	C	C	C	C	F	F
Ruby-crowned kinglet	C	C	C	C	U	-	-	R	C	C	C	C
American robin	C	C	C	C	C	C	C	C	C	C	C	C
Orange-crowned warbler	R	R	U	F	C	C	C	C	C	U	U	R
Yellow-rumped warbler	U	U	U	C	C	F	F	F	F	C	F	U
Common yellowthroat	R	R	R	F	C	C	C	C	C	R	R	R
Spotted towhee	C	C	C	C	C	C	C	C	C	C	C	C
Savannah sparrow	U	U	U	C	C	C	C	C	C	F	U	U
Fox sparrow	C	C	C	C	F	R	R	R	F	C	C	C
Song sparrow	C	C	C	C	C	C	C	C	C	C	C	C
White-crowned sparrow	F	F	C	C	C	C	C	C	C	C	F	F
Golden-crowned sparrow	C	C	C	C	F	-	-	-	F	C	C	C
Dark-eyed junco	C	C	C	C	C	C	C	C	C	C	C	C
Red-winged blackbird	C	C	C	C	C	C	C	C	C	C	C	C
Brewer's blackbird	C	C	C	C	C	C	C	C	C	C	C	C
Brown-headed cowbird	U	U	U	C	C	C	C	F	F	F	U	U

[a] Occurrence:
C = Common; F = Fairly Common; U = Uncommon; R = Rare; I = Irregular (Seattle Audubon Society 2008).

Sources: Seattle Audubon Society 2008; Wahl et al. 2005.

4.6.2 Seasonal Distribution in the Study Area

Of the 27 common species in the study area, 23 species nest along shoreline habitats, 14 species are year-round residents, and 4 species are winter residents (Table 14).

4.6.3 Uses, Status and Trends, and Regulatory Issues

All "other coastal birds" are protected by the MBTA. Except for the American coot, no other coastal birds are currently harvested in the Pacific Northwest. The relative abundance of breeding land birds in coastal and upland habitats in the study area is summarized in Table 15. Of the 22 common breeding land birds,

6 species have declined significantly in abundance and 2 species have increased significantly in abundance from 1980 to 2006. The remaining species have shown non-significant declining trends (8 species) or increasing trends (6 species) from 1980 to 2006 (Sauer et al. 2007).

Table 15. Other Coastal Bird Abundance during the 2006 Nesting Season in the Study Area and Trends for the Southern Pacific Rainforest Region

Species	Breeding Bird Survey Routes					Average for Routes	Breeding Season Trend[a]
	Ozette	Port Angeles	Warm Beach	Deception	Bay View		
Coots							
American coot	Rare breeder					-	-
Land Birds							
Anna's hummingbird	-	-	-	-	-	-	+ 2.04
Rufus hummingbird	6.88	3.36	4.97	10.14	1.58	5.39	- 0.64
Northern flicker	1.25	0.88	1.03	0.71		0.97	- 0.27
Steller's jay	8.81	2.36	1.00	0.14	2.33	2.93	*+ 1.43*
American/northwest crow	11.68	4.97	26.17	11.71	14.50	13.80	+ 0.91
Cliff swallow	8.03	16.36	100.75	7.86	10.08	28.62	- 1.49
Barn swallow	17.00	39.18	53.92	32.86	47.25	38.04	*- 2.38*
Bushtit	0.31	1.55	1.97	1.57	-	1.35	*- 6.12*
Winter wren	59.22	4.03	3.69	7.14	0.50	14.92	- 0.14
Marsh wren	0.25	0.36	0.92	-	0.33	0.47	+ 1.74
Ruby-crowned kinglet	Non-breeding					-	-
American robin	61.25	84.70	104.78	102.14	90.83	88.74	+ 0.56
Orange-crowned warbler	5.06	11.09	6.78	10.29	1.00	6.84	*- 4.02*
Yellow-rumped warbler	1.56	1.00	0.17	0.43	0.17	0.67	- 0.49
Common yellowthroat	4.50	2.24	4.47	0.14	8.33	3.94	*+ 1.94*
Spotted towhee	1.56	12.03	21.69	30.29	12.92	15.70	+ 0.74
Savannah sparrow	0.38	55.00	14.72	10.00	29.08	21.84	- 0.33
Fox sparrow	Non-breeding						
Song sparrow	31.47	37.45	33.14	26.14	23.08	30.26	*- 0.69*
White-crowned sparrow	1.28	28.06	16.61	31.29	12.25	17.90	*- 1.78*
Golden-crowned sparrow	Non-breeding						
Dark-eyed junco	4.94	3.76	6.94	12.14	0.50	5.66	- 0.56
Red-winged blackbird	2.06	17.88	32.72	8.29	40.92	20.37	+ 1.62
Brewer's blackbird	-	57.64	21.86	14.00	82.58	44.02	- 0.94
Brown-headed cowbird	2.66	19.97	19.56	19.00	12.50	14.74	*- 1.36*

Notes:

Abundance indicates the number of birds per survey route.

Average of routes, including 89001 Ozette, 89002 Port Angeles, 89003 Warm Beach, 89905 Deception, and 89066 Bay View (Sauer et al. 2007). Breeding bird survey routes include both coastal and upland habitats.

[a] Increase (+) or decrease (-) in birds per route within the Southern Pacific Rainforest Region from 1980 to 2006. Bold italics indicated significant trends at $P < 0.10$ (Sauer et al. 2007).

Source: Sauer et al. 2007.

4.6.4 Habitat Use by Life History Stages

Shoreline habitats used by other common coastal birds in the study area include coastal dunes and beaches (38 of 47 species), headlands and islets (25 of 47 species), and bays and estuaries (24 of 47 species) (Wahl et al. 2005). Table 16 shows habitats and their use by shorebirds commonly occurring in coastal habitats in the study area.

Table 16. Specific Habitats and Their Use by Shorebirds That Commonly Occur in Coastal Habitats in the Study Area

Species	Habitats[a]											
	Eelgrass	Kelp Beds	Rocky Shores	Unconsolidated Shores	Mudflats and Sandflats	Rocky Subtidal	Unconsolidated Subtidal	Estuaries	Salt Marsh	Nearshore Riparian	Backshore Spray	Cherry Point[b]
Herons												
Great blue heron	F	-	-	F	F	-	F	F	F	F	-	R
Coots												
American coot	F	-	-	-	F	-	-	F	F	F	-	-
Passerines												
Anna's hummingbird	-	-	F	F	-	-	-	-	-	-	F	-
Rufus hummingbird	-	-	B	B	-	-	-	-	-	-	B	S
Northern flicker	-	-	-	F	-	-	-	-	-	-	F	R
Steller's jay	-	-	-	F	-	-	-	-	-	-	F	R
American/northwestern crow	-	-	F	F	-	-	-	-	-	-	F	R
Cliff swallow	F	-	B	F	F	F	F	F	F	F	F	S
Barn swallow	F	F	B	F	F	F	F	F	F	F	F	S
Bushtit	-	-	-	B	-	-	-	-	-	-	B	R
Winter wren	-	-	-	F	-	-	-	-	-	-	F	R
Marsh wren	F	-	-	F	F	-	-	F	F	F	F	-
Ruby-crowned kinglet	-	-	F	F	-	-	-	-	-	-	F	R
American robin	-	-	-	F	-	-	-	-	-	-	F	R
Orange-crowned warbler	-	-	B	B	-	-	-	-	-	-	B	R
Yellow-rumped warbler	-	-	F	F	-	-	-	-	-	-	F	R
Common yellowthroat	-	-	-	-	-	-	-	B	B	B	-	S
Spotted towhee	-	-	-	B	-	-	-	-	-	-	B	R
Savannah sparrow	-	-	B	B	-	-	-	B	B	B	B	S
Fox sparrow	-	-	B	B	-	-	-	-	-	-	B	W
Song sparrow	-	-	B	B	-	-	-	B	B	B	B	R
White-crowned sparrow	-	-	B	B	-	-	-	B	B	B	B	R
Golden-crowned sparrow	-	-	F	F	-	-	-	-	-	-	F	W
Dark-eyed junco	-	-	-	B	-	-	-	-	-	-	B	W
Red-winged blackbird	-	-	-	-	-	-	-	B	B	B	-	R
Brewer's blackbird	-	-	B	B	-	-	-	B	B	B	B	R
Brown-headed cowbird	-	-	-	B	-	-	-	-	-	-	B	R

[a] Habitat use: B = Feeds and Reproduces; F = Feeds; R = Reproduces; O = Other (Wahl et al. 2005). For cross reference between the listed specific habitats, those described in the text and those listed in Wahl et al. (2005); eelgrass beds, mudflats and sandflats, estuaries, salt marsh and nearshore riparian are considered primarily bay and estuary habitats (light gray headings); kelp beds, rocky shores, unconsolidated shores, rocky subtidal, unconsolidated subtidal, and backshore spray are considered primarily marine nearshore (dark gray headings) but also occur in coastal dune and beaches habitats or headland and islet habitats.

[b] Cherry Point habitat use: W = Winter, R = Resident, S = Summer.

Sources: Wahl et al. 2005; Woodcock and Irving 2008.

Herons generally nest colonially near water in deciduous, coniferous, or mixed stands of mature trees; they feed along shorelines on fish and intertidal invertebrates. American coots nest on freshwater using marine resources such as salt marshes and coastal bays during other portions of the year. They feed

primarily on vegetation, fish, and invertebrates. The wide array of coastal land birds in the study area uses a wide variety of foraging habitats. Verbeck and Butler (1989) found that crows (American and Northwest) nesting in coastal areas spend approximately half of their time foraging on beach resources, where they preferred to feed on shore crabs and pricklebacks available at low tide. Hummingbirds feed on nectar and insects; in the Puget Sound area, they nest in huckleberry bushes, alders, blackberries, or conifer branches (Seattle Audubon Society 2008). Steller's jays feed on both vegetation and animal matter, and prey on the young of other birds. Other common land birds feed generally on insects and vegetation.

5. FISH

5.1 Protected Species

Federally and state-listed fish with the potential to occur in the study area are described below. More detailed discussions of life histories and listing status for federally listed species are provided in the draft Biological Evaluation (Appendix G).

5.1.1 Federally Listed Species

5.1.1.1 Bull Trout (Threatened)

The anadromous life history form of bull trout migrates to saltwater during spring. They use the nearshore marine ecosystem during spring and late summer, and the outer coast year-round. Juvenile bull trout rear in the nearshore ecosystem; they prefer unconsolidated habitats that may include eelgrass and kelp beds. The nearshore area provides critical foraging habitat and stable overwintering habitat for bull trout. Adults also feed in this area and then migrate into freshwater rivers and streams to spawn. Temperature is a major factor influencing bull trout distribution because spawning, egg incubation, and juvenile rearing all require specific temperatures. Since the bull trout range includes the Strait of Juan de Fuca, as well as inland marine and fresh waters of Clallam County (USFWS 2005), it is possible that this species would be present in the study area. Coastal marine waters designated as critical habitat for bull trout in the Coastal Puget Sound and Olympic Peninsula areas occur within the study area and extend from the mean higher high water line inland to 10 meters (33 feet) below the mean lower low water elevation line offshore.

Additional information on bull trout is provided in Section 5.2.1 and in the draft Biological Evaluation (Appendix G).

5.1.1.2 Chinook Salmon (Threatened)

The Puget Sound Chinook salmon evolutionary significant unit (ESU) is a composite of many individual populations of naturally spawning Chinook salmon and a number of hatchery stocks. The boundary of the Puget Sound Chinook salmon ESU extends from the Nooksack River in the north to southern Puget Sound, includes Hood Canal, and extends westerly out the Strait of Juan de Fuca to the Elwha River. The Skagit River and its tributaries constitute what was historically the predominate system in Puget Sound containing naturally spawning populations. Two independent populations of Puget Sound Chinook salmon are in the Nooksack basin: North Fork Nooksack River (including Middle Fork) and South Fork Nooksack River. These salmon are distinctive from Chinook salmon in the rest of Puget Sound in their genetic attributes, life history, and habitat characteristics. They are the only populations in the Strait of Georgia region, and they are two of only six Chinook runs left in Puget Sound that return to their rivers in spring (as opposed to fall spawners). For these reasons, the Nooksack populations are considered essential to the recovery of the Puget Sound Chinook ESU (Puget Sound TRT 2006). Adult Chinook migrate through the study area en route to spawning tributaries throughout the Washington north coast, Straits of Georgia and Juan de Fuca, Puget Sound, and Hood Canal. The Puget Sound Chinook salmon ESU includes waters that are part of the study area; therefore, it is possible that this species would be present in the study area. Critical habitat has been designated within the study area for the Strait of Juan de Fuca from the line of extreme high tide to a depth of 30 meters (98 feet).

Additional information on Puget Sound Chinook salmon is provided in Section 5.2.2 and in the draft Biological Evaluation (Appendix G).

5.1.1.3 Chum Salmon (Hood Canal Summer Run) (Threatened)

While the range of chum salmon along the Pacific coast extends from the Bering Sea to the Sacramento River in California, the range of summer chum salmon is highly restricted and extends only to discrete portions of the eastern portion of the Olympic Peninsula and south into Hood Canal. These include spawning adult returning to Snow Creek (Discovery Bay), Chimicum Creek (near Port Townsend), and many drainages in Hood Canal. Adult chum could migrate through the study area en route to spawning tributaries. Therefore, it is possible that this species would be present within the study area. Critical habitat has been designated within the study area for the Strait of Juan de Fuca from the line of extreme high tide to a depth of 30 meters (98 feet).

Additional information on chum salmon is provided in Section 5.2.2 and in the draft Biological Evaluation (Appendix G).

5.1.1.4 Puget Sound Steelhead (Threatened)

The Skagit and Nooksack Rivers, which discharge into the general vicinity of Cherry Point, support populations of native steelhead. Juvenile steelhead move rapidly out of freshwater and into offshore marine areas; recent studies in steelhead migratory behavior suggest that juveniles spend very little time in nearshore areas (NMFS 2013).The nearshore benthic survey conducted by the Lummi Nation found few (n=3) steelhead juveniles in their extensive beach seining sampling during the 2008 to 2009 survey effort, representing a 1.5-percent occurrence in all sets (Dolphin et al. 2010). In addition to the limited occurrence of steelhead documented in the vicinity of the BP Cherry Point dock, this species migrates through the Strait of Juan de Fuca en route to spawning tributaries throughout Washington's north coast. It is possible that this species would be present within the study area. No proposed critical habitat for Puget Sound steelhead occurs in the study area.

Additional information on Puget Sound steelhead is provided in Section 5.2.3 and in the draft Biological Evaluation (Appendix G).

5.1.1.5 Pacific Eulachon (Threatened)

Eulachon typically spend 3 to 5 years in saltwater before returning to freshwater to spawn from late winter though mid-spring. Most eulachon adults die after spawning. After eggs hatch, eulachon larvae are carried downstream and dispersed in the marine environment (Hay and McCarter 2000). It is not known how long larval eulachon remain in the estuary before entering the ocean (NMFS 2010b). Once juvenile eulachon enter the ocean, they move from shallow nearshore areas to deeper areas over the continental shelf. Larvae and young juveniles become widely distributed in coastal waters, where they are typically found near the ocean bottom in waters from 20 to 150 meters (66 to 292 feet) deep (Hay and McCarter 2000) and sometimes as deep as 182 meters (597 feet) (Barraclough 1964). Little information is currently available about eulachon movements in nearshore marine areas and the open ocean.

A recent WDFW technical report entitled *Marine Forage Fishes in Puget Sound* (Penttila 2007) presents detailed data on the biology and status and trends of surf smelt and longfin smelt in Puget Sound but states that "there is virtually no life history information within the Puget Sound Basin" available for eulachon. Similarly, detailed notes provided by WDFW and the Oregon Department of Fish and Wildlife as part of this review do not provide evidence of spawning stocks of eulachon in Puget Sound rivers.

Monaco et al. (1990) described eulachon as "rare" in Skagit Bay and, in addition to a personal communication, cited Miller and Borton (1980) as a supporting reference. Miller and Borton (1980) report on a total of 20 eulachon specimens collected in the San Juan Islands, southern Strait of Georgia,

and Strait of Juan de Fuca and recorded in boat logs and museum collection records; however, samples from Skagit Bay were not included in this list.

The Nooksack River frequently has been listed as supporting a run of eulachon (WDFW and ODFW 2001; Wydoski and Whitney 2003; Willson et al. 2006; Moody 2008); however, there seems to be some confusion as to the exact species encountered. The Nooksack River is known to support a run of longfin smelt [*Spirinchus thaleichthys*], which are sometimes mistaken for eulachon. The run of longfin smelt into the Nooksack River occurs in November, which is outside the normal spawning time for eulachon. Additionally, mid-water trawl surveys thought the Strait of Juan de Fuca routinely collected longfin smelt juveniles, while eulachon were rarely encountered (Anchor Environmental 2003). Pacific eulachon critical habitat does not occur within the study area.

Additional information on eulachon is provided in the draft Biological Evaluation (Appendix G).

5.1.1.6 Green Sturgeon (Threatened)

Southern DPS green sturgeon were first determined to occur in Oregon and Washington waters in the late 1950s when tagged San Pablo Bay green sturgeon were recovered in the Columbia River estuary (CDFG 2002). A few green sturgeon have been recovered in Puget Sound as incidental harvest from trawl fishers. The reason for their occurrence in the study area is unknown as they are not known to spawn, rear, or feed in coastal Washington or Puget Sound (Adams et al. 2002). The presence of green sturgeon in Puget Sound is rare (Lindley et al. 2011), but the species could occur in the study area. Critical habitat for Southern DPS green sturgeon has been designated in the study area and includes waters in the Strait of Juan de Fuca and a portion of Rosario Strait (see Figure 3.3-6 in Appendix G) (74 FR 52300). Puget Sound has been excluded from designation because the economic benefits of exclusion outweigh the benefits of inclusion and exclusion will not result in extinction of the species.

Additional information on green sturgeon is provided in the draft Biological Evaluation (Appendix G).

5.1.1.7 Rockfish (Bocaccio [Endangered], Canary [Threatened], and Yelloweye [Threatened])

The WDFW considers the north Puget Sound area to be one of the most productive areas for groundfish. This area extends from the Canadian border to Deception Pass out to the center of the Strait of Juan de Fuca, including all of the San Juan Islands. Within this area, production data in the vicinity of Cherry Point are not kept distinct. For conservation purposes, bocaccio, yelloweye, and canary rockfish populations are managed as two distinct stocks, one stock occupying areas west of Port Angeles and a separate stock unit east of Port Angeles.

Information on the actual distribution of these three listed rockfish species in the vicinity of the Cherry Point facility is vague. Rockfish adults tend to prefer rocky, deeper water habitats that are not common in the vicinity of the BP Cherry Point dock. Bocaccio has been found to occur in Central Puget Sound, Tacoma Narrows, Ports Gardner and Susan, and along the Strait of Juan de Fuca, with the most common occurrences recorded south of the Tacoma Narrows (NMFS 2010c). Detection of adult yelloweye and canary rockfish indicate that they do occur in the broader vicinity of the San Juan Islands near suitable habitat but do not occur near Cherry Point (see Figures 3.3-7 and 3.3-8 in Appendix G). Yelloweye rockfish have been reported by anglers to occur off Middle Bank in Haro Strait, Waldron Island, Hood Canal, Foulweather Bluff, Jefferson Head, Mukilteo, and Bainbridge Island (Washington 1977; Palsson et al. 2009). Canary rockfish have been documented as part of the assemblage of fishes in Puget Sound region for as long as there have been formal fisheries surveys, dating back to at least the 1930s (NMFS 2010c). It is likely that bocaccio, canary, and yelloweye rockfish could be present in the study area.

Critical habitat for rockfish has been proposed in the study area and includes waters east of Port Angeles north to the BP Cherry Point dock (78 FR 47635).

Additional information on bocaccio and yelloweye rockfish is provided in Section 4.3.2 and in the draft Biological Evaluation (Appendix G). Additional information on canary rockfish is provided in Section 5.3.1 and in the draft Biological Evaluation (Appendix G).

5.1.2 State-Listed Species

5.1.2.1 Rockfish (Candidate)

Brown rockfish belong to the nearshore complex, which is characterized by larval and/or juvenile stages that are strongly associated with the non-canopy nearshore area with a wide substrate type range. A review of the status and trends, habitat use, and distribution within the study area for this complex is provided in Section 5.3.1.

Black, China, copper, quillback, giger, and widow rockfish belong to the nearshore surface vegetation complex, which is characterized by larval and/or juvenile stages that are strongly associated with the nearshore, kelp canopy, nearshore demersal (bottom), or shelf-surface with drifting algal mats. Section 5.3.2 provides a review of the status and trends, habitat use, and distribution within the study area for this complex.

Greenstriped and redstripe rockfish belong to the offshore subsurface vegetation complex, which is characterized by larval and/or juvenile stages being strongly associated with continental slope, deep shelf, epipelagic, and demersal habitats. A review of the status and trends, habitat use, and distribution within the study area for this complex is provided in Section 5.3.3.

Brown, black, China, copper, quillback, tiger, widow, greenstriped, and redstripe rockfish are expected to occur in the study area.

5.1.2.2 Pacific Herring (Candidate)

The Pacific herring is the most widely studied forage fish in the study area, primarily because of its economic value in commercial and recreational fisheries. A review of the status and trends, habitat use, and distribution within the study area for this species is provided in Section 5.6.1. Pacific herring are expected to occur in the study area.

5.1.2.3 Pacific Cod, Pacific Hake, Walleye Pollock (Candidate)

Pacific cod, Pacific hake, and walleye pollock are roundfish; their life history stages are associated with surface waters and unconsolidated subtidal and shelf habitat. A review of the status and trends, habitat use, and distribution within the study area for these species is provided in Section 5.5.1. Pacific cod, Pacific hake, and walleye pollock are expected to occur in the study area.

5.1.2.4 Pacific Lamprey (Candidate)

Lampreys are a primitive group of fishes that are eel-like in form but lack jaws and paired fins. Shortly after hatching in freshwater streams, lamprey larvae drift downstream into areas of low velocity where they burrow and live as filter feeders for up to 7 years. After this period, they metamorphosize into their juvenile phase; this process occurs over a period of months from July to November. Once the metamorphosis is complete, they migrate to the ocean. Adult Pacific lampreys are parasitic and feed on a

variety of fish, including Pacific salmon, flatfish, rockfish, and pollock. They have been caught in depths ranging from approximately 91 to 792 meters (300 to 2,600 feet). After lampreys spend 1 to 3 years in the marine environment, they migrate back to freshwater between February and June, where they overwinter until they spawn the following year between March and July. After spawning, lamprey die.

The current distribution of Pacific lamprey in western Washington includes most large rivers and streams along the coast and the Strait of Juan de Fuca, and throughout Puget Sound including the Nisqually Reach and Hood Canal streams. Information on the abundance of Pacific lamprey in western Washington is limited and largely anecdotal; much of the data references only natal streams. Collection records show that Pacific lampreys are widely distributed on the Olympic Peninsula and streams flowing into the Strait of Juan de Fuca; however, no population status and trend data are available (USFWS n. d.). Adult Pacific lamprey are likely to be present in the study area.

5.2 Salmonids

Salmonids include salmon, trout, and char; they are the most ubiquitous, commercially significant, and ecologically and culturally prominent group of fishes in the Pacific Northwest (Groot and Margolis 1991). Salmon use an extensive network of waterbodies that include small headwater streams; rivers; lakes; wetlands and floodplain habitats; estuaries; and nearshore, off-shore, and open ocean environments.

Most of the salmonids have both freshwater and anadromous forms; however, only the anadromous forms are specifically addressed in this EIS because of the location of the study area. All juvenile salmon move along the shallows of estuaries and nearshore areas during their seaward outmigration, but some species have more extensive associations. The salmonids have been categorized into three subgroups for discussion based on similarities in utilization of surface water and nearshore habitats in the study area by life history stages. The groupings are based on early migrant distribution patterns and include the following:

- **Nearshore resident:** bull trout, Dolly Varden, coastal cutthroat
- **Nearshore outmigrant:** chum salmon and Chinook salmon
- **Neritic:**[1] pink salmon, steelhead, coho salmon, and sockeye salmon

These patterns are important determinants of the population's productivity rates because the early life history stages are generally the most sensitive to natural and anthropogenic changes to surface water and nearshore habitat condition. These three groupings are discussed in more detail below.

5.2.1 Nearshore Residents

The nearshore residents salmonid group consists of three species: bull trout, Dolly Varden (outer coast), and coastal cutthroat trout. Bull trout and Dolly Varden are two closely related native char species that co-exist; therefore, these two species were evaluated together. This group is considered *iteroparous*, which means that they are capable of spawning more than once. They exhibit resident, fluvial, adfluvial, and anadromous life history forms. Anadromous life history forms use small streams for spawning and rearing, and then migrate to the more productive nearshore marine and estuarine wetland ecosystems for growth and maturation. Fluvial forms migrate within rivers and tributaries for spawning, and adfluvial forms rear in lakes and migrate to tributaries for spawning. The life history strategies exhibited by this

[1] The neritic zone occurs between low tide and the edge of the continental shelf.

group are very flexible. Individual fish may adopt more than one strategy during the course of a lifetime and may even alternate strategies from year to year.

5.2.1.1 Geographic Distribution

Bull trout and Dolly Varden occur from the headwaters of the Yukon in Alaska to the Klamath basin (Dunham et al. 2003). The southern range of bull trout was much broader during the last major ice age and extended as far south as the McCloud River until recent times (Cavender 1978). Bull trout are widely distributed in the state of Washington (Figure 4), and the overall range is likely similar to the historical range (WDFW 2000). The USFWS recognizes five DPSs within the co-terminous United States: (1) Coastal-Puget Sound; (2) St. Mary-Belly River; (3) Klamath River; (4) Columbia River; and (5) Jarbridge River.

Coastal cutthroat trout are distributed along the western coast of North America from the Kenai Peninsula in Alaska to the Eel River in California; their inland distribution typically is limited to less than 150 km (93 mi) from the coast (Behnke 1992). NOAA Fisheries (Johnson et al. 1999) recognized six ESUs in the contiguous United States: (1) Puget Sound; (2) Olympic Peninsula; (3) Southwestern Washington; (4) Upper Willamette River; (5) Oregon Coast; and (6) Southern Oregon/California. The distribution of coastal cutthroat trout within the state of Washington includes large rivers and small tributaries of the Columbia River up to the Bonneville Dam and drainage basins on the west side of the Cascade Mountains, including the Olympic Peninsula.

5.2.1.2 Uses, Status and Trends, and Regulatory Issues

Limited information about the historical abundance of bull trout and Dolly Varden indicates that population segments are geographically isolated from each other due to natural and anthropogenic barriers. The WDFW evaluated 80 bull trout/Dolly Varden stocks within the state of Washington and found that 18 percent were healthy, 3 percent were depressed, 8 percent were critical, and the status of 72 percent of the stock was unknown (WDFW 2000). Native fish occurring throughout Washington State have been reduced from historical levels, particularly in eastern Washington (WDFW 2000). See Figure 4 for the distribution of bull trout in Washington.

Due to the similar morphology, life history requirements, and habitat utilization of bull trout and Dolly Varden, the State of Washington has developed a single management plan for both species (WDFW 2000). In addition to a reduction from historical numbers, several stocks in both eastern and western Washington have become fragmented where lower rivers are no longer utilized or free movement has been restricted. Relatively few native fish are now observed in the mainstem Columbia and Snake Rivers; and they have apparently been extirpated from the Chelan, lower Yakima, and Okanogan basins. A number of stocks have been isolated above dams in river systems where they once roamed freely. With only a few exceptions, however, the overall geographic range in Washington of both continuous and disjunct stocks is believed similar to the historical range. Only one introduction of hatchery-released native fish has been verified in Washington.

Cutthroat trout are managed as a freshwater and saltwater recreational fishery. A 2002 ruling by the USFWS determined that the coastal cutthroat trout did not require ESA protection. Coastal cutthroat trout stocks in Washington, Oregon, and California appear to be declining (Johnson et al. 1999) whereas stocks in Alaska and British Columbia are apparently stable (Wydoski and Whitney 2003). As part of the 2000 coastal cutthroat trout salmonid stock inventory, the WDFW determined that 2 percent of the stock within the state were healthy, 18 percent were depressed, and the status of 80 percent of the stock was unknown (WDFW 2000).

Figure 4. Distribution of Bull Trout in the State of Washington (2005)

5.2.1.3 Seasonal Distribution in Study Area

The anadromous life history form of bull trout and Dolly Varden migrate to saltwater during spring and use the nearshore ecosystem during spring and late summer. Their use of the outer coast can occur year-round. In the study area, this group is distributed throughout the marine and estuarine waters of Puget Sound, Hood Canal, the San Juan Islands, the Strait of Juan de Fuca, the Strait of Georgia, and the outer coast. Bull trout use the nearshore marine waters of Puget Sound seasonally for foraging and migration.

Adfluvial coastal cutthroat trout may use both littoral (nearshore) and limnetic (open water) habitats, and feed openly in the water column in the absence of predatory and competitive pressures (Wydoski and Whitney 2003). Fluvial and adfluvial coastal cutthroat trout typically migrate out of their natal streams between 1 and 4 years of age, with most migrating to saltwater during the spring at 2 to 4 years of age. In Washington, 97 to100 percent of outmigrants were ages 2 and 3 (Wydoski and Whitney 2003).

5.2.1.4 Utilization of Study Area Habitats by Life History Stages

Juvenile bull trout and Dolly Varden rear in the nearshore ecosystem, with preference for unconsolidated habitats that may include eelgrass and kelp beds. The nearshore area is important foraging habitat for this species group. Adults also feed in this area and then migrate into freshwater rivers and streams to spawn. Temperature is a major factor influencing bull trout distribution because spawning, egg incubation, and juvenile rearing all require specific temperatures. Bull trout and Dolly Varden prefer streams with abundant cover and clean gravel. They spawn from October to November in western Washington (WDFW 2013). Because their range includes the Strait of Juan de Fuca, as well as inland marine and fresh waters of Clallam County (USFWS 2005), this species may be present in the study area.

Anadromous juvenile cutthroat remain in their spawning streams for 1 or more years before migrating to saltwater. Their diet primarily consists of aquatic and terrestrial insects, planktonic crustaceans, crayfish, salmon eggs, and small fish. Coastal cutthroat trout that enter nearshore waters reportedly move moderate distances along the shoreline but typically do not cross large bodies of open water (Saiget et al. 2007). Coastal cutthroat trout forage in estuarine wetlands, as well as in nearshore coastal and inland waters, and typically occur in water less than 3 meters (10 feet) in depth (Pauley et al. 1989). Available information indicates that this species occurs at river deltas, in distributary channels, and along shallow shorelines (Pauley et al. 1989; Johnson et al. 1999), thus demonstrating some preference for unconsolidated habitats. Although this review did not find evidence of the use of consolidated and neritic habitat use in the marine environment, evidence from freshwater lakes indicates that this behavior cannot be ruled out. While evidence suggests that coastal cutthroat trout rarely occur in waters greater than 3 meters (10 feet) deep (Pauley et al. 1989), the species has been captured by fishing vessels up to 80 kilometers (55 mi) off the Oregon/Washington coast (Wydoski and Whitney 2003). Little is currently known about habitat utilization in the offshore ecosystem. Although it is widely believed that the species does not overwinter at sea, the possibility cannot currently be ruled out. This species may occur in the study area.

5.2.2 Nearshore Outmigrants

This salmonid group consists of chum and Chinook salmon. This group is anadromous (maturing in saltwater and spawning in freshwater) and semelparous (they perish after spawning). Chinook salmon are the largest of the Pacific salmon. Chinook juveniles rear in freshwater for a period of time before migrating to saltwater to mature. Chum salmon are best known for the enormous canine-like fangs and the striking body color of spawning males. Chum juveniles migrate almost immediately to saltwater after emerging from the gravel. Chinook are generally divided into three categories based on when they return to freshwater: (1) spring run (March to May); (2) summer run (June and July); and (3) fall run (August and September) (Wydoski and Whitney 2003). All Chinook spawn in fall, with the spring runs spawning

first in headwater streams, followed by summer Chinook in tributary mouths, and fall types in mainstem tributaries (Wydoski and Whitney 2003). This species also exhibits one of two life history types, or races: the stream-type and the ocean-type (Myers et al. 1998). Stream-type Chinook tend to spend one or more years in freshwater environments as juveniles prior to migrating to saltwater as smolts. Ocean-type Chinook spend between 3 months and 1 year in freshwater before smolting and migrating to estuarine or nearshore areas in saltwater. Ocean-type Chinook are more dependent on estuarine habitats to complete their life history than any other species of salmon (Healey 1991).

Chinook are the largest of the Pacific salmon, with an average length of approximately 1 meter (3 feet) and weights ranging from 1 to 56 kilograms (2 to 123 pounds) (Wydoski and Whitney 2003). They tend to spawn in large river systems (Healey 1991). The species spends between 2 and 6 years at sea prior to returning to freshwater to spawn, but this time varies between stocks and depends somewhat on ocean conditions (Wydoski and Whitney 2003). Similar to other salmonids, Chinook spawn in cold, highly oxygenated water (Healey 1991). Spring Chinook are especially dependent on high water quality and good access to spawning areas, as they move upstream during periods of lower flow and hold in rivers for extended periods of time before spawning. Adult spring Chinook salmon tend to prefer deep, cool "holding pools" with woody debris, over-hanging vegetation, and undercut banks to protect them from predators (Healey 1991).

5.2.2.1 Geographic Distribution

The historical range of Chinook salmon included most of the North Pacific Ocean from California to Alaska, through the Aleutian Islands and into Siberia. They are found in the rivers and streams of Puget Sound, including Hood Canal and the Strait of Juan de Fuca, the Pacific Coast, and the Columbia River and its tributaries (Wydoski and Whitney 2003). Ocean migrations extend well into the North Pacific Ocean.

The range of chum salmon along the Pacific coast extends from the Bering Sea to the Sacramento River in California. Chum and Chinook fully utilize Puget Sound and the study area. Chum salmon have the widest natural geographic and spawning distribution of any Pacific salmonid. Chum salmon usually spawn in coastal areas and generally spawn in the lower reaches of alluvial rivers.

5.2.2.2 Uses, Status and Trends, and Regulatory Issues

Chinook salmon are one of the predominant sport and commercial fisheries in the region. Puget Sound Chinook salmon are federally listed as threatened under the ESA. Generally, interior populations of Chinook (Columbia River and Puget Sound) have been drastically reduced from historical abundance. Chum salmon are the least commercially valuable species. Hood Canal summer-run chum, which migrate through the study area, are listed as federally threatened under the ESA. The chum salmon's minimal dependence on freshwater for rearing could be a main reason why the impacts on their runs are not as widespread as other salmon species.

Freshwater, estuarine, and marine habitat loss or degradation is thought to be the primary reason for declining populations. Instream flow abundance during summer and a rapidly rising hydrograph in urbanizing areas are impacts associated with watershed management issues that can influence population abundance. Degradation and loss of habitat in the headwaters of many Washington rivers now limit their spawning range (Wydoski and Whitney 2003).

5.2.2.3 Seasonal Distribution in Study Area

The ocean migrations of Chinook salmon extend well into the North Pacific Ocean (Myers et al. 1998). Adult Chinook and chum salmon migrate through the study area, en route to spawning tributaries throughout the Washington north coast, Straits of Georgia and Juan de Fuca, Puget Sound, and Hood Canal. Chinook salmon have different life history strategies and therefore use marine habitat (estuary, coastal, and ocean) to different extents. Chinook adult migrants are present most of the year although stock composition shifts from southern to northern basins as the year progresses. They enter Washington streams from June to November to spawn. Fry arrive in estuaries with a peak in approximately mid-May. These species are expected to occur in the study area.

5.2.2.4 Utilization of Study Area Habitats by Life History Stages

Juvenile chum and Chinook reside in estuaries longer than most other anadromous salmon species. The diet of outmigrating ocean-type Chinook salmon varies geographically and seasonally. Feeding appears to be opportunistic, with aquatic insect larvae and adults making up a large portion of the prey items.

Fry and juveniles (smolts) depend on estuaries for rearing; however, the Chinook and chum move offshore relatively quickly to increase their prey base as they increase in size. Smolts are more dependent on estuarine habitats to complete their life history than other species of salmon. Smolts migrate into estuarine or nearshore areas and make extensive use of estuarine and nearshore habitats for rearing in shallow eelgrass beds and nearshore kelp beds. Chinook generally feed on invertebrates but eat more fish with age (Healey 1991); they feed on sand lance, sticklebacks, crab larvae, and small herring while at sea (Healey 1991). Chum juveniles outmigrate to marine water almost immediately after emerging from the gravel. This ocean-type migratory behavior contrasts with the stream-type behavior of some other species in the genus *Oncorhynchus*, which usually migrate to sea at a larger size, after months or years of freshwater rearing (Johnson et al. 1997).

Adult Chinook migrate through the study area en route to spawning tributaries throughout the Washington north coast, Straits of Georgia and Juan de Fuca, Puget Sound, and Hood Canal. The Puget Sound Chinook salmon ESU includes waters that are part of the study area; therefore, this species may be present in the study area. Critical habitat has been designated in the study area for the Strait of Juan de Fuca, from the line of extreme high tide to a depth of 30 meters (98 feet). Adult chum could migrate through the study area en route to spawning tributaries. Therefore, this species may be present in the study area.

5.2.3 Neritics

This salmonid group consists of coho, pink, sockeye, and steelhead salmon. Coho, pink, and sockeye salmon are anadromous and semelparous (spawn once); steelhead are anadromous and iteroparous (capable of spawning more than once in their lifetime).

5.2.3.1 Geographic Distribution

Coho salmon were historically distributed throughout the North Pacific Ocean from central California to Alaska, through the Aleutian Islands, and from Russia south to Japan. This species probably inhabited most of the coastal streams in Washington, Oregon, and central and northern California. There are believed to be 90 distinct stocks in Washington (Wydoski and Whitney 2003), with populations occurring throughout Puget Sound, Hood Canal, the Strait of Juan de Fuca, the Olympic Peninsula, and the Columbia River Basin.

Pink salmon are the most abundant species of salmon and are found throughout the North Pacific, including northern Asia. The North American range is from the Sacramento River in northern California, north to the Bering Strait, and east to the MacKenzie River in northern British Columbia, although spawning is rare south of the Columbia River. They are common from central Alaska south to the Fraser River in British Columbia (Hard et al. 1996). Thirteen stocks of pink salmon have been identified in Washington, with actively spawning populations occurring in the Nooksack, Skagit, Stillaguamish, Snohomish, Skykomish, Snoqualmie, Puyallup, Nisqually, Hamma Hamma, Duckabush, Dosewallops, Dungeness, and Elwha Rivers (Hard et al. 1996). Pink salmon have been reported in other systems (e.g., Bogachiel River, Lake Washington), but these are considered strays, not spawning populations (Hard et al. 1996).

Sockeye naturally occur from Alaska through British Columbia and into Washington and Idaho, as far south as the Columbia River system. The historical range of this species is thought to be close to their current range (Burgner 1991; Gustafson et al. 1997). Sockeye also occur in an anadromous and a land-locked form, which is referred to as *kokanee*. The WDFW recognizes nine sockeye salmon stocks in the state, with the two largest runs occurring in Lake Washington (three stocks) and in the Columbia River (two stocks).

Currently, steelhead trout occur naturally from Alaska through British Columbia, Washington, Oregon, California, and Idaho. The historical range is thought to be from northern Mexico to Alaska in most rivers with access to the Pacific Ocean (Busby et al. 1996). Steelhead trout have also been introduced worldwide, becoming naturalized in many areas with rainbow trout, the non-anadromous form of steelhead. Steelhead populations in Washington occur in the Upper, Lower, and Middle Columbia River; in Puget Sound; on the Olympic Peninsula; in southwest Washington; and in the Snake River basin.

5.2.3.2 Uses, Status and Trends and Regulatory Issues

Neritic species are an important major component of regional, coastal, and high seas commercial, tribal, and recreational fisheries. Catch records for coho have fluctuated cyclically in the past 30 years but reached record low levels during the early 1990s (Johnson et al. 1997). In general, coho populations throughout the region are considered depressed from historical levels. In 1995, NOAA Fisheries named six ESUs for coho in the Pacific Northwest (Weitkamp et al. 1995). Three of the six ESUs are located in California and Oregon—the California Coast ESU is federally listed as endangered, and the Southern Oregon/Northern California and Coastal Oregon ESUs are federally listed as threatened. In Washington, the Lower Columbia ESU is listed as threatened. Although the Olympic Peninsula and Puget Sound ESUs are not listed, NMFS has designated the Puget Sound ESU as a species of concern.

According to Hard et al. (1996), pink salmon populations are relatively healthy in the state of Washington, except in the rivers along the Strait of Juan de Fuca. The Elwha River population is thought to be extinct, and the Dungeness River stocks are considered depressed as a result of heavy flooding in 1979 and 1980 (Hard et al. 1996). Both anthropogenic and natural disturbances have profound impacts on this species because of their strict 2-year life cycle (Bonar et al. 1989).

Catch records for sockeye have fluctuated cyclically during the last 30 years but reached record low levels during the last decade (Stouder et al. 1997). In general, sockeye populations throughout the region are considered depressed from historical levels. NOAA Fisheries identified seven individual ESUs for sockeye in Washington (Gustafson et al. 1997); two of these ESUs are considered to be in danger of or threatened with extinction (Snake River and Ozette Lake).

In general, steelhead populations throughout the region are considered depressed from historical levels; 5 of the 15 ESUs in the Pacific Northwest are federally listed as endangered, and 4 ESUs are listed as

threatened (West Coast Salmon Biological Review Team 2003). Puget Sound steelhead are federally listed as threatened under the ESA.

5.2.3.3 Seasonal Distribution in the Study Area

Pink, sockeye, and steelhead salmon migrate through the study area en route to spawning tributaries throughout the Washington north coast, Straits of Georgia and Juan de Fuca, Hood Canal, and Puget Sound. Outmigration begins in spring, with the young moving rapidly through estuaries and out to sea. As smolts begin the ocean phase of their life, they usually travel through most, if not all, of the marine environments, including estuaries, nearshore habitat, and open ocean.

Pink and sockeye salmon enter Washington streams from June to November to spawn. Fry arrive in estuaries, with a peak approximately in mid-May. Juveniles reside in estuaries longer than most other anadromous salmon species. Juvenile sockeye typically rear for 1 to 3 years in lake habitats (NOAA Fishwatch 2013a). The offspring of riverine spawners generally rear for 1 to 2 years in lower slow-velocity sections of rivers (river-type), although some populations migrate to estuarine environments after a few months in their natal stream (sea-type) (Burgner 1991). Outmigrating lake-type sockeye typically migrate to the estuary between 1 and 3 years of age (Burgner 1991).

5.2.3.4 Utilization of Study Area Habitats by Life History Stages

These species spend little time in estuarine environments, and their association with estuarine environments is limited to seaward migration and a period of osmoregulatory[2] adjustment through their smolt phase, where they experience rapid growth and move to marine nearshore habitats. Juveniles may form schools in estuaries for several months during summer before moving offshore by late summer or early fall. Coho, pink, and sockeye juveniles entering the ocean, swim north along the coast of British Columbia and Alaska, and then move offshore into the Gulf of Alaska, where they spend 2 years. Some Puget Sound populations spend their entire marine life in marine nearshore habitats.

Coho outmigration begins in spring, with the young moving rapidly through estuaries and out to sea. As smolts begin the ocean phase of their life, they usually travel through most, if not all, of the marine environments, including estuaries, nearshore habitat, and open ocean. During this time, coho tend to utilize the coastal waters, moving as far north as the Gulf of Alaska (Johnson et al. 1997).

Juvenile sockeye salmon spend the first part of their marine lives in estuarine and nearshore areas adjacent to their natal streams, although their residence time in these areas may be the shortest for any of the salmon species. Smolt migration begins in late April, with southern stocks migrating earliest. Northward migration of juveniles to the Gulf of Alaska occurs in a band relatively close to shore, and offshore movement of juveniles occurs in late autumn or winter. Sockeye salmon prefer cooler ocean conditions than do other Pacific salmon (Burgner 1991).

Pink salmon migrate downstream almost immediately after emergence; if the distance to saltwater is short, the migration may occur in 1 night. The species spends very little time in estuarine environments, moving quickly to marine nearshore habitats where they grow rapidly, feeding on small crustaceans such as euphausiids, amphipods, and cladocerans (Bonar et al. 1989). Prey may be benthic or pelagic, although foraging usually occurs in the water column in nearshore areas, along beaches, or along shorelines with complexity. Juveniles form schools in estuaries for several months during summer before moving

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[2] *Osmoregulation* refers to maintaining the mineral and salt content in the blood while transitioning from a freshwater to saltwater environment.

offshore by late summer or early fall (Hard et al. 1996). Some Puget Sound populations spend their entire marine life in marine nearshore habitats (Hard et al. 1996).

Outmigrating steelhead smolts typically leave their natal streams between 2 and 4 years of age (Groot and Margolis 1991), traveling through most, if not all, of the marine environments including estuaries, nearshore habitat, and the open ocean.

All neritic species migrate through the Strait of Juan de Fuca en route to spawning tributaries throughout Washington's north coast or spend their entire marine life in marine nearshore habitats. In addition to the general occurrence of neritic species in the study area, limited occurrences of steelhead have been documented in the vicinity of the BP Cherry Point dock. Therefore, these species may be present in the study area.

5.3 Rockfish

Rockfish are any species of fish in Puget Sound east of Cape Flattery belonging to the family Scorpaenidae and members of the *Sebastes* or *Sebastologus* genra. Species can be grouped into several assemblages, or complexes, based on their life histories and habitat associations. Rockfish complexes within the study area include:

- **Nearshore complex:** fish with strong larval or juvenile association with nearshore habitats.
- **Nearshore surface vegetation complex:** fish with pelagic larvae or juveniles and strong association with algal mats or canopy.
- **Offshore subsurface complex:** fish with larval or juvenile association with offshore and subsurface.

These three complexes are described in more detail below.

5.3.1 Nearshore Complex

The nearshore complex contains the following four species and is characterized by the larval and/or juvenile stages strongly associated with the non-canopy nearshore area, with a wide substrate type range:

- Brown rockfish (*Sebastes auriculatus*)
- Canary rockfish (*Sebastes pinniger*)
- Puget Sound rockfish (*Sebastes emphaeus*)
- Stripetail rockfish (*Sebastes saxicola*)

One representative species is used to describe the group in general. The following information is provided for the brown rockfish.

5.3.1.1 Geographic Distribution

Brown rockfish range from the northern Gulf of Alaska to southern Baja California (Stout et al. 2001; Love et al. 2002). In Washington, brown rockfish appear to be limited to central and south Puget Sound; most reports of the species occur near Seattle and Bainbridge Island (Miller and Borton 1980; Stout et al. 2001). The NOAA Fisheries status review (Stout et al. 2001) described two distinct population segments consisting of Puget Sound proper (the area south of Admiralty Inlet and east of Deception Pass) and the coastal waters west of Cape Flattery. The few brown rockfish reports outside of Puget Sound proper and

inland of Cape Flattery were considered to represent vagrant brown rockfish from the Puget Sound proper population segment.

5.3.1.2 Uses, Status and Trends, and Regulatory Issues

The importance of brown rockfish to the fresh fish commercial fishery has diminished through the years. Past recreational fishing for brown rockfish in Puget Sound accounted for up to 31 percent of the recreation harvest in Puget Sound proper (Matthews and Barker 1983). Currently, there is no recreational rockfish fishery in Puget Sound; however, they continue to be at risk from bycatch for lingcod and salmon fisheries. In Puget Sound proper, scuba surveys showed brown rockfish populations increasing by a factor of approximately 6 between 1987 and 1995 (Matthews 1990a; Stout et al. 2001).

Brown rockfish are rare in coastal ecosystems, and no data were available for analysis by the NOAA Fisheries status review (Stout et al. 2001). The risks to the survival of brown rockfish were listed by West (1997) as “anthropogenic stressors and natural limiting factors” and include “over-harvesting, loss or degradation of habitat, predation by pinnipeds and fish, and pollution-related adverse effects.” Loss of eelgrass or kelp through dredging or filling also may negatively affect juvenile and adult habitat (Palsson et al. 1998).

5.3.1.3 Seasonal Distribution in the Study Area

Brown rockfish mate in March and April (Stein and Hassler 1989) in demersal habitats, have internal fertilization, and retain embryos until larval release (Boehlert and Yoklavich 1984). In Puget Sound, ova develop during winter; females in Washington probably give birth annually from May through July (Stout et al. 2001).

5.3.1.4 Utilization of Study Area Habitats by Life History Stages

Brown rockfish are 5 to 6 millimeters (mm) (less than 0. 2 inch) in length at birth and are free floating, preying on zooplankton (Stout et al. 2001). Larvae and juveniles use the open water habitat in the nearshore ecosystem of inland and coastal waters in addition to estuaries for nursery grounds (Stein and Hassler 1989; Stout et al. 2001). After settling, juveniles feed on amphipods, copepods, polychaete worms, shrimp, and small fish (NMFS 2013; Stein and Hassler 1989). Juveniles and subadults commonly live at depths between approximately 122 and 137 meters (400 and 450 feet). Pelagic juvenile brown rockfish settle into shallow, vegetated habitats such as low-relief natural and artificial reefs and beds of kelp or eelgrass (West et al. 1994), in depths of approximately 37 meters (120 feet).

5.3.2 Nearshore Surface Vegetation Complex

The nearshore surface vegetation complex contains the following 11 species and is characterized by the larval and/or juvenile stages strongly associated with the nearshore, kelp canopy, nearshore demersal, or shelf-surface with drifting algal mats.

- Black rockfish (*Sebastes melanops*)
- Blue rockfish (*Sebastes mystinus*)
- Bocaccio rockfish (*Sebastes paucispinis*)
- China rockfish (*Sebastes nubulosus*)
- Copper rockfish (*Sebastes caurinus*)
- Quillback rockfish (*Sebastes maliger*)

- Splitnose rockfish (*Sebastes diploproa*)
- Tiger rockfish (*Sebastes nigrocintus*)
- Vermilion rockfish (*Sebastes miniatus*)
- Widow rockfish (*Sebastes entomelas*)
- Yellowtail rockfish (*Sebastes flavidus*)

Three species of Puget Sound rockfish are listed under the ESA: the bocaccio rockfish is listed as endangered, and the canary and yelloweye rockfish are listed as threatened (75 FR 22276). To describe the group in general, information is provided for the copper rockfish.

5.3.2.1 Geographic Distribution

Copper rockfish range from the Gulf of Alaska to central Baja California (AFSC n.d.). This species is widely distributed in Puget Sound and Washington's coastal waters, except for the southeast Georgia Strait area (Miller and Borton 1980). The NOAA Fisheries status review delineated three DPSs within Washington's waters: (1) Northern Puget Sound (San Juan Islands and Straits of Juan de Fuca), (2) Puget Sound Proper; and (3) Outer Coast (Cape Flattery west) (Stout et al. 2001). The Northern Puget Sound DPS includes not only Washington waters but also the Canadian Gulf Islands and the Strait of Georgia (Stout et al. 2001). The boundaries of the Outer Coast DPS are also broad and ill defined, including areas south into California and north into Alaska. Only the Puget Sound DPS was clearly defined as that area labeled "Puget Sound proper," defined as the marine waters south of Admiralty Inlet and east of Deception Pass.

5.3.2.2 Uses, Status and Trends, and Regulatory Issues

Copper rockfish is a recreationally harvested species with recorded catches of between 800 and 2,000 individuals from 2000 to 2007. As with many of the rockfishes, they have been subject to fisheries bycatch through the years. The copper rockfish is a candidate species in Washington State and does not hold a federal listing. Copper rockfish are vulnerable to overharvest by recreational fisheries in all population segments. West's (1997) presentation of risk factors for copper rockfish in greater Puget Sound points to overharvest as the probable major factor contributing to the decline of these fish. This conclusion was further supported by the findings of the NOAA Fisheries status review (Stout et al. 2001). Late-maturing, long-lived species such as rockfish are slow to rebuild depleted populations, making them particularly sensitive to overfishing.

The risks to the survival of the copper rockfish were listed by West (1997) as "anthropogenic stressors and natural limiting factors" and include "overharvesting, loss or degradation of habitat, predation by pinnipeds and fish, and pollution-related adverse effects." Habitat for juvenile rockfish could be affected through shoreline development. Adult habitat does not appear to be limiting at this time because unoccupied habitat is apparently present in Puget Sound (Stout et al. 2001). The WDFW management strategy is to eliminate targeted harvest of rockfishes in Puget Sound. These rules became effective in 2004 and will help reduce fishing effort on rockfishes.

5.3.2.3 Seasonal Distribution in the Study Area

Adult copper rockfish prefer consolidated habitats of nearshore and upper offshore ecosystems in coastal and inland waters. Their depth range is between 1 and 23 meters (3 and 75 feet) in high-relief rocky reefs and low-relief areas when kelp cover is present (Matthews 1990a). Adults are solitary or occur in small aggregations, with a small home range of 30 to 13,106 square meters (100 to 43,000 square feet)

(Mathews and Barker 1983; Matthews 1990b). During winter, this species may migrate to deeper water or retreat into crevasses (Richards 1987).

5.3.2.4 Utilization of Study Area Habitats by Life History Stages

Larval fish are extruded into the nearshore inland and coastal neritic zones, and associate with shallow-water habitats including algae attached to overwater structures, shallow consolidated reefs, and eelgrass meadows (Shaffer et al. 1995). They remain off the bottom in these habitats until they reach 20 to 45 mm (0.8 to 1.8 inches) total length (Buckley 1997; Love et al. 2002); they prey on zooplankton, polychaetes, and larval fish (Murie 1995; Hueckel and Stayton 1982).

At 50 to 90 mm (2 to 3.5 inches) total length, juveniles settle into benthic habitats on consolidated high-relief rocky reefs and/or in kelp or eelgrass beds at the unconsolidated and consolidated rock interface in water no deeper than 18 meters (59 feet) (Matthews 1990a; West et al. 1994; Shaffer et al. 1995; Buckley 1997). Movement from off bottom to benthic habitats occurs from July to October. The juveniles are crepuscular (twilight) feeders, concentrating feeding activity at dawn and dusk on small fish and crustaceans (Patten 1973; Hueckel and Stayton 1982; Hueckel and Buckley 1987).

5.3.3 Offshore Subsurface Vegetation Complex

The offshore-subsurface vegetation complex contains the following 13 species and is characterized by the larval and/or juvenile stages being strongly associated with continental slope, deep shelf, epipelagic, and demersal habitats.

- Darkblotched rockfish (*Sebastes crameri*)
- Greenstriped rockfish (*Sebastes elongatus*)
- Longspine thornyhead rockfish (*Sebastolobus altivelis*)
- Pacific Ocean perch rockfish (*Sebastes alutus*)
- Rebanded rockfish (*Sebastes babcocki*)
- Redstripe rockfish (*Sebastes proriger*)
- Rosethorn rockfish (*Sebastes helvomaculatus*)
- Rosy rockfish (*Sebastes rosaceus*)
- Rougheye rockfish (*Sebastes aleutianus*)
- Sharpchin rockfish (*Sebastes zacentrus*)
- Shortspine thornyhead rockfish (*Sebastolobus alascanus*)
- Silvergray rockfish (*Sebastes brevispinis*)
- Yelloweye rockfish (*Sebastes ruberrimus*)

To describe the group in general, information for the greenstriped and redstripe rockfish are provided.

5.3.3.1 Geographic Distribution

These species range from Alaska, the Gulf of Alaska, or the Aleutian Islands to southern California (Love et al. 2002). Distribution of greenstriped rockfish in Washington includes coastal waters, the Strait of Juan de Fuca, central and south Puget Sound, and Hood Canal (Palsson et al. 2009). Distribution of redstripe

rockfish in Washington includes the San Juan Islands, north Puget Sound (eastern San Juan Islands, Bellingham), Possession Sound (Everett), central Puget Sound, and Hood Canal (Palsson et al. 2009).

5.3.3.2 Uses, Status and Trends, and Regulatory Issues

This complex of rockfish is managed under the Pacific Coast Groundfish Fishery Management Plan (PFMC 2011), and the WDFW has strict limits for recreational take (Palsson et al. 1997). There are little data on population trends for this complex of rockfish, although population trends for many other species of rockfish show evidence of declining abundance due to overharvest as either the target species or bycatch of other fisheries (Wright 1999; Love et al. 2002).

5.3.3.3 Seasonal Distribution in the Study Area

Similar to other rockfish, this complex has internal fertilization and is ovoviviparous, producing live young. Eggs develop internally and hatch several days before they are extruded (parturition) (Love et al. 2002). Some species are multiple brooders, releasing young two or more times per year.

Greenstriped rockfish release larvae that are approximately 5 mm (less than 0.2 inch) long during late spring and early summer off Oregon, Washington, and British Columbia (Hart 1973). Redstripe rockfish release their larvae in Puget Sound during July; the larvae are 3 to 7 mm (0.1 to 0.3 inch) upon release (Kendall and Lenarz 1986). Adults of this complex primarily distribute year-round in deep shelf-demersal habitats.

5.3.3.4 Utilization of Study Area Habitats by Life History Stages

Greenstriped rockfish larvae undergo a planktonic period lasting 1 to 2 months. While drifting, these fish mostly feed on smaller plankton such as copepods and are likely preyed on by siphonophores and chaetognaths (Drake et al. 2010). In Monterey Bay, greenstriped rockfish larvae settle at 3 cm in length, in water deeper than 40 meters (131 feet) over soft bottoms. Newly settled fish have a growth rate of 0.17 mm per day, with the juveniles moving to deeper water as they mature. Juvenile prey items include krill, fishes, shrimp, calanoid copepods, squid, and gammarid amphipods (Love et al. 2002).

Redstripe rockfish larvae feed on all stages of copepods and euphausiids (Kendall and Lenarz 1986) and are likely a food source for planktonic predators such as siphonophores and chaetognaths (Drake et al. 2010). Juvenile redstripe rockfish exhibit a pelagic to semi-demersal movement pattern (Drake et al. 2010) and utilize both marine and estuarine habitat while feeding on all stages of copepods and euphausiids (Kendall and Lenarz 1986).

5.4 Flatfish

The flatfish are a group of species characterized by a demersal adult life history stage compressed form that orient themselves parallel to the substrate; both eyes are positioned on the same side, facing upward. Flatfishes in the study area are separated into two subsections (complexes) for discussion:

- **English sole complex:** fish with larval and juvenile life history stages that are strongly associated with the water surface and estuarine nursery areas.
- **Arrowtooth flounder complex:** fish with epipelagic or pelagic eggs, larvae, and juveniles and distributions of those life history stages farther offshore–in the shallow and deep shelf ecological regions.

5.4.1 English Sole Complex

The English sole complex is comprised of flatfish with similar egg stage characteristics—eggs float at the surface in the nearshore to deep shelf ecological regions—and larvae and juveniles are strongly associated with estuarine habitats. The following species are in the English sole complex:

- Butter sole (*Pleuronectes isolepis*)
- English sole (*Pleuronectes vetulus*)
- Dover sole (*Microstomus pacificus*)
- Flathead sole (*Hippoglossoides elassodon*)
- Sand sole (*Psettichthys melanostictus*)
- Starry flounder (*Platichthys stellatus*)
- Rock sole (*Lepidosetta bilineata*)
- Pacific halibut (*Hippoglossus stenolepis*)
- Pacific sanddab (*Citharichthys stigmaeus*)

English sole is discussed as an example to represent the species in this complex. The species description below, unless otherwise referenced, is a summary and adaptation of information as presented and cited in *Life History, Geographical Distribution, and Habitat Associations of 82 West Coast Groundfish Species: a Literature Review* (McCain et al. 2005).

5.4.1.1 Geographic Distribution

English sole are found from Nunivak Island in the southeast Bering Sea and Agattu Island in the Aleutian Islands, to San Cristobal Bay, Baja California Sur.

5.4.1.2 Seasonal Distribution in Study Area

Adult English sole make limited migrations. Those off Washington show a northward post-spawning migration in spring to summer feeding grounds, and a southerly movement in fall. Tidal currents appear to be the mechanism by which English sole move into estuaries; these currents also transport larvae into nearshore nursery areas (i.e., shallow coastal waters and estuaries). Although many post-larvae settle outside of estuaries, most will enter estuaries during some part of their first year of life. Larvae metamorphose into juveniles in spring and early summer, and rear until fall/winter at which time most emigrate to deeper waters. There is a general movement to deeper waters as fish grow.

5.4.1.3 Uses, Status and Trends, and Regulatory Issues

English sole is an important commercial fish, captured primarily by bottom trawls. Most of the harvest is taken in the coastal waters off the coasts of Washington, Oregon, and California. English sole are usually caught in relatively shallow water, less than 100 meters (328 feet) deep. Females dominate the catch because males seldom grow to marketable size. Along with starry flounder, sand sole, and Pacific sanddab, English sole forms a nearshore, mixed-species flatfish assemblage and fishery. It is not an important recreational species, although it is caught on hook and line by boat, shore, and pier anglers.

5.4.1.4 Utilization of Study Area Habitats by Life History Stages

In the North Pacific, English sole is an inner-shelf mesobenthal species, occurring to 55 meters (180 feet) deep. They are a member of the outer continental shelf community in southern California, the shallow sublittoral community in Puget Sound, and the intermediate depth Nestucca assemblage off Oregon. Eggs and larvae are pelagic; juveniles and adults are demersal. Larvae are found primarily in waters less than 200 meters (656 feet) deep. Larvae undergo diel vertical migrations. Juveniles reside primarily in shallow-water coastal, bay, and estuarine areas and, as they grow, they move to deeper water. Large juveniles commonly occur out to depths of 150 meters (492 feet). Spawning occurs over soft-bottom mud substrata at depths of 50 to70 meters (164 to 230 feet). Spawning occurs in Puget Sound stocks from January to April, peaking in February or March. Adults, spawning adults, and eggs have been found in Puget Sound, Hood Canal, Skagit Bay, and Grays Harbor. Larvae and juveniles occur in most estuaries between Puget Sound and San Pedro Bay, California. English sole is a very important flatfish in shallow-water, soft-bottom marine, and estuarine environments along the Pacific coast.

Adults and juveniles prefer soft bottoms composed of fine sands and mud but also are reported to occur in eelgrass habitats. Associations with sandy sediment at depths less than 110 meters (361 feet) have been reported off the coasts of Oregon and Washington. In Puget Sound, juveniles and adults prefer shallow (<12 meters [40 feet] deep) muddy substrata. Eggs are neritic and buoyant but sink just before hatching. Eggs are mostly found in polyhaline[3] waters at temperatures of 4 to 12ºC (39–54 ºF), optimally at salinities of 25 to 28 part per thousand (ppt) and 8 to 9ºC (46–48 ºF). Adults are found primarily in euhaline waters, while juveniles and larvae occur in polyhaline and euhaline waters. English sole are expected to occur in the study area (Table 17).

5.4.1.5 Trophic Interactions

English sole larvae are planktivorous. Larvae probably eat different life stages of copepods and other small planktonic organisms. Larvae appear to have a strong preference for appendicularians (shaped somewhat like a tadpole). Juveniles and adults are carnivorous, apparently feeding primarily during daylight hours, using sight and smell, and sometimes they dig for prey. Juveniles feed on harpacticoid copepods, gammarid amphipods cumaceans, mysids, polychaetes, small bivalves, clam siphons, and other benthic invertebrates. Small juvenile English sole concentrate their feeding on harpacticoid copepods and other epibenthic crustaceans until they reach approximately 50 to 65 mm (2 to 2.6 inches) in length, then they switch to feeding primarily on polychaetes. (Kravitz et al. 1976).

English sole larvae are probably eaten by larger fishes. The main predators of juvenile English sole are probably piscivorous birds (such as great blue heron), larger fishes, and marine mammals. Adults may be eaten by marine mammals, sharks, and other large fishes. English sole compete for resources with slim sculpin, blackbelly eelpout, Pacific tomcod, spotted ratfish, Dover sole, and white croaker.

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[3] *Polyhaline* and *euhaline* refer to the salt content in the seawater.

Table 17. Vertical Distribution and Ecological Zone Categories for English Sole Complex Species

Common Name	Scientific Name	Eggs	Larvae	Juvenile[a]	Subadult and Adult[a]
Butter sole	*Pleuronectes isolepis*	Nearshore Float	Offshore Surface	Nearshore to continental slope	Nearshore to continental slope
English sole	*Pleuronectes vetulus*	Nearshore Float	Nearshore Surface	Nearshore to deep shelf	Estuary to continental slope
Dover sole	*Microstomus pacificus*	Epipelagic	Epi-mesopelagic	Nearshore to continental slope	Estuary to continental slope
Flathead sole	*Hippoglossoides elassodon*	Float	Estuaries Surface to epipelagic	Nearshore	Nearshore to continental slope
Pacific halibut	*Hippoglossus stenolepis*	Float	Epipelagic	Nearshore to deep shelf	Shallow shelf to continental slope
Pacific sanddab	*Citharichthys sordidus*	Nearshore and shelf	Estuaries Epipelagic	Estuary to shallow shelf	Estuary to continental slope
Sand sole	*Psettichthys melanostictus*	Nearshore to shallow shelf Float	Estuaries to shelf Subsurface	Estuary to shallow slope	Estuary to continental slope
Starry flounder	*Platichthys stellatus*	Nearshore to shallow shelf Float	Nearshore	Estuary to shallow slope	Estuary to deep shelf
Rock sole	*Lepidosetta bilineata*	Nearshore to continental slope[a]	Subsurface Estuaries	Nearshore to continental slope	Estuary to continental slope

Notes:
Vertical distribution categories are surface, subsurface, epipelagic, and mesopelagic.
Coastal ecological zones are nearshore, shallow shelf, deep shelf, and continental slope.
A *complex* is a subgroup of species with similar distribution and life history patterns.

[a] Demersal.

Sources: McCain et al. 2005; NOAA 2008.

5.4.2 Arrowtooth Flounder Complex

The arrowtooth flounder complex consists of fish with epipelagic or pelagic eggs, larvae, and juveniles and distributions of those life stages farther offshore in the shallow and deep shelf ecological regions. The following species are in this complex:

- Curlfin sole (*Pleuronichthys decurrens*)
- Slender sole (*Lyopsetta exilis*)
- Petrale sole (*Eopsetta jordani*)
- Rex sole (*Glyptocephalus zachirus*)
- Arrowtooth flounder (*Atheresthes stomias*)
- C-O sole (*Pleuronichthys coenosus*)
- Speckled sanddab (*Citharichthys stigmaeus*)

The arrowtooth flounder is discussed as an example to represent the species in this complex. The species description below, unless otherwise referenced, is a summary and adaptation of information as presented and cited in *Life History, Geographical Distribution, and Habitat Associations of 82 West Coast Groundfish Species: a Literature Review* (McCain et al. 2005).

5.4.2.1 Geographic Distribution

Arrowtooth flounder range from the southern coast of Kamchatka to the northwest Bering Sea and Aleutian Islands, to Santa Barbara, California. Densities are low south of Cape Blanco, Oregon.

5.4.2.2 Seasonal Distribution in Study Area

Arrowtooth flounder exhibit a strong migration from shallow-water summer feeding grounds on the continental shelf to deep-water spawning grounds over the continental slope. Depth distribution may vary from as little as 50 meters (164 feet) in summer to more than 500 meters (1,640 feet) in winter.

5.4.2.3 Uses, Status and Trends, and Regulatory Issues

Aarrowtooth flounder is the third most common commercially caught flatfish species off the Washington coast, exceeded only by Dover sole and petrale sole. The catch is made almost exclusively by deepwater trawl. Arrowtooth flounder are not a recreationally important species, but they are caught incidentally.

5.4.2.4 Utilization of Study Area Habitats by Life History Stages

Arrowtooth flounder is the dominant flounder species on the outer continental shelf from the western Gulf of Alaska to Oregon. Eggs and larvae are pelagic; juveniles and adults are demersal in depths of 9 to 900 meters (30 to 3,000 feet). Larvae are neritic, generally in 200 meters (656 feet) of water or less, with larger fish tending to be found deeper. Young juveniles are typically found in waters shallower than 200 meters (656 feet), while older juveniles and adults may be found from 50 to 500 meters (164 to 1,640 feet). However, arrowtooth flounder have been reported to exhibit only weak depth-distribution patterns. Juveniles and adults are most commonly found on sand or sandy gravel substrata but occasionally occur over low-relief rock-sponge bottoms. A strong association with mud, pebble, and mud-pebble substrate has been reported off the coasts of Oregon and Washington. All life stages of the arrowtooth flounder occur almost exclusively in euhaline waters.

The arrowtooth flounder is a batch spawner, and spawning may occur deeper than 500 meters (1,640 feet) off the Washington coast. Spawning occurs off the coast of Washington between fall and winter, and in Puget Sound during winter. This species is unlikely to occur in the study area (Table 18).

5.4.2.5 Trophic Interactions

Larvae eat copepods, their eggs, and copepod nauplii (a larval form). Juveniles and adults feed on crustaceans (mainly ocean pink shrimp and krill) and fish (mainly gadids, herring, and pollock). Arrowtooth flounder exhibit two feeding peaks, at noon and at midnight. The main predators reported for arrowtooth flounder include the Pacific halibut and killer whales.

5.5 Roundfish

Roundfish tend to have elongate body forms, and all of the species are oviparous with external fertilization. Roundfish in the study area are separated into two complexes for discussion:

- **Pacific hake-walleye pollock-Pacific cod-sablefish complex (Complex 1):** species with life history stage associations with surface waters and unconsolidated subtidal and shelf habitats.
- **Lingcod-cabezon-greenling complex (Complex 2):** species that are strongly associated with rocky intertidal and subtidal habitats and sensitive early life history stage associations with surface water and nearshore habitats.

5.5.1 Pacific Hake – Walleye Pollock – Pacific Cod – Sablefish Complex

Pacific hake, Pacific cod, and walleye pollock have sensitive early life stage associations with shallow water or nearshore habitats in the study area and other management issues that warrant more detailed discussion. Sablefish are considered here as part of the hake-pollack-cod complex because of similarities in distribution patterns of larvae and juveniles at and near the ocean surface, as well as in commercial importance. However, sablefish larvae and juvenile distribution are associated only with the western margin of the study area; therefore, sablefish are addressed in less detail.

Table 18. Vertical Distribution and Ecological Zone Categories for Arrowtooth Flounder Complex Species

Common Name	Scientific Name	Eggs	Larvae	Juvenile[a]	Subadult and Adult[a]
Curlfin sole	*Pleuronichthys decurrens*	Nearshore to continental slope	N/A	N/A	Shallow shelf to continental slope
Slender sole	*Lyopsetta exilis*	N/A	N/A	Shallow shelf to deep shelf	Shallow shelf to continental slope
Petrale sole	*Eopsetta jordani*	Shallow shelf to continental slope	Shallow shelf to continental slope	Nearshore to continental slope	Nearshore to continental slope
Rex sole	*Glyptocephalus zachirus*	Nearshore to continental slope	Shallow shelf to continental slope	Deep shelf to continental slope	Estuary to continental slope
Arrowtooth flounder	*Atheresthes stomias*	Shallow shelf to continental slope	Shallow shelf to continental slope	Shallow shelf to continental slope	Shallow shelf to continental slope
C-O sole	*Pleuronichthys coenosus*	N/A	Nearshore	Nearshore to continental slope	Nearshore to continental slope
Speckled sanddab	*Citharichthys stigmaeus*	Pelagic	Nearshore Pelagic	Nearshore to continental slope	Nearshore to continental slope

Notes:

N/A = Not applicable.

Vertical distribution categories are surface, subsurface, epipelagic, and mesopelagic.

Coastal ecological zones are nearshore, shallow shelf, deep shelf, and continental slope.

A *complex* is a subgroup of species with similar distribution and life history patterns.

[a] Demersal.

Source: McCain et al. 2005.

Other deepwater offshore species of roundfish, such as Pacific grenadier, Pacific flatnose, and Pacific midshipman were considered in association with this complex. Because these and similar species are found at the outer margins and beyond the study area, and at depths that isolate them from the events at issue, they are not further addressed here.

The following species are included in the hake-pollack-cod complex:

- Pacific hake (Pacific whiting) (*Merluccius productus*)
- Pacific cod (*Gadus macrocephalus*)
- Walleye pollock (*Theragra chalcogramma*)
- Sablefish (*Anoplopoma fimbria*)
- Pacific grenadier (*Coryphaenoides acrolepis*)

The species descriptions below, unless otherwise referenced, are largely a summary and adaptation of information as presented and cited in *Life History, Geographical Distribution, and Habitat Associations of 82 West Coast Groundfish Species: a Literature Review* (McCain et al. 2005).

5.5.1.1 Geographic Distribution

Coastal stock Pacific hake range from Attu Island in the western Gulf of Alaska to Magdalena Bay, southern Baja California. They are most abundant in the California Current System. A smaller stock unit (designated as a Georgia Basin Pacific hake DPS) occupies the study area, and other stocks may exist within the above range outside the study area that are not considered further here (Bailey et al. 1982; Hart 1973). Smith (1995) recognized three habitats utilized by the offshore stock of Pacific hake: (1) a narrow 30,000-km^2 (18,640-mi^2) feeding habitat near the shelf break of British Columbia, Washington, Oregon, and California, populated 6–8 months per year; (2) a broad 300,000-km^2 (186,400-mi^2) open sea area of California and Baja California populated by spawning adults in winter and embryos and larvae for 4-6 months; and (3) a continental shelf juvenile rearing area of unknown size off the coast of California and Baja California.

Walleye pollock are found in the waters of the northeastern Pacific Ocean from the Sea of Japan, north to the Sea of Okhotsk, east in the Bering Sea and Gulf of Alaska, and south in the northwestern Pacific Ocean along the Canadian and U.S. West Coast to Carmel, California. Currents, eddies, and meso-scale physical structures along a coast influence the distribution of early life history stages. The distributions of later life history stages of walleye pollock appear to be influenced by temperature, light, and prey abundance—variables that may change in an area from year to year (Bailey et al. 1996; Bailey 1989; Swartzman et al. 1994; Olla et al. 1996; Sogard and Olla 1996a, 1996b; Brodeur et al. 1995; Ciannelli et al. 2002). Adult walleye pollock are generally a semi-demersal species that inhabit the continental shelf and slope. Moreover, various life history stages are capable of inhabiting nearshore areas, large estuaries such as Puget Sound, coastal embayments, and open ocean basins. The primary densities of numerous populations are in the North Pacific Ocean, including the northern Gulf of Alaska, Bering Sea, and the Sea of Okhotsk, suggesting that walleye pollock populations in Puget Sound are relatively isolated. Adults occur as deep as 366 meters (1,200 feet), but the vast majority occur between 100 and 300 meters (330 and 985 feet) deep. Spawning takes place at depths of from 50 to 300 meters (165 to 985 feet). Eggs are pelagic and are found throughout the water column. Larvae and small juveniles are pelagic and are generally found in the upper water column to depths of 60 meters (200 feet). Post-larvae and small juveniles occupy a wider depth range, generally with diel movements that involve rising to the surface at night to feed and sinking down in schools during the day. Juvenile pollock have been found in a variety of habitat types, including eelgrass (over sand and mud), gravel, and cobble. Because of their pelagic mode, however, they are not thought to consistently associate with many types of substrates (Hart 1973; Merati and Brodeur 1996; Bailey et al. 1996; Miller et al. 1977).

Pacific cod are found in the waters of the northeast Pacific from the Sea of Japan, east to the Bering Sea in Alaska, and south along the West Coast to Santa Monica, California. Pacific cod in Puget Sound are generally categorized into three components: (1) the North Sound component (located in U.S. waters north of Deception Pass, including the San Juan Islands, Strait of Georgia, and Bellingham Bay); (2) the West Sound component (located west of Admiralty Inlet and Whidbey Island, and in the U.S. section of the Strait of Juan De Fuca, including Port Townsend); and (3) the South Sound component (located south of Admiralty Inlet). The primary densities of numerous populations historically have been in the North Pacific, including the Bering Sea and the waters near northern Japan, suggesting that cod populations in Puget Sound are relatively isolated (Allen and Smith 1988; Fredin 1985; Shimada and Kimura 1994; Westrheim 1996; Stout et al. 2001).

Sablefish range from Baja California to the western Bering Sea and the northeastern Pacific Ocean to Japan. Three stocks of sablefish appear to exist along the west coast of North America. Two of those stocks appear to overlap off the coasts of southwest Vancouver Island and northwest Washington and in the study area: a northern population inhabits Alaska and northern British Columbia waters; and a southern population inhabits southern British Columbia and Washington, Oregon, and California waters as summarized by Schirripa (2007).

5.5.1.2 Seasonal Distribution in Study Area

The Pacific hake is unorthodox among the roundfishes because it is highly migratory, moving into many areas of the West Coast, including nearshore shelf, shelf break, and slope (McCain et al. 2005). The offshore Pacific hake stock spawns off the California coast in winter and then mature adults begin moving northward and inshore, following the food supply and Davidson currents, and reaching the study area and into British Columbia by fall. By late fall, they are migrating back to the southern spawning grounds (Bailey et al. 1982; Dorn 1995; Smith 1995; Stauffer 1985). Pacific hake stocks in the Strait of Georgia and Puget Sound undergo similar migration patterns but on a greatly reduced scale. In both areas, spawning occurs in locations proximate to major sources of freshwater inflow: near the Frazer River in the Strait of Georgia and near the Skagit and Snohomish Rivers in Port Susan. The Puget Sound and Strait of Georgia stocks spend their entire lives in these estuaries (McFarlane and Beamish 1985; Pedersen 1985; King and McFarlane 2006).

Walleye pollock are not considered to be a migratory species, but pre-spawning adults do make relatively short migrations to regional spawning grounds. These grounds are generally in sea valleys, canyons, indentations in the outer margin of the continental shelf, or in fjords such as Puget Sound (Schumacher and Kendall 1995). A seasonal bathymetric movement occurs from deep spawning areas of the outer shelf and upper slope in fall and winter to shallow middle-upper shelf feeding grounds in spring. Larvae may be transported by tidal current to nursery areas. Some evidence suggests that the fish move into deeper water with growth, but they are not found exclusively in deeper water (Dunn and Matarese 1987; Hart 1973; Shimada and Kimura 1994; Brodeur et al. 1995; Palsson et al. 1998).

5.5.1.3 Uses, Status and Trends, and Regulatory Issues

Pacific hake support one of the most important commercial fisheries off the West Coast. Coastal stocks are fished with midwater trawls off the northern California coast starting in April and moving northward to British Columbia by late July. Fishing ceases in October. The interior stocks of Pacific hake in Puget Sound and the Strait of Georgia are fished from January through May (Gustafson et al. 2000). Historically, commercial fisheries for Pacific hake in Puget Sound centered on the Port Susan, Saratoga Passage, Port Gardner, and southern Carr Inlet areas. Pacific hake is not a recreationally sought after species; almost all recreational catch is incidental to salmon fishing (Gustafson et al. 2000).

Pacific cod also support commercial fisheries along the West Coast. Primary fishing methods are bottom trawling and longlining. Pacific cod also are fished recreationally from boats and piers. The fisheries in Puget Sound have been restricted in recent years to address concerns for the depressed status of the stock (Gustafson et al. 2000). In a recent status review, a Biological Review Team (BRT)—a scientific panel convened by NOAA Fisheries—concluded that inshore resident Pacific hake within the marine waters of the Strait of Georgia, Puget Sound, and eastern Strait of Juan de Fuca constitute a discrete segment of the species that warrants separate consideration relative to offshore Pacific hake. The unit has been designated as the Georgia Basin Pacific hake DPS and is considered a species under the ESA. The BRT further concluded that the Georgia Basin Pacific hake DPS was not presently in danger of extinction, but it continues to be under ongoing review as a species of concern. In the same review, the BRT further concluded that the Lower Boreal Eastern Pacific walleye pollock DPS extends from Puget Sound

northward to encompass all of southeast Alaska. The BRT also concluded there is good reason to believe that Pacific cod from Puget Sound are part of a DPS that extends beyond the boundaries of the Puget Sound ecosystem, to at least as far north as Dixon Entrance. Quantitative information on the abundance of Pacific cod stocks and on potential factors affecting their abundances is limited, and members of the BRT expressed considerable uncertainty in assessing extinction risks. Members of the BRT identified several concerns, especially about the status of Puget Sound stocks. Given the general synchronicity of the changes in apparent Pacific cod abundance from Puget Sound to southeast Alaska, some BRT members are concerned that factors affecting the decline of the Puget Sound stocks will similarly affect the stocks in British Columbia and southeast Alaska in the future. Overall, it is uncertain which factors, either singly or in combination, may be significantly contributing to the current low stock sizes of Pacific cod. (Gustafson et al. 2000.)

5.5.1.4 Utilization of Study Area Habitats by Life History Stages

Pacific hake adults are epi-mesopelagic; they most frequently occur between 100 and 150 meters (328 to 492 feet), with nearly all taken at depths of 50 to 400 meters (164 to 1,312 feet). All life stages of Pacific hake feed near the surface late at night and early in the morning (Bailey et al. 1982; Sumida and Moser 1980; Allen and Smith 1988). Pacific hake larvae tend to aggregate near the base of the thermocline or mixed layer (Stauffer 1985). This association with the thermocline or mixed layer may partially explain why Pacific hake in the Strait of Georgia and Puget Sound spawn near major sources of freshwater, which would cause a stratified layer of low-salinity water on top of the well mixed marine waters common during winter. Larvae would likely be found in the study area in the southern Strait of Georgia, San Juan archipelago, Skagit Bay, and Port Susan during late winter through spring (Gustafson et al. 2000). Juveniles reside in shallow coastal waters, bays, and estuaries and move to deeper water as they get older. Older juveniles and adults therefore would be found throughout those same areas in the southern Strait of Georgia, San Juan archipelago, and the rest of the eastern region of the study area throughout the year (Bailey et al. 1982; Dark 1975; Dark and Wilkins 1994; Dorn 1995; Sakuma and Ralston 1995; Smith 1995).

The distribution of juvenile and adult walleye pollock is determined by a variety of biological and environmental factors, including hydrographic fronts, temperature, light intensity, prey availability, and depth. Larvae tend to aggregate in patches under the influence of currents, geographical formations, and availability of prey. Puget Sound information on the relationship between the bathymetric distribution and size suggests that the tendency for juvenile walleye pollock to move into deeper waters with age, as has been reported in coastal walleye pollock populations, also occurs in Puget Sound. Both adult and juvenile walleye pollock exhibit diel vertical migrations in order to forage on prey practicing that behavior (Sogard and Olla 1996a; Bailey et al. 1999).

Pacific cod are historically an important groundfish of shallow, soft-bottom habitats in marine and estuarine environments along the West Coast (Gustafson et al. 2000). All life stages of Pacific cod occur in various bays in Puget Sound and in the Strait of Juan de Fuca near Vancouver Island. Adults and large juveniles prefer mud, sand, and clay, although adults have been found associated with coarse sand and gravel substrata (Gustafson et al. 2000). Adult Pacific cod are a member of the inner shelf-mesobenthal community. Adults are found in marine waters, whereas juveniles are found in polyhaline to euhaline waters. Adults occur as deep as 875 meters (2,870 feet), but the vast majority occurs between 50 and 300 meters (164 and 984 feet) (Allen and Smith 1988; Hart 1973). Spawning occurs from 40 to 265 meters (131 to 1,526 feet) deep; eggs are demersal adhesive and are found sublittorally in polyhaline to euhaline waters. Larvae and small juveniles are pelagic; large juveniles and adults are parademersal. Larvae are found in the upper 45 meters (148 feet) of the water column, with the highest abundances between 15 and 30 meters (49 and 98 feet). Eggs and larvae are found over the continental shelf between Washington and central California from winter through summer. Small juveniles usually settle between

60 and 150 meters (197 and 492 feet) deep, gradually moving into deeper water with increased age (Alderdice and Forrester 1971; Dunn and Matarese 1987; Hart 1973; Matarese et al. 1981). Pacific cod juveniles and adults are carnivorous and feed at night. Juveniles have been reported to eat a variety of size-dependent suitable prey such as shrimp, mysids, amphipods, crabs, sand lance, and walleye pollock (Allen and Smith 1988). Adult Pacific cod have been described as euryphages (able to subsist on a wide variety of foods) because the main part of their diet is whatever prey species is most abundant (Klovach et al. 1995).

In the North Pacific, sablefish is considered an inner shelf-bathybenthal species. Adults are found as deep as 3,000 meters (9,843 feet) but are most abundant between 200 and 1,000 meters (656 and 3,281 feet). Spawning takes place at depths greater than 300 meters (983 feet). Sablefish eggs, larvae, and young juveniles are pelagic, whereas older juveniles and adults are benthopelagic on soft bottoms. Eggs are usually found deeper than 300 meters (983 feet). Eggs and newly hatched larvae are found in these deep waters from January through March. Newly hatched larvae are demersal until the yolk sac is absorbed, at which time larvae become pelagic and rise to the neuston layer at the surface. Larvae and young juveniles are found up to 370 km (230 mi) offshore, often near drifting kelp. Young juveniles inhabit the upper 100 meters (328 feet) of the water column. Larvae and small juveniles move inshore after spawning and may rear there for up to 4 years. McFarlane et al. (1997) reported that larval sablefish collected off the west coast of Vancouver Island tended to be most abundant in waters where mean currents were weakest. They suggest that the distribution of the larvae in the water column at the time of the spring transition (i.e., the onset of upwelling conditions) strongly influences the abundance and distribution of sablefish larvae. Older juveniles and adults inhabit progressively deeper waters, although juveniles are rarely found at depths greater than 200 meters (656 feet) (Hart 1973; Kendall and Matarese 1987; Boehlert and Yoklavich 1985; Beamish and McFarlane 1988; Grover and Olla 1990).

5.5.1.5 Reproduction

The coastal stock of Pacific hake spawns from December through March, peaking in late January. In the Strait of Georgia, spawning occurs from March through May and peaks in late April. Spawning occurs primarily during February through April, peaking in March. Spawning aggregations begin to form up to a month before actual spawning (Smith 1995; Beamish and McFarlane 1985). Within Puget Sound (including Hood Canal), Pacific hake are known to spawn in Port Susan and in Dabob Bay, and there may be other spawning aggregations of Pacific hake in Puget Sound (Bailey and Yen 1983; Pedersen 1985). The main Pacific hake stock in the Strait of Georgia aggregates to spawn in the deep basins of the southcentral Strait of Georgia, with peak spawning occurring from March to May. This area is bound by Halibut Bank and Gabriola Island to the east and west, and Texada Island and Galiano Island to the north and south. Spawning aggregations of Pacific hake in the southcentral Strait of Georgia occur in two depth strata: between 50 and 120 meters (164 and 394 feet) and between 150 and 330 meters (492 and 1,083 feet). A second discrete stock of Pacific hake in the Strait of Georgia has been found spawning northwest of Texada Island near Montgomery Bank, and reports of other spawning and fish in spawning condition throughout the year suggest further diversity within the stock (Goñi 1988; Kieser et al. 1999).

Walleye pollock are oviparous with external fertilization; eggs are pelagic. During spawning, walleye pollock apparently pair and spawn after a complex courtship. Females spawn several batches of eggs over a short period of time (multiple-batch spawning). Eggs are usually spawned in deep water and remain at 100 to 400 meters (328 to 1,312 feet) deep at most spawning localities but also can be spawned in shallower waters in coastal bays such as those in the eastern region of the study area (Baird and Olla 1991; Hinckley 1987).

Pacific cod spawning occurs from late fall to early spring in Puget Sound (Gustafson et al. 2000); stocks farther north in the Gulf of Alaska and the Bering Sea spawn in winter through spring (Klovach et al.

1995). Eggs are demersal, adhesive, and found in polyhaline (dense saltwater) to euhaline waters between 1EC and 10EC (Alderdice and Forrester 1971; Dunn and Matarese 1987; Hart 1973). Cod eggs have been found associated with coarse sand and cobble bottoms (Phillips and Mason 1986). Because most winter concentration areas have bottom sediments consisting of coarse sand and cobble, it is inferred that cod preferentially spawn near these bottom types (Phillips and Mason 1986).

Sablefish spawning takes place largely or totally out of the study area.

5.5.2 Lingcod – Cabezon – Greenling Complex

This subsection of the roundfish group describes the lingcod-cabezon-greenling complex. Lingcod, cabezon, and kelp greenling are important commercial and recreational fishery resources. They have sensitive early life stage associations with surface water and nearshore habitats in the study area and therefore warrant discussion here.

The following species are included in the lingcod-cabezon-greenling complex:

- Lingcod (*Ophiodon elongatus*)
- Cabezon (*Scorpaenichthys marmoratus*)
- Kelp greenling (*Hexagrammos decagrammus*)

The species descriptions below, unless otherwise referenced, are largely a summary and adaptation of information as presented and cited in *Life History, Geographical Distribution, and Habitat Associations of 82 West Coast Groundfish Species: a Literature Review* (McCain et al. 2005).

5.5.2.1 Geographic Distribution

Lingcod occur from Shumagin Island in the Gulf of Alaska to Punta San Carlos, Baja California. Highest densities are found from Cape Spencer, Alaska to Point Conception, California. Cabezon are found in southeast Alaska to as far south as Punta Abreojos in central Baja California. Kelp greenling are relatively common all along the west coast of North America, from the Aleutian Islands to southern California off La Jolla.

5.5.2.2 Seasonal Distribution in Study Area

Adult lingcod are considered a relatively sedentary species. Mature males may live their whole lives associated with a single rock reef. However, migrations greater than 100 km (62 mi) have been reported, typically undertaken by sexually immature fish. Adult cabezon and kelp greenling appear to be more sedentary and are not known to make any significant migrations. Pacunski and Palsson (2001) reported no changes in kelp greenling density between 1993 and 1998 in northern Puget Sound, indicating that no individuals were leaving or entering the study area.

In late winter, newly hatched lingcod larvae are carried by tidal currents into rearing areas within estuaries. Larvae metamorphose in late spring to early summer into juveniles that settle from surface waters and migrate to bottom habitats, frequently around kelp and eelgrass beds, and rear until winter before moving to deeper waters. Both cabezon and kelp greenling larvae have been reported to be carried great distances by offshore oceanic currents, and kelp greenling may take up to a year for larvae to return and settle into nearshore habitats.

5.5.2.3 Uses, Status and Trends, and Regulatory Issues

Lingcod support an important commercial and recreational fishery throughout their range. Lingcod are caught commercially through five main gear types: bottom trolling, handline jigging, otter trawls, set nets, and set lines. Catches are generally highest in depths of 70 to 150 meters (230 to 492 feet), and catches on the West Coast have been highest from Vancouver Island to the Columbia River estuary. Lingcod, cabezon, and kelp greenling are all taken throughout their range by recreational fishers from boats, docks, and shore, and by spear-fishing divers.

5.5.2.4 Utilization of Study Area Habitats by Life History Stages

In the North Pacific, lingcod occupy the estuarine-mesobenthal zone, occurring from intertidal areas to 475 meters (1,558 feet) deep. Older larvae and very young juveniles are epipelagic, primarily found in the upper 3 meters (10 feet) of the water column in waters less than 150 meters (492 feet) deep. Eggs, young larvae, older juveniles, and adults are demersal. Spawning generally occurs in waters from 3 to 10 meters (10 to 33 feet) below mean lower low water over rocky reefs in areas of swift current. Adults, spawning adults, and eggs are common in Puget Sound, Hood Canal, and Skagit Bay in Washington.

Eggs masses are found in association with rocky reefs. Egg masses usually are found wedged in rock crevices or under overhanging boulders in areas with currents 3.5 km/hour (2.2 mi/hour) or greater to maintain interstitial oxygen levels in the center of the mass. Juveniles and larval lingcod are common in most Washington estuaries. Eggs and larvae occur in nearshore areas from winter through late spring. Small juveniles settle in estuaries and shallow waters all along the coast but are more common in northerly extents of the range. Juveniles move to deeper waters as they grow but are still most common in waters less than 150 meters (492 feet) deep. Juvenile lingcod prefer sandy and rocky substrata in subtidal zones and estuaries. All life history stages occur in polyhaline to euhaline waters (18 to 30+ ppt) that are between 5 and 15 ^{o}C, although juveniles may also be found in mesohaline waters (5 to 18 ppt). Adult and large juvenile lingcod have been reported to prefer rocky subtidal and other associated habitats, including slopes of submerged banks, ridges, and boulders. In some cases, they are found on soft bottoms and channels with swift currents that flow around rocky reefs, concentrating plankton and plankton-feeding fish.

Cabezon are found on hard bottoms in shallow water from intertidal pools to depths of 76 meters (250 feet). Cabezon are found intertidally or in shallow, subtidal areas on a variety of habitats, often in the vicinity of kelp beds, jetties, isolated rocky reefs, or pinnacles and in shallow tide pools. Rocky bottoms and cobble substrata are utilized most frequently. Eelgrass beds and occasionally sandy bottoms are used. Cabezon are abundant all year in estuarine and subtidal areas, as well as to mid-depths along the continental shelf. Eggs, large juveniles, and adults are demersal; larvae and small juveniles are pelagic and planktivorous. Juveniles and adults reside primarily in shallow water bays and estuarine areas. Pelagic juveniles are silvery when small, spending their first 3 to 4 months in the open ocean feeding on tiny crustaceans and other zooplankton. Off the Washington coast, adults are found as deep as 80 meters (262 feet) but are most common intertidally to 25 meters (82 feet). Cabezon are most abundant in estuaries of the West Coast, where all life stages can be found. Eggs and larvae are found there from winter through spring. Eggs, juveniles, and adults are not reported to occur far offshore. However, neustonic planktivorous larvae have been reported as far from shore as 322 km (200 mi).

Kelp greenling adults, spawning adults, and large juveniles are abundant in coastal waters and in inland seas, such as Puget Sound. Adults are demersal, inhabiting rocky reefs of shallow nearshore areas. Kelp greenlings show a high affinity to rocky banks near dense algae or kelp beds, or in kelp beds. Eggs are demersal and found subtidally. Larvae and small juveniles are pelagic whereas large juveniles are demersal. In Puget Sound, adults are most abundant between 7 and 12 meters (23 and 39 feet) and are not

commonly found below 20 meters (66 feet). Larvae and small juveniles are found in the upper 45 meters (148 feet) of the water column in spring and summer, and may be found up to 965 km (600 mi) offshore. Juveniles are commonly associated with rocky reefs and macroalgae, and occasionally are found in tide pools.

5.5.2.5 Reproduction

Lingcod are iteroparous and gonochoristic (individuals are either male or female and maintain the same sex throughout their lifespan). Spawning takes place in Washington waters (Puget Sound, Hood Canal, and Skagit Bay) and peaks from February to March. Embryonic development is indirect and external. Egg masses are adherent and usually are laid in rock crevices or on rocky reefs. Males guard the nest until hatching.

The spawning season for cabezon in Puget Sound is from November to early May, peaking in March. Cabezon may spawn more than once per year. Cabezon males build and guard nests, and more than one female may deposit egg masses in the same male's nest. Fertilized eggs are adherent to rocks and macroalgae.

Kelp greenling spawning in Puget Sound occurs in fall and peaks in October and November. Fertilized eggs are laid on or between rocks, or in algae beds and are guarded by the males. Upon hatching, larvae immediately move to open seas for approximately 1 year and return as demersal juveniles.

5.6 Forage Fish

Small, schooling fish species known as forage fish play an important ecological role as the link between lower trophic levels (primary and secondary planktonic production) and higher trophic level species (such as salmon, marine mammals, and marine birds). Several forage fish species occur in Puget Sound and in the nearshore waters of Washington State and British Columbia. The three primary species found in the study area include Pacific herring, surf smelt, and Pacific sand lance. These species are described in more detail below.

5.6.1 Pacific Herring

In the past, Pacific herring in Puget Sound commonly were encountered up to 10 years of age. In more recent years, herring rarely live over 6 years. This curtailed age structure may be due to fishing pressure or disease (Hershberger et al. 2002). Pacific herring are iteroparous, spawning once per year after they reach sexual maturity at approximately age 2 to 4.

Pacific herring are zooplanktivores, feeding on pelagic plankton. Larvae feed on copepods, invertebrate eggs, and diatoms (Stout et al. 2001; Hart 1973; Lasker 1985). Juveniles eat copepods, decapod larvae in sublittoral habitats, and copepods and euphausiids in pelagic habitats (Stout et al. 2001; Fresh et al. 1981). Adults eat planktonic crustaceans and smaller fishes (Stout et al. 2001; Hart 1973). Herring in turn are eaten by many species throughout their life cycle. Eggs and larvae are eaten by other fish, invertebrates, and birds. Adult herring form large pelagic schools and are preyed upon by many species of fish, including salmon, hake, sablefish, and dogfish, as well as pinnipeds, orcas, and birds (Stout et al. 2001; Hourston and Haegele 1980).

Spawning occurs in the intertidal and shallow subtidal zone (0 to 3 meters [0 to 10 feet]) of sheltered inlets, sounds, bays, and estuaries. Prior to spawning, herring congregate in holding areas near the spawning site for several weeks, where they are most susceptible to fishing pressure and predation. Eggs are deposited over, and adhere to, various types of substrate—the most common being kelp or eelgrass,

but in some instances, gravel or bare rock. Incubation ranges from 10 to 14 days, depending on temperature, with much longer incubation in colder waters. Once the eggs hatch, larvae drift with the currents for several months until they metamorphose into juveniles. The timing and location of spawning in relation to the local oceanography are important factors that determine whether larvae will be retained in food-rich waters close to shore or will be transported to less hospitable areas offshore. Juveniles form large schools in protected nearshore areas during their first summer and then either migrate offshore to feed or remain inshore until maturity. The former life history is the most common, especially for north Puget Sound and Strait of Georgia stocks, whereas the latter life history is relatively more common in herring from southcentral Puget Sound (Gao et al. 2001).

5.6.1.1 Geographic Distribution

Pacific herring are distributed widely across the temperate coastal waters of the North Pacific Ocean. Along North America, Pacific herring range from the Bering Sea to Baja California. In the northwest Pacific, this species ranges from Arctic waters of the Aleutian chain and Kamchatka Peninsula south to the Sea of Japan.

In the study area, Pacific herring are distributed throughout the marine and estuarine waters of Puget Sound, Hood Canal, the San Juan Islands, the Strait of Juan de Fuca, the Strait of Georgia, and the outer coast. There is some dichotomy in the life history because some individuals from each stock are migratory, leaving the inland waters to feed in the nutrient-rich coastal upwelling zone, and some remain resident to their respective areas. It is generally known that herring exhibit some level of fidelity to spawning sites although stray rates could be as much as 20 percent (Hourston 1982). The study area includes the migration corridor for south and central Puget Sound stocks as well as the spawning locations and residence areas of north Puget Sound and Strait of Juan de Fuca stocks.

5.6.1.2 Uses, Status, Trends, and Regulatory Issues

Many different types of herring fisheries have existed historically to meet demand for either eggs or adults. Currently, commercial harvest of herring is limited to a sport bait fishery, which targets 1.5-year-old herring with small seines in southcentral Puget Sound. From 1995 to 2004, the average annual landing by the herring sport bait fishery was 414 tons (Stick 2005). Until the late 1990s, a spawn-on-kelp fishery took place mostly in north Puget Sound. Gravid fish were captured prior to spawning, retained in net pens strung with pieces of kelp until eggs were released, and then released back into the wild. A significant drop in abundance of the primary stock used for this fishery, the Cherry Point stock, led to more stringent regulations and the effective end of the spawn-on-kelp fishery. A spawning biomass of 3,200 tons for the Cherry Point herring stock is required before the fishery will be reconsidered. The recreational fishery is believed to be relatively insignificant in terms of landings. Anglers either jig or dip herring for use as bait for other fisheries such as salmon and groundfish.

The WDFW manages Pacific herring as 22 distinct stocks, with 19 in Puget Sound (Table 19). Each stock's status is reviewed biannually based on biomass estimates achieved by spawning deposition surveys and acoustic/trawl surveys. The status of these stocks is variable but generally has declined in recent years, especially in the north Puget Sound and Strait of Juan de Fuca regions (Stick 2005).

Other than the direct mortality incurred from fishing pressure, which is managed in a precautionary way by the WDFW, the most significant threat to the health and abundance of herring populations is the trend in stabilizing beaches with bulkhead structures to facilitate commercial and residential construction. Shoreline armoring alters beach formation processes and wave action, which leads to erosion and loss of intertidal and subtidal vegetation (Thom and Hallum 1990). Non-point source pollution and stormwater issues stemming from increased human activities also can lead to a loss of eelgrass beds that are critical

for herring spawning success. Pacific herring are considered a Washington State Priority Species, and all known spawning beds are considered Saltwater Habitat Areas of Special Concern (WAC 220-110-250), which means that disturbance may be prohibited or conditional.

The conservation status of Pacific herring in Washington State also has drawn the attention of the National Oceanic and Atmospheric Administration (NOAA) because of several petitions submitted to the agency to list certain herring stocks under the ESA. In response to the multiple petitions, NOAA reviewed the status of Pacific herring with a focus on determining whether the population (defined by the petitioners) met the requisite criteria to be considered a DPS (USFWS and NMFS 1996). Namely, evidence was needed to show that the Cherry Point stock is both distinct from other nearby herring stocks and significant to the long-term persistence of the species throughout its range. Based on the best scientific evidence available at the time, the initial status review determined that Cherry Point herring were part of the Georgia Basin DPS and not at risk of extinction (Stout et al. 2001). In the updated status review, NOAA determined that, although the Cherry Point herring stock is discrete, it does not warrant consideration as a DPS because it does not constitute a significant part of the species range (Gustafson et al. 2006). As part of a metapopulation, the local decline of the Cherry Point herring stock does not threaten the persistence of the species.

5.6.1.3 Seasonal Distribution in Study Area

Pacific herring are present year-round in the study area. Herring that undergo seasonal migrations to offshore feeding areas primarily utilize the nearshore habitats of north Puget Sound and the Strait of Juan de Fuca only in late winter as spawning grounds (or in the case of the Cherry Point stock, in late spring). Migratory herring from throughout Puget Sound utilize the study area as a feeding and migration corridor prior to and after winter spawning. Any adult herring that remain resident, along with young-of-the-year, may be present in the study area during summer.

5.6.1.4 Use of Study Area Habitats by Life History Stages

Pacific herring spawning locations throughout the greater Puget Sound area, including the study area, are illustrated in Figure 5. Spawn timing in Puget Sound generally occurs in late winter and early spring, with a peak during the last week of February through the first week of March (Stout et al. 2001). The Cherry Point herring stock is an exception, with peak spawning occurring on approximately May 10 (O'Toole et al. 2000). Intertidal and subtidal vegetation are important features of the habitat to ensure egg survival. Larvae use the entire water column, with depth distribution linked to temperature preferences (Batty 1994). Juvenile herring settle into protected nearshore areas. Because of their dichotomous life history, adults (migratory or resident) can be found within all estuarine, shallow nearshore, and pelagic habitats. The western Strait of Juan de Fuca and outer coast areas are used primarily for feeding by adults in summer.

5.6.2 Pacific Sand Lance

Pacific sand lance are a narrow, elongated forage fish common to marine and estuarine waters throughout Puget Sound, the Strait of Georgia, the Strait of Juan de Fuca, and the protected bays and inlets of coastal Washington State and Vancouver Island. Sand lance are perciformes, in the class Actinopterygii (related to sand eels, commonly known to burrow in sandy substrates). They can attain a maximum length of 30 centimeters (cm) (1 foot) and an age of 11 years. Also referred to as *candlefish*, post-larval Pacific sand lance school in nearshore waters and serve as an important prey item for piscivorous fish, birds, and marine mammals.

Table 19. Pacific Herring Stocks in Washington State Waters

Spawning Ground	Spawning and Holding Sites Present in Study Area[a]	Region[b]	Months of Peak Spawning	Pre-Spawning Holding Area	1977–1996 Average Run Size (tons)	Current Stock Status	Recent Trend	Federal/ State Status
Squaxin Pass	N	South/Central PS	Jan-Apr	Nisqually Reach	439	Moderately healthy	Stable	N/A
Wollochet Bay	N	South/Central PS	Jan- Feb	Hale Passage on NE side of Fox Island	117[c]	Unknown	Stable	N/A
Quartermaster Harbor	N	South/Central PS	Jan-Apr	S Maury Island	1,224	Healthy	Stable	N/A
Port Orchard/ Port Madison	N	South/Central PS	Jan-Apr	(1) Near Fletcher Bay to Port Orchard (2) Between Indianola, Agate Pass, and Port Madison	1,281	Depressed	Stable	N/A
South Hood Canal	N	South/Central PS	Jan-Mar	SW Hood Canal	272	Unknown	Stable	N/A
Quilcene Bay	N	South/Central PS	Jan-Apr	Not listed	251	Healthy	Stable	N/A
Port Gamble	N	South/Central PS	Jan-Apr	NE Hood Canal	2,214	Healthy	Decreasing	N/A
Kilisut Harbor	Y	South/Central PS	Feb-Mar	NW Indian Island, SE Port Townsend	405	Unknown	Stable	N/A
Port Susan	Y	South/Central PS	Jan-Apr	E off Southern Camano Island	823	Depressed	Stable	N/A
Holmes Harbor	Y	South/Central PS	Feb-Apr	Not listed	373	Unknown	Increasing	N/A
Skagit Bay	Y	South/Central PS	Feb-Apr	Between SE Whidbey and NE Camano	867	Healthy	Stable	N/A
Fidalgo Bay	Y	North PS	Jan-Apr	E Guemes Island	775	Healthy	Stable	N/A
Samish-Portage Bay	Y	North PS	Feb-Apr	(1) SE Lummi Island (2) NE Samish Island	283	Healthy	Stable	N/A
Interior San Juan Islands	Y	North PS	Jan-Apr	Between Blakely, Lopez, and Orcas	254	Unknown	Insufficient	N/A

Table 19. Pacific Herring Stocks within Washington State Waters (Continued)

Spawning Ground	Spawning and Holding Sites Present in Study Area[a]	Region[b]	Months of Peak Spawning	Pre-Spawning Holding Area	1977–1996 Average Run Size (tons)	Current Stock Status	Recent Trend	Federal/ State Status
NW San Juan Islands	Y	North PS	Jan-Apr	Not listed	200	Unknown	Insufficient	N/A
Semiahmoo Bay	Y	North PS	Feb-Apr	W off Birch Bay S to Cherry Point	1,461	Healthy	Stable	N/A
Cherry Point	Y	North PS	Mar-Jun	W off Birch Bay S to Neptune Beach	6,095	Depressed	Increasing	FC/SC[d]
Discovery Bay	Y	SJF	Feb-Apr	Northern Discovery Bay and mouth	1,468	Critical	Increasing	FC/SC[d]
Dungeness Bay	Y	SJF	Jan-Mar	N off mouths of Sequim and Discovery Bays	188	Healthy	Decreasing	N/A
Willapa Bay	N	Outer Coast	Feb-Mar	Not listed	256[c]	Unknown	Insufficient	N/A
Grays Harbor	N	Outer Coast	Feb-Mar	Not listed	133[c]	Unknown	Insufficient	N/A

[a] Y = Yes; N = No.

[b] PS = Puget Sound; SJF = Strait of Juan de Fuca; N/A = Not applicable

[c] Initial sampling occurred annually from 2000 to 2004, and data quality are considered poor by the Washington Department of Fish and Wildlife. The amount represents the mean 5-year biomass (in tons).

[d] Federal and State Candidate (FC, SC) species have been, or are being, reviewed for possible federal and state listing as sensitive, threatened, or endangered species.

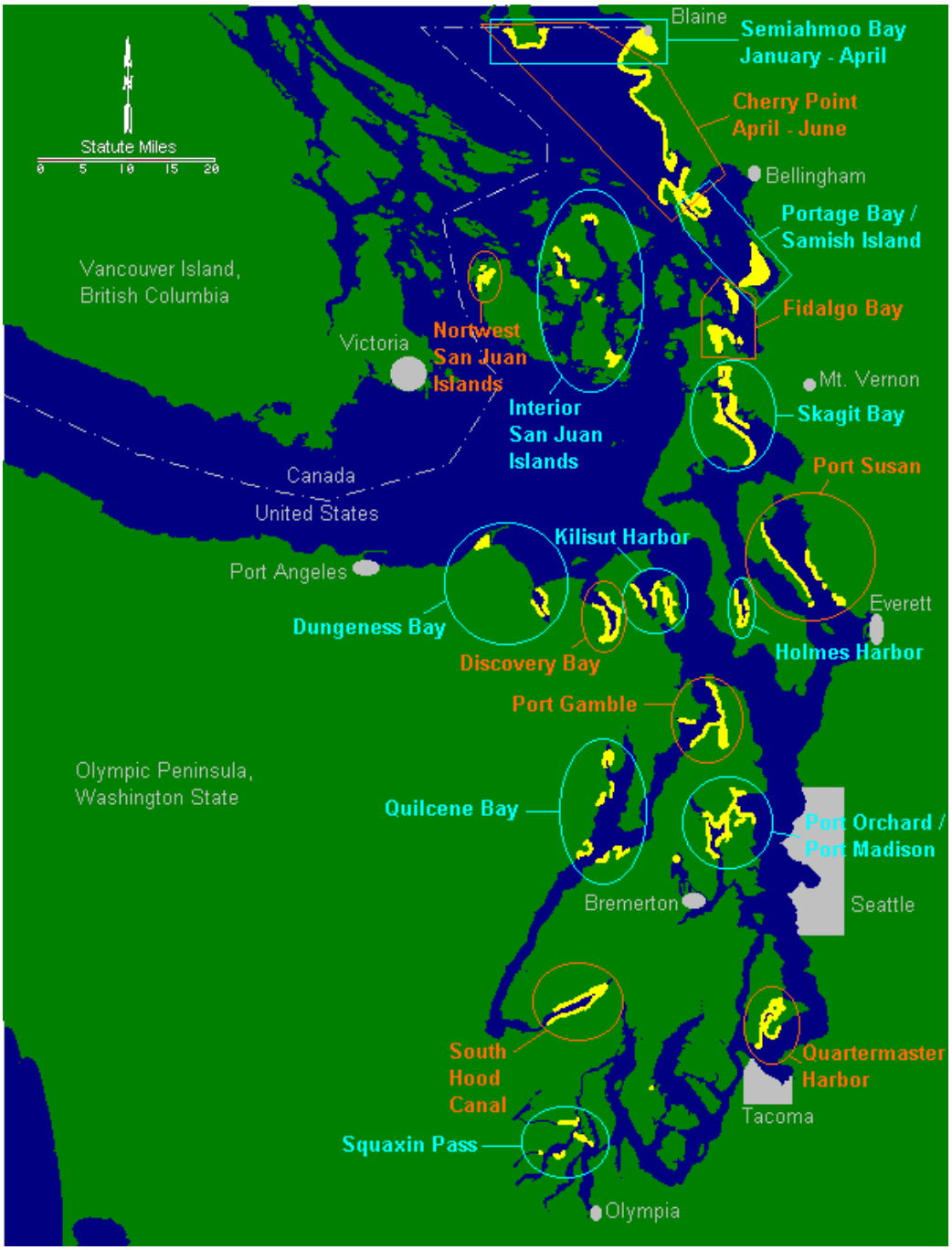

Figure 5. Herring Spawning Locations in Greater Puget Sound

Source: WDFW 1997b.

5.6.2.1 Geographic Distribution

Pacific sand lance occur throughout the temperate waters of the northeast and northwest Pacific Ocean, from Alaska to southern California and to the Sea of Japan (Eschmeyer and Herald 1983). They are common in shallow nearshore areas, in depths ranging from intertidal to almost 50 meters (164 feet) and

can be distributed throughout the water column and buried up to 6 cm (2.4 inches) below the surface in sandy substrates (Pinto et al. 1984). Sand lance also occur over deeper waters and offshore but remain in the epipelagic portion of the water column (Eschmeyer and Herald 1983).

Shoreline spawning habitat has been documented by identifying sand lance egg deposition on beaches in Puget Sound, the San Juan Islands and the Strait of Juan de Fuca. WDFW beach surveys in the 1990s found sand lance eggs in 208 km (129 mi) of shoreline in Puget Sound (Penttila 1995, 2007) and found that few bays and inlets in Puget Sound do not support sand lance spawning.

5.6.2.2 Uses, Status, Trends, and Regulatory Issues

Within the study area, Pacific sand lance are common and serve an important role in the marine food web, but they are not commonly fished. No commercial fishery targets sand lance, and they rarely occur as bycatch in other fisheries because their body shape makes them unsusceptible to being caught in most types of net gear. Only occasionally do recreational fishermen target them for use as bait, using dip nets on balls of tightly packed schools.

The status of Pacific sand lance is difficult to assess; no efforts have been made to estimate biomass, and historical catch records do not exist. Pacific sand lance are one of five forage fish considered a Washington State Priority Species, and their spawning beds are considered Saltwater Habitats of Special Concern (Bargmann 1998).

Pacific sand lance are obligate upper intertidal spawners, making them vulnerable to shoreline armoring and other modifications to nearshore habitat that can directly bury sand-gravel portions of beaches or disrupt the natural supply and movement of beach sediments.

5.6.2.3 Seasonal Distribution in Study Area

Pacific sand lance are present in the study area year-round and spawn in winter, from early November to mid-February.

5.6.2.4 Use of Study Area Habitats by Life History Stages

Figure 6 shows documented Pacific sand lance spawning locations in the greater Puget Sound area. Pacific sand lance spawn on sand/gravel beaches in the upper intertidal zone (between +1.5 meters [5 feet] and mean higher high water) during high tide. Eggs adhere to grains of sand and disperse along the beach with tide and wave action. After incubating for approximately 4 weeks, the eggs hatch and the larvae become part of the epipelagic plankton community. Pacific sand lance spawn on beaches with a wide range of substrate types and sizes, between fine sand and 3-mm (0.1-inch) gravel. Adult sand lance exhibit diel behavior, feeding in open water during the day and burrowing in the sand at night, to conserve energy and avoid predation. Pinto et al. (1984) found that sand lance chose burrowing locations primarily based on sediment grain size and contamination; they avoid burrowing in sediments contaminated with crude oil.

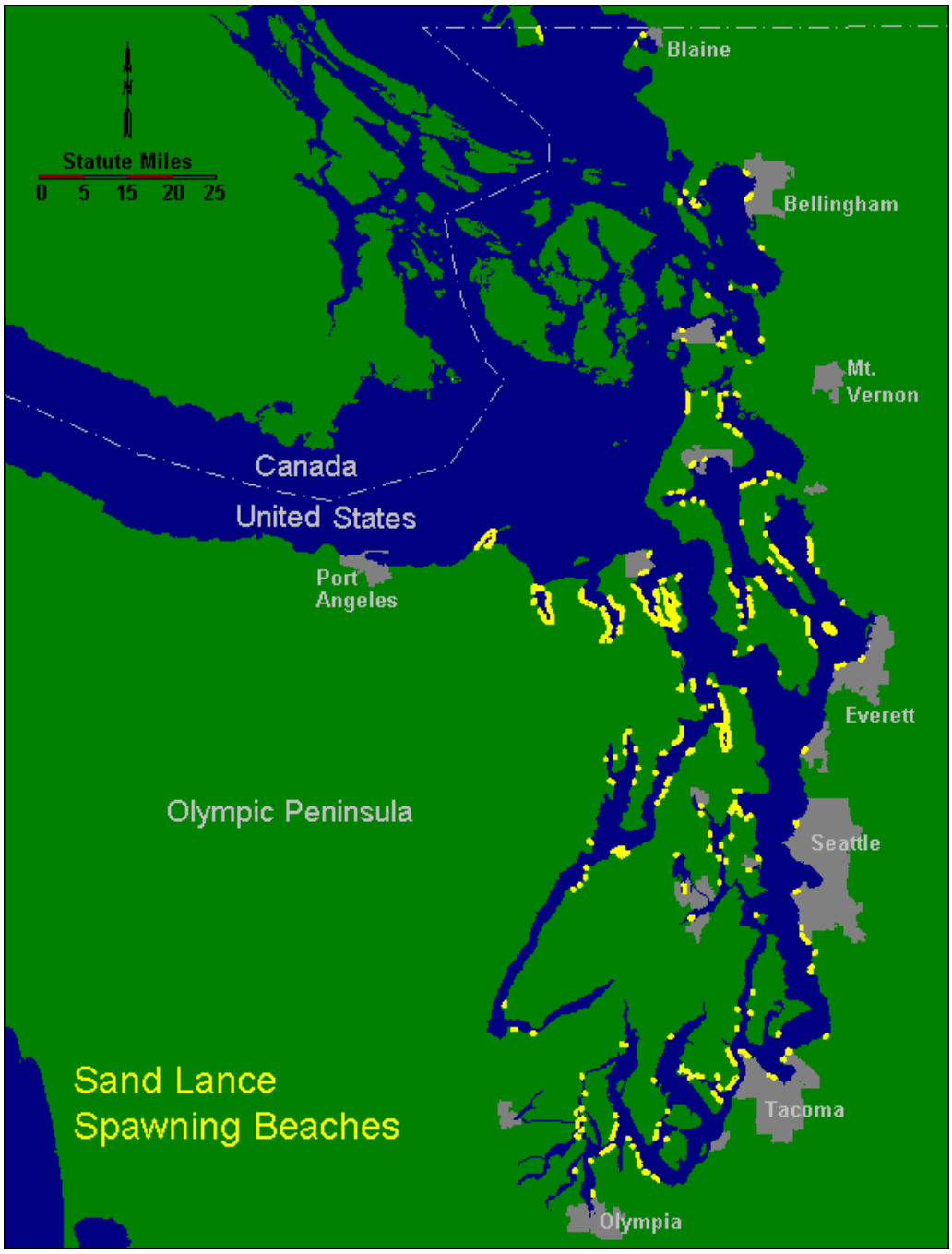

Figure 6. Documented Sand Lance Spawning Locations in Greater Puget Sound

Note: Spawning surveys covered approximately 75 percent of the shoreline. The occurrence of sand lance eggs on the remaining 25 percent of shoreline is unknown. Therefore, this figure likely underrepresents the total distribution of sand lance spawning activity.

Source: WDFW 1997c.

5.6.3 Surf Smelt

Surf smelt are in the family Osmeridae and are closely related to two other forage fish species in the region: eulachon (*Thaleichthys pacificus*) and longfin smelt (*Spirinchus thaleichthys*). Unlike these other two species, surf smelt spend their entire life cycle in marine/estuarine waters. The maximum reported size of surf smelt is 30.5 cm (12 inches). They can live to 5 years of age and become sexually mature after 1 year. The majority of surf smelt in spawning aggregations range from 1 to 2 years old. Similar to sand lance, surf smelt spawn and deposit eggs at high tide in the upper intertidal portions of coarse sand and gravel beaches, often near freshwater seeps. Eggs adhere to grains of sand and substrate, and are distributed across the beach with tide and wave action. Surf smelt eggs incubate for 2 to 5 weeks depending on temperature; once hatched, the larvae become part of the epipelagic plankton community. Adult surf smelt are dissimilar from herring in that they rarely form schools in the open water and do not migrate to offshore feeding areas. They are believed to distribute close to the bottom in nearshore shallow areas and establish long-term residency (Bargmann 1998).

5.6.3.1 Geographic Distribution

Surf smelt are distributed widely across the coast of the eastern Pacific Ocean from Prince William Sound in the Gulf of Alaska to Southern California. In Washington, surf smelt are common in the outer coast estuaries of Willapa Bay and Grays Harbor, along the Olympic Peninsula, and throughout greater Puget Sound. Spawning beach surveys conducted by WDFW identified 201 lineal km (195 mi) of beach used by surf smelt for spawning and egg incubation (Figure 7). This is likely an underestimate of the total available spawning habitat because the survey was unable to be completed (only 75 percent of the shoreline was surveyed) (Bargmann 1998).

5.6.3.2 Uses, Status, Trends, and Regulatory Issues

Surf smelt play an important role in the marine food web, serving as a prey item for a wide range of piscivorous fish, sea birds, and marine mammals. They are also the focus of small-scale commercial and recreational fisheries that occur throughout Puget Sound, Hood Canal, the Strait of Juan de Fuca, and the outer coast. The highest annual statewide commercial catch recorded between 1980 and 1996 was 123 tons in 1994, but the average has been approximately 57 tons per year (Bargmann 1998). Drag seines are the most common gear used to commercially harvest surf smelt and are used to target spawning aggregations. In recent years, much of the spawning stock has been protected from harvest through time and area restrictions on the fishery and through limited access to beach spawning grounds. The recreational fishery in Washington State is not as well monitored but is believed to land more surf smelt than the commercial fishery in some years. Jigging is commonly used to catch non-spawning fish, and dip nets are commonly used to catch fish schooled in spawning aggregations.

The current status and recent population trends of surf smelt abundance are not well known. However, there is little concern that this species is overfished because of its widespread spawning distribution, its non-schooling behavior, and limits to fishing on spawning grounds. Surf smelt are one of five forage fish species considered a Priority Species in Washington State, and all surf smelt spawning beds are considered Saltwater Habitats of Special Concern (WAC 220-110-250), meaning that they are protected from disturbance.

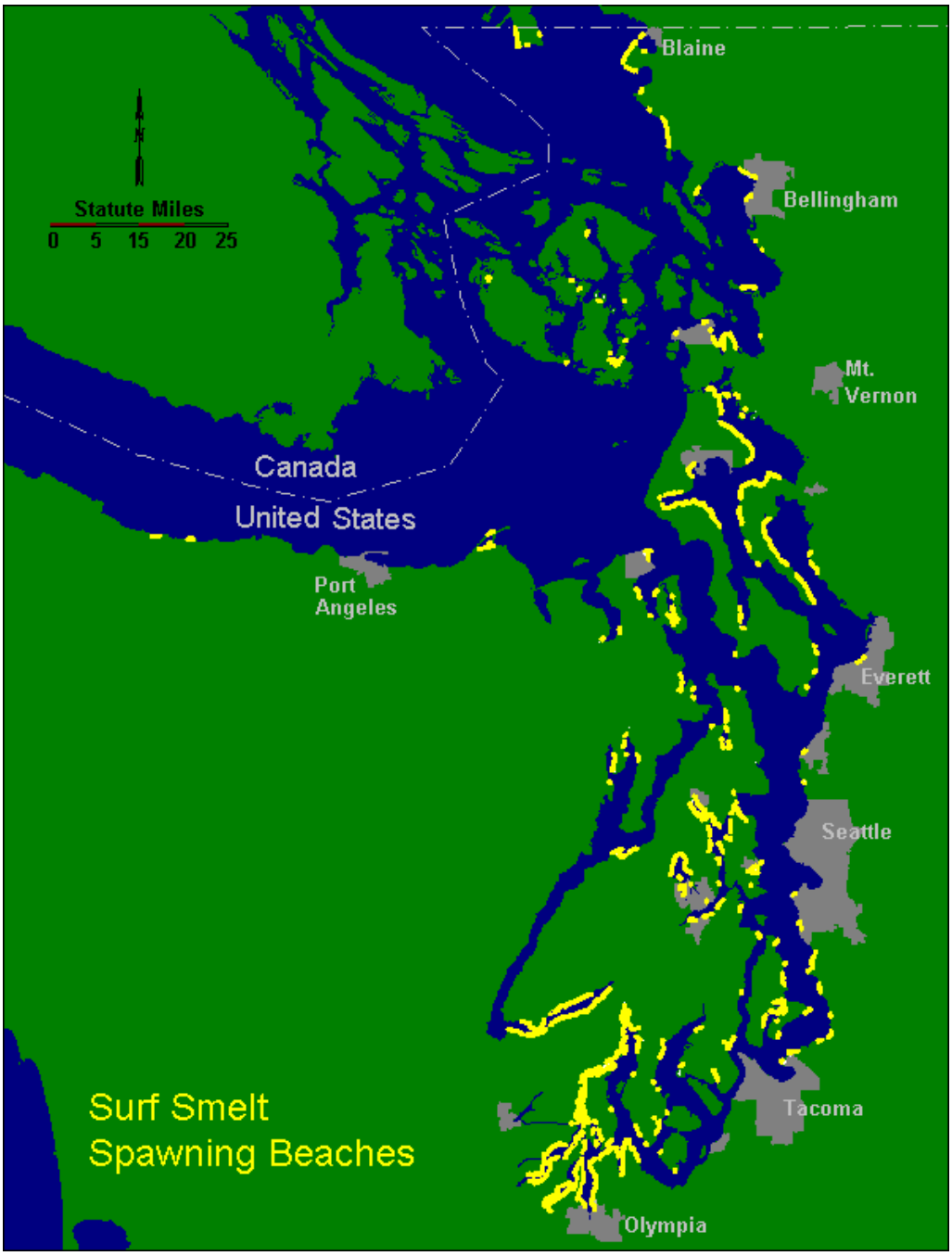

Figure 7. Documented Surf Smelt Spawning Locations in Greater Puget Sound

Note: Spawning surveys covered approximately 75 percent of the shoreline. The occurrence of surf smelt eggs on the remaining 25 percent of shoreline is unknown. Therefore, this figure likely underrepresents the total distribution of surf smelt spawning activity.

Source: WDFW 1997a.

Similar to Pacific sand lance, the most significant threat to surf smelt in Puget Sound is the loss of spawning habitat as a result of shoreline armoring practices. Coastal development often requires stabilizing beaches, banks, and bluffs, which can alter erosional processes and natural beach function.

Shoreline modifications affect longshore currents and redirect wave energy, which can lead to loss of finer-grained substrates needed for spawning (Thom and Hallum 1990). Structures such as bulkheads and docks that directly cover upper intertidal beaches also reduce the amount of available spawning habitat.

5.6.3.3 Seasonal Distribution in Study Area

Surf smelt are present in the study area year-round and are not believed to migrate. Spawning occurs over an extensive spawning season, with peaks during summer and fall/winter. At some locations, spawning has been documented throughout the year.

5.6.3.4 Utilization of Study Area Habitats by Life History Stages

Surf smelt eggs utilize the upper intertidal portion of beach habitat and incubate in coarse sand and gravel substrates. Spawning activity, and consequently incubating eggs, may occur on beaches throughout the year. Larvae drift from these beaches with prevailing oceanographic currents and can be found in the water column throughout Puget Sound, the Strait of Georgia, and the Strait of Juan de Fuca. Juveniles settle in shallow nearshore areas with sandy substrates and prefer coverage of aquatic vegetation such as algae and seagrass (Shaffer 2004). Adults use nearshore marine, estuarine, and pelagic habitat and are believed to associate closely with the bottom.

5.7 Coastal Pelagic Species

Coastal pelagic species (CPS) include the following species:

- Northern anchovy (*Engraulis mordax*)
- Jack mackerel (*Trachurus declivis*)
- Pacific sardine (*Sardinops sagax*)
- Pacific mackerel (*Scomber Japonicus*)
- Market squid (*Loligo opalescens*)

These species groups are discussed briefly because the members have limited associations with habitats or locations with a high probability of oil exposure, with the exception of anchovy. CPS can occur in shallow embayments or brackish water, but not to a significant degree. These water-column dwellers can generally be found anywhere from the surface to 1,006 meters (3,300 feet) deep and at significant distances offshore.

Jack mackerel and northern anchovy are part of the CPS Fisheries Management Plan (FMP) and, along with market squid, are considered monitored species (they do not need management by harvest guidelines or quotas according to the provisions of the FMP). Jack mackerel and northern anchovy are actively monitored by the California Department of Fish and Game.

The species descriptions below, unless otherwise referenced, are a summary and adaptation of information as presented and cited in the *Coastal Pelagic Species Fishery Management Plan (Amendment 8 to the Northern Anchovy Fishery Management Plan)* (PFMC 1998).

5.7.1 Geographic Distribution

Northern anchovy are distributed from the Queen Charlotte Islands, British Columbia, to Magdalena Bay, Baja California and have recently colonized the Gulf of California. Northern anchovy in the central

subpopulation are typically found in waters that range from 12 to 21.5^{o} C. Jack mackerel range widely throughout the northeastern Pacific from Cabo San Lucas in Baja California, with much of the range beyond 322 km (200 mi) from the coast. Pacific sardine are distributed from the tip of Baja California to southeastern Alaska and throughout the Gulf of Mexico. Pacific (chub) mackerel in the northeastern Pacific range from Banderas Bay, Mexico to southeastern Alaska, including the Gulf of California. They usually occur within 32 km (20 mi) of shore but have been observed up to 402 km (250 mi) offshore. Adult and juvenile market squid are distributed throughout the California and Alaska current systems from the southern tip of Baja California, Mexico to southeastern Alaska (Vojkovich 1998).

The geographic range of all CPS finfish varies widely over time in response to the temperature of the upper mixed layer of the ocean. Sea surface temperatures and habitat boundaries for CPS finfish are dynamic both seasonally and from year to year. Year-to-year variation in temperature and habitat boundaries is most pronounced during summer. In addition, variations in the boundaries of preferred habitat are more pronounced than variation in the boundaries of thermal tolerance. These relationships mean that highly mobile mackerels and sardine are seasonally much more abundant in the Oregon to Alaska region during summer and warm water years (e.g., El Niño) than during winter and cold water years due to increased habitat availability.

5.7.2 Uses, Status, and Trends

Northern anchovy supports a small bait fishery off the coasts of Oregon and Washington. In Washington, anchovies are not consistently available in numbers necessary for commercial use. They are, however, important along the Columbia River estuary as live bait for salmon and sturgeon fisheries. No anchovy stock condition or habitat assessment activities are presently conducted for Washington coastal anchovies.

Pacific sardines supported extensive historical fisheries from British Columbia to Mexico. Modern fisheries focused in southern and central California are mostly for overseas markets and bait. From peak populations levels in 1940 to extremely low levels in 1970, the sardine has experienced a modest increase in abundance. NOAA (Lo et al. 2006) stock assessment modeling indicates a general decline in stock productivity (recruits per spawning biomass) that began in the mid-1990s. In Washington, Pacific sardine is managed under the Emerging Commercial Fishery provisions as an experimental commercial fishery. Sardines landed in Washington are typically caught from 16 to 56 km (10 to 35 mi) offshore.

Pacific (chub) mackerel in the northeastern Pacific are harvested by commercial fisheries in California and Mexico (outside the study area); some recreational harvest also occurs.

Minor amounts of market squid are landed in Washington during their spawning season (winter), primarily in central and southern California. Catch records were at their highest from 1994 to 1996, primarily in support for bait and the export market.

5.7.3 Seasonal Distribution in the Study Area

Anchovy spawning occurs year-round, with increases in late winter and early spring. Anchovy eggs and larvae are found near the surface, generally at depths of less than 50 meters (164 feet) and in the same areas as spawning adults. Their eggs and larvae fall prey to an assortment of invertebrate and vertebrate planktivores. Northern anchovy eat phytoplankton and zooplankton by either filter feeding or biting, depending on the size of the food. Anchovies are thought to move inshore in spring and summer and offshore in fall and winter. They are a pelagic species and are particularly susceptible to changes in water temperature. Nearshore habitats can support ten times higher juvenile anchovy densities than other habitat areas and at least 70 percent of the juvenile anchovy population (Methot 1981; Smith 1985).

Pacific sardines are pelagic at all life history stages. They can occur in estuaries but are most common in nearshore and offshore coastal habitats. Spatial and seasonal distribution of spawning is influenced by temperature. Spawning in the upper 50 meters (165 feet) of the water column (their northern distribution for spawning) increases during periods of warmer sea surface temperatures—sometimes as far as Oregon. Juveniles have been found in British Columbia coastal waters coincident with northern spawning periods.

5.7.4 Utilization of Study Area Habitats by Life History Stages

Puget Sound and nearshore coastal areas, bays, estuaries, and river mouths of Washington and British Columbia generally do not experience extensive use by these pelagic species, except for the northern anchovy. Northern anchovy of all life stages are found in these areas and can be abundant, particularly during warmer water periods in summer and fall. Increasing sea surface temperatures related to climate change may shift the northern distribution of the spawning areas for the CPS, resulting in increasing frequency and abundances in juvenile use of Puget Sound and nearshore coastal areas of Washington, or increased abundance in the offshore areas. Recent nearshore surveys have documented increased abundances of larval and juvenile anchovies in the study area and other areas within Puget Sound (USGS Western Fisheries Research Center 2013).

Young Pacific jack mackerel frequently school near kelp and under piers, but more typically in the northern regions; the adults are foraging offshore. Market squid spawning areas are nearshore areas adjacent to submarine canyons.

CPS are most common in the upper mixed layer of the ocean (above the thermocline) in a broad band (up to hundreds of miles wide) along the coast. CPS may occur in shallow embayments and brackish water but do not depend on these habitats to any significant degree. In general, older and larger individuals occur farther north and offshore. The northern extent of the distribution and essential fish habitat for CPS depends on temperature and biomass. Northern areas tend to be used most extensively when water temperatures are warm and abundance is high. Adult CPS prefer water temperatures in the range from 10 to 26 °C (50 to 79 °F). Spawning and successful reproduction occurs at approximately 14 to 16 °C (57 to 61 °F).

5.8 Sharks, Skates, and Chimaeras

Sharks and skates are members of the subclass Elasmobranchi, and chimaeras are of the subclass Holocephali. All species within these subclasses are cartilaginous fishes and consist of the following.

- Soupfin shark (*Galeorhinus zyopterus*)
- Spiny dogfish (*Squalus acanthias*)
- Big skate (*Raja binoculata*)
- California skate (*Raja inornata*)
- Longnose skate (*Raja rhina*)
- Spotted ratfish (*Hydrolagus colliei*)

The soupfin shark is iteroparous and viviparous, with fertilization occurring internally and embryogenesis occurring within the female. The spiny dogfish is also viviparous. The three species of skates, big skate, California skate, and longnose skate, are in the family Rajidae, known as hardnose skates. They are all oviparous; eggs are fertilized internally and deposited on the bottom to develop and hatch. When the eggs hatch, the young are fully developed although they do have a yolk sac that is gradually absorbed. The

spotted ratfish is a chimaera. They are generally found in deep waters along the continental slope and are oviparous (Branstetter 1993; Talley 1983).

This species group is discussed briefly, as the members have limited associations with habitats with a high probability of being exposed to oil in the event of a spill. The species descriptions below, unless otherwise referenced, are a summary and adaptation of information as presented and cited in *Life History, Geographical Distribution, and Habitat Associations of 82 West Coast Groundfish Species: a Literature Review* (McCain et al. 2005).

5.8.1 Geographic Distribution

Soupfin sharks are found from northern British Columbia to Abreojos Point, Baja California and the Gulf of California. Spiny dogfish are found in temperate and subarctic latitudes in both the northern and southern hemispheres and occur from the Bering Sea to Baja California.

Big skates are found from the eastern Bering Sea to Cabo Falsa, southern Baja California. California skates range from the Strait of Juan de Fuca, Canada, southward to Cedros Island, central Baja California, and in the Gulf of California. Longnose skates are found from the Bering Sea and Aleutian Islands to Cedros Island, Baja California, and the Gulf of California. Spotted ratfish are found from the western Gulf of Alaska to Sebastian Vizcaino Bay, Baja California, and in the northern part of the Gulf of California (Compagno 1984; Hart 1973; Allen and Smith 1988).

5.8.2 Seasonal Distribution in Study Area

Soupfin sharks form dense shoals and have a coast-wide movement that is not completely understood. The soupfin migrates north in summer and south in winter. Their movements are extensive without recognizable patterns. They travel up to 56 km (35 mi) per day, with sustained speeds of 16 km/hour (10 mi/hour) for 1,600 km (994 mi) (Johnson and Horton 1972).

Dogfish often migrate in large schools and feed avidly on their journeys. Dogfish undertake seasonal migrations to stay in their preferred temperature range. Schooling behavior occurs with inshore populations and with migratory offshore populations. The schools, numbering in the hundreds, exhibit north-south coastal movements and onshore-offshore movements that are not completely understood. Spiny dogfish can travel long distances. In one instance, a dogfish tagged from Queen Charlotte Sound in 1980 was recovered off the northeast coast of Japan in 1982. They also make diel migrations from near bottom during the day to near surface at night (McFarlane and Beamish 1986). Big skates can be found in waters from the intertidal range to depths of 120 meters (394 feet); they inhabit the coast in estuaries, in bays, and over the continental shelf. Big skates are commonly found on sandy and muddy bottoms where they hide with only eyes protruding, although they are also sometimes observed in low stands of kelp.

The spotted ratfish makes significant seasonal and diel migrations. In winter, spotted ratfish move into shallow nearshore waters and estuaries, probably for feeding and pre-spawn mate selection. In Puget Sound and other estuaries, spotted ratfish move from deep water, where they reside during the day, to much shallower water at night (Love 1996; Quinn et al. 1980; Johnson and Horton 1972).

5.8.3 Uses, Status and Trends, and Regulatory Issues

During the late 1930s and 1940s, the soupfin shark was one of the most economically important of the sharks on the West Coast. Currently, most catches are made as bycatch in other commercial fisheries or by recreational fishers.

Spiny dogfish are currently the most abundant and economically important shark off North American coasts. In recent years, large numbers have been taken in commercial trawl, set net, and longline fisheries, especially in Puget Sound, to supply foreign markets and for biology class dissections and research. They can be readily caught by rod and reel, longline, trawl, or set net. Spiny dogfish often are regarded as a menace to fisheries because they cause damage to nets and lines, and they rob hooks (Northeast Consortium 2010).

Big skates are generally taken as bycatch in other fisheries. The coastal trawl fleets account for the majority of the catch off the West Coast. Only the pectoral fins, or *wings*, are bought commercially. Big skates also occasionally are taken by recreational fishers. California and longnose skate have little commercial value. The majority of catch is in the form of bycatch by the coastal trawl fleets.

There is no directed fishery for spotted ratfish in the northeast Pacific, but they are taken quite often as bycatch in bottom trawls. Spotted ratfish are not sought by recreational fishers but are caught occasionally while fishing for other demersal species (NOAA Fishwatch 2013b).

5.8.4 Utilization of Study Area Habitats by Life History Stages

Soupfin sharks are an abundant coastal-pelagic species of temperate continental and insular waters. They are often associated with the bottom, inhabiting bays and muddy shallows. Although soupfin sharks often occur as shallow as 2 meters (7 feet), they also can occur in submarine canyons up to 471 meters (1,545 feet). The population of soupfin sharks along the western Pacific Coast is considered to be homogeneous (Compagno 1984).

The spiny dogfish is reported to be an inner shelf-mesobenthal species with a depth range of 0 to 1,236 meters (0 to 4,055 feet) in the North Pacific and Bering Sea. They occur from the surface and intertidal areas to greater depths and are common in inland seas, such as Puget Sound and in shallow bays from Alaska to central California. Adult females move inshore to shallow waters during spring to release their young. Small juveniles (<10 years old) are pelagic, while subadults and adults are mostly sublittoral-bathyal. Subadults can also be found on muddy bottoms (Allen and Smith 1988; Saunders and McFarlane 1993).

The big skate occupies inner and outer shelf areas, particularly on soft bottom. Records show big skates inhabiting water as shallow as 3 meters (10 feet), but they are found most frequently on the outer shelf in waters 50 to 200 meters (164 to 6,562 feet) deep and rarely deeper than 350 meters (1,148 feet). Juveniles are associated with soft bottom sediments. Egg cases of big skates are deposited on the bottom. Off Oregon, egg cases were taken at depths up to 120 meters (394 feet) but were by far most abundant at 64 meters (210 feet). The longnose skate is one of the more common skates and occurs on the bottom in inner and outer shelf areas from 0 to 1,069 meters (3,507 feet) (Allen and Smith 1988).

In the North Pacific, spotted ratfish are considered a middle-shelf-mesobenthal species and have been reported at depths of 0 to 971 meters (0 to 3,186 feet). Spotted ratfish are a common demersal fish in larger estuaries throughout their range, especially from early winter to late spring. In Puget Sound, spotted ratfish often occur in less than 10 meters (32 feet) of water, depending on the time of day and season. Generally, spotted ratfish are a deepwater species that prefers low-relief rocky bottoms with exposed gravel and cobble; they are not common on sand or over boulders. Eggs are attached by the mother to rocks, or placed upright in the sand in polyhaline to euhaline waters. In summer and fall, spotted ratfish move offshore into deep waters, where egg cases are most often deposited (Allen and Smith 1988; Quinn et al. 1980; Hart 1973; Johnson and Horton 1972).

5.8.5 Reproduction

Soupfin shark mating occurs during spring. After a gestation period of approximately 1 year, females move into bays to bear live young. The number of young (from 6 to 52) depends on the size of the mother; larger females produce more young. Spiny dogfish mating and fertilization occurs on the ocean bottom between September and January. Females release their young in the midwater zone over depths of 165 to 350 meters (541 to 1,148 feet) during spring, in shallow waters. Reproduction and egg laying in skates are not well understood. Spotted ratfish spawning occurs at all times throughout the year but seems to peak from late summer to early fall (Andrews and Quinn 2012).

5.8.6 Trophic Interactions

Soupfin sharks are opportunistic, carnivorous feeders. They feed at the bottom, mid-depths, and the surface. Soupfin feed primarily on moderate-sized bony fishes but also readily feed on invertebrates, including squid.

Spiny dogfish are opportunistic carnivorous scavengers that prey on many commercial fishes and invertebrates. Their diet consists primarily of fish (especially sand lance, herring, smelts, cods, capelin, hake, and ratfish) and of invertebrates (particularly shrimp, crabs, worms, krill, squid, octopus, jellyfish, and sea cucumbers).

Big skate adults feed on crustaceans, small benthic fishes, polychaete worms, and mollusks. Juveniles consume primarily polychaete worms and mollusks. Big skate are preyed on by sevengill shark and northern elephant seals. The California skate feeds on shrimp and other invertebrates, such as polychaete worms.

Spotted ratfish at all life history stages are opportunistic feeders; no one single food item usually makes up more than 25 percent of their diet. Spotted ratfish are, in turn, preyed on by Pacific halibut, soupfin shark, and spiny dogfish. (Allen and Smith 1988; Quinn et al. 1980).

6. INVERTEBRATES

Marine invertebrates are organisms without backbones, such as shrimps, crabs, sponges, corals, worms, jellyfishes, snails, and squids. Crustaceans, of which nearly all are marine invertebrates, make up the greatest biomass of any marine animal group. These include economically valuable species such as crabs and shrimps. Marine invertebrates that are present in the study area provide important commercial, recreational, and tribal fisheries.

6.1 Protected Species

No federally listed invertebrates occur in the study area. Two state listed species have the potential to occur: Pinto abalone and Newcomb's littorine snail. These species are described below.

6.1.1 State-Listed Species

Pinto Abalone (Candidate)

Pinto abalone are medium-sized abalone (marine snails) that are distributed from Point Conception, California to southeast Alaska. They are generally found on hard, rocky substrates in exposed coastal areas, including Puget Sound, the Strait of Juan de Fuca, and the San Juan Archipelago (Puget Sound Restoration Fund 2014). The pinto abalone is considered functionally extinct in Washington waters; natural populations have plummeted and there are too few left in the wild to reproduce successfully (Puget Sound Restoration Fund 2014). The species could be present in the study area; however, their occurrence would be rare.

Newcomb's Littorine Snail (Candidate)

Newcomb's littorine snail is a medium-small marine snail whose biology and ecology is incompletely understood (Larsen et al. 1995). The snail inhabits a narrow strip of land on glasswort salt marshes at the edges of bays and estuaries where fresh and ocean water mix. Within the study area, Newcomb's littorine snail has been reported in Neah Bay (Larsen et al. 1995). The snail may be present in the pickleweed zone of the high intertidal marshes in the study area, but a literature review did not reveal any documented sightings.

6.2 Mollusks

Mollusks have soft bodies with a mantel, head, foot for locomotion, radula for feeding (except bivalves), and a fully developed digestive tract. The study area provides habitat for a wide variety of mollusks; species expected to occur in the study area are described in more detail below.

6.2.1 Geoduck Clam

Geoduck are the largest of the burrowing clams, commonly reaching weights of more than 1.4 kilograms (3 pounds), with some weighing more than 4.5 kilograms (10 pounds). Geoducks are also among the longest-lived animals in the ocean, some living 140 years or more. They bury themselves up to 1 meter (3 feet) deep in mud, silt, and gravel bottoms. Goeduck larvae drift with the currents for 2 to 7 weeks, after which they settle to the bottom and metamorphose into non-swimming juvenile clams. Because of the long planktonic larval period, the young may be carried by water currents many miles from their parents before settling (WSDNR 2001).

6.2.2 Native Littleneck

Adult and juvenile native littleneck clams are found in coarse, sandy-rock muds of the upper intertidal beaches of estuaries and on the open coast where there is appropriate substrate, detritus (decaying plant material), and protection from predators. They are found in quiet waters in the mid to upper low intertidal (to a depth of 37 meters [121 feet]) but also may be found under boulders in gravel substrates along the outer coast. Native littlenecks burrow to a depth of approximately 80 mm (1.3 inch) due to their relatively short siphons (WSU 2007; Kegel 1998). Their siphons allow this species to gather food by filtering water for phytoplankton and diatoms. Rock crabs, fish, birds, sea otters, and others feed on these clams, depending on the region. They spend 2 to 3 weeks in the larval form (Shaw 1986).

6.2.3 Manila Clam

Manila clams are found in the intertidal zone under cobbles in rocky crevices, in gravel, roots, and other protected holdfasts. Manila clam is the second-most important commercial clam species on the Pacific Coast. It also is one of the most important recreationally dug clams. The species is found from the intertidal zone to depths of approximately 10 meters (32 feet) but is primarily found at 0.9 to 2.4 meters (3 to 8 feet) above the mean lower low water. An ideal substrate appears to consist of gravel (much of which is <25 mm [0.9 inch] in diameter), sand, some mud (4 to 5 percent), and shell. Beaches with this type of substrate are often relatively stable and occur in many protected areas of Pacific Northwest inlets and bays. However, Manila clams can inhabit a wide range of substrates. The Manila clam often occurs with Pacific littleneck clam, butter clam, softshell clam, *Macoma* spp. clams, and other estuarine infauna (Emmett et al. 1991).

6.2.4 Giant Pacific Oyster

The giant Pacific oyster is an intertidal and subtidal species that attaches to rocks and debris. They prefer firm surfaces in sheltered waters, but they also live in muddy or muddy and sandy substrates. Fertilization occurs externally and larvae are planktonic, spending approximately 3 weeks in this free-swimming stage. When settling, the larvae group together and crawl around the sea floor, searching for a suitable hard substratum to which they can cement their lower shell valves (NIMPIS 2002).

6.2.5 Butter Clam

The butter clam (*Saxidomus giganteus)* inhabits the low intertidal and subtidal zones, in quiet protected beaches. They bury themselves from 25 to 35 cm (10 to 14 inches) into mud, sand, or gravel substrate. They spawn throughout the year.

6.2.6 Spiny Scallop

The spiny scallop is very common in waters near Rosario Strait. They often attach to the bottom by a few byssal threads in the low intertidal zone of muddy and sandy substrate and on rocky reefs. The species filter feeds approximately 4 liters of water per gram per hour (Kozloff 1993).

6.2.6.1 Pink Scallop

Pink scallops may live on rocky or soft bottoms, although they are most common on gravel/mud bottoms in the low intertidal to subtidal zones (Kozloff 1993).

6.2.7 Pacific Razor Clam

Pacific razor clams *(Siliqua patula)* inhabit the low intertidal and subtidal zones on flat, sandy exposed beaches, burrowing rapidly into the sand. Spawning of razor clams occurs simultaneously (on the same day) along several kilometers of beach, triggered by a sudden rise in water temperature in late May or June. The larvae persist in a pelagic form for approximately 8 weeks. Predators include flatfish such as the starry flounder and the Dungeness crab. Razor clams may have a commensal nemertean worm (*Malacobdella grossa*) or the pea crab (*Pinnixia faba*) in its mantle cavity.

6.3 Echinoderms

Echinoderms include sea stars, starfish, brittle stars, sea urchins, sand dollars, sea cucumbers, and others. Echinoderms present in the study area and noted for their value to commercial and recreational fisheries include California sea cucumber, green sea urchin, and red sea urchin. These species are described in more detail below.

6.3.1 California Sea Cucumber

California sea cucumbers are found under rocks and in mussel beds, in the intertidal and subtidal areas of beaches with a fair amount of wave energy—particularly in the Strait of Juan de Fuca and western portions of Haro Strait and the San Juan Islands. Commercial harvesting of this species is limited to 3 weeks during fall or winter. The giant California sea cucumber is a scavenger that feeds on plankton and other organic matter. They feed by sifting through sediments with their tentacles or by positioning themselves so they can use their tentacles to catch food passing by in the current. Spawning usually takes place in November, and each female can produce thousands of eggs. After fertilization, a larva is formed that metamorphoses into a juvenile life stage after a few weeks (Soltani et al. 2010).

6.3.2 Green Sea Urchin

Green sea urchin are found in the low intertidal to subtidal zone on seaweed, surfgrass, eelgrass, and rocks. There is a small commercial fishery for this species. Sea urchins feed mainly on algae but also can feed on a wide range of invertebrates such as mussels, sponges, brittle stars, and crinoids. Sea urchins provide a substantial food source for sea otters and are also the main source of nutrition for wolf eels. Sea urchins reproduce annually, with spawning occurring in spring—generally between February and May, but sometimes as late as June. They spawn externally, releasing gametes into the water column, resulting in a larval stage that develops planktonically for 1 to several months before settling.

6.3.3 Red Sea Urchin

Red sea urchins are found in similar habitat, with similar foraging and reproductive characteristics, as green sea urchins. While the commercial fishery for the red sea urchin is small, it is larger than that of the green sea urchin and the species is noted as a WDFW Priority Species of commercial, tribal, and recreational importance.

6.4 Crustaceans

Crabs, shrimp, and barnacles are crustaceans. Crustaceans are harvested recreationally and commercially, and are an important source of food to other marine species. Crustaceans present in the study area include Dungeness crab, Alaska prawn, red rock crab, and goose barnacle. These species are described in more detail below.

6.4.1 Dungeness Crab

Dungeness crabs are fished from Alaska to California and are thought to be the oldest known shellfish fishery in the Pacific Northwest (WDFW 2002). According to the WDFW (2002), Dungeness crabs are the only commercially important crab within Washington's territorial waters, making this species important for fisheries commercially and economically. The female Dungeness crab lays up to 2.5 million eggs and lives up to at least 6 years. Females can store sperm received during one mating season and use it during the next season. Dungeness crab spawn in spring, and the larvae from the Puget Sound region may disperse as far as Alaska (Park et al. 2007). This species is a carnivore that feeds on more than 40 different species including small clams, oysters, fish, shrimp, and worms.

6.4.2 Alaska Prawn

The Alaska prawns, or spot prawns, inhabit the deep sandy bottoms in the Rosario Strait area. Spot prawns feed on crustaceans, polychaetes, limpets, and carcasses. The breeding season for spot prawns ends in late October, after which females carry their eggs on the abdomen for 4 to 5 months, while remaining in deep water. The eggs hatch in March or April, and the larvae settle a few months later in May and June. Juveniles feed in shallow water during summer, especially among *Agarum fimbriatum* and *A. clathratum* kelp. During their second fall (carapace length 2.8 cm [1 inch]), they become males. They remain males until they grow to 3.3 cm (1.3 inch) carapace length, at which time they become females. Females may mate only once, and they may not live longer than 4 years. (O'Clair and O'Clair 1998.)

6.4.3 Red Rock Crab

Red rock crabs inhabit rocky and soft bottoms, and are most common around rocks. They may be found partially buried in sand or under rocks during the day, while they are more active at night. Red rock crabs forage on barnacles and smaller crabs, amphipods, sea cucumbers, polychaetes, many other intertidal invertebrates, and dead fish and other carcasses. Males often will guard a female who is preparing to molt by holding her under his abdomen. This may last for several weeks until she molts. He then guards her until her exoskeleton hardens again. Mating occurs in summer after a female has molted. Gravid females may be found from October to June. Females may carry from 172,000 to 597,000 eggs on the pleopods of the abdomen. Males overwinter in shallow areas, while females seem to overwinter in deeper water (Kozloff 1993). While not recognized as a state Priority Species, the red rock crab is part of a commercial and recreational fishery.

6.4.4 Goose Barnacle

Goose barnacles, also called *gooseneck barnacles*, inhabit open, surf-swept coastlines (Kozloff 1993). In Puget Sound, gooseneck barnacles breed from April to October, peaking in July. Individuals are hermaphroditic, meaning they possess both male and female reproductive organs, but will always cross-fertilize. Each sexually mature individual may produce up to four broods per year, with up to 20,000 developed young per brood. The young temporarily aggregate at the base of the adults, where their survival rate increases. Within 1 month, young disperse to locations separate from adults. Many areas prohibited the commercial harvesting of goose barnacle until enough information about the species is available to determine sustainable harvest rates with biologically based management.

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Appendix G

Draft Biological Evaluation

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Draft Biological Evaluation

BP Cherry Point Marine Terminal

May 22, 2014

Prepared for
BP Cherry Point Refinery
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Acronyms

µPa	micropascal unit
°C	Celsius
°F	Fahrenheit
AIS	U.S. Coast Guard Nationwide Automatic Identification System
ARCO	Atlantic Richfield Company
ATBs	Articulated Tugs-and-Barges
Bbls	barrels
BE	Biological Evaluation
CCG	Canadian Coast Guard
CFR	Code of Federal Regulations
CHUs	critical habitat units
cm	cubic meter
DO	dissolved oxygen
DPS	distinct population segment
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
ESA	Endangered Species Act

ESUs	Evolutionary Significant Units
FR	Federal Register
FWS	(U.S.) Fish and Wildlife Service
Kcfs	thousands of cubic feet per second
kg	kilogram
KGB	Kelp, Gopher, and Black rockfish
kHz	kilohertz
km	kilometer
LIBI	Lummi Intertidal Baseline Inventory
MLLW	mean low low-water
ms	millisecond
msl	mean sea level
MTBE	methyl tert-butyl ether
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
ODFW	Oregon Fish and Wildlife Service
PNW Forest Plan	Pacific Northwest Forest Plan
ppt	parts per thousand
PSRCP	Puget Sound Rockfish Conservation Plan
SaSI	Salmonid Stock Inventory
SE	Standard Error
SPL	Sound Pressure Level
TSS	Traffic Separation Scheme
TTS	temporary threshold shift
USACE	U.S. Army Corps of Engineers
U.S.C	United States Code
USCG	United States Coast Guard
VEAT	Vessel Entries and Transits for Washington Waters
VTRA	Vessel Traffic Risk Analysis
WDFW	Washington Department of Fish and Wildlife

Chapter 1

Introduction

1.1 Background and Consultation History

The BP Cherry Point Refinery[1] currently holds a Rivers and Harbors Act Section 10 permit (33 U.S.C. 403) issued on March 1, 1996 (Department of the Army permit number 92-1-00435) for the construction of a pier extension (North Wing) to the existing Cherry Point Marine Terminal. The purpose of the extension was to improve the efficiency of unloading crude oil for processing at the refinery and loading and unloading of refined products for distribution to markets in the Puget Sound Region and West Coast of the U.S. Prior to the expansion; unloading and loading operations were performed at a single berth (South Wing). The addition of the second berth (North Wing) allows the South Wing to be largely dedicated to unloading crude oil and the North Wing to be dedicated to loading and unloading refined products. This separation of task improves the efficiency and safety of operations. The North Wing was constructed and became operational in 2001.

In November 2000, Ocean Advocates filed a lawsuit in the U.S. District Court challenging the issuance of the 1996 permit. The district court ruled in favor of the U.S. Army Corps of Engineers (USACE) finding an Environmental Impact Statement (EIS) is not required and the permit did not violate the Magnuson Amendment of the Marine Mammal Protection Act (33 US.C.§ 476). Ocean Advocates filed an appeal at the U.S. Court of Appeals for the Ninth Circuit. As part of its March 2005 ruling, the Ninth Circuit required the USACE to prepare a full EIS considering the impact of reasonably foreseeable increases in tanker traffic and reevaluate the dock extension's potential violation of the Magnuson Amendment. The USACE has prepared a draft EIS, and the Proposed Action is for BP to continue to operate the North and South Wings in their present configuration, but USACE would modify a DA permit for the continued operation and maintenance of the dock, with limitations including prohibiting the use of the North Wing for unloading or loading crude oil. Due to the Proposed Action of modifying the 1996 permit, USACE would like to re-initiate consultation under the Endangered Species Act (ESA). 50 CFR § 402.16(c).

As part of the original USACE Section 10 permit issuance process, ARCO[1] with the assistance of Berger/ABAM Engineers Inc., submitted a biological evaluation (BE) on March 31, 2000 to assist the USACE in fulfilling its obligation to consult with National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (FWS) (each individually referred to as a “Service” and together as the “Services”) under section 7(a)(2) of the ESA. The 2000 BE reached the following conclusions for the species noted:

[1] The BP Cherry Point refinery was previously owned by Atlantic Richfield Company (ARCO); the facility, including the marine terminal was acquired by BP in April 2000 and became operational in 2001. The names ARCO and BP are used in this document as appropriate to reflect ownership.

- Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) –Threatened, NMFS, may affect but is not likely to adversely affect.
- Puget Sound/Strait of Georgia Coho (*O. kisutch*) – Candidate, NMFS, may affect but is not likely to adversely affect.
- Bull trout (*Salvelinus confluentus*) – Threatened, FWS, may affect but is not likely to adversely affect.
- Humpback whale (*Megaptera novaeangliae*) – Endangered, NMFS, no effect.
- Leatherback sea turtle (*Dermochelyes coriacea*) – Endangered, NMFS, no effect.
- Bald eagle (*Haliaeetus leucocephalus*) – Endangered, FWS, no effect.
- Marbled murrelet (*Brachyramphus marmoratus*) – Threatened, FWS, no effect.

Based on the analysis in the 2000 BE, the USACE requested informal consultation with NMFS on May 24, 2000, and with the FWS on May 25, 2000. In both cases, the USACE sought concurrence with its "not likely to adversely affect" findings for listed Chinook and bull trout. [2] On June 13, 2000, FWS concurred with the "may affect but is not likely to adversely affect" finding for bull trout and on June 19, 2000, NMFS concurred with the "may affect but is not likely to adversely affect" finding for Puget Sound Chinook salmon.

Since the project was constructed and informal consultation was concluded in 2000, additional species have been listed and critical habitats have been either designated or proposed under the ESA in the Action Area (defined in Section 1.3). These species are listed in Table 1.1-1.

In addition, during those intervening years, bald eagles and the Eastern DPS for Steller sea lion have been removed from the ESA species list, and Puget Sound coho salmon, which was a candidate species in 2000, is now considered a Species of Concern, which does not require ESA Section 7 consultation.

Because the USACE is evaluating the effects of the Proposed Action, and in accordance with 50 CFR § 402.16(c), this BE has been prepared in support of the USACE's re-initiation of consultation with FWS and NMFS.

[2] Consultation is required when a federal agency determines an action it intends to authorize, fund, or carry out is likely to affect a listed species or designated critical habitat (50 CFR §402.14). Consultation may be concluded informally if FWS or NMFS, as appropriate, concurs that the Proposed Action is "not likely to adversely affect" listed species or designated critical habitat (50 CFR §402.13). Consultation or concurrence is not required if the action agency (here, the USACE) concludes that the Proposed Action will have "no effect" on listed species or designated critical habitat. In addition, consultation is not required for candidate species.

Table 1.1-1 ESA-listed Species and Critical Habitat Designated/Proposed Post Project Construction.

Species	Listing	Critical Habitat
Southern Resident Killer whale	Endangered (70 FR 69903)	Designated (71 FR 69054)
Green Sturgeon Southern DPS	Threatened (71 FR 17757)	Designated (74 FR 52300)
Puget Sound Steelhead	Threatened (72 FR 26722)	Proposed (78 FR 2725)
Eulachon	Threatened (75 FR 13012)	Designated (76 FR 65324)
Bocaccio Puget Sound/Georgia Basin DPS	Endangered (75 FR 22276)	Proposed (78 FR 47635)
Canary Rockfish Puget Sound/Georgia Basin DPS	Threatened (75 FR 22276)	Proposed (78 FR 47635)
Yelloweye Rockfish Puget Sound/Georgia Basin DPS	Threatened (75 FR 22276)	Proposed (78 FR 47635)

1.2 Proposed Action

1.2.1 Federal Action

The USACE proposes to modify Department of the Army permit number 92-1-00435 for the continued operation and maintenance of the BP Marine Terminal with conditions including prohibiting the use of the North Wing for unloading or loading crude oil. BP has limited the use of the North Wing to loading and unloading of refined petroleum product only since the North Wing became operational in 2001.

1.2.2 Scope of Analysis

This BE provides an analysis of the effects of ongoing operations of the North Wing of the BP Marine Terminal, including anticipated changes in vessel traffic to and from the existing facility as currently operated by BP. The effects analyzed result from the change in environmental risk between operation of the BP Marine Terminal at maximum capacity with a single berth (the South Wing) and the dock operating with two berths (following construction of the North Wing) at a level of utilization projected for the year 2030. The future year 2030 was selected for consistency with a vessel traffic study prepared to support the Draft EIS. In that study, forecasts of future traffic were made to analyze the cumulative effects of future vessel traffic growth over a baseline of vessel traffic in the year 2010. Given that BP was only able to forecast traffic levels for vessels calling at the BP Cherry Point dock to a 20 year future time horizon, the USACE determined that a forecast beyond a 20-year time horizon (2030) was unlikely to yield reliable results.

The currently permitted project has two components[3]:

- Vessel traffic –tanker, tug and barge traffic to and from the BP Marine Terminal, including the marine route through the Strait of Juan de Fuca and the San Juan Archipelago, and moorage at the dock facility during loading and unloading;

[3] The Biological Evaluation does not include an analysis of catastrophic oil spills as they are not reasonably certain to occur. Activities that would occur if a catastrophic spill were to occur are under the regulatory authority of the Washington Department of Ecology and the U.S. Coast Guard. An analysis of the potential effects of a catastrophic oil spill is included in the draft EIS.

- Operation and maintenance of the BP Marine Terminal's North Wing – consisting of a ship berth, loading and unloading equipment, control and metering equipment for refined product loading and unloading, and oil spill preparedness and response which includes the staging and deployment of work boats for pre-booming operations; deployment of oil spill containment booms for pre-booming during loading and unloading operations; and the staging of additional oil spill boom, sorbent pads, and an oil spill skimmer in the event of an oil spill at the dock. Regular oil spill drills are conducted to ensure a quick and appropriate response to an unintentional release.

The operation of the refinery, tank farm, and interconnecting piping between these facilities and the South Wing of the BP Marine Terminal are part of the environmental baseline, as is the existence of the North Wing and its connection to onshore facilities. Effects of these components are included as part of the environmental baseline when analyzing the effects of this action. The existence of the North Wing is included in the environmental baseline because it has already been constructed.

1.2.3 Description of Project Components

1.2.3.1 Vessel Traffic to BP Marine Terminal

Under potential future business development scenarios in which marine transportation continues to be the predominate mode of transportation, the construction and operation of the North Wing could result in an incremental increase in vessel calls at the BP Marine Terminal. However, there are future business development scenarios in which increasing volumes of oil are moved by rail and pipeline. Under these scenarios, the number of calls at the BP Marine Terminal would decline (Figure 1.2.1). BP has prepared a forecast of vessel traffic through 2030 for the current configuration of the BP Marine Terminal that considers vessel size, crude availability, refinery operations, and market conditions.

The 2030 forecast predicts that under the maximum predicted future vessel traffic growth conditions, the BP Marine Terminal could receive between 350 and 420 vessel calls per year through 2030. This represents a potential increase of 15 to 85 vessel calls a year above the baseline capacity of 335 vessel calls per year for operation of the South Wing only (see Chapter 3 Environmental Baseline). This would result in a 4.5 percent to 25.3 percent increase in vessel calls over baseline conditions. Vessels would likely be a mix of tank vessels carrying crude oil and refined products and barges carrying refined product. It also represents a change in the proportion of calls for unloading crude oil versus loading and unloading refined product. Under current conditions, 40 to 50 percent of vessel calls are for delivery of crude oil and 50 to 60 percent are for loading and unloading refined product. Under the future growth scenario for marine transportation, the proportion of vessels calls for unloading crude oil would decline to 30 to 40 percent of total vessel calls and the proportion of calls for loading and unloading refined product would increase to 60 to 70 percent of total vessel calls. Under business development scenarios in which crude oil delivery by rail and pipeline would increase, vessel calls would likely decline from current numbers and the proportion of calls for loading and unloading refined product would increase to 90 to 95 percent of all vessel calls, and the remaining 5 to 10 percent would be for unloading crude oil.

Vessels transiting to the BP Marine Terminal from Alaska, Oregon, California and international origins would enter the Strait of Juan de Fuca, utilize the U.S. Coast Guard (USCG) Vessel

Traffic Service Puget Sound and abide by the USCG requirements for the Strait of Juan de Fuca and Puget Sound traffic Separation Scheme (described more completely in Chapter 3 Environmental Baseline). Likewise, tank vessels and barge traffic calling at the BP Marine Terminal from, or departing to, other destinations with the greater Puget Sound must participate in and abide by the requirements of the USCG vessel traffic management provisions.

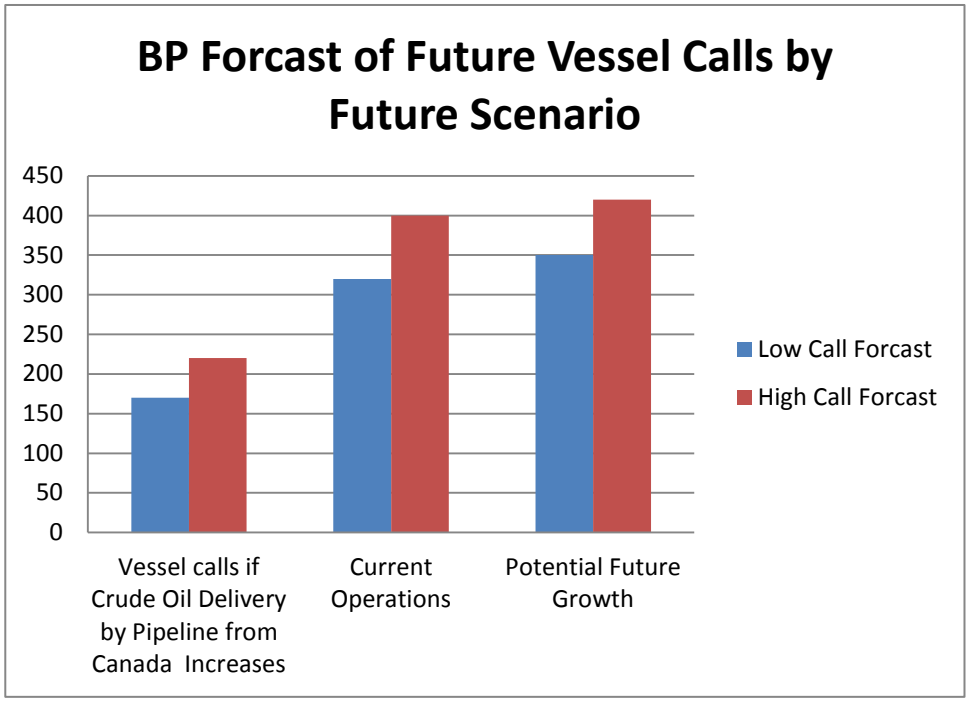

Figure 1.2-1 BP Forecast of Future Vessel Calls by Future Scenario.

1.2.3.2 Dock Operations

Dock operations would increase proportionately to the changes in vessel calls predicted by BP. These operations are discussed in more detail in Chapter 3 Environmental Baseline. With the North Wing in place, the tasks of crude oil unloading and refined product handling have largely been separated. The pipelines connecting the dock facility to the BP Cherry Point Refinery tank farm are configured so that crude oil can only be unloaded in commercially sustainable quantities at the South Wing. The North Wing is used exclusively for loading and unloading refined petroleum products. While the South Wing retains the capability to load and unload refined petroleum product, such operations on this wing now rarely occur.

Between 2001 when the North Wing became operational and 2010, throughput at the BP Marine Terminal has averaged 102,773,473 barrels (bbls) per year, consisting of 70,457,034 bbls of crude oil and 32,316,438 bbls of refined product. With operations at both wings underway, all crude deliveries occurred at the South Wing and most product loading occurred at the North Wing.

The existing oil spill prevention plan and response measures currently in place at the BP Marine Terminal are discussed in Chapter 3 Environmental Baseline. Implementation and adherence to these requirements would continue with the increase in vessel calls at the BP Marine Terminal.

1.3 Action Area

The Action Area is defined as all areas that may be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action (50 CFR 402.20). The Proposed Action is broken into two major components: Vessel Traffic and Operation and Maintenance of the BP Marine Terminal's North Wing (Section 1.2.1). Each of these activities has its effects, some of which overlap. For example, vessels have the potential to displace larval fish as they move through the water; noise from vessels and dock operations can disturb animals causing them to become alert, temporarily suspend behaviors, or temporarily leave areas. The most far-reaching effects of the Proposed Action derive from the increase in vessel traffic likely to occur. Therefore, the Action Area for the project is defined as the area encompassed by and adjacent to the Vessel Traffic Service System, beginning eight miles west of J Buoy at the entrance to the Strait of Juan de Fuca to the BP Marine Terminal, by vessel routes from the BP Marine Terminal to refineries near March Point, and vessels departing to the north (Figure 1.3-1)[4]. In addition, the area within 1 km (0.6 mile) around the BP Marine Terminal is included in the Action Area based on the analysis of area likely to be affected by terminal operations in the previous BE (Berger/Abram Engineers Inc. 2000).

1.4 Presence of Federally Listed Species in the Project Action Area

This BE addresses potential effects of the Proposed Action on the federal ESA listed species and designated critical habitat that are likely to occur in the project Action Area. It addresses direct and indirect effects of the action. Based on previous agency consultation and a review of species lists available from USFWS and NMFS, USACE, and state agencies including Washington Department of Fish and Wildlife (WDFW) and Washington Department of Natural Resources (WDNR), the species list in Table 1.3-1 was developed. In addition, critical habitat is proposed for three species and has been designated for eight species (Table 1.3-1). Species on which continued operation of the North Wing dock will have “no effect” are discussed in Section 1.5 below.

1.5 Species Considered and Determined to Have “No Effect” from Project

The following species may occur in the general vicinity of the project (e.g., Puget Sound), and were evaluated and determined not to be affected by the Proposed Action: Canada lynx (*Lynx Canadensis*), northern spotted owl (*Strix occidentalis caurina*), short-tailed albatross (*Phoebastria albatrus*), loggerhead sea turtle (*Caretta care4-1, tta*), olive ridley sea turtle (*Lepidochelys olivacea*), green sea turtles (*Chelonia mydas*), sei whale (*Balaenoptera borealis*), and sperm whale (*Physeter macrocephalus*). A summary for each of these species is provided below:

[4] The J buoy was selected as the westward extent of the Action Area because the effects of the Proposed Action beyond this point would not be distinguishable from the effects of other actions.

- **Canada lynx** are found in coniferous and hardwood forests, at high elevations with cold winters that have deep (1 meter [3.3 feet]), fluffy snow for extended periods (Stinson 2001 and 78 FR 56430). Canada lynx den in mature or old timber forests with large woody debris, such as downed logs and windfalls, which provide denning sites with security and thermal cover for kittens. No lynx have been found nor does suitable habitat for Canada lynx occur within the Action Area. Critical habitat was designated for the lynx in 2006, and revised in 2009 and 2013. Under all iterations, critical habitat was not designated within the Action Area, therefore neither this species, nor its critical habitat, would be affected by ongoing operation of the BP Marine Terminal.
- **Northern spotted owls** occur primarily on the eastern and western slopes of the Cascade Mountains and the Olympic Peninsula. Historic records show it used to occupy the Puget Trough (which runs the length of Washington, between the Cascade Mountains on the east and the Olympic Mountains and Willapa Hills on the west). But occurrence here is now rare (Buchanan and Swedeen 1995). In addition, WDFW surveys conducted over the last 35 years 1976-2011) did not find any occurrences within the Action Area (WDFW 2012). Where present, spotted owls nest in mature, coniferous forests and hunt in forest habitat, neither of which are present in the Action Area. Therefore, it is not anticipated that spotted owls would be affected by continued operation of the BP Marine Terminal. No Northern Spotted Owl critical habitat has been designated within the Action Area and so it would not be affected by ongoing operations of the BP Marine Terminal.
- **Short-tailed albatross** may occur in the Action Area, but it is unlikely that continued operation of the BP Marine Terminal would have an effect on this species. The marine range of short tailed albatross covers most of the northern Pacific Ocean, but it occurs in highest densities in areas of upwelling along shelf waters of the Pacific Rim, particularly along the coasts of Japan, eastern Russia, the Aleutians and Alaska (Piatt et al. 2006, Suryan et al. 2007). Satellite tracking has indicated that during the post-breeding period, females spend more time offshore of Japan and Russia, while males and juveniles spend greater time around the Aleutian Islands, Bering Sea and off the coast of North America (Suryan et al. 2008). Juveniles have been shown to travel twice the distances per day and spend more time within continental shelf habitat than adult birds (Suryan et al. 2008, BirdLife International 2013). Based on this pattern of distribution, migration and the apparent preference for shelf waters, short tailed albatross are not likely to occur in the Action Area. Additionally, the operation of the BP Marine Terminal and ongoing vessel traffic associated with the terminal would not disrupt albatross normal migrations or reduce the availability of prey for albatross that could forage in the area. Critical habitat has not been designated for the short-tailed albatross.
- **Sea Turtles** loggerhead, olive ridley, and green sea turtles rarely occur in Puget Sound and near the coast of Washington. The Action Area is considered beyond the normal range of species occurrences and contain unsuitable habitat due to cold water temperatures. Most hard-shell turtles seek optimal seawater temperatures near 18°C (65°F) and are cold-stressed at seawater temperatures below 10°C (50°F) (Mrosovsky 1980 and Schwartz 1978). Water temperatures recorded at various locations throughout the Action Area are under 10°C (50°F) the majority of the year and do not approach 18°C (65°F) (NOAA 2014). Loggerhead, olive ridley, and green sea turtles would not be expected to occur within the Action Area, and therefore would not be affected by ongoing operation of the BP Marine Terminal. Critical habitat has been designated for green sea turtles but occurs outside of the Action Area and

therefore green sea turtle critical habitat would not be affected by ongoing operations of the BP Marine Terminal. Critical habitat has not been designated for loggerhead and olive ridley turtles.

- **Sei whales** typically occur over deep waters on the continental shelf edge and slope and rarely appear off the U.S. west coast. Extensive ship and aerial surveys conducted over 18 years between 1989 and 2008 resulted in only nine confirmed sightings of sei whales in California, Oregon, and Washington waters (WDFW 2011b). Sei whales would not be expected to occur within the Action Area, and therefore would not be affected by ongoing operation of the BP Marine Terminal. Critical habitat has not been designated for the sei whale.

  Sperm whales typically occur far from land in waters with a depth of 600 meters (1,968 feet) or greater and are uncommon in waters less than 300 meters (984 feet) deep (NMFS 2012a). Extensive ship surveys conducted off the Washington, Oregon and California coast between 1991 and 2008 did identify sperm whales off the Washington coast; however, documented occurrences were well outside of the Action Area (NMFS 2012a). Sperm whales would not be expected to occur within the Action Area, and therefore would not be affected by ongoing operation of the BP Marine Terminal. Critical habitat has not been designated for the sperm whale.

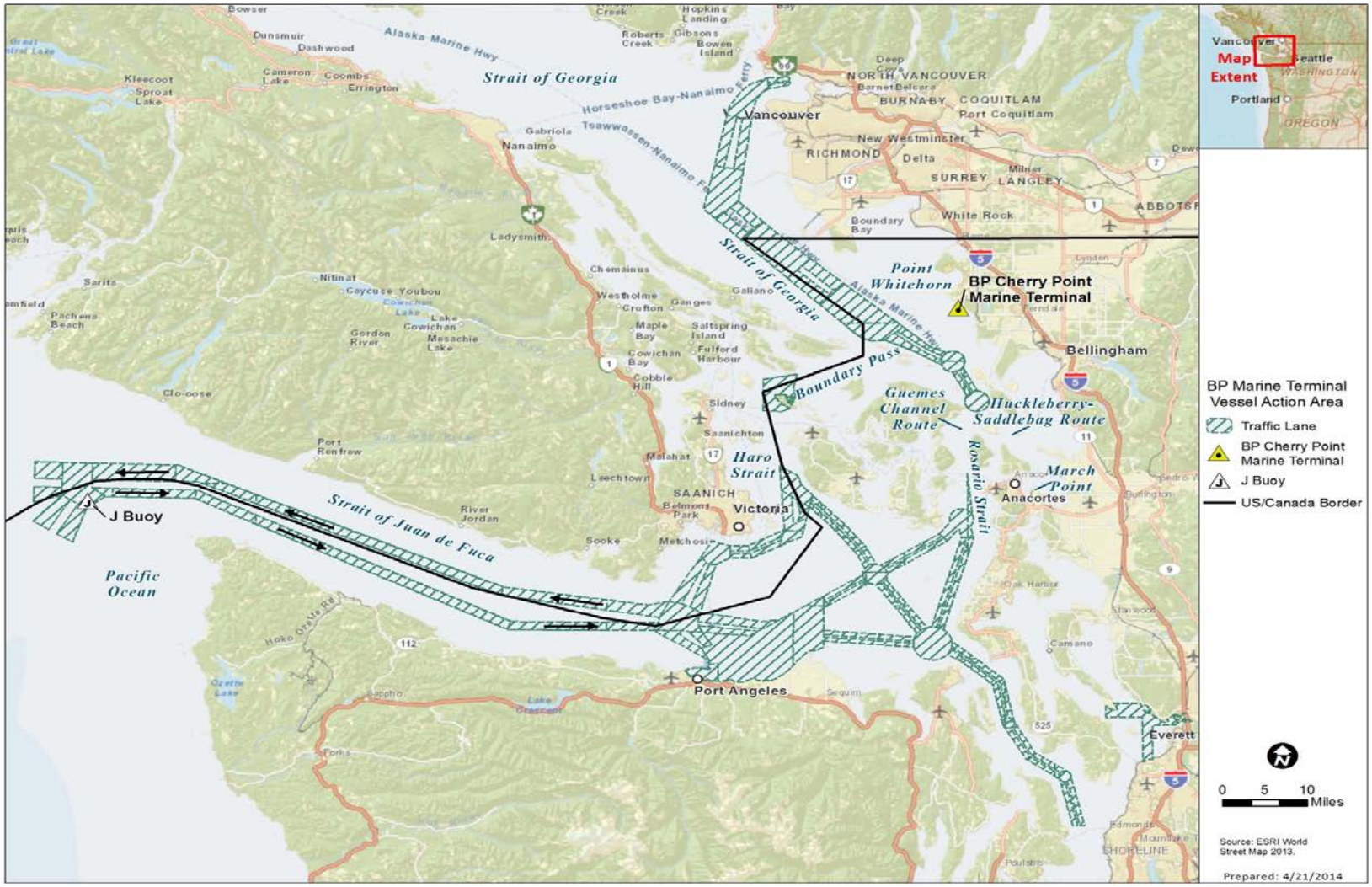

Figure 1.3-1 BP Cherry Point Action Area

Table 1.3-1 ESA-listed Species Potentially in the Action Area, their Status and whether Critical Habitat has been Formally Designated by the Services

Species	Status	Critical Habitat
Mammals		
Humpback whale (*Megaptera novaeangliae*)	Endangered	No
Blue Whale (*Balaenoptera musculus*)	Endangered	No
Fin Whale (*Balaenoptera physalus*)	Endangered	No
Southern Resident killer whale (*Orcinus orca*)	Endangered	Yes
Fish		
Eulachon (Southern DPS) (*Thaleichthys pacificus*)	Threatened	Yes
Green sturgeon (Southern DPS) (*Acipenser medirostris*)	Threatened	Yes
Salmonids		
Bull Trout (*Salvelinus confluentus*)	Threatened	Yes
Chinook salmon (Puget Sound ESU) (*Oncorhynchus tshawytscha*)	Threatened	Yes
Chum salmon (Hood Canal summer-run) *(Oncorhynchus keta*)	Threatened	Yes
Puget Sound steelhead (*Oncorhynchus* mykiss)	Threatened	Proposed
Groundfish		
DPS Bocaccio (*Sebastes pauispinis*)	Endangered	Proposed
DPS Canary rockfish (*Sebastes pinniger*)	Threatened	Proposed
DPS Yelloweye rockfish (*Sebastes ruberrimus*)	Threatened	Proposed
Birds		
Marbled Murrelet (*Brachyramphus marmoratus*)	Threatened	Yes
Reptiles		
Leatherback Turtle (*Dermochelys coriacea*)	Endangered	Yes

1.6 Interrelated and Interdependent Actions

An interrelated activity is an activity that is part of the Proposed Action and depends on the Proposed Action for its justification. An interdependent activity is an activity that has no independent utility apart from the action under consultation. At this time, no actions have been identified that are considered interrelated or interdependent with the Proposed Action.

Chapter 2

Status of Listed Species

2.1 Humpback Whale

The humpback whale is in the Balaenopteridae Family but are distinguished from other whales of that family by extraordinarily long flippers, a more robust body, fewer throat groves, more variable dorsal fin, and utilization of very long, complex, repetitive vocalizations during courtship (NMFS 1991).

2.1.1 Distribution

Humpback whales are distributed worldwide in all ocean basins though they are less common in Arctic waters. In winter, most humpbacks are found in temperate and tropical waters of both hemispheres. In summer, most humpbacks are in waters of high biological productivity, usually in the higher latitudes. Humpbacks generally inhabit waters over continental shelves, along their edges, and around some ocean islands (NMFS 1991). Primary humpback whale habitat is located in offshore waters; they utilize both continental shelves and seaward. Some humpbacks have been spotted in coastal bays. Humpback whales can be seen off Washington's coast, where some spend their summers feeding. When winter arrives, humpbacks migrate to Mexico or Hawaii. They may travel 8,047 km (5,000 miles) or more to warmer waters to breed.

2.1.2 Life History

Humpback whales mate during their winter migration. They become sexually mature at 6 to 8 years of age or when males reach the length of 11.6 meters (30.6 feet) and females reach 12 meters (39.37 feet) in length. Each female typically calves every 2 to 3 years and the gestation period is 12 months. A humpback whale calf is between 3 and 4.5 meters (9.8-14.8 feet) long at birth, and weighs up to 907 kg (2,000 pounds). It nurses frequently on the mother's rich milk, which has a 45 to 60 percent fat content. The mother must feed her newborn about 45 kg (99.2 pounds) of milk each day for a period of 5 to 7 months until it is weaned; calves may stay with the mother for up to one year. After weaning, the calf has doubled in length and increased in weight by 5 times, attaining a size of about 8.2 meters (27 feet) and 9,072 kg (20,000 pounds). Scientists estimate the average life span of humpbacks in the wild to be between 30 and 40 years (NFMS 1991).

2.1.3 Prey

Humpback whales' diet consists primarily of krill and schooling fish such as herring, sandlance, and capelin. As they are filter feeders, they use lunge feeding or bubble netting to capture their prey, often in cooperative groups. Each whale eats up to one and a half tons of food a day in their summer feeding grounds. Humpbacks are thought to feed only during summer months, losing 25 to 40 percent of their body mass during migration to winter breeding grounds.

2.1.4 Threats

Humpback whales were once on the brink of extinction due to commercial whaling practices. Their tendency to frequent coastal waters and their habitual return to the same regions each year

made humpback whales vulnerable to exploitation by commercial whalers. Current anthropogenic (or human-induced) threats to humpback whales include, entanglement in fishing gear, ingestion of marine debris, chemical pollution, and vessel strikes.

2.1.5 Regulatory Status

The humpback whale was classified as an endangered species under the Endangered Species Conservation Act (predecessor to the current Act) and was transferred to the current list of endangered species when the ESA was passed in 1973. It remains listed as an endangered species today, however, NMFS is currently performing a status review of the species to determine if Humpback whales should be delisted (78 FR 53391). Critical habitat has not been designated for the humpback whale.

2.2 Blue Whale

The blue whale is in the Balaenopteridae Family and is the largest mammal known to inhabit the Earth. Blue whales have a long-body and comparatively slender shape, a broad, flat rostrum (beaklike prolongation) when viewed from above, a proportionally smaller dorsal fin than other baleen whales, and a mottled gray color patter that appears light blue when seen through the water.

2.2.1 Distribution

Although blue whales inhabit and feed in both coastal and pelagic environments, they are thought to occur more offshore than other whale species (NMFS 1998). Little information is available to evaluate stock differences in the North Pacific, however, whaling and sighting data indicates at least five subpopulations exist in the North Pacific, with an unknown degree of mixing among them. The Eastern stock is thought to spend winters off Mexico and Central America, and feed during the summer off the U.S. West Coast, and to a lesser extent in the Gulf of Alaska and central North Pacific waters (NMFS 1998).

2.2.2 Life History

On average blue whales are between 23-24.5 meters (75.5-80-4 feet) long and weigh approximately 99,800 kg (220,021 lbs.) with females being larger than males of the same age. Though they may be found singly or in small groups, it is more common to observe them in pairs and are sometimes seen in larger groups. Blue whales are thought to reach sexual maturity between 5-15 years; however, the actual age is unknown. Most reproductive activity, including births and mating, occurs during the winter with an average calving interval of two to three years and a gestation of 12 months. Weaning probably occurs on or en route to, the summer feeding areas.

2.2.3 Prey

Blue whales in the North Pacific prey almost entirely on euphausiid (krill) with their diet consisting mainly of North Pacific krill (*Euphausia pacifica*) and *Thysanoessa spinifera*.

2.2.4 Threats

Anthropogenic (or human-induced) threats to blue whales include collisions with vessels, entanglement in fishing gear, reduced zooplankton production due to habitat degradation, and disturbance from low-frequency noise.

2.2.5 Regulatory Status

The blue whale is listed as endangered throughout its range under the ESA of 1973, and is therefore listed as "depleted" throughout its range under the Marine Mammal Protection Act of 1972. Recovery of the blue whale is managed under the NMFS' 1998 Recovery Plan. In 2012 NMFS published a Notice of Intent to update the current recovery plan (77 FR 22760). An updated plan has not yet been released for public comment. Critical habitat has not been designated for the blue whale.

2.3 Fin Whale

The fin whale is in the Balaenopteridae Family and is the second largest species of whale, behind the blue whale.

2.3.1 Distribution

Fin whales are found in deep, offshore waters of all major oceans, primarily in temperate to polar latitudes (north of approximately 30° N latitude), and less commonly in the tropics (NFMS 2010c). They are a pelagic species, seldom found in waters less than 200 meters (656 feet). Fin whales are migratory, moving seasonally into and out of high-latitude feeding areas. Migration patterns are complex and specific routes have not been documented. Acoustic signals from fin whales have been detected year-round off northern California, Oregon and Washington with a concentration of activity between September and February (Carretta et al. 2013).

2.3.2 Life History

Fin whales are thought to migrate seasonally. They feed intensively at high latitudes during the summer and reduce their food intake at lower latitudes during the winter. Fin whales in a population near carrying capacity may not reach sexual maturity until ten years of age or older while exploited populations can reach sexual maturity as early as 6-7 years of age (NMFS 2010c). Most reproductive activity occurs in the winter with a gestation period of somewhat less than a year. The average calving interval is approximately two years.

2.3.3 Prey

In the North Pacific, fin whales prefer euphausiids (mainly *E. pacifica*, *Thysanoessa longipes*, *T. spinifera*, and *T. inermis*) and large copepods (mainly *Calanus cristatus*), followed by schooling fish such as herring, walleye pollock (*Theragra chalcogramma*), and capelin (NMFS 2010c).

2.3.4 Threats

Harvest of fin whales, although rare today, was the main cause of the initial depletion of the species. Current anthropogenic (or human-induced) threats to fin whales include injury from marine debris, entanglement in fishing gear, coastal development, chemical pollution, noise exposure and vessel strikes. Among all species of large whales, fin whales are most often reported as struck by vessels, with one strike reported off Cherry Point in 2002 (Jensen and Silber 2004).

2.3.5 Regulatory Status

The fin whale was classified as an endangered species under the Endangered Species Conservation Act (predecessor to the current Act) and was transferred to the current list of

endangered species when the ESA was passed in 1973. It remains listed as an endangered species today. Critical habitat has not been designated for fin whales.

2.4 Southern Resident Killer Whale

Killer whales are the world's largest dolphin. The sexes show considerable size dimorphism, with males attaining maximum lengths of 9.0 meters (30 feet) and weight of 5,568 kg (12,275 pounds). Females are somewhat smaller at 7.7 meters (25 feet) in length and 3,810 kg (8,400 pounds) in weight. Adult males develop larger pectoral flippers, dorsal fins, tail flukes, and girths than females. Maximum life span is estimated to be 80-90 years for females and 50-60 years for males. Animals are black dorsally and have a white ventral region extending from the chin and lower face to the belly and anal region. Each whale has a uniquely shaped and scarred dorsal fin and saddle patch, which permits animals to be recognized on an individual basis (NMFS 2008a).

2.4.1 Distribution

Killer whales occur in all oceans, but are generally most common in coastal waters and at higher latitudes. Fewer sightings occur in tropical regions. In the North Pacific, killer whales are found in waters off Alaska, including the Aleutian Islands and Bering Sea , and range southward along the North American coast and continental slope. Populations are also present along the northeastern coast of Asia from eastern Russia to southern China. Northward occurrence in this region extends into the Chukchi and Beaufort seas. Sightings are generally infrequent to rare across the tropical Pacific, extending from Central and South America westward to much of the Indo-Pacific region. Killer whales occur broadly in the world's other oceans, with the exception of the Arctic Ocean (NMFS 2008a).

There are three distinct forms of killer whales recognized in the northeastern Pacific Ocean; resident, transient, and offshore. Although there is considerable overlap in the ranges of these three forms, they display significant genetic differences due to a lack of interchange between member animals. Important differences in ecology, behavior, morphology, and acoustics also exist (NMFS 2008a).

2.4.1.1 Resident Killer Whales

Resident killer whales in the U.S. are distributed from California to Alaska, with four distinct communities recognized: Southern, Northern, Southern Alaska, and Western Alaska. The Southern Resident distinct population segments (DPS) consists of three pods, identified as J, K, and L pods. These pods reside for part of the year in the inland waterways of Washington State and British Columbia (Strait of Georgia, Strait of Juan de Fuca, and Puget Sound), principally during the late spring, summer, and fall (NMFS 2008a). Pods visit coastal sites off Washington and Vancouver Island (Ford et al. 2000), but may travel as far south as central California and as far north as the Queen Charlotte Islands. Offshore movements and distribution are largely unknown for the Southern Resident DPS.

2.4.2 Movement and Dispersal

Southern Resident killer whales spend most of the year in the inland waterways of the Strait of Georgia, Strait of Juan de Fuca, and Puget Sound, particularly during the spring, summer, and fall (NMFS 2008a). Southern Residents also occur in coastal waters off Washington, Oregon,

and Vancouver Island and are known to travel as far south as central California and as far north as the Queen Charlotte Islands, British Columbia (NMFS 2006).

2.4.3 Life History

Most mating in the North Pacific is believed to occur from May to October (Olesiuk et al. 1990, Matkin et al. 1997). However, small numbers of conceptions apparently happen year-round, as evidenced by births of calves in all months (NMFS 2008a). Gestation periods in captive killer whales average about 17 months. Mean interval between the births of viable calves is 4 years. Newborns measure 2.2-2.7 meters (7.2-8.6 feet) long and weigh about 200 kg (441 pounds [Olesiuk et al. 1990; Clark et al. 2000; Ford 2002]). Calves remain close to their mothers during their first year of life, often swimming slightly behind and to the side of the mother's dorsal fin. Weaning age remains unknown, but nursing probably ends at 1-2 years of age. Mothers and offspring maintain highly stable social bonds throughout their lives and this natal relationship is the basis for the matrilineal social structure. (Ford et al. 2000, NMFS 2008a).

2.4.4 Prey

As top-level predators, killer whales feed on a variety of marine organisms ranging from fish to squid to other marine mammal species. Cooperative hunting, food sharing, and innovative learning are notable foraging traits in killer whales (NMFS 2008a). Cooperative hunting presumably increases hunting efficiency and prey capture success of group members, and may enhance group bonds. Additionally, group living facilitates knowledge of specialized hunting skills and productive foraging areas to be passed from generation to generation. Some foraging styles require extensive practice and learning (Ford et al. 1998, NMFS 2008a).

Southern Resident killer whales show a strong preference for Chinook salmon (78 percent of identified prey) during late spring to fall (Ford and Ellis 2006; NMFS 2008a). Chum salmon (11 percent) are also taken in significant amounts, especially in autumn. Other fish species eaten include coho (5 percent), steelhead (*O. mykiss*, 2 percent), sockeye (*O. nerka*, 1 percent), and non-salmonid fish species (e.g., Pacific herring and quillback rockfish [*Sebastes maliger*] 3 percent combined).

2.4.5 Threats

NMFS 2009 Recovery Plan for Southern Resident Killer Whales cites three primary factors that threaten killer whales: toxic pollution, vessel activity and sound, and the quantity and quality of prey.

Exposure to contaminants may result in harm to the species. The presences of high levels of persistent organic pollutants such as polychlorinated biphenyls and dichlorodiphenyltrichloroethane have been documented in Southern Resident killer whales. Because of their long life span, position at the top of the food chain, and their blubber stores, killer whales are capable of accumulating high concentrations of fat-soluble contaminants. This contaminant load may be associated with reproductive failure or mortality.

Commercial shipping, whale watching, ferry operations, and recreational boat traffic have increased in recent decades. Several studies have linked vessels with short-term behavioral changes in northern and Southern Resident killer whales (NMFS 2008a and 76 FR 20870). Although the potential impacts from vessels and the sounds they generate are poorly understood,

these activities may affect foraging efficiency, communication, and/or energy expenditure through their physical presence, increased underwater sound level, or both. Collisions with vessels are another potential source of serious injury and mortality and have been recorded for both Southern and Northern Resident killer whales.

Southern Resident killer whale survival and fecundity are correlated with Chinook salmon abundance (NMFS 2008a). Many salmon populations are themselves at risk, with 9 ESUs of Chinook salmon listed as threatened or endangered under the ESA. Southern Resident killer whales have been found to have a strong preference for Chinook salmon during late spring to fall, chum are also consumed in significant amounts. Little is known about winter and early spring dietary preferences (NMFS 2008a).

Since completing the Recovery Plan, NMFS has prioritized actions to address threats to killer whales according to their potential benefits to whales. The 5-Year review of the Southern Resident Killer Whales (NMFS 2011g) has identified the following management and research actions as priorities:

- Finalizing and implementing regulations to protect killer whales from vessel impacts, including an effectiveness analysis of the regulations in reducing vessel impacts;
- Continuing preparations for a major oil spill, including developing response protocols, training personnel, and securing equipment;
- Synthesizing existing information, filling data gaps, and evaluating potential effects of salmon harvest and hatchery actions on the prey base of killer whales;
- Conducting research on the health status of individual whales, including health assessments in different seasons to determine when and where prey limitation may affect reproduction and survival, conducting full examinations of stranded animals, and examining links between contaminant levels and health; and
- Data collection of coastal distributions, habitat use, and prey consumption to inform critical habitat determination, identify any unknown threats, and assess and minimize impacts of ongoing and new coastal activities.

2.4.6 Regulatory Status

The Southern Resident killer whale was listed as an endangered species on November 18, 2005 (NMFS 2005a). NMFS' recent 5-Year Review concluded that the species remains in danger of extinction and should remain listed as endangered (NMFS 2011g). As early as 2003, NMFS determined that the Southern Resident stock was below its optimum sustainable population and designated it as depleted under the Marine Mammal Protection Act in May 2003 (NMFS 2003). After the listing in 2005, NMFS released a Proposed Conservation Plan for Southern Resident killer whales (NMFS 2005b) and designated critical habitat for Southern Resident killer whales in 2006. Critical habitat includes all waters relative to a contiguous shoreline delimited by the line at a depth of 6.1 meter (20 feet) relative to extreme high water. Some of these areas overlap with military sites, which are not designated as critical habitat because they were determined to have national security impacts that outweigh the benefit of designation and are therefore excluded under ESA section 4(b)(2). Coastal and offshore areas have not been designated as critical, though they are recognize as important for the Southern Resident killer whales (NMFS 2006).

Based on the natural history and habitat needs of Southern Resident killer whales, the following primary constituent elements of critical habitat were identified as essential to conservation: (1) water quality to support growth and development; (2) prey species of sufficient quantity, quality and availability to support individual growth, reproduction and development, as well as overall population growth; and (3) passage conditions to allow for migration, resting, and foraging.

From observed sightings and other data, three "specific areas" were identified as containing important physical or biological features. The designated areas are: (1) the Summer Core Area in Haro Strait and waters around the San Juan Islands; (2) Puget Sound; and (3) the Strait of Juan de Fuca, which comprise approximately 4,120 square km (2,560 square miles) of marine habitat within the area occupied by Southern Resident killer whales in Washington.

In April 2011, NMFS established regulations under the ESA and MMPA to prohibit vessels from approaching within 200 yards of a killer whale and intercepting the path of any killer whale in inland waters of Washington State (76 FR 20870). Cargo vessels transiting in the shipping lanes are exempt from these regulations.

2.5 Bull Trout

Bull trout occur in the Pacific Northwest in Washington, Oregon, Idaho, Nevada, Montana, and Canada. Compared to other salmonids, bull trout have more specific temperature requirements. They occur in cold water streams, and are rarely found in waters where temperatures exceed 15 to 18 degrees Celsius (°C), (59 to 64 degrees Fahrenheit [°F]). They also require stable stream channels, clean spawning and rearing gravel, complex and diverse cover, as well as migration corridors (McPhail and Baxter 1996). Populations of bull trout are often distributed in watersheds based on available habitat and may not be connected (Rieman and McIntyre 1995). Bull trout are identified by several characteristics: spots never appear on the dorsal (back) fin, and the spots that rest on the fish's olive green to bronze back are pale yellow, orange or salmon-colored. The bull trout's tail is not deeply forked. Bull trout exhibit two forms: resident and migratory. Resident bull trout range up to 25.4 cm (10 inches) long and migratory forms may range up to 89 cm (35 inches) and up to 14.5 kg (32 pounds) [McPhail and Baxter 1996]).

2.5.1 Distribution

The historic range of bull trout includes major river basins in the Pacific Northwest from Canada to northern California, and inland the Jarbridge River in Nevada, as well as Puget Sound and the Columbia and Snake River Basins (USFWS 2002).

Although both resident and migratory forms of bull trout are present in the Coastal/Puget Sound bull trout population segment, it is the only known segment of bull trout in the United States that includes the anadromous life history form (spawns in freshwater, migrates to saltwater and returns to freshwater to spawn). These sub-adult bull trout move into marine waters and return to freshwater to take advantage of seasonal forage opportunities to feed on salmonid eggs, smolts, or juveniles. Bull trout in the Coastal/Puget Sound distinct population segment also move through the marine areas to gain access to independent streams to forage or take refuge from high water flows.

The Olympic Peninsula bull trout management unit is thought to differ from those in the Puget Sound management unit, which originate in watersheds on the western slopes of the Cascade

Mountains. Although the two units are connected by marine waters, there is currently no evidence that bull trout from Puget Sound migrate to the Strait of Juan de Fuca or Hood Canal.

2.5.2 Life History

Bull trout exhibit two basic life history strategies: resident and migratory, but there are several variations including an anadromous form which spawns in rivers and streams but rears young in the ocean. Most bull trout are migratory. Migratory bull trout live in larger river and lake systems where juvenile fish usually rear from one to four years before migrating to either a larger river or lake where they spend their adult life, returning to the tributary stream to spawn (Fraley and Shepard 1989). In general, migratory fish are larger than resident fish. Stream-resident bull trout complete their entire life-cycle in the tributary streams where they spawn and rear (Rieman and McIntyre 1993). Research indicates that resident and migratory forms may be found together, and interbred at times, which helped maintain viable populations throughout the range (Rieman and McIntyre 1993).

An anadromous form of bull trout exists in the Coastal-Puget Sound population. Unlike strictly anadromous species, such as Pacific salmon, bull trout are better termed amphidromous species since they often return seasonally to fresh water as subadults, sometimes for several years, before returning to freshwater to spawn. The amphidromous life history form of bull trout is unique to the Coastal–Puget Sound population (64 FR 58921; November 1, 1999).

Bull trout typically spawn from late July to December, with peak spawning in September and October. Bull trout eggs incubate over the winter and hatch in the late winter or early spring. Emergence usually requires an incubation period up to 210 days. Anadromous populations spend the early portion of their life in streams, grow to adulthood in the ocean, and eventually return to the tributaries in which they were born to spawn.

2.5.3 Prey

Resident and juvenile bull trout prey on invertebrates and small fish. Adult migratory bull trout primarily eat fish.

2.5.4 Threats

The factors that have contributed to the decline of bull trout include: restriction of migration routes; forest management practices; grazing; agricultural practices; road construction; mining; introduction of non-native species (including brook trout); and residential development (USFWS 2002). Changes in stream temperature and other water quality attributable to land and water use resulted in habitat loss. Poaching is also considered a significant threat and misidentification of bull trout as brook trout or lake trout result in some fish being killed accidentally.

Predation on bull trout by non-native species may exacerbate stresses on bull trout from habitat degradation, fragmentation, and isolation (Rieman and McIntyre 1993). Brook trout readily spawn with bull trout creating a hybrid that is often sterile (Markel 1992). Lake trout have out-competed and replaced adfluvial populations of bull trout in some lakes.

2.5.5 Regulatory Status

On June 10, 1998, FWS listed bull trout as threatened under the ESA (63 FR 31647). On October 18, 2010, FWS designated critical habitat for bull trout throughout their U.S. range (75 FR 63898) in streams, lakes and reservoirs in Idaho, Oregon, Washington, Montana, and Nevada. In Washington, portions of marine shoreline were also designated.

Bull trout have more specific habitat requirements than most other salmonids (75 FR 63898). The predominate habitat components influencing their distribution and abundance include water temperature, cover, channel form and stability, spawning and rearing substrate conditions, and migratory corridors. The primary constituent elements of bull trout critical habitat are: (1) adequate freshwater quantity, (2) quality and connectivity; migration habitats; (3) an abundant food base, including riparian organisms, aquatic macroinvertebrates, and forage fish; (4) complex freshwater and marine shoreline aquatic environments with features such as large wood, side channels, pools, undercut banks and unembedded substrates; (5) water temperatures ranging from 2 to 15 °C (36 to 59 °F), with adequate thermal refugia available for temperatures that exceed the upper end of this range; (6) suitable substrate in spawning and rearing areas; a natural hydrograph; sufficient water quality and quantity; and (7) sufficiently low levels of occurrence of nonnative predatory, interbreeding, or competing species that, if present, are adequately isolated from bull trout (75 FR 63898).Coastal marine waters designated as critical habitat for bull trout in the Coastal Puget Sound and the Olympic Peninsula areas extend from the mean high high-water (MHHW) line inland (including the tidally influenced freshwater heads of estuaries) to 10 meters (33 feet) below the mean low low-water (MLLW) elevation line offshore. This zone equates to the photic zone where most bull trout activity occurs.

The Olympic Peninsula critical habitat unit (CHU) is located in northwestern Washington. Bull trout populations inhabiting the Olympic Peninsula comprise the coastal component of the Coastal–Puget Sound population. The unit includes approximately 748.7 km (465.2 miles) of stream, 3,064.2 hectares (7,571.8 acres) of lake surface area, and 529.2 km (328.8 miles) of marine shoreline designated as critical habitat. This CHU is bordered by Hood Canal to the east, Strait of Juan de Fuca to the north, the Pacific Ocean to the west, and the Lower Columbia River Basins and Puget Sound CHUs to the south. It extends across portions of Grays Harbor, Clallam, Mason, Pacific, and Jefferson Counties. All of the major river basins initiate from the Olympic Mountains. The Olympic Peninsula CHU is sub-divided into 10 critical habitat subunits. Although delta areas and small islands are difficult to map and may not be specifically identified by name, they are included within the critical habitat. The subunits within the Olympic Peninsula CHU provide spawning, rearing, foraging, migratory, and overwintering habitat.

The Puget Sound CHU includes approximately 1,840.2 km (1,143.5 miles) of streams; 16,260.9 hectares (40,181.5 acre) of lake surface area; and 684.0 km (442.5 mile) of marine shoreline designated as critical habitat. The CHU is bordered by the Cascade Range to the east, Puget Sound to the west, Lower Columbia River Basins and Olympic Peninsula CHUs to the south, and the U.S. – Canada border to the north. The Puget Sound CHU extends across Whatcom, Skagit, Snohomish, King, Pierce, Thurston, and Island Counties in Washington. The major river basins initiate from the Cascade Range and flow west, discharging into Puget Sound, with the exception of the Chilliwack River system, which flows northwest into British Columbia, discharging into the Fraser River. The Puget Sound CHU is sub-divided into 13 critical habitat

subunits. The subunits within the Puget Sound CHU provide spawning, rearing, foraging, migratory, connecting, and overwintering habitat.

2.6 Chinook Salmon (Puget Sound ESU)

Chinook salmon is the largest species of salmon with adults often exceeding 18 kg (40 pounds). They, along with steelhead exhibit the most diversity in terms of life history. Populations in Puget Sound have dropped precipitously in the last few decades, due to a combination of direct overharvest, pollution, habitat losses, possible interspecific competition, and negative effects of hatchery production, changing ocean conditions, and other indirect outcomes of human activities. Chinook smolts are very dependent upon nearshore marine and estuary habitats to provide them critical conditions to grow during their early marine life history stage. Chinook at sea look similar to coho salmon (blue-green back with silver flanks), but are distinguishable by their large size, small black spots on both lobes of the tail, and black pigment along the base of their teeth.

2.6.1 Distribution

The Puget Sound ESU is a composite of 22 individual populations of naturally spawning and hatchery Chinook stocks (NMFS 2007b). The boundary of this ESU extends from the Nooksack River in the north to southern Puget Sound, includes Hood Canal, and extends westerly out the Strait of Juan de Fuca to the Elwha River. The Skagit River and its tributaries constitute the historically predominant system in Puget Sound containing naturally spawning populations.

Some Puget Sound Chinook are thought to spend their entire life within Puget Sound; however, most migrate to the ocean and north along the Canadian coast. There appears to be a substantial difference in migratory patterns from Chinook that originate from Puget Sound Rivers and those from the Washington coast. Chinook from the northern rivers of Puget Sound, particularly the Nooksack, tend to utilize the Strait of Georgia more than other Puget Sound Chinook. Migratory return routes appear to vary from year to year, with Chinook migrating along the west Coast of Vancouver Island or though Johnston Strait and the Strait of Georgia (NMFS 2007b).

2.6.2 Life History

Chinook salmon exhibit considerable variation in their size and age of maturity. Coast-wide, Chinook salmon remain at sea for one to 6 years (more commonly 2 to 4 years), with the exception of a small proportion of yearling males (called “jacks”) which mature in freshwater or return after two or three months in salt water. Puget Sound Chinook tend to mature at ages 3 and 4.

Chinook salmon typically spawn in larger streams and higher velocity areas with larger gravels than those areas utilized by the other salmon species. Some Chinook salmon may select spawning areas close to or even within estuaries, but their size and strength enable them to travel for hundreds of miles upstream in some river systems. Once the adult fish have arrived at the spawning grounds and “ripened,” a female Chinook will dig a redd (nest) with her tail and deposit her eggs into four or five nesting pockets. The number of eggs for each Chinook female can range from fewer than 2,000 eggs to more than 17,000 eggs, but in Puget Sound it is estimated that 2,000 to 5,500 per female is typical. The eggs are fertilized by one or more males, and the female Chinook will guard the redd from 4 to 25 days before dying. Males may seek other spawning opportunities before they too, expire. Depending on the water temperature, Chinook eggs will hatch between 32 to 159 days after deposition. Alevins (newly hatched

salmon with attached yolk sacs) will remain in the gravel for another 14 to 21 days before emerging. Water quality, depth, velocity, and temperature are all critical for the survival of eggs. Shallow water may make eggs more vulnerable to predators and disturbance. High velocity can cause scouring of the stream bed, dislodging the eggs from their redds. Puget Sound Chinook tend to have relatively large eggs, greater than 8.0 mm (0.3 inch) in diameter on average. (Croot and Margolis 1991) (63 FR 11482).

The majority of Puget Sound Chinook leave the freshwater environment during their first year, making extensive use of the protected estuary and nearshore habitats. However, each of the populations exhibits a great deal of variation in the pattern of outmigration by juveniles. For example, Chinook native to the Skagit Basin exhibit at least four different strategies in terms of the time they enter and the duration of their stay in estuaries and near-shore marine waters. Nearshore ecosystems provide areas for the young Chinook to forage and hide from predators. Juvenile salmon experience the highest growth rates of their lives while in the highly productive estuaries and nearshore waters. These estuarine habitats are ideal for juvenile salmon to undergo the physiological transition to saltwater, and to readjust to freshwater when they return to spawn as adults. Nearshore areas serve as the migratory pathway to ocean feeding areas. The vegetation, shade, and insect production along river mouth deltas and protected shorelines help to provide food, cover, and the regulation of temperatures in shallow channels. Forage fish spawn in large aggregations along protected shorelines, thus generating a base of prey for the migrating salmon fry. Salmon often utilize “pocket estuaries”-small estuaries located at the mouths of streams and drainages, where freshwater input helps them to adjust to the change in salinity, food production is high, and where the shallow waters protect them from predation. As the juvenile salmon grow and adjust, they move out to more exposed shorelines such as eelgrass, kelp beds, and rocky shorelines where they continue their transition to the ocean environment.

2.6.3 Prey and Predators

In freshwater juveniles feed opportunistically on terrestrial and aquatic insects, in salt water juveniles eat crustaceans as well as other bottom invertebrates. Adult Chinook eat mostly other fish including sandlance, herring, surf smelt (*Hypomesus pretiosus*), and squid.

Sharks, killer whales, seals, sea lions and other marine mammals prey on adult Chinook salmon. Terrestrial predators include bears, coyotes, and eagles. Young salmon face a variety of predators including other fish species, otters, aquatic snakes, and a variety of birds.

2.6.4 Threats

Chinook salmon are one of the predominant sport and commercial fisheries in the PNW. In general, populations of Chinook throughout their entire range have been drastically reduced from historic abundance, especially in Puget Sound, the Columbia Basin and California’s Central Valley rivers.

Freshwater, estuarine, and marine habitat loss or degradation is thought to be the primary reason for declining populations, although nearly a century of over-fishing by commercial and sport fisheries has made a significant contribution to these declines. Cumulative development of land and water use, including expansion of agricultural, mining, hydropower development, water withdrawals, urbanization, transportation infrastructure expansion and broad-scale pollution have significantly contributed to these losses (Good et al. 2005). Chinook salmon’s spawning range is

limited by degradation and loss of habitat in the headwaters of many Washington Rivers (Wydoski and Whitney 2003).

2.6.5 Regulatory Status

Puget Sound Chinook salmon were listed as a threatened species on March 24, 1999 with the status reaffirmed on June 28, 2005 and July 26, 2011. A final ESA 4(d) rule adopting regulations to conserve Puget Sound Chinook was issued on July 10, 2000 (65 FR 42422). Critical habitat was designated for this species on September 2, 2005 (70 FR 52630). The specific geographic area of the designated critical habitat includes portions of the Nooksack River, Skagit River, Sauk River, Stillaguamish River, Skykomish River, Snoqualmie River, Lake Washington, Green River, Puyallup River, White River, Nisqually River, Hamma Hamma River and other Hood Canal watersheds, the Dungeness/ Elwha Watersheds, and nearshore marine areas of the Strait of Georgia, Puget Sound, Hood Canal and the Strait of Juan de Fuca. This designation includes the stream channels within the designated stream reaches, and includes a lateral extent as defined by the ordinary high water line.

Designated critical habitat for this species includes freshwater and marine sites necessary to support one or more Chinook salmon life stages. These areas are important for the species' overall conservation by protecting quality growth, reproduction, and feeding. Specific primary constituent elements include (1) freshwater spawning sites, (2) freshwater rearing sites, (3) freshwater migration corridors, (4) offshore marine areas, (5) nearshore marine habitat, and (6) estuarine areas. The physical or biological features that characterize these sites include water quality and quantity, natural cover, forage, adequate passage conditions, and floodplain connectivity.

2.7 Chum Salmon (Hood Canal Summer Run)

Chum salmon, also known as dog salmon, are usually the last of the Pacific salmon to enter fresh water, generally spawning in early winter. Chum salmon are known for the striking calico pattern of spawning males, which exhibit a bold, jagged reddish and black line along their flank. Chum salmon are second only to Chinook salmon in adult size, with individuals reported up to 1.1 meter (43 inches) in length and 20 kg (46 pounds) in weight. The average size for the species is around 3.6-6.8 kg (8-15 pounds).

2.7.1 Distribution

The Hood Canal summer chum salmon ESU includes all naturally spawned populations (eight existing runs) of summer-run chum in tributaries to the Hood Canal, and in Discovery Bay, Sequim Bay, and the Dungeness River on the Strait of Juan de Fuca (NMFS 2007b). Most of the historical summer chum stocks on the east side of Hood Canal have been extirpated.

2.7.2 Life History

Chum salmon spend more of their life history in marine waters than any other Pacific salmonid species. Juvenile chum migrate to saltwater almost immediately after emerging from gravel, thus their early marine survival depends substantially on estuarine conditions (unlike other salmonid species that depend extensively on freshwater habitat). Also unlike other salmon species, chum salmon form schools, a characteristic that is presumed to help them reduce predation.

Eggs are deposited in the gravel of freshwater natal streams from December to February with the fry emerging in the spring. Chum fry are long, slim, and silvery, with a blue-green iridescence quite distinct from the fry of other Pacific salmon, and go directly to sea with no hold-over residence in either stream or lake. Chum salmon reach maturity at 3 to 5 years of age, with 60 to 90 percent of the fish maturing at four years of age.

Chum salmon usually spawn in the lower reaches of rivers, probably due to their lack of persistence in overcoming blockages and falls. Although chum may migrate upstream for over 160 km (100 miles) on some river systems, most of these rivers are low gradient and without substantial blockages. Redds are usually dug in the mainstem or in side channels of rivers beginning just above tidal influence. Some chum salmon even spawn in intertidal zones of streams at low tide, particularly where groundwater upwelling is present.

Some scientific observations of chum suggest that the returning adults have a greater tendency to stray to other river systems than other salmonids. This is thought to be due to a number of possible factors such as their spawning location near the mouths of rivers, which does not afford the juveniles the long downstream migration undertaken by other species during the process of imprinting. Additionally, chum salmon enter streams when they are sexually mature and may not be able to endure a delay, leading them to spawn at the first available location. Additional studies on straying by chum have been inconclusive and are affected by hatchery releases.

The timing of hatching and the young fry's emergence from gravel varies by stream temperature, dissolved oxygen level, gravel size, salinity, and nutritional conditions. Summer chum eggs and alevins (juveniles with egg-sac attached) develop in the redds for approximately 18 to 20 weeks before emerging as fry between February and the last week of May. Outmigration to saltwater may take only hours or days where the spawning sites are close to the river mouth. Estuarine residency is the most critical phase in the life history of chum. They remain close to the surface, rearing in shallow eelgrass beds, tidal creeks, sloughs or other productive estuarine areas for several weeks between January and July.

Although migratory information on chum is limited, both Asian and North American chum are found in the North Pacific and Bering Sea. North American chum salmon are rarely found west of the mid-Pacific ocean, while Asian-origin chum have been shown to migrate eastward of that point. After two to four years in the northeast Pacific ocean, Puget Sound-origin chum reaching maturity follow a southerly migration path parallel to the coastline of southeast Alaska and British Columbia.

In Washington State, fall-timed runs of chum predominate, generally returning to their streams of origin from October to November. However, distinct summer runs of chum in Hood Canal and the eastern Strait of Juan de Fuca spawn from late August to mid-October. Hood Canal summer chum spawn soon after they enter freshwater in the lowest reaches of their natal streams. Ninety percent of summer chum in the Quilcene River spawn in the lowest mile. In Salmon Creek the summer chum also spawn within the lowest mile, and in Snow and Jimmycomelately Creeks they spawn in the lowest one-half mile.

Genetic data indicate a strong and long-standing reproductive isolation between Hood Canal summer chum and other chum populations in the United States and British Columbia. Summer chum populations are rare in the southern portion of the specie's range. The high water

temperatures and low stream flows in the late summer and early fall are unfavorable for salmonids south of northern British Columbia. The ability of Hood Canal Summer Chum to persist in the face of such hostile conditions led the NMFS Biological Review Team to conclude that these populations contribute to the ecological and genetic diversity of the species as a whole (Good et al. 2005). Although a few summer-run populations are also present in southern Puget Sound, the genetic data indicate that the summer-run populations of Hood Canal and the eastern Strait of Juan de Fuca are part of a much more ancient lineage.

2.7.3 Prey and Predators

In fresh water juveniles feed on Diptera larvae, diatoms, and cyclops; in salt water juveniles feed on a variety of zoo plankton. Adults feed on polychaetes, pteropods, squid, crustacean larvae, copepods, amphipods, and fish (NatureServe 2010). A variety of fish and birds prey upon juvenile chum salmon; sharks, sea lions and seals, and orcas eat adults.

2.7.4 Threats

Chum salmon are the least commercially valuable species. Hood Canal summer run chum migrate through the study area. The chum salmon's minimal dependence on freshwater for rearing could be a main reason why the impacts to their runs are not as widespread as other salmon species.

Freshwater, estuarine, and marine habitat loss or degradation is thought to be the primary reason for declining populations. Instream flow abundance during summer and rapidly rising hydrograph in urbanizing areas are impacts associated with watershed management issues that can influence population abundance.

Degradation and loss of habitat in the headwaters of many Washington rivers now limits their spawning range (Wydoski and Whitney 2003).

2.7.5 Regulatory Status

Hood Canal summer-run chum salmon were listed as threatened on March 25, 1999 and reaffirmed on June 28, 2005 and July 26, 2011. A final ESA 4(d) rule adopting regulations to conserver Hood Canal summer-run chum was issued on July 10, 2000 (65 FR 42422). Critical habitat for this species was designated on September 2, 2005 (70 FR 52630). The specific geographic area includes the Skokomish River, Hood Canal subbasin, which includes the Hamma Hamma and Dosewallips rivers and others, the Puget Sound subbasin, Dungeness/Elwha subbasin, and nearshore marine areas of Hood Canal and the Strait of Juan de Fuca from the line of extreme high tide to a depth of 30 meters (98 feet).

The specific primary constituent elements identified for Hood Canal summer-run chum salmon are (1) freshwater spawning sites, (2) freshwater rearing sites, (3) freshwater migration corridors, (4) offshore marine areas, (5) nearshore marine habitat, and (6) estuarine areas. The physical or biological features that characterize these sites include water quality and quantity, natural cover, forage, adequate passage conditions, and floodplain connectivity.

2.8 Puget Sound Steelhead

Steelhead are the sea-going or anadromous form of rainbow trout and perhaps the most acclaimed sport fish on the West Coast of North America. As a member of the taxonomic genus

Oncorhynchus, they exhibit the most diversity in life history of perhaps any other species of salmon, which is expressed both within and between distinct populations. This diversity makes steelhead possibly the most difficult of all Pacific salmonid species to protect and manage. Steelhead and resident rainbow trout are genetically identical, and resident forms typically retain the ability to revert to their anadromous life history form if environmental circumstances are favorable, and vice versa if conditions are unfavorable.

2.8.1 Distribution

The Puget Sound steelhead DPS includes more than 50 stocks of summer- and winter-run fish, with winter-run being the most widespread and numerous of the two runs (NMFS 2007c). This DPS includes all naturally spawned anadromous winter-run and summer-run populations in streams in the river basins of the Strait of Juan de Fuca, Puget Sound, and Hood Canal, bounded to the west by the Elwa River and to the north by the Nooksack River and Dakota Creek. The Green River natural run and Hamma Hamma winter-run hatchery stock are also included.

2.8.2 Life History

Steelhead occupy both mainstem rivers and tributary streams throughout Puget Sound, and are known for their use of the uppermost reaches of headwater streams, when accessibility allows. The life history diversity of steelhead populations is expressed in a variety of ways, including multiple return times (i.e., a “winter” run and a “summer” run) within a given year to their natal streams, varying periods of freshwater and ocean residency, and distinct changes in life history strategy between generations even within a distinct population. The life history of steelhead also differs from many *Oncorhynchus* species in several fundamental way including; the frequent concurrent presence of resident forms of *O. mykiss* (often referred to as rainbow or redband trout) as well as the ability to complete more than one cycle of spawning This diversity enables the species to persist in highly variable environments and historically was highly distributed across the landscape of Puget Sound.

Winter and summer run are the two major life history types expressed by steelhead, which are related to the degree of sexual development at the time of adult freshwater entry (Smith 1969, Burgner et al. 1992). The winter run of steelhead is the predominant run in Puget Sound, in part because there are relatively few basins in the Puget Sound ESU with the geomorphological and hydrological characteristics necessary to establish the summer run life history. The summer run steelhead’s extended freshwater residence prior to spawning results in higher pre-spawning mortality levels relative to winter run steelhead.

2.8.2.1 Winter Run Steelhead

In general, winter run, or ocean maturing, steelhead return as adults to the tributaries of Puget Sound from December to April (WDF et al. 1973). Spawning occurs from January to mid- June, with peak spawning occurring from mid-April through May. Prior to spawning, maturing adults hold in pools or in side channels to avoid high winter flows. Steelhead tend to spawn in moderate to high gradient sections of streams. In contrast to semelparous (death after spawning) Pacific salmon, steelhead females do not guard their redds, or nests, but return to the ocean following spawning (Burgner et al. 1992). Spawned out females that return to the sea are referred to as “kelts.”

2.8.2.2 Summer Run Steelhead

The life history of summer run steelhead is highly adapted to specific environmental conditions. Because these conditions are not common in Puget Sound, the relative incidence and size of summer run steelhead populations is substantially less than that for winter run steelhead. Summer run steelhead also have not been widely monitored, in part, because of their small population size and the difficulties in monitoring fish in their headwater holding areas.

2.8.2.3 Juvenile Life History

The majority of steelhead juveniles reside in fresh water for two years prior to emigrating to marine habitats with limited numbers emigrating as 1- or 3-year-old smolts. Smoltification and seaward migration occur principally from April to mid-May (WDF et al. 1973). Two-year-old naturally produced smolts are usually 140 to 160 mm (5.5 to 6.3 inches) in length (Wydoski and Whitney 1979, Burgner et al. 1992). While the inshore migration pattern of steelhead in Puget Sound is not well understood, it is generally thought that steelhead smolts move quickly offshore (Hartt and Dell 1986 as cited in Hard et al. 2007).

Juvenile steelhead will often reside in freshwater for a longer period of time than juveniles of pink, chum, Chinook, and coho salmon, and are thus, more susceptible to changes in habitat quality that may lower their freshwater survival rate (Scott and Gill 2008). Steelhead also typically spawn in the winter through spring months, rather than late summer early fall spawning exhibited by other species.

2.8.2.4 Ocean Migration

Steelhead oceanic migration patterns are poorly understood. Puget Sound steelhead feed in the ocean for 1 to 3 years before returning to their natal stream to spawn. Evidence from tagging and genetic studies indicates Puget Sound steelhead travel to the central North Pacific Ocean (French et al. 1975; Burgner et al. 1992; Hartt and Dell 1986 as cited in Hard et al. 2007). Typically, Puget Sound steelhead spend two years in the ocean although, notably, Deer Creek summer run steelhead spend only a single year in the ocean before spawning.

2.8.3 Prey

In streams, steelhead feed primarily on drift organisms and may ingest aquatic vegetation (likely for attached invertebrates), while their ocean diet consists of fish and crustaceans. (NatureServe 2013)

2.8.4 Threats

Degradation of riverine, estuarine, and nearshore habitat has resulted in the loss of an average of 83 percent of the potential production of the 42 steelhead populations assessed in Washington (Scott and Gill 2008).

Habitat utilization by steelhead has been primarily affected by reductions in habitat quality and fragmentation. The mechanisms that have contributed to significant decline in native steelhead populations in Puget Sound are varied and cumulative, and are largely the same as those leading to the decline of other native salmon stocks. Over-harvesting by sport and commercial fisheries, loss of significant portions of freshwater habitats from 150 years of land development and water uses, deterioration in water quality, intraspecific and interspecific conflicts with hatchery

produced salmonids planted to freshwater habitats, and a wide variety of other cumulative and synergistic effects. The loss of freshwater and nearshore marine habitats are among the most pervasive and insidious causes in the decline of steelhead, including those resulting from agricultural practices, expansion of urban areas into tributary rivers, mining, hydropower development, alteration of river corridors, expansion of transportation corridors, discharge of pollutants from industrial, municipal sources and stormwater runoff (Hard et al. 2007).

A number of large water supply and hydropower dams in the Puget Sound basin have affected steelhead. In addition to eliminating accessibility to habitat, dams affect habitat quality through changes in river hydrology, temperature profile, and channel form affects sediment supply and routing, and the recruitment and movement of large woody debris. Nearly all of the lower reaches of Puget Sound rivers and their tributaries in Puget Sound have been dramatically altered by urban development, including the expansion of transportation corridors and its associated runoff of polluted stormwater associated with large areas of impervious surfaces including, buildings, roads and parking lots (Hard et al. 2007, Collins et al. 2003).

The loss of wetland and riparian habitat has dramatically changed the hydrology of many urban streams, with increases in flood frequency and peak flow during storm events and decreases in groundwater-driven summer flows. Flood events result in gravel scour, bank erosion, and sediment deposition. Land development for agricultural purposes has also altered the historical land cover; however, because much of this development took place in river floodplains, there has been a direct impact on river morphology. River braiding and sinuosity have been reduced through the construction of dikes, hardening of banks with riprap, and channelizing the main stem. Where rivers are constrained by levees, there is an increased risk of gravel bed scour of redds and dislocation of rearing juveniles during high flow events.

2.8.5 Regulatory Status

Steelhead was first listed as threatened in 2007 and relisted in 2011(FR 76, No. 157 / Monday, August 15, 2011 / Proposed Rules). In the Puget Sound region, NMFS listed 44 stocks for protection under federal ESA in May 2007. In Puget Sound, the DPS of this species includes all naturally spawned anadromous winter-run and summer-run steelhead populations, in streams in the river basins of the Strait of Juan de Fuca, Puget Sound, and Hood Canal, Washington, bounded to the west by the Elwha River (inclusive), and to the north by the Nooksack River and Dakota Creek (inclusive), as well as the Green River natural and Hamma Hamma winter-run steelhead hatchery stocks. On September 25, 2008, NMFS issued a final ESA 4(d) rule adopting protective regulations for threatened West Coast salmon and steelhead to this DPS of steelhead in Puget Sound (73 FR 55451). Critical habitat has been proposed by NMFS (January 2013) and would include approximately 1,880 stream miles (3,026 km) that are currently occupied by steelhead and contain physical and biological features essential to the conservation of the species (NMFS 2013). However, the proposed critical habitat does not include marine waters, so it would not be affected by the proposed action.

Primary constituent elements of steelhead critical habitat include (1) freshwater spawning, rearing and migration sites, (2) estuarine areas, (3) nearshore marine areas, and (4) offshore marine areas. The physical or biological features that characterize these sites include water quality, natural cover, adequate passage conditions, floodplain connectivity, and forage including aquatic invertebrates and fishes.

2.9 Pacific Eulachon

Eulachon are a short lived, high fecundity, high mortality forage fish, and tend to have extremely large population sizes. Eulachon abundance exhibits considerable year-to-year variability. Eulachon typically spend 3 to 5 years in saltwater before returning to freshwater to spawn from late winter through mid-spring.

2.9.1 Distribution

Pacific eulachon is an anadromous fish that occurs in the lower portions of certain rivers draining into the northeastern Pacific Ocean, ranging from Northern California to the southeastern Bering Sea in Bristol Bay, Alaska (Hubbs 1925, Schultz and DeLacy 1935, McAllister 1963, Scott and Crossman 1973, Willson et al. 2006). Beacham (2005) identified 33 eulachon spawning rivers in British Columbia, 14 of these were classified as supporting regular yearly spawning runs. The southern population of Pacific eulachon consists of populations spawning in rivers south of the Nass River in British Columbia, Canada, to, and including, the Mad River in California (74 FR 10857). Eulachon have been found in numerous coastal rivers in northern California, Oregon, and Washington (including the Quinault and Elwha Rivers) (Emmett et al. 1991, Willson et al. 2006).

2.9.2 Life History

Eulachon eggs average 1 mm (0.04 inch) in size and are broadcast into the water column, attaching to a variety of substrates from sand to pea-sized gravel. Eggs are fertilized in the water column. After fertilization, the eggs sink and adhere to the river bottom, typically in areas of gravel and coarse sand. Most eulachon adults die after spawning. Eulachon eggs hatch in 20 to 40 days with incubation time depending on water temperature (Howell et al. 2001). Newly hatched young, which are transparent, and 4 to 7 mm (0.2 to 0.3 inch) in length are carried to the sea with the current (Hay and McCarter 2000). It is not known how long larval eulachon remain in the estuary before entering the ocean (NMFS 2010a). Similar to salmon, juvenile eulachon are thought to imprint on the chemical signature of their natal river basins. However, because juvenile eulachon spend less time in freshwater environments than do juvenile salmon, researchers hypothesize that this short freshwater residence time may cause returning eulachon to stray between spawning sites at higher rates than salmon (Hay and McCarter 2000).

Once juvenile eulachon enter the ocean, they move from shallow nearshore areas to deeper areas over the continental shelf. Larvae and young juveniles become widely distributed in coastal waters, where they are typically found near the ocean bottom in waters 20 to 150 meters deep (66 to 292 feet) (Hay and McCarter 2000) and sometimes as deep as 182 meters (597 feet) (Barraclough 1964). There is currently little information available about eulachon movements in nearshore marine areas and the open ocean. However, eulachon occur as bycatch in the pink shrimp fishery (Hay et al. 1999; Olsen et al. 2000; NWFSC 2008; Hannah and Jones 2009), which indicates that the distribution of these organisms overlaps in the ocean.

Historically, eulachon runs in northern California were thought to start as early as December and January and peak in abundance during March and April. Historically, large numbers of eulachon migrated upstream in March and April to spawn, but they rarely moved more than 13 km (8 miles) inland (NAS 2004). Spawning occurs in gravel riffles, with hatching about a month later. The larvae generally move downstream to the estuary following hatching.

Eulachon rear in the pelagic zone and return to freshwater to spawn. Spawning grounds are typically in the lower reaches of larger rivers fed by snowmelt (Hay and McCarter 2000). Willson et al. (2006) concluded that the age distribution of eulachon in a spawning run varies considerably, but typically consists of fish that are between 2 and 5 years old. Eulachon eggs commonly adhere to sand (Langer et al. 1977) or pea-sized gravel (Smith and Saalfeld 1955), though eggs have been found on a variety of substrates, including silt, gravel to cobble sized rock, and organic detritus (Smith and Saalfeld 1955; Langer et al. 1977; Lewis et al. 2002). Eggs found in areas of silt or organic debris reportedly suffer much higher mortality than those found in sand or gravel (Langer et al. 1977). The sexes must synchronize their activities closely, unlike some other group spawners such as herring, because eulachon sperm remain viable for only a short time, perhaps only minutes (Hay and McCarter 2000).

Eulachon spawn once and then die. During spawning, males have a distinctly raised ridge along the middle of their bodies. Eulachon generally spawn in rivers that are either glacier or snowpack fed and that experience spring freshets (flooding). Spawning grounds are typically in the lower reaches of larger rivers fed by snowmelt and spawning typically occurs at night. In many rivers, spawning is limited to the part of the river that is influenced by tides (Lewis et al. 2002), some exceptions exist. In the Berners Bay system of Alaska, the greatest abundance of eulachon is observed in tidally-influenced reaches, but some fish ascend well beyond the tidal influence (Willson et al. 2006). In addition, eulachon once ascended more than 160 km (100 mile) in the Columbia River system (Smith and Saalfeld 1955).

Spawning occurs at between 0 and 10 °C (32 and 50 °F) throughout the range of the species, and is largely limited to the part of the river that is tidally influenced (Lewis et al 2002). Entry into spawning rivers appears to be related to water temperature and the occurrence of high tides (Smith and Saalfeld 1955; Spangler 2002). Spawning generally occurs in January, February, and March in the Columbia River, Klamath River, and the coastal rivers of Washington and Oregon, and April and May in the Fraser River. It has been argued that because these freshets rapidly move eulachon eggs and larvae to estuaries, it is likely that eulachon imprint and home to an estuary into which several rivers drain rather than to individual spawning rivers (Hay and McCarter 2000). There is some evidence that water velocity greater than 0.4 meters/second (1.3 feet per second) begins to limit the upstream movements of eulachon (Lewis et al. 2002).

Eulachon runs in central and northern British Columbia typically occur in late February and March or late March and early April. However, attempts to characterize eulachon run timing are complicated by marked annual variation in timing. Willson et al. (2006) give several examples of spawning run timing varying by a month or more in rivers in British Columbia and Alaska. Water temperature at the time of spawning varies across the distribution of the species. Although spawning generally occurs at temperatures from 4 and 7 °C (39 and 45° F) in the Cowlitz River (Smith and Saalfeld 1955), and at a mean temperature of 3.1 °C (37.6 °F) in the Kemano and Wahoo Rivers, peak eulachon runs occur at noticeably colder temperatures (between 0 and 2 °C [32 and 36 °F]) in the Nass River. The Nass River run is also earlier than the eulachon run that occurs in the Fraser River, which typically has warmer temperatures than the Nass River (Langer et al. 1977).

2.9.3 Prey and Predators

Eulachon adults feed on zooplankton, chiefly eating crustaceans such as copepods and euphausiids, including *Thysanoessa* spp. (Hay and McCarter 2000, WDFW and ODFW 2001), unidentified malacostracans (NMFS 2011c), and cumaceans (Smith and Saalfeld 1955). Eulachon larvae and juveniles eat a variety of prey items, including phytoplankton, copepods, copepod eggs, mysids, barnacle larvae, worm larvae, and eulachon larvae (WDFW and Oregon Fish and Wildlife Service [ODFW] 2001). Adults and juveniles commonly forage at moderate depths (20-150 meter [66-292 feet]) in nearshore marine waters (Hay and McCarter 2000). Eulachon adults do not feed during spawning (McHugh 1939; Hart and McHugh 1944).

Eulachon have a very high lipid content (Iverson et al. 2002), and their historical large spawning runs made them an important part of the Pacific coastal food web. They have numerous avian predators, including sea birds such as harlequin ducks (*Histrionicus histrionicus*), pigeon guillemots (*Cepphus Columba*), common murres *(Uria aalge*), mergansers, cormorants, gulls, and eagles (NMFS 2010a). Marine mammals such as baleen whales, orcas, dolphins, pinnipeds, and beluga whales (*Delphinapterus leucas*) are known to feed on eulachon. Fish that prey on eulachon include white sturgeon (*A. transmontanus*), spiny dogfish (*Squalus acanthias*), sablefish (*Anoplopoma fimbria*), salmon sharks (*Lamna ditropis*), arrowtooth flounder (*Atheresthes stomias*), Pacific hake (*Merluccius productus*), salmon, Dolly Varden (*S.malma malma*), Pacific halibut (*Hippoglossus stenolepis*), and Pacific cod (*Gadus macrocephalus*) (NMFS 2010a). In particular, eulachon and their eggs seem to provide a significant food source for white sturgeon in the Columbia and Fraser rivers (McCabe et al. 1993; NMFS 2010a).

2.9.4 Threats

Habitat loss and degradation threaten eulachon, particularly in the Columbia River basin. Hydroelectric dams block access to historical eulachon spawning grounds and affect the quality of spawning substrates through flow management, altered delivery of coarse sediments, and siltation. The release of fine sediments from behind a USACE sediment retention structure on the Toutle River has been negatively correlated with Cowlitz River eulachon returns 3 to 4 years later and is thus implicated in harming eulachon in this river system, though the exact cause of the effect is undetermined. Dredging activities in the Cowlitz and Columbia rivers during spawning runs may entrain and kill eulachon or otherwise result in decreased spawning success.

Eulachon have been shown to carry high levels of chemical pollutants, and although it has not been demonstrated that high contaminant loads in eulachon result in increased mortality or reduced reproductive success, such effects have been shown in other fish species. Eulachon harvest has been curtailed significantly in response to population declines. However, existing regulatory mechanisms may be inadequate to recover eulachon stocks.

Global climate change may threaten eulachon, particularly in the southern portion of its range where ocean warming trends may be the most pronounced and may alter prey, spawning, and rearing success.

2.9.5 Regulatory Status

On March 13, 2009, NMFS proposed listing the Southern DPS of eulachon as a threatened species (74 FR 10857). This DPS encompasses all populations within the states of Washington, Oregon, and California, and extends from the Skeena River in British Columbia (inclusive) south

to the Mad River in Northern California (inclusive). The DPS is divided into four sub-areas: Klamath River, Columbia River, Fraser River, and British Columbia coastal rivers south of the Nass River. Adult eulachon to have been recorded from several locations on the Washington and Oregon coasts and were previously common in Oregon's Umpqua River and the Klamath River in northern California (Hay and McCarter 2000; Willson et al. 2006; NMFS 2010a).

On March 18, 2010, NMFS listed the southern DPS of eulachon as threatened under the ESA (75 FR 13012). NMFS determined that the species is comprised of at least two DPS units:

- A southern DPS consisting of populations spawning in rivers south of the Nass River in British Columbia, Canada, to, and including, the Mad River in California; and
- At least one (and perhaps several) additional DPS from the Nass River to the northern and western extent of the species' range.

The southern DPS listing as "threatened" is based on an evaluation of its status and of existing efforts to protect the species. The current abundance of eulachon is low and declining in all surveyed populations throughout the DPS. Eulachon populations spawning in the Klamath River, lower Columbia River Basin, and Fraser River have declined substantially and the southern DPS will likely become endangered in the near future if ongoing threats are not addressed. Past and ongoing Federal, state, and local protective efforts (many of them habitat-based) have contributed to the conservation of the southern DPS, but these efforts alone do not sufficiently reduce the extinction risks faced by the southern DPS. On July 3, 2013 NMFS issued a Notice of Intent to prepare a recovery plan for Pacific eulachon for the conservation and survival of the species (78 FR 40104). To date, no recovery plan has been released.

Specific threats for the Klamath River and lower Columbia River Basin portions of the southern DPS (NMFS 2010a; 75 FR 13012, March 18, 2010), as identified by NMFS(2010) are listed below:

- Climate change impacts on ocean conditions;
- Eulachon by-catch;
- Climate change impacts on freshwater habitat;
- Dams / water diversions;
- Water quality; and
- Dredging.

NMFS designated critical habitat for eulachon on October 20, 2011 (76 FR 65324) including approximately 539 km (335 miles) of riverine and estuarine habitat in California, Oregon, and Washington within the geographical area occupied by southern DPS eulachon. These critical habitat areas contain one or more of the physical or biological features essential to the conservation of the species; tribal land is excluded from this listing. Unoccupied areas have not been designated as critical habitat at this time.

The physical or biological features essential to the conservation of the southern DPS eulachon fall into three major categories reflecting key life history phases:

- Freshwater spawning and incubation sites with water flow, quality and temperature conditions and substrate supporting spawning and incubation, and with migratory access for adults and juveniles.
- Freshwater and estuarine migration corridors associated with spawning and incubation sites that are free from obstruction and with water flow, quality and temperature conditions supporting larval and adult mobility, and with abundant prey items supporting larval feeing after the yolk sac is depleted.
- Nearshore and offshore marine foraging habitat with water quality and available prey, supporting juveniles and adult survival.

2.10 Green Sturgeon (Southern DPS)

Green sturgeon is a long-lived, slow-growing fish and the most marine-oriented of the sturgeon species.

2.10.1 Distribution

Green sturgeon is a widely-distributed and marine-oriented species found in nearshore waters from Baja, California to Canada. Green sturgeon are anadromous, spawning in the Sacramento, Klamath, and Rogue rivers in the spring. Adults enter their natal river and spawn in the spring, and typically leave the river the following autumn (NMFS 2007a). Green sturgeon inhabit certain estuaries on the northern California, Oregon, and Washington coasts during the summer, and inhabit coastal marine waters along the central California coast and between Vancouver Island, B.C. and southeast Alaska over the winter (NMFS 2007a).

2.10.2 Life History

Green sturgeon have a complex anadromous life history, spending more time in the ocean than any other sturgeon species. The majority of green sturgeon are thought to spawn in the Klamath River, but spawning also occurs in the Columbia River, Sacramento, and Rogue rivers. Green sturgeon is a long-lived, slow-growing species. First spawning occurs at 15 years for males and 17 years for females. Female green sturgeon are thought to spawn only every 5 years. Adults migrate into rivers to spawn from April to July with a May to June peak. Eggs are spawned among rocky bottom substrates and juveniles spend 1 to 4 years in freshwater. After green sturgeon enter the ocean, they make northern migrations. Green sturgeon concentrate in coastal estuaries, particularly the Columbia River estuary and coastal Washington estuaries during the late summer and early fall. Neither feeding nor spawning occurs in association with these concentrations. Grays Harbor is the northern most estuary with green sturgeon summer concentrations. A few green sturgeon have been recovered in Puget Sound as incidental harvest (Adams et al. 2002).

2.10.3 Prey

The only feeding data collected on adult green sturgeon indicates that they are consuming benthic invertebrates including shrimp, mollusks, amphipods, and small fish (Moyle et al. 1992 as cited in NMFS 2007a).

2.10.4 Threats

Green sturgeon face several threats, including the loss of spawning habitat, degradation of water quality in occupied areas, fisheries harvest, and poaching. The freshwater habitat used by green

sturgeon for spawning has been affected by habitat alteration from water development and land-use practices causing sedimentation (NMFS 2007a and 75 FR 30714).

2.10.5 Regulatory Status

There are two DPSs defined for green sturgeon – a northern DPS with spawning populations in the Klamath and Rogue rivers and a southern DPS that spawns in the Sacramento River (NMFS 2008c). The southern DPS includes all spawning populations of green sturgeon south of the Eel River in California, of which only the Sacramento River currently contains a spawning population. The southern DPS of green sturgeon has been listed as a threatened species under the ESA (71 FR 17757), whereas the northern DPS is a Species of Concern.

On April 7, 2006 NMFS listed the Southern DPS of green sturgeon threatened under the Endangered Species Act (71 FR 17757). A final ESA 4(d) rule adopting regulations to conserve the southern DPS of green sturgeon was issued on June 2, 2010 (75 FR 30714). On October 24, 2012, NMFS initiated a 5-year review of the southern DPS to ensure the accuracy of the listing classification of the species.

Critical habitat for the southern DPS was designated on October 9, 2009 (74 FR 52300). The specific geographic area includes coastal U.S. marine waters within 60 fathoms depth from Monterey Bay, California (including Monterey Bay), north to Cape Flattery, Washington, including the Strait of Juan de Fuca, Washington, to its United States boundary; the Sacramento River, lower Feather River, and lower Yuba River in California; the Sacramento-San Joaquin Delta and Suisun, San Pablo, and San Francisco bays in California; the lower Columbia River estuary; and certain coastal bays and estuaries in California (Humboldt Bay), Oregon (Coos Bay, Winchester Bay, Yaquina Bay, and Nehalem Bay), and Washington (Willapa Bay and Grays Harbor). This rule designates approximately 515 km (320 miles) of freshwater river habitat, 2,323 km^2(897 $mile^2$) of estuarine habitat, 29,581 km^2(11,421 $mile^2$) of marine habitat, 784 km (487 miles) of habitat in the Sacramento-San Joaquin Delta, and 350 km^2(135 $miles^2$) of habitat within the Yolo and Sutter bypasses (Sacramento River, CA).

The specific primary constituent elements identified for green sturgeon in costal marine areas include (1) migratory corridor, (2) water quality, and (3) food resources.

2.11 Rockfish (Bocaccio Rockfish, Canary Rockfish, Yelloweye Rockfish)

At least 63 species of rockfishes (Family Scorpaenidae: Genus *Sebastes*) inhabit waters of the northeast Pacific, from the Gulf of Alaska to California (Robins et al. 1980 as cited in Love et al. 1990). Once supporting an important commercial and sport fishery, numbers of some species have become severely depleted in recent decades. Of the many species of rockfish, there are three native to Northern Puget Sound listed on the endangered species list: bocaccio, canary, and yelloweye rockfish. Washington State has recently completed a conservation management strategy that attempts to protect remaining populations and rebuild depleted stocks (WDFW 2011a).

2.11.1 Distribution

Rockfish as a group are among the most common species of fish found in Puget Sound. They are year-round residents and can be found in nearly every area, depth, and habitat type. The three listed rockfish species (bocaccio, canary, and yelloweye) are all considered members of the

"deep water" assemblage of this species, and are not typically found in nearshore marine areas, but rather, prefer rocky, deep water habitat.

2.11.2 Life History

Rockfish are some of the longest lived fish known in Puget Sound, with some individuals living to beyond 50 years. Some species of rockfish may mature as early as age two, but it is more common for these species take from 6 to 11 years to reach sexual maturity, while the yelloweye rockfish may not become sexually mature until age 22 (Palsson et al. 2009). Old, large female fish produce exponentially more offspring than younger fish. Rockfishes are unusual among the bony fishes in that fertilization and embryo development is internal and female rockfish give birth to live larval young (timing provided in Table 2.10-1). Larvae are found in surface waters and may be distributed over a wide area extending several hundred miles offshore. Larvae and small juvenile rockfish may remain in open waters for several months being passively dispersed by ocean currents. Juvenile rockfish "settling-out" or recruiting to nearshore habitats in Puget Sound move along specific "recruitment pathways" that include many types and a succession of habitats. Early in the recruitment process, each successive habitat is occupied for short periods, varying from days to weeks, or one to two months. These recruitment pathways end at specific nursery habitats that are benthic, usually composed of rock substrate, and have abundant food resources. Juvenile rockfish usually occupy nursery habitats for several months (Palsson et al 2009). A dominant feature of rockfish reproduction is a pattern of infrequent and irregular successful recruitment and many years with poor recruitment (WDFW 2011a). Reproductive success may occur only during narrow spatial and temporal windows when conditions are favorable for larval survival.

Table 2.10-1 Life History Timing

Deep-water Assemblage Rockfish Species listed under ESA	Timing of Larvae Release	Size of Larvae	Transform into Pelagic Juveniles @ Size	Time Interval till Juveniles Settle to Shallow Areas	Age at Sexual Maturity (years)	Lifespan (years)
Bocaccio (S. *paucispinis*)	January thru April	4.0 – 5.0mm at release	1.5 – 3.0 cm	3.5 to 5 months @ 3 to 4 cm in length	4-6	54
Canary rockfish (S. *pinniger*)	Winter	4.0 – 5.0 mm	19 – 40 mm	~ 4 months	5-(8	84
Yelloweye rockfish (S. *ruberrimus*)	February thru September	--	--	NA[1]	6-22	118

Source: 74 FR 18516; Palsson et al 2009
NA – data not available, expected to be similar or lower than for bocaccio or canary rockfish

At various times during their life history, members of this genus are found from the shallow intertidal zone to at least 768 meters (2,520 feet) in depth, over almost every bottom type and throughout much of the water column. Most rockfish species have small home territories as adults, making larvae the primary mode of dispersal (Berkely et al. 2004). Juveniles and subadults tend to be more common than adults in shallower water, and are associated with rocky reefs, kelp canopies, and artificial structures such as piers and oil platforms. Adults generally move into deeper water as they increase in size and age, but usually exhibit strong site fidelity to rocky bottoms and outcrops (Palsson et al. 2009; Drake al. 2010).

2.11.2.1 Bocaccio Rockfish

Bocaccio are large Pacific coast rockfish that reach up to 1 meter (3 feet) in length. They have a distinctively long jaw extending to at least the eye socket. Their body ranges in color from olive to burnt orange or brown as adults. Young bocaccio are light bronze in color and have small brown spots on their sides.

Bocaccio rockfish are found throughout the coastal waters of the eastern Pacific Ocean from the Gulf of Alaska south to Baja California Mexico. Two tagging studies conducted off the coast of California suggest that bocaccio movement occurs during the first few years of life and they become more sedentary as they age. The amount of movement appears to drop off after they reach a length of 47 cm (18.5 inches). The depth of catch is slightly shallower during summer than winter, with median depth of catch in the trawl fishery of 110 meters (361 feet) in summer to 180 meters (591 feet) in winter (Groundfish Atlas 2011).

Bocaccio rockfish bear live young and produce between 20,000 and 230,000 eggs. Fecundity tends to increase with the size of a female. Copulation occurs early in the fall with larval release over the winter. Off Washington and Oregon, larval release begins in January and runs through April and February, respectively (Lyubimova 1965; Moser 1967; Westrheim 1975; Wyllie-Echeverria 1987, and Love et al. 2002 all as cited in Drake et al. 2010). The larvae are 4-5 mm (0.16-0.20 inch) in length at parturition and metamorphose into pelagic juveniles at 19 - 40 mm (0.75- 1.57 inch) over a period of several months. The growth of juveniles is rapid at around 0.56 - 0.97 mm (0.02-0.04 inch) per day. They can reach 24 cm (9.45 inches) in length by the end of the first year. The juveniles settle into littoral and demersal habitat from late spring throughout the summer. Young-of-the-year live near the surface for a few months and then settle in nearshore areas where they form schools over bottom depths of 30-120 meters (98-394 feet). Adults may be semi-pelagic and are found over a variety of bottom types between depths of 60-300 meters (197-984 feet) [Groundfish Atlas 2011]) Maximum age is estimated at 54 years (Ralston and Ianelli 1998 as cited in Drake et al. 2010).

Demographically, this species demonstrates some of the highest recruitment variability among rockfish species, with many years of failed recruitment being the norm (Tolimieri and Levin 2005). High fecundity and episodic recruitment events, largely correlated with environmental conditions, mean that bocaccio populations do not follow consistent growth trajectories. Zabel et al. (2011) modeled the effect of climate variability and density of recruitment rates and demonstrated the climate indices accounted for 52 percent of the variability in recruitment, whereas density only explained 1.4 percent of the variance.

2.11.2.2 Canary Rockfish

Canary rockfish, (*Sebastes pinniger*) are distributed in the northeast Pacific Ocean from the western Gulf of Alaska to northern Baja California; however, the species is most common off the coast of central Oregon. Canary rockfish primarily inhabit waters 50-250 meters (160-820 feet) deep but may be found up to 425 meters (1,400 feet). Juveniles and sub-adults tend to be more common than adults in shallow water and are associated with rocky reefs, kelp canopies, and artificial structures, such as piers and oil platforms. Adults generally move into deeper water as they increase in size and age but usually exhibit strong site fidelity to rocky bottoms and outcrops where they hover in loose groups just above the bottom (NMFS 2011a).

Very little is known about the early life history strategies of canary rockfish, but limited research indicates larvae are strictly pelagic (near ocean surface) for a short period of time, begin to migrate to demersal waters during the summer of their first year of life, and develop into juveniles around nearshore rocky reefs, where they may congregate for up to three years (Methot and Piner 2001). Like all rockfish, they give birth to live young that drift in the surface layers as larvae for a few months, before growing into juveniles that begin to settle to deeper water and more structurally complex habitats (WDFW 2011a). Evaluations of length distributions by depth developed from NMFS shelf trawl survey data generally supports research that suggests this species is characterized by an increasing trend in mean size of fish with depth (Boehlert 1980, Archibald et al. 1981). Female canary rockfish generally grow faster and reach slightly larger sizes than males, but do not appear to live longer than males.

Canary rockfish off the U.S. Pacific coast exhibit a protracted spawning period from September through March, probably peaking in December and January off Washington and Oregon (Johnson et al. 1982, Hart 1988). Female canary rockfish reach sexual maturity at roughly eight years of age. Like many members of *Sebastes*, canary rockfish are ovoviviparous, whereby eggs are internally fertilized within females, and hatched eggs are released as live young (Bond 1979, Golden and Demory 1984, Kendall and Lenarz 1987). Canary rockfish are a relatively fecund species, with egg production correlated with size, e.g., a 49 cm (19.3 inch) female can produce roughly 0.8 million eggs and a female that has realized maximum length (say 60 cm [23.6 inches]) produces approximately 1.5 million eggs (Gunderson et al. 1980). Maximum age of canary rockfish is at least 84 years although 6 to 75 years is more common (Cailliet et al. 2000 as cited in Drake et al. 2010).

2.11.2.3 Yelloweye Rockfish

Yelloweye Rockfish range from northern Baja California to the Aleutian Islands, Alaska, but are most common from central California northward to the Gulf of Alaska. Juveniles and subadults tend to be more common than adults in shallower water, and are associated with rocky reefs, kelp canopies, and artificial structures such as piers and oil platforms. An inshore to offshore ontogenetic movement of yelloweye rockfish is documented, with juveniles moving from shallow rock reefs to deeper pinnacles and rocky habitats. Yelloweye rockfish adults do not move much and are generally considered to be site-attached (Love 1978, Coombs 1979, DeMott 1983 all cited in Drake et al. 2010). Yelloweye rockfish occur in waters 25 to 475 meters (80 to 1560 feet) deep, but are most commonly found between 91 to 180 meters (300 to 590 feet) [NMFS 2011a]).

Female yelloweye rockfish can produce from 1.2 million to 2.7 million eggs over a reproductive season, with a mean eggs per gram of body weight of 300 (MacGregor 1970, Hart 1973). Reports on maturity for yelloweye rockfish vary among areas and are ambiguous, given the use of whole otoliths for ageing in some studies, but generally seem to reach 50 percent maturity at around 40 to 50 cm and ages of 15 to 20 years (Rosenthal et al. 1982; Wyllie-Echeverria 1987; Yamanaka and Kronlund 1997).

2.11.3 Prey and Predator

Larval rockfish feed on diatoms, dinoflagellates, tintinnids, and cladocerans; while juveniles consume copepods and euphausiids of all life stages. Adults eat demersal invertebrates and small fishes, including other species of rockfish, associated with kelp beds, rocky reefs, pinnacles, and sharp drop-offs (Groundfish Atlas 2011).

Rockfish are important prey for several species of marine birds, marine mammals, and lingcod (WDFW 2011a). The main predators of juvenile rockfish are seabirds including the least tern. The main predators of adults are marine mammals such as harbor seals and northern elephant seals (Groundfish Atlas 2011).

2.11.4 Threats

Rockfish are fished directly and are often caught as bycatch in other fisheries, including those for salmon. Adverse environmental factors led to recruitment failures in the early-to-mid-1990s. These declines were largely caused by historical fishing practices, although other stress factors have also played a part in their decline. Rockfish in urban areas are exposed to high levels of chemical contamination, which may be affecting their reproductive success. Poor water quality in Hood Canal has resulted in massive periodic kills of rockfish as well as other species. In addition, lost or abandoned fishing nets trap and kill large numbers of rockfish.

2.11.5 Regulatory Status

On July, 27, 2010 NMFS listed the Puget Sound/Georgia DPSs of yelloweye and canary rockfish as threatened, and bocaccio rockfish as endangered under the ESA (75 FR 22276). Proposed protective regulations for yelloweye and canary rockfish under ESA section 4(d) will be addressed in a separate rulemaking. In 2011, WDFW released a Final EIS for the Puget Sound Rockfish Conservation Plan (PSRCP), which aims to maintain and improve rockfish abundance, distribution, diversity, and long-term productivity in their natural habitats. The plan also provides a framework for state managers to follow when developing regulations, establishing priorities, and providing guidance.

Critical habitat was proposed for these three rockfish species on August 6, 2013 (78 FR 47635). The specific areas proposed for designation for canary rockfish and bocaccio include approximately 1,184.75 sq. miles (3,068.5 sq. km) of marine habitat in Puget Sound, including 610.0 sq. miles of nearshore habitat for canary rockfish and bocaccio, and 574.75 sq. mi (1,488.6 sq. km) of deepwater marine habitat. Specific areas for yelloweye rockfish are the same 574.75 sq. mi (1,488.6 sq. km) of deepwater marine habitat in Puget Sound. Critical habitat for yelloweye rockfish does not include nearshore areas.

The primary constituent elements identified for proposed rockfish critical habitat are described in the following two major categories reflecting key life history phases (NOAA 2013):

Adult canary rockfish and bocaccio, and adult and juvenile yelloweye rockfish: Benthic habitats or sites deeper than 30 meters (98 feet) that contain rock or highly uneven habitat features to provide the structure needed for rockfish to avoid predation, seek food and persist for decades. The quality of the habitat is dependent upon the quantity, quality, and availability of prey species, water quality and sufficient levels of dissolved oxygen (DO), and the type and amount of habitat structure and rugosity.

Juvenile canary rockfish and bocaccio only: Juvenile settlement habitats located in the nearshore[5] with substrates such as sand, rock and/or cobble compositions that also support kelp to enable forage opportunities and refuge from predators, and also enable behavioral and physiological changes needed for juveniles to occupy deeper adult habitats. The quality of the habitat is dependent upon the quantity, quality, and availability of prey species, and the water quality and sufficient levels of DO to support growth, survival, reproduction, and feeding opportunities.

2.12 Marbled Murrelet

The marbled murrelet (*Brachyramphus marmoratus*) is a small diving seabird in the Alcidae Family. It is distinguishable by its chubby compact body, very short neck, thin black bill, and dark sooty upper feathers, and white marbled under belly. In the summer months the feathers molt and turn to a mottled brown. They display no sexual dimorphism and both sexes have identical plumages; juvenile marbled murrelet plumage closely resembles adult birds during the summer molting season (Marshall 1988). The small wings and rear-placed legs have adapted these birds to excel at diving and underwater maneuvering to hunt for prey (Murphy 1988).

2.12.1 Distribution

North American populations of marbled murrelet are found along the Pacific coast, ranging from south-central California up to Alaska. During the summer months their range extends further north to Alaska's Kodiak Peninsula and the Aleutian Islands. Some wintering birds have been found as far south as northern Baja California, Mexico (USFWS 1997). They primarily colonize the ocean coasts and saltwater bays and sounds, but have also been found inhabiting rivers and lakes within close proximity to the ocean. During breeding and nesting season they fly inland to mature forests up to 80 km (50 miles) from the coast, with rare instances of occupation recorded slightly further inland (Marshall 1988 and USFWS 1997).

2.12.2 Life History

Marbled murrelets are generally solitary or paired, but have been found to interact in small groups or loose flocks. They do not reach sexual maturity until at least 2 years of age and females do not lay eggs until they are at least 3 years old. Marbled murrelets nest once a year on the limbs of large trees in old-growth forests, using a small depression in existing moss or other materials on the tree limbs as a nest to lay a single egg (Marshall 1988 and USFWS 1997). The nesting season is late March to late September, with the highest activity from early May through early August in Washington (Nature Serve 2014a). Both sexes incubate the egg in alternating 24-hour periods for about a month, and the young stay in the nest for another 28 days (Marshal 1998 citing Hirsch et al. 1981, Nelson and Hamer 1995a, Simons 1980). Marbled murrelets are estimated to live an average of 10 years (USFWS 1997).

[5] Most nearshore areas are contiguous with the shoreline from the line of extreme high water out to a depth no greater than 30 meters (98 feet) relative to mean lower low water. Several nearshore areas proposed as critical habitat are not associated with a beach, but are shallower than 30 meters and can support kelp and rearing habitat. They include areas of Hein Bank, Partridge Bank, Coyote Bank, and Middle Bank, and several areas north of Orcas Island.

2.12.3 Prey

Marbled murrelet subsists mostly on small fish and the occasional crustacean. They dive for prey in nearshore open waters up to 80 meters (260 feet) deep, and have been known to dive up to 30 meters (98 feet) below the surface for food (Nature Serve 2014a). In the Pacific Northwest, the main fish prey include Pacific sand lance (*Ammodytes hexapterus*), Pacific herring (*Clupea harengus*), northern anchovy (*Engraulis mordax*), and smelts (*Osmeridae*). Adults and foraging subadults, feed primarily on smaller larval or juvenile fish, whereas nestlings are most commonly brought large adult or subadult fish. The Pacific sand lance is the most common food of the species across its range and appears to be the most significant prey species in a fledgling's diet (USFWS 1997). Sardines and rockfish (Scorpaenidae) may also make up important dietary components, particularly at the southern range of the marbled murrelets habitat. In Washington and Canada, murrelets have been observed foraging in inland lakes for salmonid species during the breeding and nesting season (USFWS 1997 citing Carter and Sealy 1986). Crustaceans are not a common part of the marbled murrelets diet during the summer, but have been observed as a supplemental prey for populations during the winter and early spring months (USFWS 1997).

2.12.4 Threats

The primary anthropogenic threat to marbled murrelets is the historical and continued logging of old-growth and mature coastal coniferous forests, which reduces critical nesting areas and creates greater vulnerability of nest-predation due to fragmented tree cover. Aquatic threats include marine pollution, entanglement in fishing gear and changes in prey availability linked to fishing pressures (USFWS 1997 and USFWS 2009).

The 2009 5-year review indicates that murrelets in the Pacific Northwest have been in decline over the past decade (7 percent per year; Pearson et al. 2011) with the most recent population estimated at 4,300 birds (USFWS 2009). The primary factor contributing to the decline of murrelets is loss of nesting habitat (USFWS 1997).

2.12.5 Regulatory Status

On September 28, 1992 the USFWS listed marbled murrelet as threatened under the ESA(57 FR 45328), and is state listed as threatened in Oregon and Washington and as endangered in California. On January 21, 2010, a petition to delist the marbled murrelet was rejected (75 FR 3424) in a determination that removing the species from the endangered species list was not warranted, and it reaffirmed that the marbled murrelet continues to meet the definition of a threatened species under the ESA (USFWS 2011).

Critical habitat was designated for the marbled murrelet in Washington, Oregon, and California on May 24, 1996 (61 FR 26256) and included approximately 3,887,800 acres of terrestrial land. A revised rule was adopted on November 4, 2011 (76 FR 61599) and reduced the critical habitat acreage in northern California and southern Oregon by approximately 189,671 acres (USFWS 2011). Primary constituent elements for marbled murrelet include trees with potential nesting platforms and forested areas within 0.8 km (0.5 mile) of potential nest trees with a canopy height of at least half of the site potential tree height (USFWS 2009).

2.13 Leatherback Turtle

The leatherback turtle is the only extant member of the taxonomic family Dermochelyidae, distinguishable by their unique slightly-flexible, leathery, barrel-shaped carapace (top shell), while other sea turtle species have bony, plated carapaces and belong to the Cheloniidae family. Leatherbacks are the largest sea turtle; they can grow to be 1-2.5 meters (4-8 feet) long, and weigh up to around 900 kg (2,000 lbs.) Their skin is predominately black with varying small white spots. A leatherback's ridged carapace is made up of tough, oil-saturated connective tissue, their front flippers are long with no scales or claws, and their back flippers are paddle-shaped (Nature Serve 2014b). With adaptations that help self-regulate body temperature, a stream-lined body shape, and powerful large flippers, leatherbacks are well-adapted to quickly navigate oceans of varying depths and temperatures. They have been known to dive to depths > 1200 meters (4,000 feet), although they typically remain closer to the surface (Eckert 2012, citing Hays et al. 2004 and Doyle et al. 2008). Leatherbacks are highly pelagic, specialized for life at sea and are capable of undertaking exceptionally long-distance migrations between nesting and foraging areas.

2.13.1 Distribution

Leatherbacks are found circumglobally in tropical and temperate oceans, but smaller numbers of migratory, foraging adults can range up to cooler waters of the Gulf of Alaska and northern Europe, and south to the Cape of Good Hope and Australia. While they are more densely populated in tropical regions—such as south Pacific islands, Costa Rica, and the west coast of Mexico, and in the Atlantic along the coast of Florida, the Caribbean islands, and the western African coast—the leatherback's foraging behavior expands their range considerably. This ocean-going turtle is the most migratory and widely distributed turtle species on the planet.

Despite its wide range, leatherback nesting habitat is confined to sandy tropical/sub-tropical beaches, with quick, easy access to the water's edge from the sand. In the U.S. nesting sites are primarily found in Puerto Rico, the Virgin Islands and southeast Florida (NMFS 2013). Leatherbacks are generally considered to be a pelagic (open ocean) species, but more recent research has shown they also rely upon productive coastal regions for food (NMFS 2013). In the less temperate waters off the U.S. west coast, Pacific populations are known to forage along coastal regions with wind-driven upwelling, or eddies and fronts, that host phytoplankton blooms feeding on nutrient-rich waters rising to the surface (NMFS 2013). The Juan de Fuca eddy, which is active from spring through fall, and the mouth of the Columbia River, both provide a temporal nutrient-rich coastal environment preferred by leatherbacks (NMFS 2013, WDFW 2012). Appearances along the Pacific Northwest coast generally occur seasonally, and are likely correlated with the higher ranges of sea temperature (14-16 °C; 57-61°F) (NMFS 2013 and WDFW 2012).

2.13.2 Life History

Research on leatherbacks typically delineates five different life stages: (1) egg/hatchling, (2) post-hatchling, (3) juvenile, (4) sub-adult, and (5) adult. Uncertainties remain, due to a lack of data, about when leatherbacks reach sexual maturity; estimates range from 2 to 13-14 to 29 years of age (NMFS 2013 citing Pritchard and Trebbau 1984, Dutton et al. 2005, Avens et al. 2009). Nesting season lasts 3-6 months (in the U.S. from March to July), and the females typically lay about six clutches per season. Individual nesting seasons can have intervals of 2-4 years (Eckert

et al. 2012). Females lay nests of around a hundred 5-cm (2-inch) eggs, and hatchlings emerge after approximately two months of incubation (Nature Serve 2014b). Sex is strongly determined by incubation temperature. Male hatchling are generally dominate during cooler, wet seasons while females are dominate during dryer, warmer temperatures, however the pivotal temperature that will generate a 1:1 ratio of male to female differs by locale (Eckert et al. 2012). Hatchling's emergence success is generally about 50 percent (Eckert et al. 2012), and the hatchlings then face a high risk of predation on their journey to the sea. Data indicates leatherbacks follow a similar life history strategy as other long-lived reptile species, having lower survival rates of eggs and juveniles, delayed age of maturity, and then a relatively constant and high annual survival rate after reaching the subadult stage (NMFS 2013). It has been documented that that most leatherbacks populations have some degree of nesting site fidelity, and adults generally migrate to the region where they were born to lay their eggs (Eckert et al. 2012). Lifespan of the leatherback sea turtle is largely unknown, average estimates range around 40 years of age; some leatherbacks alive today have been tagged for close to 20 years (Eckert et al. 2012).

2.13.3 Prey

Leatherback turtles subsist almost entirely upon jellyfish, but have also been known to opportunistically forage on other gelatinous organisms and small invertebrates. They generally consume 20-30% of their body weight daily to gain their required nutritional value (Eckert et al. 2012).

2.13.4 Threats

Leatherbacks face the highest threat at their nesting beaches from worldwide, illegal harvest of eggs and incidental take in commercial fishing gear (WDFW 2012). Floating plastic debris, often resembling their staple diet of jelly fish is commonly found to be accidentally ingested, and is responsible for higher rates of mortality. Leatherbacks also face nesting and foraging habitat loss, the disorientation of hatchlings from artificial lighting, and natural nest-predation (WDFW 2012).

2.13.5 Regulatory Status

The leatherback turtle was listed under the Endangered Species Act as an endangered species throughout its range in 1970 and was transferred to the current list of endangered species when the ESA was passed in 1973. It remains listed as an endangered species today. In 2012, NMFS designated leatherback critical habitat areas (50 CFR 226.207) off the coast of Washington and Oregon, these areas serve as important nearshore foraging areas for the species (NMFS 2012b). Designated critical habitat include waters 0-80 meters (0-260 feet) deep extending to the 2,000 meter (6,562 foot) depth contour and bound within the U.S. Exclusive Economic Zone (EEZ) from Cape Blanco, Oregon north along the shoreline to Cape Flattery, Washington (WDFW 2012). Primary constituent elements of leatherback critical habitat include (1) migratory pathway conditions and (2) quality and quantity of prey.

Chapter 3

Environmental Baseline

The environmental baseline is the past and present impacts of all Federal, State, or private actions and other human activities in the Action Area, the anticipated impacts of all proposed Federal projects in an Action Area that have already undergone formal or early section 7 consultation, and the impact of State or private actions that are contemporaneous with the consultation in process. [50 CFR §402.02] It identifies the effects of past and ongoing human and natural factors leading to the status of the species, its habitat, and ecosystem within the Action Area.

The currently permitted project is included in the baseline because it was subject to a prior consultation, it was constructed and it has been operational and has been affecting the baseline since 2001. The project as it is currently being operated has two components:

- Vessel traffic –tanker, tug and barge traffic to and from the BP Marine Terminal, including the marine route through the Strait of Juan de Fuca and the San Juan Archipelago, and moorage at the dock facility during loading and unloading;
- Operation and maintenance of BP Marine Terminal including North Wing – consisting of a ship berth, loading and unloading equipment, control and metering equipment for refined product loading and unloading, and oil spill preparedness and response which includes the staging and deployment of work boats for pre-booming operations; deployment of oil spill containment booms for pre-booming during loading and unloading operations; and the staging of additional oil spill boom, sorbent pads, and an oil spill skimmer in the event of an oil spill at the dock. Regular oil spill drills are conducted to ensure a quick and appropriate response to an unintentional release.

In addition, the operation of the refinery, tank farm, and interconnecting piping between these facilities and the South Wing of the BP Marine Terminal are part of the environmental baseline, as is the existence of the North Wing and its connection to onshore facilities. Effects of these components are included as part of the environmental baseline when analyzing the effects of this action because they have already been constructed. Effects from the Proposed Action, which are related to the North Wing and not considered part of baseline, are associated with an incremental increase in vessel traffic expected as part of the Proposed Action.

3.1 Vessel Traffic

Since 2000, Ecology has maintained data and produced an annual report entitled ‘Vessel Entries and Transits for Washington Waters’ (VEAT) to provide information about commercial vessel traffic in Washington waters. These annual reports include relevant classifications of Cargo and Passenger vessels (C&P), Tank Ships and Tank Barges that travel along the routes likely to be used by the tank vessels calling at the North Wing of the BP Marine Terminal. The VEAT reports show that overall vessel traffic in Puget Sound has experienced a slight decline over the past 11 years (Table 3.1-1; Figure 3.1-1). The 2011 sum annual traffic, of relevant classification,

in the Action Area was 16,789 transits (Table 3.1-1) which is based on two transits per call (a vessel must make a trip in and a trip out of Puget Sound to complete a "call").

Table 3.1-1 Puget Sound Shipping Traffic 2000-2011

Vessel Entries and Transits for Washington Waters — Total Traffic (Transits)												
Traffic Type	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
C&P	9,260	9,616	9,208	9,348	8,948	9,542	9,074	8,376	8,936	8,182	8,220	9,038
Tank Ships	1,182	2,646	1,234	1,286	1,350	1,250	1,442	1,690	1,464	1,680	1,640	1,322
Tank Barges	7,928	5,712	5,436	6,014	6,372	7,826	6,250	4,944	5,934	7,138	6,446	6,192
Fishing Vessels	652	748	672	574	566	506	414	464	496	386	340	246
Sum of Traffic	19,022	18,722	16,550	17,222	17,236	19,124	17,180	15,474	16,830	17,386	16,646	16,798

Source: Ecology 2000-2011

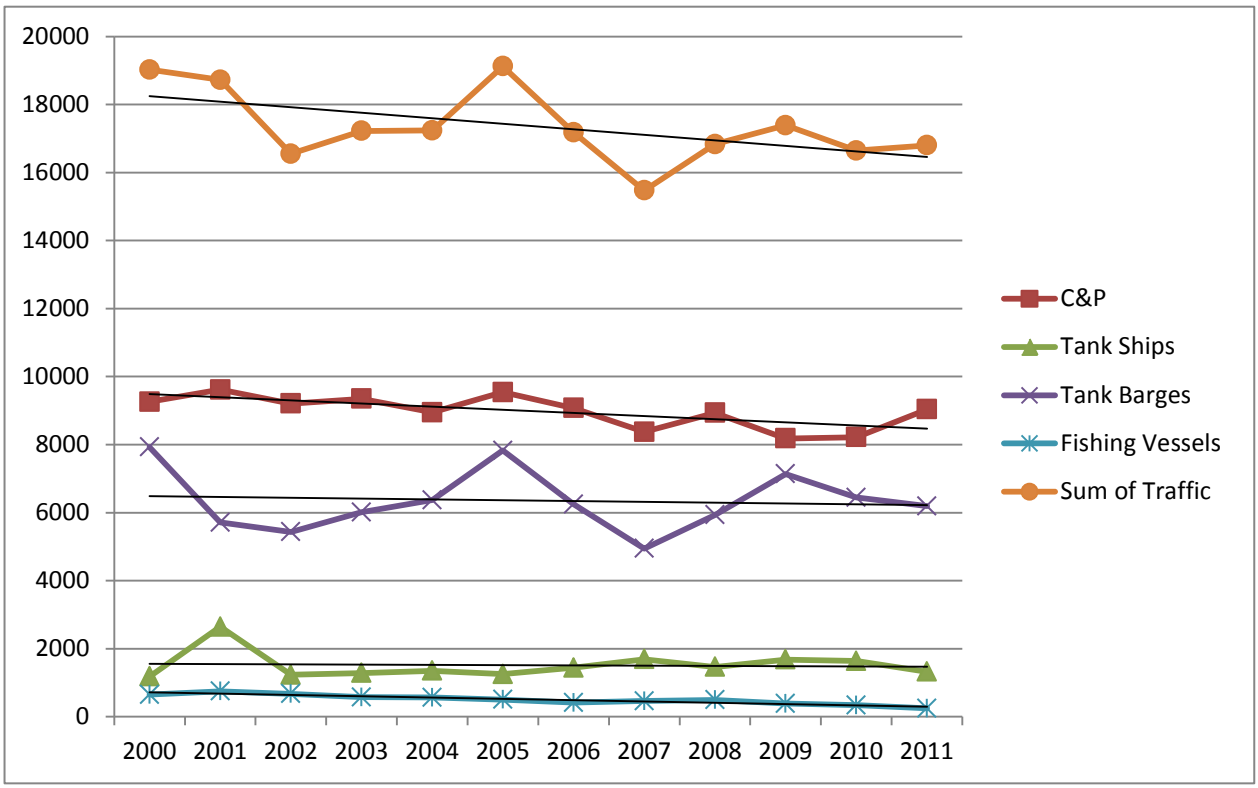

Figure 3.1-1 Puget Sound Shipping Traffic 2000-2011

Source Ecology 2000-2011

3.1.1 Vessel Traffic to BP Marine Terminal

Vessels transiting to the BP Marine Terminal from Alaska, Oregon, California, and international origins enter the Strait of Juan de Fuca and travel to Port Angeles, Washington, where a pilot comes onboard. Tankers (except double hull tankers less than 40,000 deadweight [DWT]) carrying oil or oil products are required to pick-up two escort tugs between buoy "R," north of New Dungeness Lighthouse, before transiting to the BP Marine Terminal. Most vessels then

transit through Rosario Strait to the southern reach of the Strait of Georgia and onto the BP Marine Terminal at Cherry Point. In Rosario Strait large commercial vessels – typically laden tankers, are limited to one-way traffic by USCG vessel traffic rules. Thus, no large commercial ship may enter Rosario Strait for passage if another large commercial ship is transiting in the opposite direction. In rare instances, vessels transiting to the BP Marine Terminal may travel north through Haro Strait then north east through Boundary Pass to the BP Marine Terminal at Cherry Point. Vessels check-in with the joint USCG/Canadian Coast Guard (CCG) Cooperative Vessel Traffic Service prior to entering the Strait of Juan de Fuca and remain under either USCG or CCG control the entire time they are transiting to/from ports within the Strait of Juan de Fuca, Puget Sound, or the Georgia Strait. Transits of vessels to and from the BP Marine Terminal occur primarily within a Traffic Separation Scheme (TSS; Figure 3.1-2) operated jointly by the USCG and CCG.

Articulated Tugs-and-Barges (ATBs) and traditional barges (collectively referred to as barges), and some tank ships may transit to the BP Marine Terminal from Puget Sound (generally Seattle and Tacoma). From Puget Sound, these vessels transit westbound through Admiralty Inlet then turn north and pursue a course in the traffic separation lane along the western side of Whidbey Island to its intersection with Rosario Strait. They then enter Rosario Strait and transit north to the BP Marine Terminal.

Vessels approaching the BP Marine Terminal at Cherry Point may be required to come to anchor at the designated temporary anchorage offshore of Vendovi Island if the berths are already in use (Figure 3.1-2).

Vessels departing from the BP Marine Terminal at Cherry Point would take the routes described above in reverse utilizing the southbound or outbound traffic separation lanes as appropriate. Tank ships and barges having called at the BP Marine Terminal at Cherry Point may transit to the refineries located at March Point in Padilla Bay adjacent to Anacortes. There are two routes to Anacortes; the Huckleberry-Saddlebag Route and the Guemes Channel Route. To use the Huckleberry-Saddlebag Route vessels depart the traffic separation lane adjacent to Lummi Island and enter the channel between Lummi Island and Sinclair Island. Passing Vendovi Island, they navigate between Huckleberry and Saddlebag Islands to enter Padilla Bay. The second route makes use of the one-way traffic lane south through Rosario Strait past Cypress Island. The route then turns eastward into Guemes Channel and enters Padilla Bay (Figure 3.1-2).

Prior to construction of the North Wing, the highest number of calls to the BP Marine Terminal occurred in 2000 with 303 vessels calls to the South Wing. However, this number of calls does not reflect the estimated maximum capacity of the BP Marine Terminal with only the South Wing operating. Based on an allocation of dock time between crude and cargo vessels, BP estimates that the South Wing could accommodate up to 335 vessel calls per year when the North Wing is not operational. This value was calculated based on the assumptions shown in Table 3.1-2, and identifies the baseline level of vessel calls at the BP Marine Terminal.

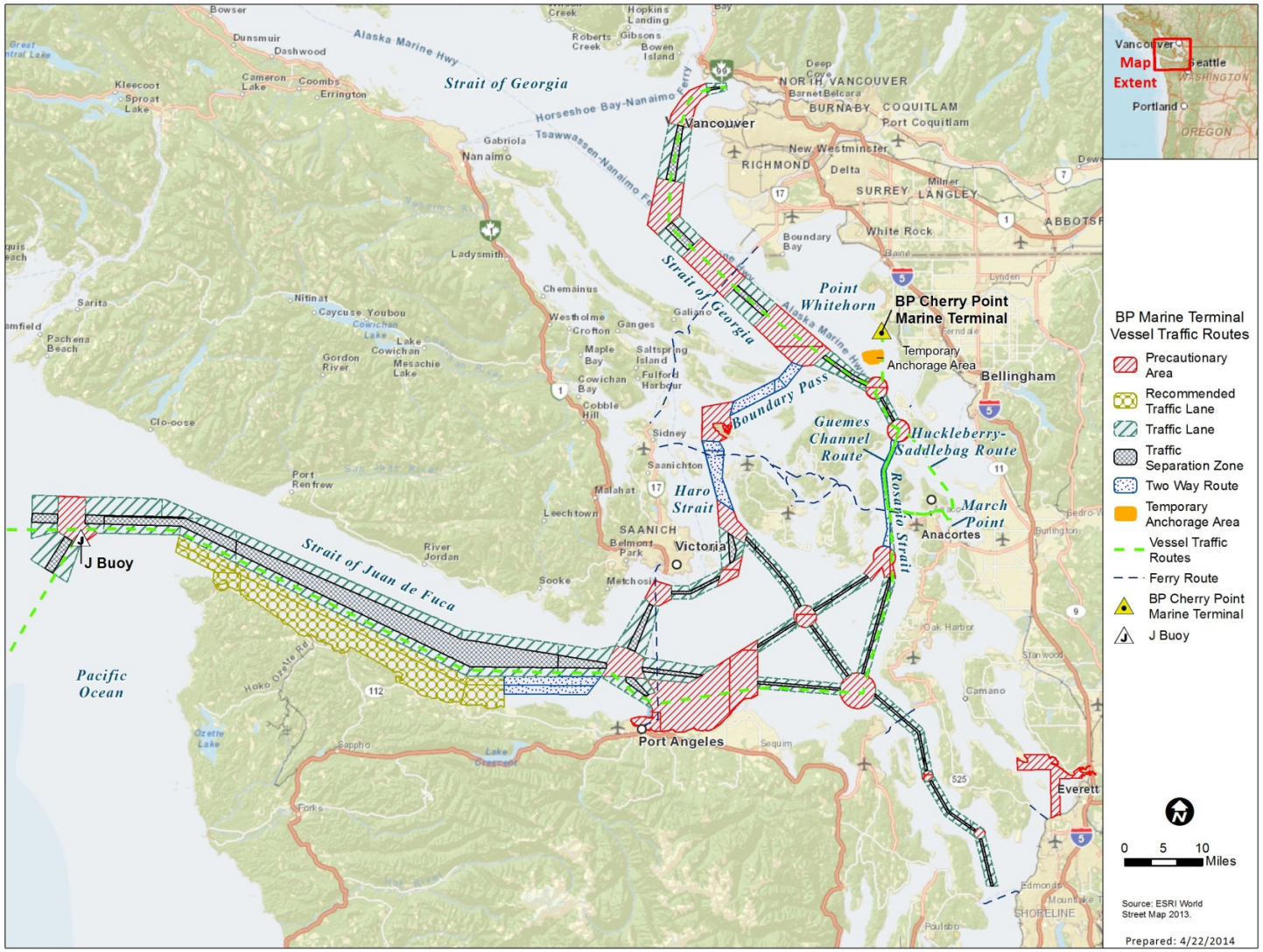

Figure 3.1-2 BP Marine Terminal Vessel Traffic Routes and Temporary Anchorage Area

Table 3.1-2 Maximum Single Wing Dock Capacity Calculation

Out of Service for Maintenance (days/year)	5.5
Out of Service for Weather (days/year)	2.1
Available for Operation (days/hours per year)	357.4 / 8,577.6
Average Time per Call - Excluding Loading/Unloading (hours)[1]	5.2
Average Crude Oil Cargo Size (bbl)	620,000
Average Crude Oil Unloading Rate (barrels per hour)	28,100
Average Crude Oil Unloading Time (hos)	22.06
Number of Crude Oil Vessels/Total Volume (bbl)	138 / 85,560,000
Total Time at Dock – Crude Oil Vessels (hours)	3,762
Average Refined Petroleum Product Cargo Size (barrels)	194,000
Average Refined Petroleum Product Loading Rate (bbl per hour)	10,100
Average Product Unloading Time (hours)	19.21
Number of Refined Petroleum Product Vessels/Total Volume (bbl)	197 / 38,218,000
Total Time at Dock – Refined Petroleum Product Vessels (hours)	4,809.
Total Dock Utilization Time (hours per year)	8,571.

[1]Includes mooring and unmooring, connecting and testing loading and unloading equipment, setting booms, etc.

Between 2001 and 2010, the number of vessel calls exceeded BP's low-range estimate of future calls (170-220 calls) every year, exceeded the medium-range forecast (320–400) in 2007, but did not exceed the high-range estimate of future calls (350–420) in any year. Since the North Wing became operational in 2001, the number of calls has averaged approximately 321 vessels per year, which is within the range of the current conditions scenario.

A Vessel Traffic Risk Assessment (VTRA) study was conducted by The George Washington University (2008) that evaluated the incremental environmental risk of: (1) the vessel traffic associated with the BP Marine Terminal operating with both crude and product transfers occurring only at the South Wing; and (2) the terminal operating with both wings at current and forecasted future vessel traffic levels, with the future year specified as 2025 (The George Washington University 2008). The VTRA notes that tank ship traffic calling at the BP Marine Terminal accounts for 1.1 percent of all traffic in Puget Sound (normalized for time spent in transit) and 2.6 percent of all traffic in Puget Sound when adding barges calling at Cherry Point. Since the majority of the barge traffic is on routes to the southern reaches of Puget Sound, it can be inferred that approximately 1.1 percent of the traffic entering Puget Sound and transiting the Strait of Juan de Fuca is traffic destined for the BP Marine Terminal.

3.1.2 Vessel Sound

Existing underwater sound levels in the Action Area can serve as a baseline from which to measure potential impacts associated with the Proposed Action on ESA listed species. Ambient noise conditions in the marine environment are dependent on source, propagation, and absorption conditions. Commercial shipping traffic, ferry vessel traffic, wind, rain, and biological organisms

are the main contributors to ambient noise levels in Puget Sound. Oceanic traffic influences sound spectral levels from 10 Hz to beyond 10 kHz (Bassett 2010) with the dominant components occurring at low frequencies (5 to 500 Hz; Hildebrand 2004). Ships generate noise primarily by (a) propeller action, (b) propulsion machinery, and (c) hydraulic flow over the hull. The broadband and tonal components produced by cavitation account for 80-85 percent of ship-radiated noise power (Ross 1987 as cited in Hildebrand 2005). Additional vessel noise results from propulsion machinery such as diesel engines and gears, and major auxiliaries such as diesel generators. Likewise, Bassett (2010) states that the source level of sound from commercial ships varies based on ship speed, condition of the vessel, vessel load, and on board activities. While true, the received sound levels recorded in various studies on the effects of sound on marine mammals in Puget Sound (Bassett 2010, Bassett *et al*., 2012, and Veirs and Veirs 2005) record the integrated output from all these sources. Given these available studies do not analyze the component contributions to vessel sounds and the overwhelming component is cavitation, the component contributions to underwater sound levels are not consider further in this analysis.

The fact that information on the component contributions to vessel noise is not available in the cited studies is not a limitation of this analysis because no changes in the fleet calling at BP's Marine Terminal are expected under the Proposed Action. The vessels size, speed, and condition are regulated by the U.S. Coast Guard as part of Puget Sound Vessel Traffic Service (VTS User's manual 2013 Edition, available online http://www.uscg.mil/d13/psvts/). Therefore, other than frequency of vessel calls, no changes in ship speed, condition of the vessels, vessel loads, and on board activities are expected as a result of the Proposed Action.

The most common source of anthropogenic noise in Admiralty Inlet is vessel traffic (Bassett et al. 2012). Background sound data has not been collected specific to the Proposed Action. However, Bassett et al. (2010) analyzed ambient noise sources at a location in eastern Admiralty Inlet, just west of Admiralty Head at Fort Casey State Park and identified permanent noise (noise present when all identifiable sources have been removed, lowest level of background recurring noise) at the site as 98 dB re 1 μPa. Further, from May 2010 to May 2011, Bassett *et al*. (2012) conducted an assessment of ambient noise at a location in northern Admiralty Inlet and prepared a sound budget in which sound energy levels are attributed to various source levels. The study area for the 2012 study included the contiguous waters within a 20 km (12.4 mile) radius of a point 700m (0.43 mile) to the southwest of Admiralty Head. As in Bassett (2010) the major contributor to sound was vessel traffic, but unlike Bassett (2010), Bassett et al .(2012) included vessel traffic in their definition of ambient sound levels. The sound recordings were paired with information from the U.S. Coast Guard Nationwide Automatic Identification System[6] (AIS), which allowed for the association of a specific vessel with its recorded signal. Over the course of their study, Bassett *et al.* (2012) collected data on 1,363 unique AIS transmitting vessels. The AIS data allowed them to calculate source sound level for each of the vessels observed.

Bassett et al. (2012) found, based on overall presence, container ships, passenger ferries and tugs, were the most common vessel types in their study area. As expected the larger faster ships

[6] The Maritime Transportation Security Act of 2002 §70114 requires that all self-propelled commercial vessels of at least 65 ft. overall in length to be equipped with and operate an automatic identification system. These systems transmit vessel identification, course, and speed; similar to transponders used by the aircraft industry.

were the loudest. They estimated the source levels (re 1 µPa at 1 meter) for each of the vessel types as 186 dB_{rms} for containerships, 185 dB_{rms} for bulk carriers, 180 dB_{rms} for vehicle carriers, 180 dB_{rms} for general cargo ships, 181 dB_{rms} for oil and chemical tankers, 173 dB_{rms} for ferries, and 172 dB_{rms} for tugs. Larger fishing vessels (trawlers) and fishing vessels with diesel engines were estimated to generate a source level of 165 dB_{rms} re 1 µPa at 1 meter. Basset et al. (2012) also estimated that total sound energy input in their study area by vessel traffic was over the course of the year of their study was 438 mega joules and of that container ships were responsible for 57% of the input, followed by bulk carriers at 16%. Oil/chemical tankers were responsible for 2% of the energy input.

As in 2010, Bassett *et al.* (2012) found large commercial vessels, including vehicle carriers and bulk carriers, were also common. An AIS-transmitting vessel was found to be present within the study area 90% of the time, and multiple vessels were present 68% of the time. The mean broadband sound pressure level (SPL[7]) at the recording site was 119.2 ± 0.2 dB re 1 µPa (95% confidence interval), and the maximum was 140 dB_{rms} re 1 µPa associate with the passage of container ships transiting at a speed of 23.4 knots at a distance of 2.7 km at its closest approach to the recorder. These measured noise levels are comparable to values from Haro Strait off of the west coast of San Juan Island, reported by Veirs and Veirs (2006), indicating they are likely representative of baseline conditions within the Action Area. Veirs and Veirs (2006) also found that recreational vessels can increase background noise on average 5-10 dB higher than the average large commercial ships.

Given the relatively small contribution oil/chemical carriers made to the energy budget at Admiralty Inlet and assuming that it is representative of the Action Area, the small increase in vessel calls at BP Marine Terminal would not be expected to increase ambient noise levels. The noise from these vessels would be transient and therefore would not result in long term effects to biological organisms. Short-term effects due to an increase in noise from close approaches of passing vessels could be experienced by both baleen and toothed whales and may include temporary call masking and potential changes in diving and foraging behavior (NRC 2005).

3.1.3 Regulatory Context for Assessing the Effects of Sound

All threatened and endangered marine mammals are protected by the Marine Mammal Protection Act, as well as, the ESA. Both statutes prohibit the “take” of covered animals. Although the definitions of the term “take” differ between the statutes, they share comment elements of harassment and killing. In addition, the MMPA defines “harassment” as any act of pursuit, torment, or annoyance which a) has the potential to injure a marine mammal or marine mammal stock in the wild; or b) has the potential to disturb a marine mammal or marine mammal stock in the wild by causing a disruption of behavioral patterns, including but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering. This definition is relevant because NMFS uses it in the administration of the ESA as it applies to listed marine mammals. NMFS currently uses conservative thresholds of received sound pressure levels from broad band sounds that may cause behavioral disturbance and injury (interim guidance):

[7] Meaning, the received sound pressure level was that loud or quieter 50% of the time.

- Level A Harassment (potential injury) from all non-explosive sound sources: 180 and 190 dB re 1 µPa (rms) received level for cetaceans and pinnipeds, respectively.
- Level B Harassment (behavioral harassment) from impulsive sound sources (e.g., seismic air guns): 160 dB re 1 µPa (rms) received level for all species.
- Level B Harassment (behavioral harassment) from continuous sound sources (e.g., drilling): 120 dB re 1 µPa (rms) received level for all species.

With respect to the effects of noise on marine mammals, NMFS considers the onset to permanent threshold shift (PTS) as Level A harassment under the MMPA and harm under the ESA and the onset of temporary threshold shift (TTS) as Level B harassment under the MMPA and harassment under the ESA.

In December 2013, NMFS, published: Draft Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammals – Acoustic Threshold levels for Onset of Permanent and Temporary Threshold Shifts. NMFS proposed this new guidance to reflect the increasing understanding of marine mammal hearing. The proposed guidance recognizes that hearing sensitivity varies among marine mammal groups and organizes marine mammal species into five groups: low frequency cetaceans, which are the baleen whales; mid-frequency cetaceans which are most dolphins, including killer whales, and beaked whales; high frequency cetaceans, which include true porpoise, and pygmy sperm whales; pinnipeds in water; and pinnipeds on land. The guidance also presents dual criteria for each group: one measure in dB_{peak} re 1µPa, and one in dB SEL_{cum}. This latter criterion was developed to take into account that exposures to a sound source over extended periods of time can accumulate as much energy as exposure to a louder sound source for shorter period of time. That is to say the exposure to sound levels that would cause TTS for extended periods of time could result PTS. In addition to the interim guidance discussed above, this draft guidance will be considered below in Chapter 4, as it reflects the best scientific and commercial data available.

3.2 Dock Operations

The BP Marine Terminal consists of a dock with two wings (south and north) that are connected to the shore and the BP Cherry Point Refinery Tank Farm with a trestle and pipelines. The general configuration of the terminal is shown on Figure 3.2-1 BP Marine Terminal – Plan View. The figure shows a “Y” shaped facility that is located approximately 655 meters (2,150 feet) offshore where water depths are approximately 15 to 21 meters (49 to 69 feet) mean sea level (msl). The existing trestle connecting both wings of the dock is approximately 548.64 meters (1,800 feet) long and includes a roadway and piping. Each wing consists of a single vessel berth, a loading platform, and a connecting trestle. The loading platform for the North Wing is 58.67 meters (192.48 feet) long and 27.43 meters (90 feet) wide. It is positioned at the center of the 296-meter (971 foot) long berth, which has mooring positions that allow for both tankers and barges to call at the BP Marine Terminal for unloading and loading operations. Water depth at the loading platform is 18.28 meters (60 feet) msl. The connecting trestle is 290 meters (951 feet) long and includes a platform for vehicle maneuvering, oil spill response equipment, and two hoists for support vessels (workboats/oil spill response vessels).

All mooring dolphins and piles supporting the loading platform and connecting trestle that were constructed as part of the North Wing are steel caissons that have been coated with Tideguard® to prevent corrosion. The coating material is non-ablative and not toxic to marine life.

Figure 3.2-1 BP Cherry Point Refinery and Marine Terminal showing "Y" shaped North and South wings of dock

The pipelines connecting the dock facility to the BP Cherry Point Refinery tank farm are configured so that crude oil can only be loaded or unloaded in commercially sustainable quantities at the South Wing. The North Wing is used exclusively to load or unload refined petroleum product, and BP has stipulated that the North Wing will not be used for the transfer or crude oil cargoes. While the South Wing retains the capability to load or unload refined petroleum product, such operations are rare and the South Wing is used almost exclusively for unloading or loading crude oil.

Ships approach the BP Marine Terminal under the direction of the ships master and harbor pilot and are assisted to the dock by a tug. After docking and securing all lines, an oil spill containment boom is placed against the vessel to enclose the loading area of the vessel. An additional containment boom is deployed surrounding the ship during loading/unloading operations when it is safe and effective to do so.

Vessels only conduct loading/unloading operations in calm and moderate wind/wave conditions as set forth in the Oil Handing Facility Operations Manual. When winds reach a predetermined strength of 35 mph, a precursor to increased wave height, the Dock Operations personnel and the Vessel Captain determine whether to cease transfer operations and unmoor the vessels. If winds

reach a sustained level of 40 mph and waves are estimated at five feet, operations must cease and the vessels are unmoored. After unmooring, vessels move to a temporary anchorage as directed by the USCG to wait for winds/waves to subside to a safe level.

Loading and unloading occurs through large overhead loading arms, which consist of an articulated pipe that connects transfer pipelines to a shipboard manifold. After the loading arm is connected and the connection is leak tested, crude oil or refined products are pumped from/to storage tanks ashore through dedicated pipelines that run across the trestle to the loading/unloading area. The loading arms include safety equipment for rapid shutdown in the event of premature disconnect or failure of the loading arm, or failure at the vessel manifold, that results in loss of primary containment of the material being transferred.

All areas on the dock that contain piping, control valves, and loading arms are confined within containment curbs that drain to an oily-water collection system. All liquids collected within this system are piped ashore and processed by the refinery. The dock also has a roadway that provides vehicle access to the trestle and docks. Spill records at the dock for the period from 1990 through 2010 indicate that incidents are infrequent (typically average two per year), and the volume of spills is usually very small. Many of the incidents reported were in quantities of drops or sheen on the water, and with an average spill volume of 37 liters (9.8 gallons). Since the North Wing became operational in 2001, the average spill volume at the BP Marine Terminal has decreased to 2.5 liters (0.65 gallons).

The BP Marine Terminal has the capacity to receive ballast water from product tankers; however, no ballast water has been received at the BP Marine Terminal since early 2001. If a vessel does wish to discharge ballast water at the BP Marine Terminal, the ballast water must undergo laboratory analysis prior to discharge. The laboratory test results must be received by Cherry Point prior to acceptance of ballast water. This requirement often makes it impractical for vessels to unload ballast water during the short period they are at dock. Vessels arriving with segregated ballast that will be discharged into harbor waters must follow federal and Washington State laws concerning ballast water exchanges before entering state waters. The BP Marine Terminal does not handle bilge water and oily slops.

Annual maintenance of dock equipment occurs in the summer and consists of equipment inspection, replacement, cleaning, painting, and repair, as appropriate. Major maintenance projects are conducted periodically. These projects may involve a large number of workers and include work in the water from workboats. Annual preventive maintenance activities involving in-water, on-water and underwater work are conducted under permits issued by the USACE and other appropriate state and federal agencies. Project-specific activities or other maintenance activities that fall outside the scope of the permits for annual dock maintenance are permitted separately. During in-water work, such as the recent installation of mooring dolphins for the vessel containment boom system, monitoring vessels stand off the dock to monitor the presence of killer whales in the vicinity and to require shutdown of work that would affect killer whales while they are in the immediate vicinity of the dock.

The year with highest throughput at the BP Marine Terminal was 2000, which was prior to the North Wing coming online. In that year, 115,282,883 bbls of crude and product crossed over the South Wing: 64,624,712 bbls of crude oil and 50,658,171 of refined product. Scenarios for

possible changes in the numbers of vessels calling at the BP Marine Terminal are presented in Table 1.2-1.

3.2.1 Oil Spill Prevention and Response Measures:

The BP Marine Terminal is equipped with containment booms and clean-up equipment, which can be readily deployed in the case of an oil spill. The vessel master is responsible for ensuring that adequate precautions have been taken to so that pollution incidents are avoided or minimized. The following measures are checked prior to the vessels arrival at the dock:

- All deck scuppers and drains shall be plugged and sealed.
- An adequate supply of absorption material shall be available on deck for instant use.
- A pumping system shall be in place to draw-off all deck water contaminated by oil or grease, and transfer to a containment tank
- If pumping system cannot keep up with rainwater, dock supervision may authorize pulling of scuppers under direct supervision of deck crew, with absorption pads using a “decant” procedure.
- A pumping system shall be in place to draw-off all oil or oily liquid from the cargo manifold containment pan, with associated pipeline arrangement, for prompt transfer to a cargo or slop tank.
- All sea suctions (pipeline from sea chest which sea water flows into a ship for cooling engines, ballasting, or other shipboard needs) shall be closed and sealed (except the segregated ballast system).
- No bilge water of any composition or from any compartment shall be discharged overboard while in US waters.
- No sewage from any compartment shall be discharged in US waters.
- No garbage or refuse shall be discharged overboard while in US waters.
- There shall be no blowing of boiler tubes or stack (funnel) uptakes.
- Engine watch is advised that no stack (funnel) emission; white or black smoke, be allowed.

A curb-type barrier surrounds the area of the dock containing the piping system manifolds and loading arms. All surface runoff from the curbed dock areas, including rainwater and oil from drips and leaks, is drained into an oily water tank and pumped ashore via the ballast water line to be processed thorough the refinery’s wastewater treatment system. A floating oil containment boom is placed beneath the loading area prior to the beginning of cargo transfers to contain any releases during transfer operations.

In the event of a spill, the Master or designee immediately stops oil transfer operations, notifies the Dock Operator, and secures the vessel. Notifications and clean-up action are implemented immediately and oil transfer between ship and shore does not resume until the USCG grants permission to resume the transfer.

Vessels are limited to thirty hours at the dock including the time taken for: handling ballast, connecting/disconnecting transfer hoses, and mooring/unmooring.

3.2.2 Sound

Murray (2007) monitored and reported marine and terrestrial sound levels during pile driving at a ConocoPhillips petroleum refinery in the vicinity of Cherry Point. During cessations in construction activities ambient sound levels were recorded at a distance of 30.5 meters (100 feet) from the construction site and a depth of 6.1 meters (20 feet). Ambient sound ranged from 117 dB_{rms} to 139 dB_{rms} re 1 μPa with a mean of 130 dB_{rms} re 1 μPa, this ambient level included routine activities at the dock as well as nearby tug traffic. This likely is a reasonable representation of ambient conditions at the BP Marine Terminal. Taken together with the Bassett (2010) and Bassett et al. (2012) studies discussed in Section 3.1.2, Puget Sound has a high level of underwater ambient background noise, punctuated by frequent high levels associated with large commercial traffic. Therefore, the additional vessel calls and operations to serve them are not likely to result in a meaningful increase in sound levels in the Action Area.

3.3 Status of ESA-Listed Species in the Action Area

3.3.1 Humpback Whale

Humpback whales were common in Puget Sound and the Georgia Strait in the early 1900s. However, there have been few sightings of humpback whales in Puget Sound in the last 20 years (Calambokidis et al. 1990). While humpback whales have been recovering from commercial whaling (Carretta et al. 2011), they are still are rare visitor to Puget Sound and Georgia Strait. Sightings, however, have been reported in recent years and anecdotal evidence indicates that five whales have been observed in Puget Sound and Georgia Strait in recent years (PWWA 2013). A study by Calambokidis et al. (2004) found humpback whale sightings were concentrated between the Juan de Fuca Canyon and the outer edge of the continental shelf, in an area known as “the Prairie” (Figure 3.3-1). A small area east of the mouth of Barkley Canyon and north of Nitnat Canyon where water depth was 125-145 meters (410-476 feet) had the highest density of sightings all year (Calambokidis et al. 2004). These areas are outside of the projects Action Area; therefore humpback whale occurrences are not expected to be common in the Action Area.

3.3.2 Blue Whale

The Eastern North Pacific population of blue whales is the population occurring within the closest proximity to the Action Area. They feed in Californian waters in the summer/fall (from June to November) and migrate south to productive areas off Mexico in the winters (Carretta et al. 2007). Historically blue whales were not common along the coast of Washington; however, they did occasionally occur (Calambokidis et al.2004). Vessel surveys conducted in Washington waters in 1996 and 2001 did not detect blue whale presence (Carretta et al. 2013; Figure 3.3-2). Consequently, blue whales may occur, but are not expected to be common in the Action Area.

3.3.3 Fin Whale

Fin whales are year-round residents off the coast of California and are summer residents off Oregon and possibly pass through Washington. Aerial surveys conducted by Brueggeman et al. (1992) off the Oregon and Washington coasts observed 13 groups of 27 fin whales between June and January. All of the fin whales were observed off Oregon, with all but five whales in waters on the continental slope (200 to 2,000 meters [656- to 6,562 feet] deep). The whales not observed in slope waters included a group of two about 200 km (124 miles) offshore in November and a group of three on the shelf just south of the Columbia River in January. The

former group was traveling south, suggesting they were migrating back to the wintering grounds. Except for these two groups, all of the other whales were observed during June and July. No calves were observed with any of the whales. Green et al. (1993) reported sighting two fin whales during aerial surveys off Oregon and Washington between March and May in 1992 but did not report the location. An estimated 2,636 fin whales occur off the coasts of California, Oregon, and Washington during summer/fall based on shipboard surveys in 2001 and 2005 (NMFS 2010c) (Figure 3.3-3). These areas are outside of the projects Action Area; therefore fin whale occurrences are not expected to be common in the Action Area.

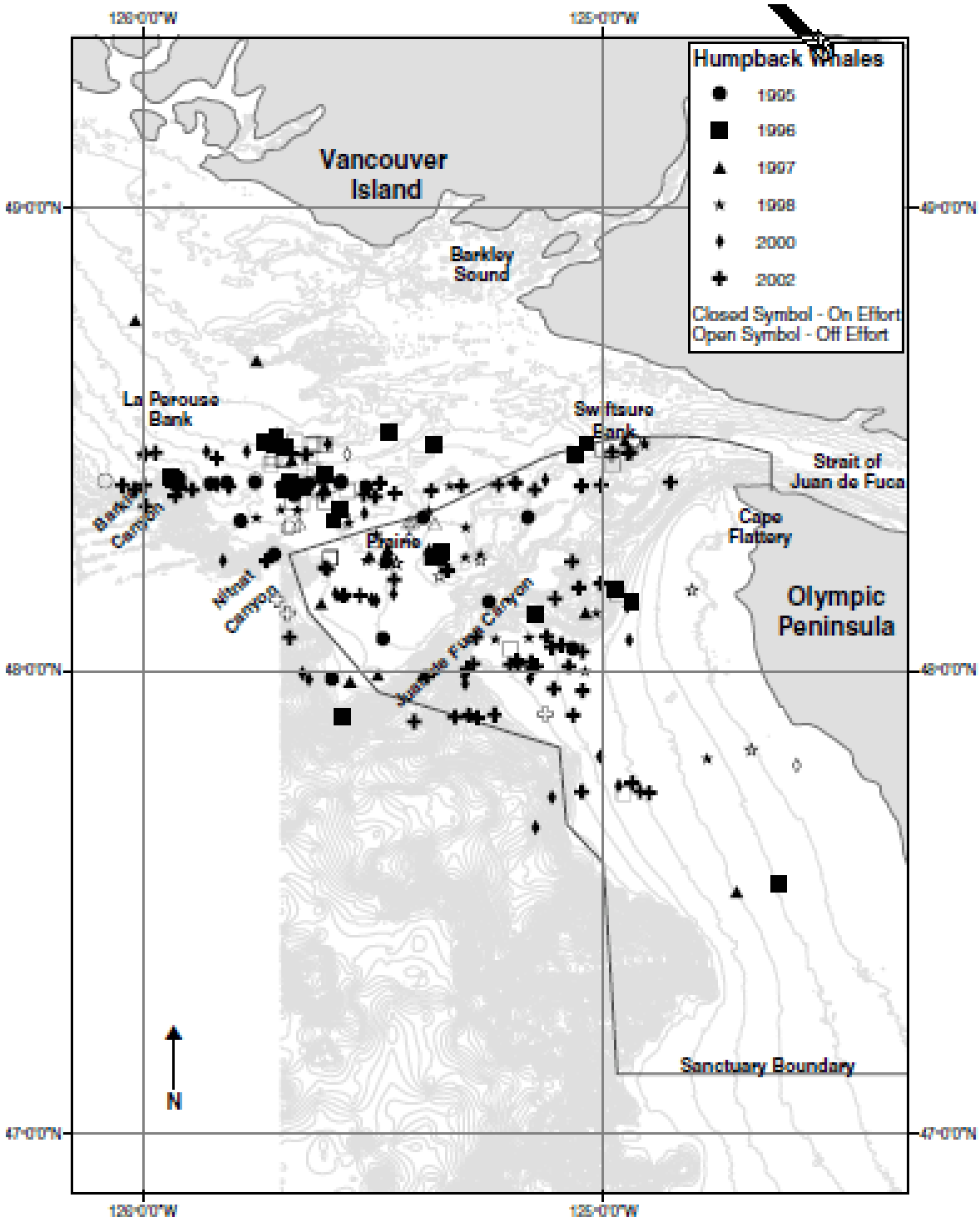

Figure 3.3-1 Locations (by year) for humpback whales seen during ship surveys off the northern Washington coast between 1995 and 2002

Source: Calambokidis et al. 2004

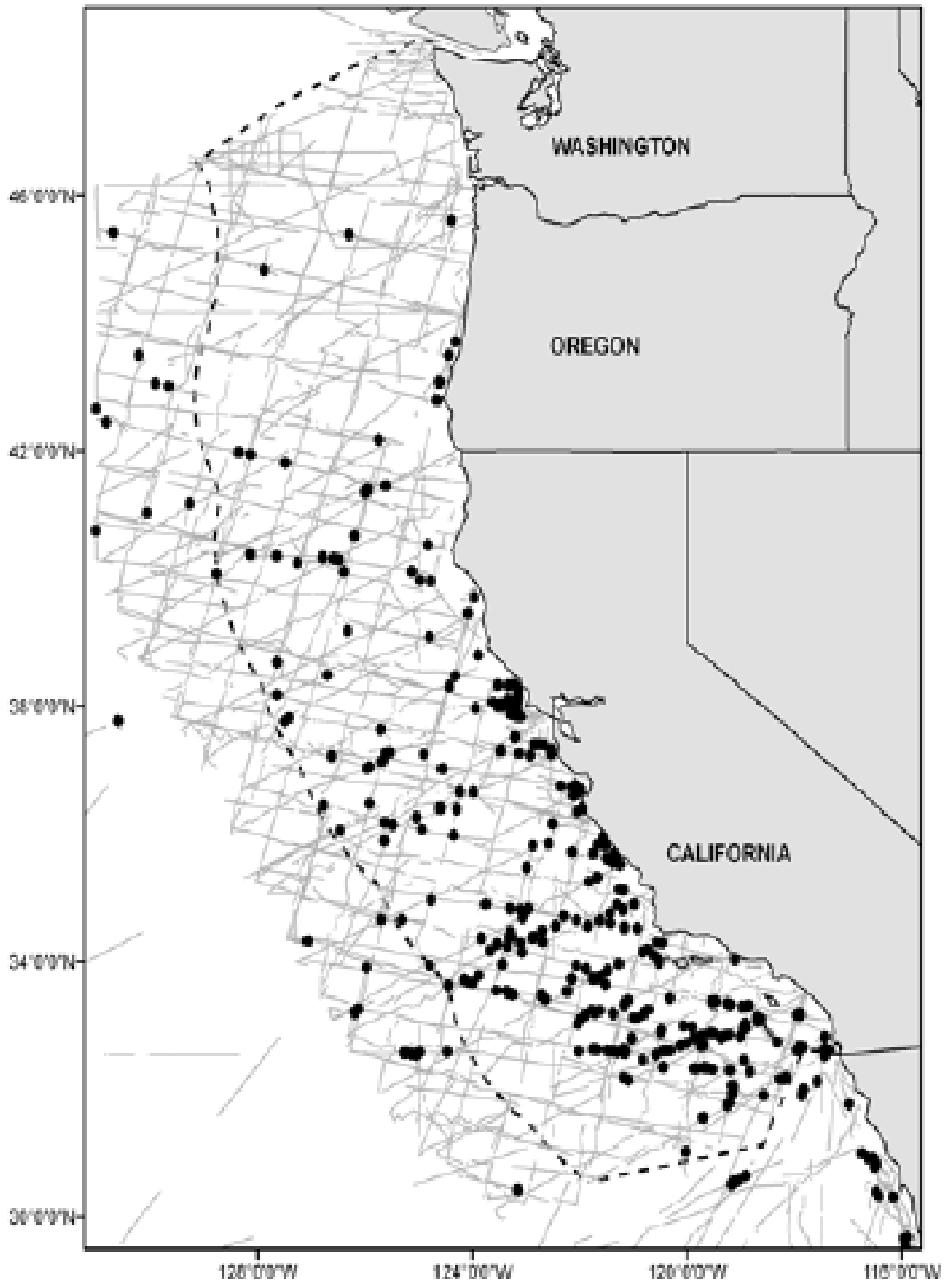

Figure 3.3-2 Blue whale sighting locations based on aerial and summer/autumn shipboard surveys (1991-2008).

Source: Carretta et al. 2013

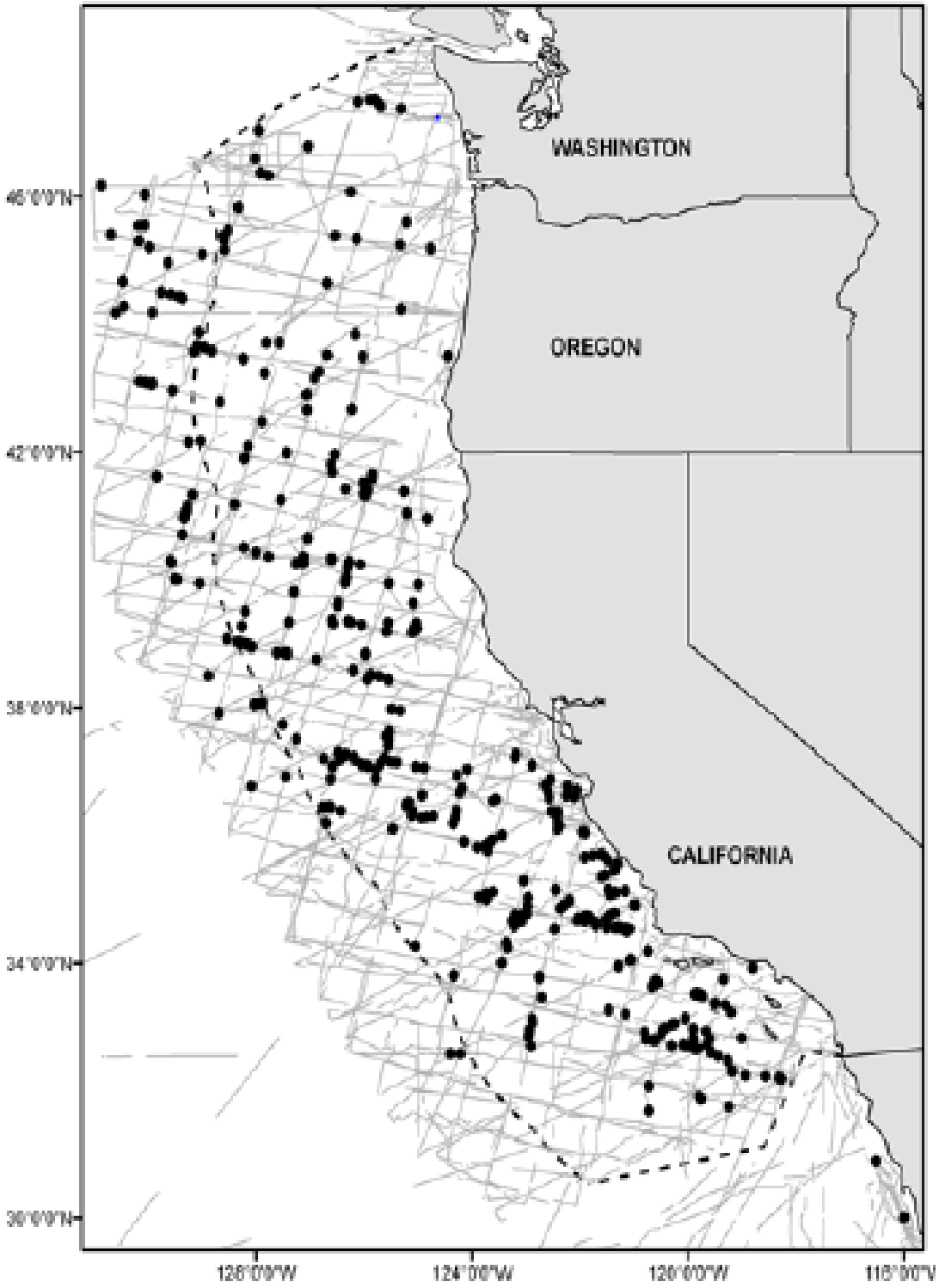

Figure 3.3-3 Fin whale sighting locations based on shipboard surveys (1991-2008).

Source: Carretta et al. 2013

3.3.4 Southern Resident Killer Whale

The Southern Resident killer whale DPS is a trans-boundary population comprised of 89 animals split among three pods (J, K, and L) which are considered one stock under the Marine Mammal Protection Act. Southern Resident killer whales reside for part of the year in the protected inshore waters of the Strait of Georgia and Puget Sound (especially in the vicinity of Haro Strait, west of San Juan Island, and off the southern tip of Vancouver Island). Southern Resident killer whales occur in the area principally during the late spring, summer, and fall (May through October) (NMFS 2006). Winter movements and range are poorly known for this stock; however, the J pod is more commonly sighted in inland waters, while Pods K and L spend more time offshore during winter (Ford et al. 2000). The Southern Resident stock is differentiated from the Northern and Southern Alaska Resident stocks, which do not inhabit waters off Washington. Distribution of Southern Resident DPS killer whales within Puget Sound is shown in Figure 3.3-4.

Two critical habitat areas have been designated for Southern Resident killer whales within the Action Area; Area 1 - Summer Core Area and Area 3 – Strait of Juan de Fuca (Figure 3.3-5). Southern Resident killer whales are expected to occur in the Action Area.

The Summer Core Area is bordered to the North and West by the US/Canadian border, and includes waters surrounding the San Juan Islands, the U.S. portion of the Southern Strait of Georgia, and areas directly offshore of Skagit and Whatcom counties. This area is important for all pods (J, K, and L [NMFS 2006]). Vessels calling at the BP Marine Terminal would pass through the Summer Core Area designated as critical habitat.

The Strait of Juan de Fuca Area is bordered on the southeast by the entrance to Admiralty Inlet, Deception Pass Bridge, San Juan, and Skagit Counties to the northeast, the U.S. Canadian border to the north, and Bonilla Point/Tatoosh line to the west. All pods regularly use the Strait of Juan de Fuca as a passage from the Summer Core Area and Puget Sound to access oceanic waters, however, the whales are not known to spend long periods of time in localized areas in the Strait and sightings of Southern Residents in the Strait are limited (NMFS 2006). Vessels calling at the BP Marine Terminal would pass within the Strait of Juan de Fuca Area designated as critical habitat.

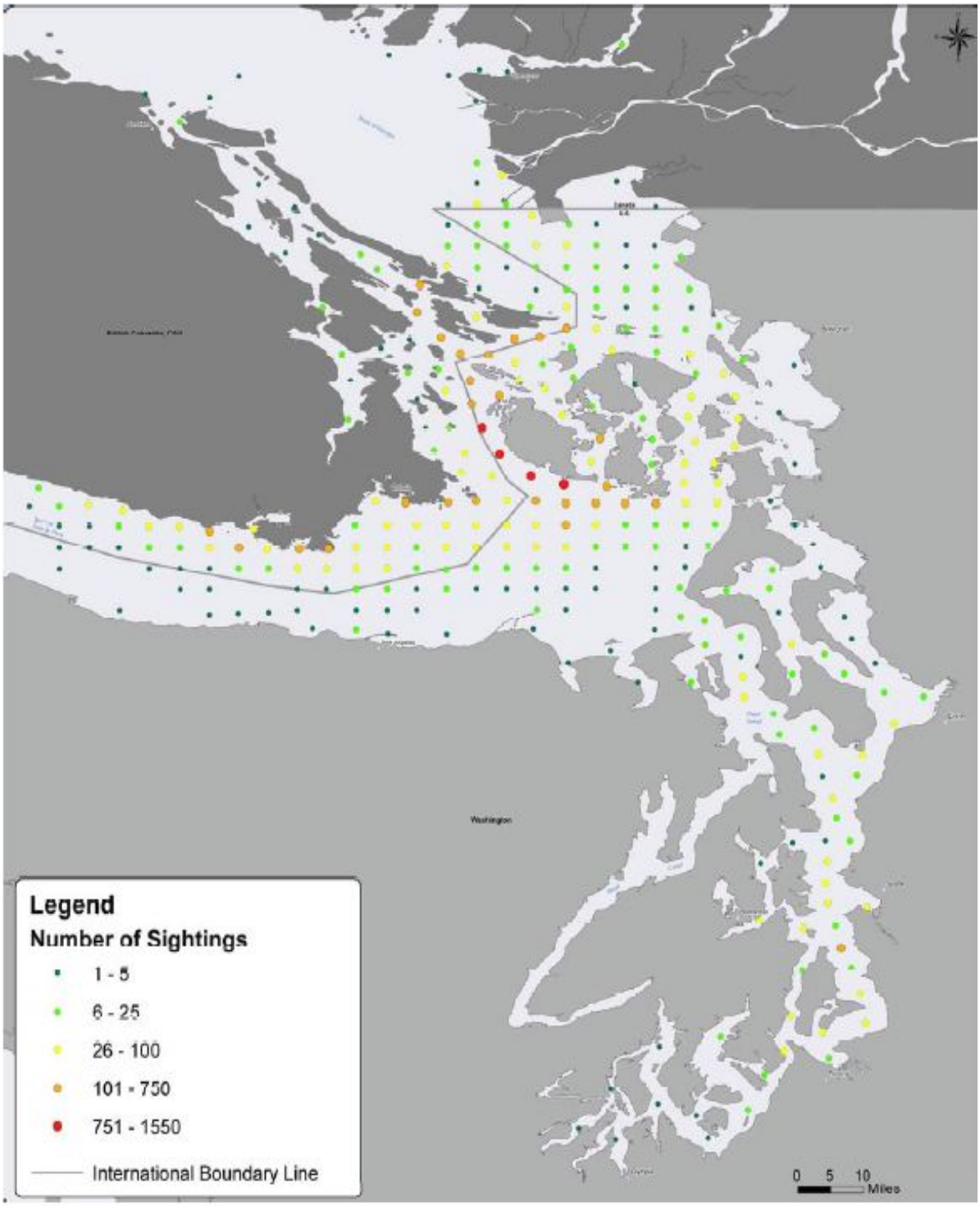

Figure 3.3-4 Distribution of Southern Resident killer whale sightings from 1990-2005

(The Whale Museum 2005, as cited in NMFS' Recovery Plan for Southern Resident Killer Whales, NMFS 2008a)

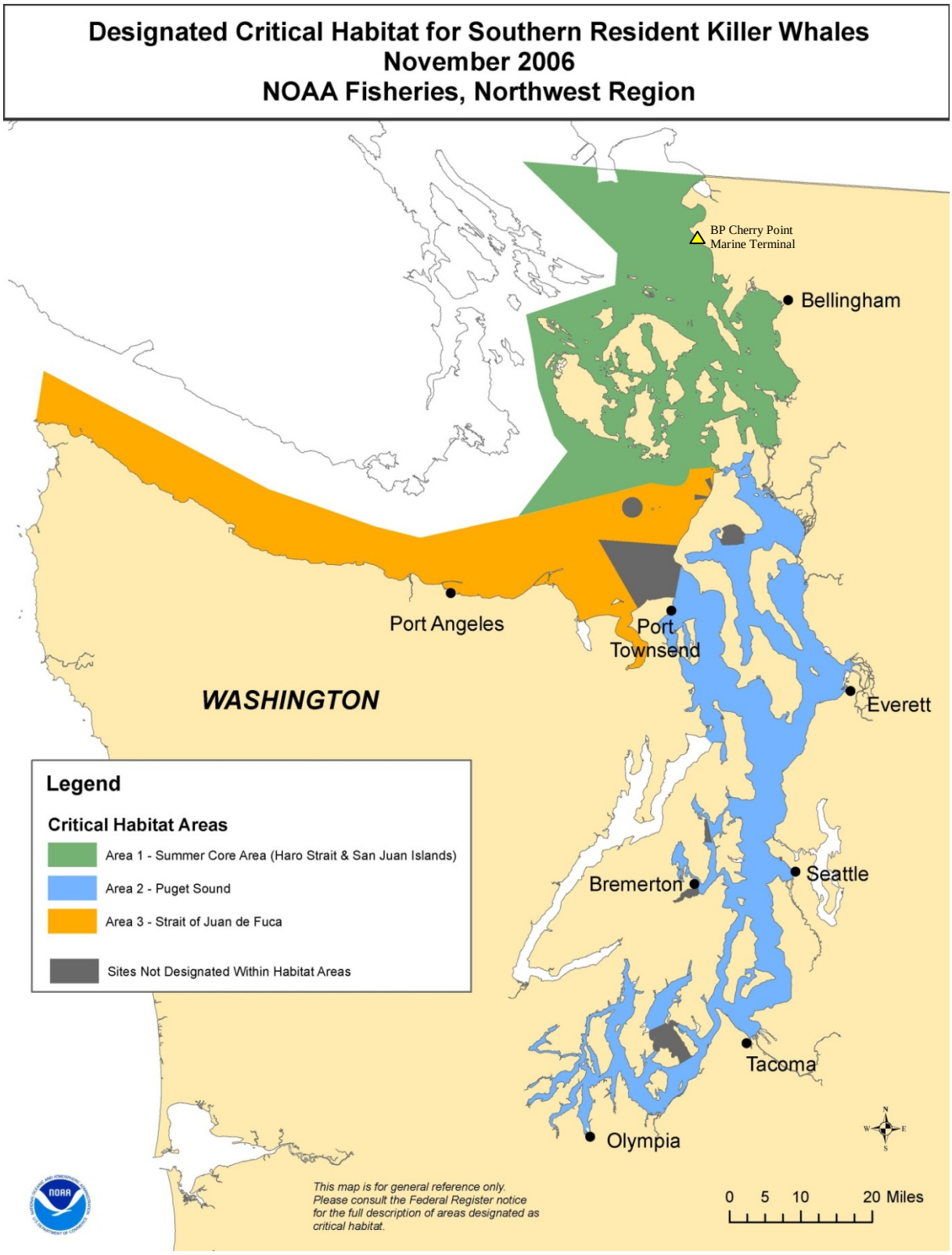

Figure 3.3-5 Designated Critical Habitat for Southern Resident Killer Whales

Source: NOAA 2006

3.3.5 Bull Trout

Bull trout rely on foraging, migration, and overwintering habitat to complete extensive and important parts of their life cycle. The anadromous life history form of bull trout migrates to saltwater during the spring. They use the nearshore marine ecosystem during the spring and late summer months, and the outer coast year-round. Juvenile bull trout rear in the nearshore ecosystem with preference for unconsolidated habitats that may include eelgrass and kelp beds. The nearshore area provides critical foraging habitat as well as stable overwintering habitat for bull trout. Adults also feed in this area and then migrate into freshwater rivers and streams to spawn. Temperature is a major factor influencing bull trout distribution, since spawning, egg incubation, and juvenile rearing all need specific temperatures. Since the bull trout range includes the Strait, as well as inland marine and fresh waters of Clallam County (USFWS 2005), it is possible that this species would be present in the Action Area.

Coastal marine waters designated as critical habitat for bull trout in the Coastal Puget Sound and Olympic Peninsula areas occur within the Action Area and extend from the MHHW line inland to 10 meters (33 feet) below the MLLW elevation line offshore. Vessels calling at the BP Marine Terminal would not pass through areas designated as bull trout critical habitat.

3.3.6 Chinook Salmon

The Puget Sound Chinook salmon ESU is a composite of many individual populations of naturally spawning Chinook salmon, and a number of hatchery stocks. The boundary of the Puget Sound Chinook salmon ESU extends from the Nooksack River in the north to southern Puget Sound, includes Hood Canal, and extends westerly out the Strait of Juan de Fuca to the Elwha River. The Skagit River and its tributaries constitute what was historically the predominate system in Puget Sound containing naturally spawning populations. There are two independent populations of Puget Sound Chinook salmon in the Nooksack basin: North Fork Nooksack River (including Middle Fork), and South Fork Nooksack River. These salmon are distinctive from Chinook salmon in the rest of Puget Sound in their genetic attributes, life history, and habitat characteristics. They are the only populations in the Strait of Georgia region, and they are two of only six Chinook runs left in Puget Sound that return to their rivers in spring (as opposed to fall spawners). For these reasons, the Nooksack populations are considered essential to the recovery of the Puget Sound Chinook ESU (Puget Sound TRT 2006).

Critical habitat has been designated within the Action Area for the Strait of Juan de Fuca from the line of extreme high tide to a depth of 30 meters (98 feet). Vessels calling at the BP Marine Terminal would likely pass through areas designated as Chinook salmon critical habitat. Adult Chinook migrate through the Action Area en route to spawning tributaries throughout the Washington north coast, Straits of Georgia and Juan de Fuca, Puget Sound, and Hood Canal. The Puget Sound Chinook salmon ESU includes waters that are part of the Action Area; therefore it is possible that this species would be present in the Action Area.

3.3.7 Chum Salmon (Hood Canal Summer Run)

While the range of chum salmon along the Pacific coast extends from the Bering Sea to the Sacramento River in California, the range of summer chum salmon is highly restricted and extends only to discrete portions of the eastern portion of the Olympic Peninsula and south into

Hood Canal. These include spawning adult returning to Snow Creek (Discovery Bay), Chimicum Creek (near Port Townsend) and many drainages in Hood Canal.

Critical habitat has been designated within the Action Area for the Strait of Juan de Fuca from the line of extreme high tide to a depth of 30 meters (98 feet). Vessels calling at the BP Marine Terminal would likely pass through areas designated as chum salmon critical habitat. Adult chum could migrate through the Action Area en route to spawning tributaries. Therefore, it is possible that this species would be present within the Action Area

3.3.8 Puget Sound Steelhead

The Skagit and Nooksack rivers, which discharge into the general vicinity of Cherry Point, do support populations of native steelhead. Juvenile steelhead move rapidly out of freshwater and into offshore marine areas and recent studies in steelhead migratory behavior suggest that juveniles spend very little time in nearshore areas (NMFS 2013).The nearshore benthic survey conducted by the Lummi Nation found few (n=3) steelhead juveniles in their extensive beach seining sampling during the 2008 to 2009 survey effort, representing a 1.5 percent occurrence in all sets (Dolphin et al 2010). In addition to the limited occurrence of steelhead documented in the vicinity of the BP Marine Terminal, this species also migrate through the Strait of Juan de Fuca en route to spawning tributaries throughout Washington's north coast. It is possible that this species would be present within the Action Area.

No proposed critical habitat for Puget Sound steelhead occurs in the Action Area.

3.3.9 Pacific Eulachon

Outside of the Columbia River Basin, eulachon have been occasionally reported from other coastal Washington rivers including Willapa Bay, Gray's Harbor, and at the mouth of various small streams of the coast (Swan 1881 as cited in Moody 2008). Spawning runs outside the Columbia River Basin have been documented at Willapa Bay (North, Naselle, Nemah, Bear, and Willapa rivers), Grays Harbor (Humptulips, Chehalis, Aberdeen, and Wynoochee rivers), and the Copalis, Moclips, Quinault, Queets, and Bogachiel rivers (WDFW and ODFW 2001 and Willson et al. 2006).

Shaffer et al. (2007) reported on the capture of 58 adult eulachon in the Elwha River on Washington's Olympic Peninsula between March 18 and June 28, 2005. This was the first formal documentation of eulachon in the Elwha River, although anecdotal observations suggest that eulachon "were a regular, predictable feature in the Elwha until the mid-1970s" (Shaffer et al. 2007). Other Olympic Peninsula rivers draining into the Strait of Juan de Fuca have been extensively surveyed over many years for salmonid migrations; however, eulachon have not been observed in any of these other systems (Shaffer et al. 2007).

A recent WDFW technical report entitled "Marine Forage Fishes in Puget Sound" (Pentilla 2007) presents detailed data on the biology and status and trends of surf smelt and longfin smelt in Puget Sound, but states that "there is virtually no life history information within the Puget Sound Basin" available for eulachon. Similarly, detailed notes provided by WDFW and ODFW as part of this review, do not provide evidence of spawning stocks of eulachon in Puget Sound rivers.

Monaco et al. (1990) described eulachon as "rare" in Skagit Bay and, in addition to a personal communication, cited Miller and Borton (1980) as a supporting reference. Miller and Borton (1980) report on a total of 20 eulachon specimens collected in the San Juan Islands, southern Strait of Georgia, and Strait of Juan de Fuca and recorded in boat logs and museum collection records; however, samples from Skagit Bay were not included in this list.

The Nooksack River has frequently been listed as supporting a run of eulachon (WDFW and ODFW 2001, Wydoski and Whitney 2003, Willson et al. 2006; Moody 2008); however, there seems to be some confusion as to the exact species encountered. The Nooksack River is known to support a run of longfin smelt [*Spirinchus thaleichthys*], which are sometimes mistaken for eulachon. The run of longfin smelt into the Nooksack occurs in November, which is outside the normal spawning time for eulachon. Additionally, mid-water trawl surveys thought the Strait of Juan de Fuca routinely collected longfin smelt juveniles, while eulachon were rarely encountered (Anchor Environmental 2003).

Freshwater critical habitat does not occur in the Action Area and there have been no nearshore or offshore foraging sites in the Pacific Ocean identified as meeting the definition of critical habitat under section 3(5)(A)(i) of ESA. Pacific eulachon critical habitat does not occur within the Action Area.

3.3.10 Green Sturgeon (Southern DPS)

Southern DPS green sturgeon were first determined to occur in Oregon and Washington waters in the late 1950s when tagged San Pablo Bay green sturgeon were recovered in the Columbia River estuary (CDFG 2002). A few green sturgeon have been recovered in Puget Sound as incidental harvest from trawl fishers; the reason for their occurrence in the Action Area is unknown as they are not known to spawn, rear, or feed in coastal Washington or Puget Sound (Adams et al. 2002). The presence of green sturgeon in Puget Sound is rare (Lindley et al. 2011), but the species could occur in the Action Area. Critical habitat for Southern DPS green sturgeon has been designated in the Action Area and includes waters in the Strait of Juan de Fuca and a portion of Rosario Strait (Figure 3.3-6; 74 FR 52300). Puget Sound has been excluded from designation because the economic benefits of exclusion outweigh the benefits of inclusion and exclusion will not result in extinction of the species. Vessels calling at the BP Marine Terminal would not pass through areas designated as green sturgeon critical habitat.

Figure 3.3-6 Designated Critical Habitat for Southern DPS Green Sturgeon

Source: 74 FR 52300

3.3.11 Rockfish (Bocaccio Rockfish, Canary Rockfish, Yelloweye Rockfish)

The WDFW considers the north Puget Sound area to be one of the most productive areas for groundfish. This area extends from the Canadian border to Deception Pass out to the center of the Strait of Juan de Fuca, including all of the San Juan Islands. Within this area, production data in the vicinity of Cherry Point are not kept distinct. Bocaccio, yelloweye, and canary rockfish populations and for conservation purposes, are managed as two distinct stocks, one stock occupying areas west of Port Angeles and a separate stock unit east of Port Angeles.

Information on actual distribution of these three listed rockfish species in the vicinity of the Cherry Point facility is vague at best. Rockfish adults tend to prefer rocky, deeper water habitats of the kind that are not common in the vicinity of the BP Marine Terminal dock facility (see Figure 3.3-6). Bocaccio has been found to occur in Central Puget Sound, Tacoma Narrows, Ports Gardner and Susan, and along the Strait of Juan de Fuca, with the most common occurrences recorded south of the Tacoma Narrows (NMFS 2010b) . Detection of adult yelloweye and canary rockfish indicate they do occur in the broader vicinity of the San Juan Islands near suitable habitat, but do not occur near Cherry Point (Figure 3.3-7 and 3.3-8). Yelloweye rockfish have been reported by anglers to occur off Middle Bank in Haro Strait, Waldron Island, Hood Canal, Foulweather Bluff, Jefferson Head, Mukilteo, and Bainbridge Island (Washington 1977, Palsson et al. 2009). Canary rockfish have been documented as part of the assemblage of fishes in the Puget Sound region for as long as there have been formal fisheries surveys, dating back to at least the 1930s (NMFS 2010b).

A 2011 study (Greene and Godersky 2012) of larval rockfish presence in Puget Sound surface waters indicate there is a difference in densities between deepwater and nearshore sites. Based on this preliminary study, the highest relative abundance of rockfish larva would be expected to occur in the Action Area during August and September.

Table 3.3-1 identifies the most likely factors limiting rockfish populations in Puget Sound. Critical habitat for rockfish has been proposed in the Action Area and includes waters east of Port Angeles north to the BP Marine Terminal (78 FR 47635) (Figure 3.3-9) Vessels calling at the BP Marine Terminal would pass through areas designated as rockfish critical habitat.

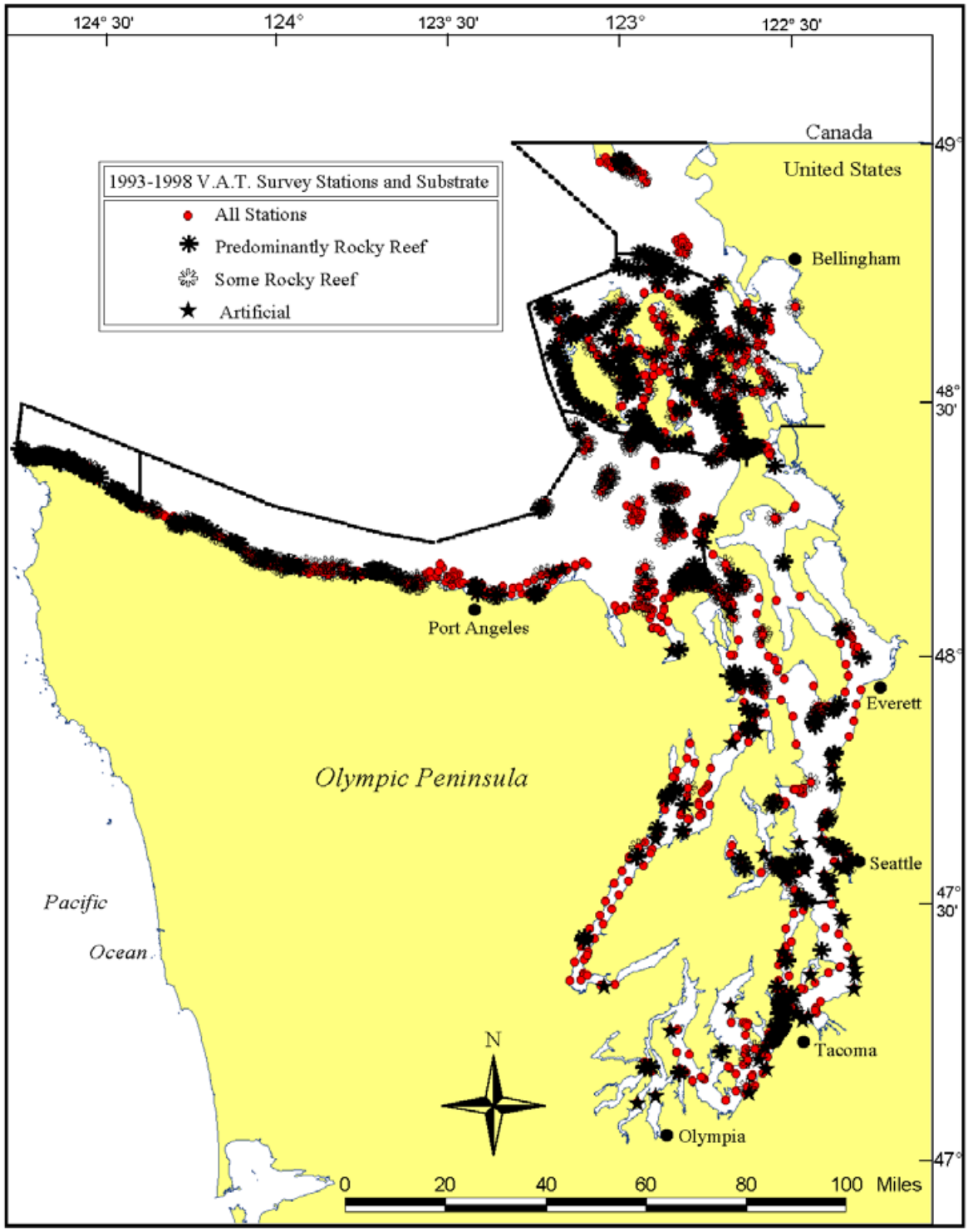

Figure 3.3-7 Distribution of Nearshore Rocky Habitats in Puget Sound

Source: Palsson et al. 2009

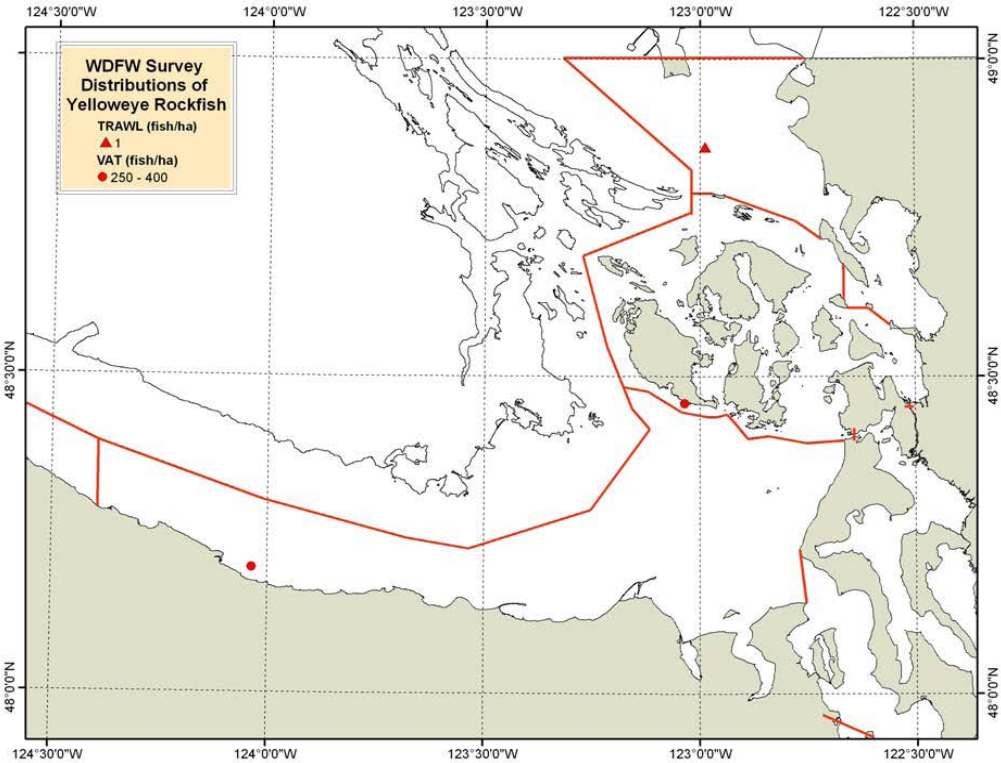

Figure 3.3-8 Distribution of Yelloweye Rockfish in North Puget Sound determined from Trawl, Video, and Scuba Surveys[8]

[8] Limitations of rockfish surveys methods are described below:
Trawl: this species finds refuge in high-relief habitat where bottom trawl surveys are ineffective (Jones et al. 2012).
Video: provides a better mechanism than trawls to quantify species abundance for bottom-oriented rockfish (Jones et al. 2012).
Scuba: distribution includes depths that exceed the safe scuba diving depth (Haggarty 2014)

Table 3.3-1 Likely Stressors Limiting Rockfish Populations in Puget Sound

FACTOR	LIKELY IMPACT
Past Fishery Removals	High
Habitat Disruption	Low
Derelict Gear	High
Climate Change	Low
Water Quality Dissolved oxygen Nutrients Chemical Contamination	 Moderate Low Moderate
Species Interactions Food Web Competition Salmon Hatchery Practices	 Moderate Low Low
Diseases	Low
Genetic Changes	Low

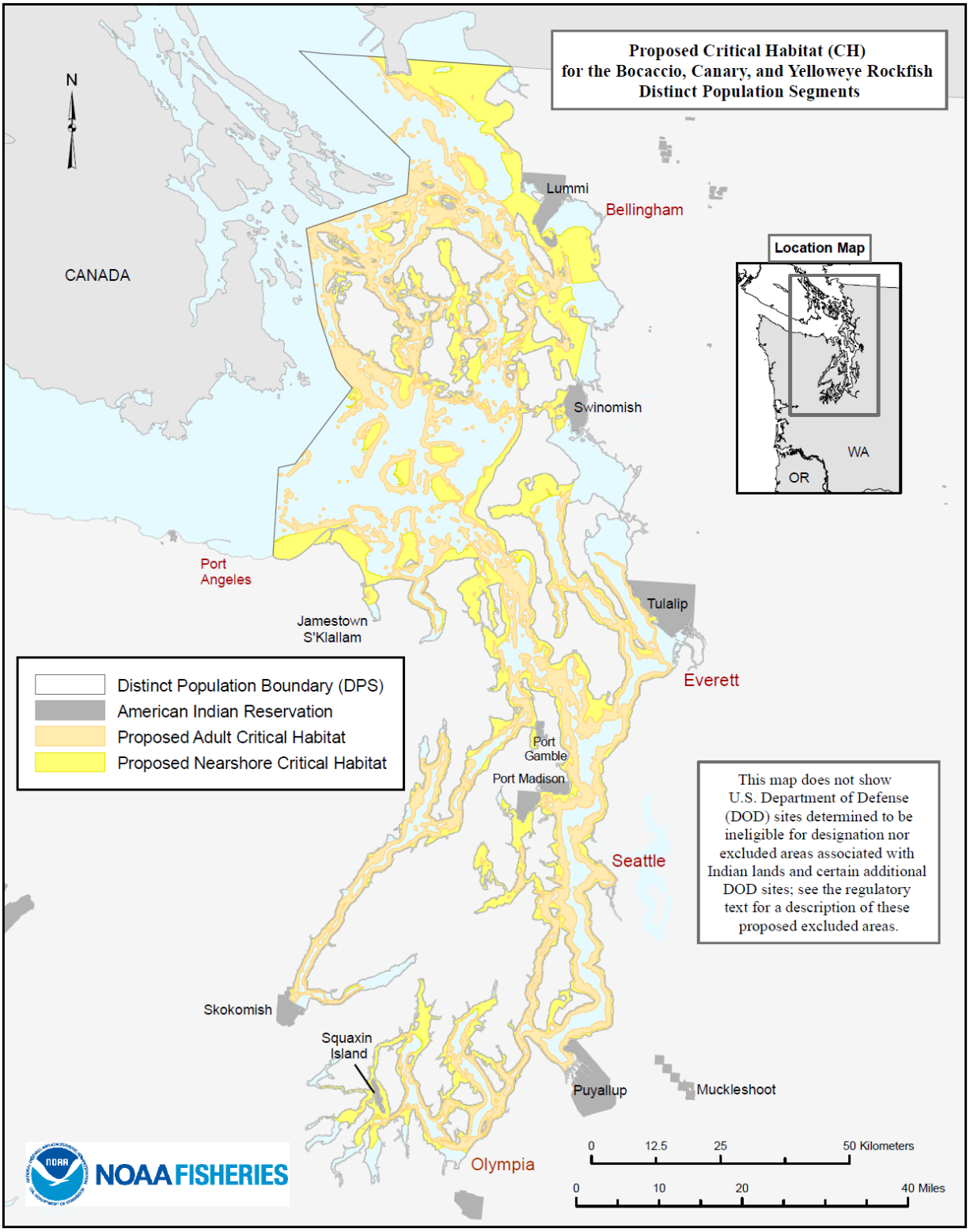

Figure 3.3-9 Proposed Critical Habitat for the Bocaccio, Canary, and Yelloweye Rockfish Distinct Population Segments

Source: NOAA 2013

3.3.12 Marbled Murrelet

There are six marbled murrelet conservation zones (WDFW 2014), one of which occurs in the Action Area. Zone 1 includes the Strait of Juan de Fuca, Hood Canal, and the San Juan Islands and is monitored by the Pacific Northwest Research Station, and the United States Department of Agriculture Forest Service. The most recent murrelet population estimate for Zone 1 is 4,393 birds, with the majority occurring around the south end of the San Juan Islands and along the northern coast of the Olympic Peninsula (WDFW 2014). Primary fish prey of marbled murrelets includes Pacific sand lance, Pacific herring, northern anchovy, and smelts. Documented smelt and sand lance spawning locations occur throughout the Strait of Juan de Fuca and in the vicinity of the BP Marine Terminal. Herring and smelt spawning occur along the shoreline from Blaine, WA south to Bellingham and the BP Marine Terminal falls within these areas (WDFW 2014b). Sand lance spawning occurs within the Action Area, but has not been documented in close proximity to the terminal (WDFW 2014b). While the presence of forage fish suggests that marbled murrelets may feed within the Action Area, nesting habitat is limited by a lack of the required old-growth forests. No critical habitat has been designated for marbled murrelet within the Action Area (USFWS 2013) Therefore; it is possible that marbled murrelets will be present within the Action Area, but only for foraging.

3.3.13 Leatherback Turtle

Leatherbacks regularly occur off the coast of Washington, especially off the mouth of the Columbia River during the summer and fall when large aggregations of jellyfish form (WDFW 2012). Observations, telemetry data, and gillnet captures of leatherbacks off the Washington coast, identified turtles south of Cape Flattery and in deeper offshore water (WDFW 2012). Leatherback turtles could occur in the Action Area; however, occurrences are not expected to be common.

Critical habitat for leatherback turtle has been designated at the western extent of in the Action Area in the vicinity of J Buoy (Figure 3.3-10; 77 FR 4170). Critical habitat does not extend into the Strait of Juan de Fuca or Puget Sound; therefore, vessels calling at the BP Marine Terminal would only pass through a small portion of leatherback turtle critical habitat.

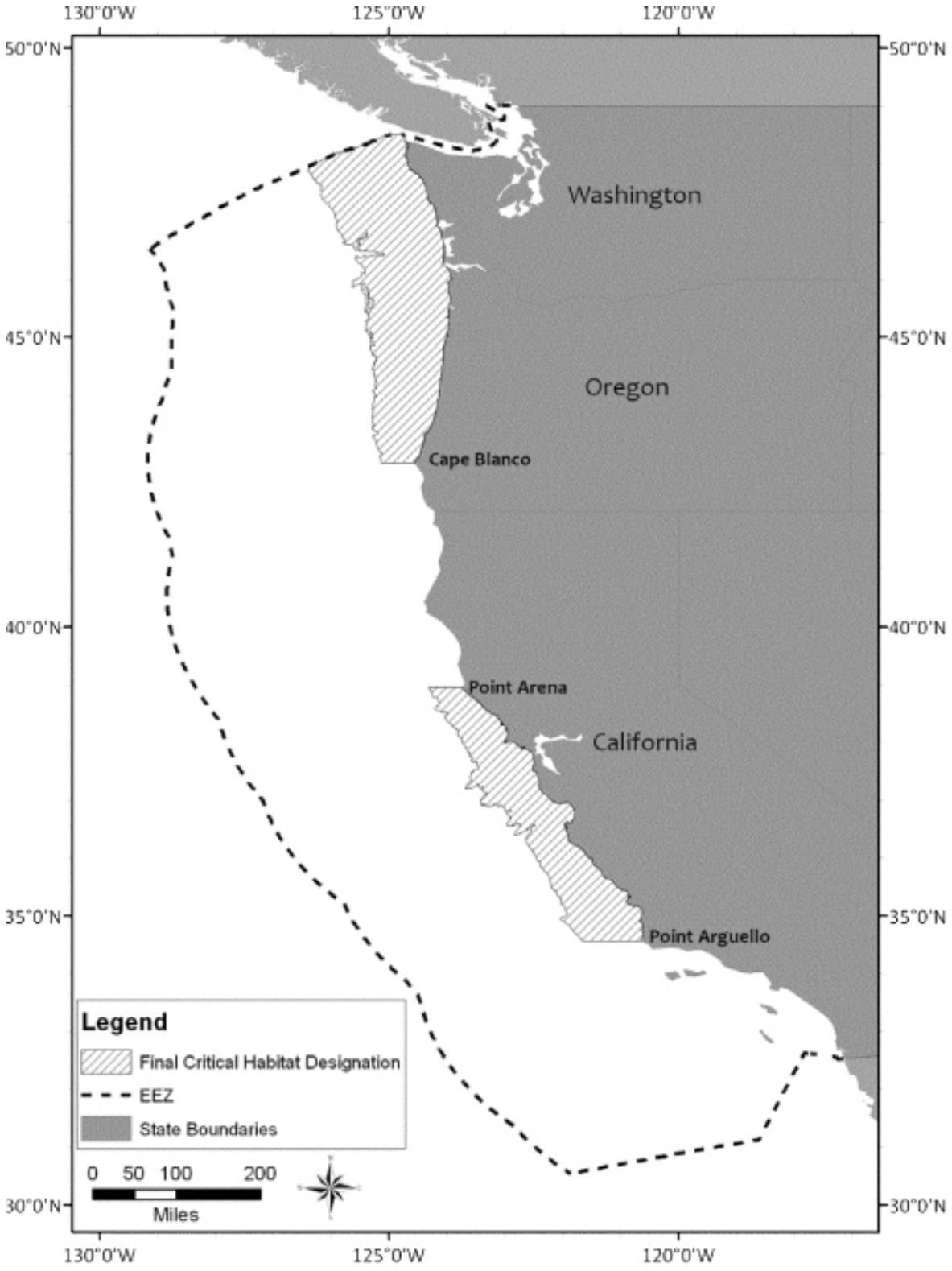

Figure 3.3-10 Designated Critical Habitat for U.S. West Coast Leatherback Turtle

Source: 77 FR 4170

Chapter 4

Effects of the Proposed Action on ESA-Listed Species

The federal action under consideration in this BE is the USACEs' modification of the current Department of the Army permit number 92-1-00435 for the continued operation and maintenance of the BP Marine Terminal. The project is broken into two major components: vessel traffic and marine terminal operations. Each of these activities has its effects to listed species, some of which overlap.

This section addresses effects of the Proposed Action. The regulations implementing the ESA define "effects of the action" as "the direct and indirect effects of an action on the species or critical habitat, together with the effects of other activities that are interrelated or interdependent with that action, that will be added to the environmental baseline" (50 CFR §402.02). Direct effects are the immediate effects of the project on the species or its critical habitat. Direct effects result from the Proposed Action and include the effects of interrelated and interdependent actions, of which there have been none identified for this BE (Section 1.5). The primary direct effects of the Proposed Action derive from the nature, extent, and duration of the activities on humpback whales, Southern Resident DPS killer whales, Steller sea lions, and ESA-listed fish species. Indirect effects are those effects that are caused by or would result from the Proposed Action and are later in time, but are still reasonably certain to occur. Potential effects of the action are summarized in table 4.1-1.

Table 4.1-1 Potential Effects of the Action

Project component	Stressor	Potential Effect
Vessel traffic	Noise	Startle, disruption of behavior, temporary change of habitat for marine mammals
	Introduced species/pollution	Change of habitat for all listed species
	Intake of cooling water	Injury and/or mortality of larva rockfish
	Vessel strikes	Injury and/or mortality of marine mammals
Terminal Operations	Noise	Startle, disruption of behavior, temporary change of habitat all listed species
	Pollution	Change of nearshore habitat could affect all listed salmonids

Since the North Wing has already been constructed and has been in operation since 2001, the effects of the Proposed Action are already part of the environmental baseline, these effects will continue into the future. The effects of the Proposed Action analyzed in this BE focus on the ongoing effects of current operations and vessel traffic levels and potential increased vessel traffic up to 420 calls per year.

4.1 Marine Mammals

4.1.1 Humpback Whale, Blue Whale and Fin Whale (Baleen Whales)

Humpback, blue and fin whales do not commonly occur within the Action Area. Calambokidis et al. (2003) reports five humpback individuals identified in the Puget Sound from 1986-2003. Humpback whales presence in the Action Area, if at all, would be during the summer and fall months when humpback whales are foraging off of the Washington and British Columbia coasts. Vessel surveys conducted in 1996 and 2001 did not detect blue or fin whales in Washington waters (Carretta et al. 2013).

Potential effects on baleen whales associated with the BP Marine Terminal would include interactions with vessels in transit, effects due to increased background noise, effects from discharge of hazardous materials into the marine environment and catastrophic oil spills.

4.1.1.1 Effects of Vessel Traffic

Vessel Strikes

A study reviewing ship strikes on whales in Washington State reviewed 130 records from 1980-2006 and found only one incident of a possible ship-struck humpback, two possible ship-struck fin whales and no known ship-struck blue whales despite the known presence of these species in the shipping lanes in the region (Douglas et al. 2008). Although vessel strikes of humpback, blue and fin whales have been recorded in NMFS' Large Whale Ship Strike Database (Jensen and Silber 2004), the probability of a whale strike occurring as a result of the Proposed Action is unlikely for the following reason. The vessel traffic calling at the BP Marine Terminal currently comprise about 1 percent of the commercial traffic in the Action Area and the increase in vessel traffic attributable to the Proposed Action is very small. The low likelihood that a humpback, blue or fin whale will be present it the Action Area combined with the small potential increase in vessel traffic calling at the BP Marine Terminal makes a measurable increase in the probability of a vessel strike over baseline conditions unlikely.

Sound

Humpback, blue and fin whale calls occur at predominately low frequencies from 0.03 to 8 kHz and their hearing is presumed good at corresponding frequencies (NMFS 2010c). Unlike toothed whales, baleen whales have not been shown to use echolocation to detect the size and nature of objects. However, baleen whales use sound as a long-range acoustic communication system to facilitate mating and social interactions. The auditory system of baleen whales is presumed to be more sensitive to low-frequency sounds than those of small-to-moderate-sized toothed whales (NMFS 2010c). Baleen whales are thought to be most sensitive to a range of low-frequency sounds occurring in the 0.01 to 1 kHz range. (Okeanos 2008).

Vessel sounds attributed to large ships, tankers, and tugs traveling to the BP Marine Terminal would generate low frequency sound in the 5Hz to several hundred kHz range (NRC 2003). Noise from increased vessel traffic associated with the Proposed Action has the potential to mask biologically significant sounds baleen whales use to communicate, avoid predators, and gain awareness of the environment. Although there are many documented, clearly discernable responses of marine mammals to anthropogenic sound, reactions are typically subtle, consisting of shorter surfacing intervals, shorter dives, fewer blows per surfacing, longer intervals between

blows, ceasing or increasing vocalizations, shortening or lengthening duration of vocalizations, and changing frequency or intensity of vocalizations. While some of these changes may be statistically significant, it is unknown if they have an effect on whales at the individual or population level (NRC 2003).

A review of past industrial activities indicates that these activates do have some impact on whales. For example, in the calving lagoon of Guerrero Negro, Baja California Sur, Mexico, daily dredging and vessel traffic caused gray whales to abandon the area for ten years, from 1957 to 1967. Whales did not return to the area until six years after the industrial operations ceased (Gard 1974 and Bryant and Lafferty 1980, cited in Rice et al. 1984). While separating the effect of noise from the other stimuli present in the lagoon is not possible, the increase in noise likely played a role in this habitat abandonment. Likewise, Borggaard et al. (1999) observed temporary changes in habitat use during marine construction activities involving dredging, blasting, and increased vessel traffic in Trinity Bay, Newfoundland, Canada. Given these whales would primarily occur on the periphery of the Action Area, and in the case of humpback whales, who are infrequent visitor to the Action Area, habitat abandonment associated with increased vessel traffic and associated noise would not be expected under the Proposed Action.

Exposure to anthropogenic sounds may increase stress levels and affect the fitness of individuals by lengthening migration, increasing the duration of foraging bouts, or limiting foraging opportunities before long periods of fasting and migration begin (NRC 2003). The North Pacific populations of all three species are increasing (Carretta et al., 2011). Although, small numbers of individual humpback whales could venture through the Strait of Juan de Fuca into Georgia Basin, none of these populations are expected to be affected by stress reactions from increased vessel traffic.

As discussed in section 3.1.2, and 3.2.2 the incremental increase in vessel traffic due to calls of oil tankers and oil barges at the BP Marine Terminal could result in exposing these whales to increased sound levels from a transiting vessel. Basset et al. (2012) estimate the source level for oil/chemical tankers to be 181 dBrms re 1 µPa at 1 m and tugs at 173rms dB re 1 µPa at 1 m. These levels are likely representative of the vessels calling at the BP Marine Terminal including those vessels contributing to the increase in calls as a result of the operation of the North Wing, because no change is expected in the ship speed, condition of the vessel, vessel load, and on board activities of the vessels calling at the marine terminal other than a small incremental increase in frequency of calls.

While the source level for tankers transiting to the BP Marine Terminal approach NMFS interim criterion for injury of 180 dBrms re 1 µPa at 1 m, no whales are likely to occur within 1 m of a vessel, and given their tendency to avoid vessels upon detection, the received level experienced by these whales is likely to be well below the interim injury criterion. Some individuals could be exposed to received levels that exceed the 120 dB_{rms} re 1 µPa at 1 m for defining disturbance (i.e. level B harassment) under the MMPA. The effect of this disturbance is likely to involve avoidance behaviors, such as adjusting migration paths to avoid close approach to a vessel. These responses are not expected to result in adverse effect to the fitness of any of the individuals exposed.

With respect to NMFS 2013 proposed guidelines for potential injury or harassment to marine mammals, humpback, blue and fin whales are in NMFS low frequency hearing group with a functional hearing range of 7 Hz to 30 kHz, a range that overlaps with the frequency range of sound generated by commercial vessel traffic. NMFS proposed dual criteria for TTS are received levels of 224 dBpeak re 1 µPa and 198 dB SELcum re 1 µPa2-s. While NMFS cautions against comparing these criteria to the interim criteria because dBrms, dBpeak, and dB SELcum are all based on different metrics, as a rule of thumb dBpeak is generally a few dB higher than dB_{rms}. Thus, the estimated source levels for oil/chemical carriers in Bassett et al. (2012), even if adjusted to peak levels, would be well below NMFS proposed TTS criterion for peak received level.

The SELcum measurement is indeterminate in this case because it requires knowing how long an animal is exposed to a sound level. In the case of whale/vessel interactions, whales are likely to begin moving away from the vessel when they hear the vessel (Richardson et al. 1995), reducing the whale's exposure to sound both in time and intensity. Given the source level of vessel calling at the BP Marine Terminal is considerably below the TTS peak criterion and whales are unlikely to remain in the vicinity of vessels for an extended period of time, the SEL_{cum} criterion is not likely to be violated either. Even though these proposed criteria currently have no regulatory effect, consideration of them indicate that the incremental increase in exposure to vessels calling at the BP North Wing is not likely to result in TTS or level "B" harassment. . And as discussed in section 3.1.2 and 3.2.2 the overall increase in sound energy contributed to the sound budget by the increase in vessels calls at the BP Marine Terminal is expected to be minimal and likewise is not likely to adversely affect humpback, blue and fin whales.

4.1.1.2 Operations of the Marine Terminal

Ongoing operation and maintenance activities at the BP Marine Terminal could result in accidental spills of oil or other hazardous materials (e.g., hydraulic fluid). Instances of spills associated with the operation of the BP Marine terminal, described in Section 3.2, is very small and unlikely to adversely affect the species.

It is possible that baleen whales could be present in the vicinity when ships are arriving or departing from the BP Marine Terminal. The low likelihood that a humpback, blue or fin whale will be present in the Action Area combined with the small potential increase in vessel traffic calling at the BP Marine Terminal makes a measurable increase in the probability of a vessel strike over baseline conditions unlikely.

Measures to reduce potential effects on whales include observers at the dock during maintenance activities, when required. If, in these circumstances a whale is observed near the terminal, maintenance activities are suspended until the whale moves away from the area.

4.1.1.3 Conclusion

Should humpback, blue or fin whales occur in the Action Area, the ongoing operation and maintenance activities of the BP Marine Terminal would be unlikely to result in increased collisions in the shipping lanes, or increased effects due to noise exposure or water pollution. Because ongoing operation and maintenance of the terminal is unlikely to adversely affect humpback, blue and fin whales, the Proposed Action may affect, but is not likely to adversely affect humpback, blue and fin whales.

4.1.2 Southern Resident DPS Killer Whale

Southern Resident killer whales could be present in the Action Area from May to October. Their range and movements during the late fall, winter, and early spring are less well known, but they are thought to spend less time in inland waters during these months (NMFS 2008a). Therefore the six months between May and October represent the time when the greatest potential for effects from the project would occur. Potential effects of the Proposed Action on killer whales associated with the BP Marine Terminal would include potential interactions with vessels in transit, effects due to increased noise, and effects from discharge of hazardous materials into the marine environment.

4.1.2.1 Effects of Vessel Traffic

Commercial shipping, ferry operations, military vessels, and recreational vessels all occur within the Action Area. Several studies (NMFS 2008a) in the inland waters of Washington State and British Columbia have linked interactions of vessels and Southern Resident killer whales with short-term behavioral changes. Effects from vessels and the sounds they generate include effects to foraging efficiency, communication, and/or energy expenditure though their physical presence, increased underwater sound level, or both.

Vessel Strikes

Collisions of killer whales with vessels are rare, but remain a potential source of serious injury or mortality. Shipping vessels and tugboats proceed in a usually predictable straight path toward the BP Marine Terminal at relatively low speeds. Such vessels do not target whales and are likely detected and avoided by Southern Residents (NMFS 2008a). Vessels and barges bound for the BP Marine Terminal utilize Rosario Strait almost exclusively. Killer whale densities are lower in Rosario Strait compared to Haro Strait (Figure 3.3-2); therefore, there would be a lower probability of killer whales encountering vessels in the Rosario Strait route, as compared to the Haro Strait route. Known collisions of vessels, of any type, with Southern Resident killer whales in the lower British Columbia region (near Vancouver Island) was limited to three observations between the 1960s and 2006 (NMFS 2008a). Given the composition of vessel types and numbers of vessel are comparable to levels in northern Puget Sound, vessel collisions would be likely to be similarly infrequent with all traffic utilizing the Cherry Point area and Rosario Strait. Since vessel traffic calling at the BP Marine Terminal represents only a small portion of all shipping traffic (approximately one percent), the likelihood of a vessel collision with killer whales attributed to BP Marine Terminal vessel traffic would be expected to be very low.

Sound

Killer whales produce a wide variety of clicks, whistles, and pulsed calls. Their clicks are relatively broadband, short (0.1 to 25 milliseconds), and range in frequency from 8 to 80 kHz with an average center frequency of 50 kHz and an average bandwidth of 40 kHz (Au et al. 2004). Killer whales use these signals to sense objects in their environment, such as prey; whales foraging on salmon produce these signals at peak-to-peak source levels ranging from 195 to 225 dB re 1 μPa at 1 meter (Holt 2008).

Killer whale whistles are tonal signals that have longer duration (0.06 to 18 seconds) and frequencies ranging from 0.5 to 10.2 kHz (Holt 2008). Killer whales are reported to whistle most

often while they have been engaged in social interactions rather than during foraging and traveling (Holt 2008).

Killer whale pulsed calls are the most commonly observed type of signal. With Southern Resident killer whales, these signals are relatively long (600 to 2,000 milliseconds [ms]) and range in frequency between 1 and 10 kHz; but may contain harmonics up to 30 kHz. The variable calls of killer whales have source levels ranging from 133 to 165 dB 1 µPa at 1 meter (3.3 feet) while stereotyped calls have source levels ranging from 135 to 168 dB re 1 µPa at 1 meter. Killer whales use these calls when foraging and traveling. (Holt 2008)'

Killer whales are classified by NMFS as belonging to the mid-frequency hearing group, with a functional hearing range of 150Hz to 160 KHz. Bassett et al. (2012) reported that below 1 kHz, where the majority of acoustic energy associated with commercial ships is concentrated, ship traffic regularly increases noise levels by 25 dB re 1 µPa above background levels, but that mid-frequency cetaceans are about 5 db less sensitive to sounds in this range than in the more sensitive parts of their hearing range. However, at higher frequencies (extending up to 30 kHz), which are more biologically important, one-third octave band SPLs regularly increase by 10–20 dB re 1 µPa, which has the potential to mask biologically significant sounds killer whales use to communicate, forage, and otherwise gain awareness of the environment. While there are many documented, clearly discernable responses of marine mammals to anthropogenic sound, reactions are typically subtle, consisting of shorter surfacing intervals, shorter dives, fewer blows per surfacing, longer intervals between blows, ceasing or increasing vocalizations, shortening or lengthening duration of vocalizations, and changing frequency or intensity of vocalizations. While some of these changes become statistically significant in given exposures, it remains unknown when and how these changes translate into biologically significant effects at either the individual or the population level (NRC 2003).

Whale displacement by acoustic ''pollution'' has been difficult to document, even in cases where it is strongly suspected, because noise effects can rarely be separated from other stimuli. However, Morton and Symonds (2002) report a significant decline in sightings of killer whales during a 5-year period when acoustic-harassment devices were operated in an area of water about 10 km × 10 km in Boughton Archipelago, British Columbia, Canada. The acoustic-harassment devices emitted a 10 kHz signal at 194 dB_{peak} re 1 µPa at1 m, which was estimated to reach ambient noise levels 50 km (31 miles) from the source. These devices were designed to be loud enough to deter pinnipeds from breaking into fish farms to feed, but they had the unintended consequences of excluding inshore cetaceans from the area. Williams *et al.* (2002) investigate the effect of "leapfrogging" whale watch vessels on killer whales in Johnstone Strait, British Columbia, Canada. They observed whales engaging in avoidance behavior in response to increase noise levels as vessels speed up to overtake another whale watch vessel for a closer approach to the whales. While these studies document cause for concern for the endangered southern resident killer whales, they are distinguishable from the effects anticipated as a result of the Proposed Action. Source levels from dock operations and vessel transits are much lower in frequency and intensity than the signal generated by the acoustic harassment devices in the Boughton Archipelago. And the vessels transiting to the BP Marine Terminal would be moving slowly (likely < 15 knots) on consistent and predicable courses, unlike leapfrogging whale watch vessels.

Exposure to anthropogenic sounds may increase stress levels and affect the fitness of individuals by lengthening migration, increasing the duration of foraging bouts, or limiting foraging opportunities before long periods of fasting and migration begin (NRC 2003). In 2011, NMFS published "Protective Regulations for Killer Whales in the Northwest Region Under the Endangered Species Act and Marine Mammal Protection Act" (76 FR 20870), to address the effects of vessels on killer whales. However, in recognitions of the fact that vessels such as government vessels, commercial and tribal fishing boats, cargo ships, tankers, tug boats, and ferries represent a small proportion (typically 5–7 percent in most years) of the vessels within one-quarter mile of the whales, NMFS provided an exception for vessels participating with the VTS and following a Traffic Separation Scheme or complying with a VTS Measure of Direction. This exception also includes support vessels escorting vessels in the traffic lanes, such as tug boats (76 FR 20870). All of the vessels calling at BPs Marine Terminal would qualify for this exception. The incremental increase in vessel traffic resulting from the Proposed Action is not anticipated to result in adverse effects to southern resident killer whales, as it is a small incremental increase in an already small component of the vessel traffic that occurs in the vicinity of the whales.

As discussed in section 3.1.2, and 3.2.2 the incremental increase in vessel traffic due to vessel calls at the BP Marine Terminal could result in exposing killer whales to increased sound levels from a transiting vessel. Basset et al. (2012) estimate the source level for oil/chemical tankers to be 181 dB re 1 µPa at 1 m and tugs at 173 dB re 1 µPa at 1 m. These are likely representative levels for the vessels calling at BP's Marine Terminal and for the vessels contributing to the increase in calls as a result of the operation of the North Wing, because no change is expected in the ship speed, condition of the vessel, vessel load, and onboard activities of the vessels calling at the marine terminal other than a small incremental increase in frequency of calls.

While the source level for tankers approach NMFS interim criterion for injury of 180 dB_{rms} re 1 µPa at 1 m, no killer whales are likely to occur within 1 m of a vessel, and given their tendency to avoid vessels upon detection, the received level experienced by these whales is likely to be well below the interim injury criterion. They are likely though to be exposed to received levels that exceed the 120 dB_{rms} re 1 µPa at 1 m for defining disturbance (i.e. level B harassment) under the MMPA. The effect of this disturbance is likely to involve avoidance behaviors which are not expected to result in adverse effect to the fitness of any of the individuals exposed.

With respect to NMFS 2013 proposed guidelines for potential injury or harassment, killer whales fall in NMFS mid-frequency hearing group and while there are overlaps with the frequency range of sound generated by commercial shipping traffic, much of the energy contributed by vessels calling at BP's terminal and operations at the terminal fall in frequency ranges not particularly important to killer whales. NMFS proposed dual criteria for TTS are received levels of 224 dB_{peak} re 1 µPa and 198 dB SEL_{cum} re 1 µPa2-s. While NMFS cautions against comparing these criteria to the interim criteria because dB_{rms}, dB_{peak}, and dB SEL_{cum} are all based on different metrics, as a rule of thumb dB_{peak} is generally a few dB higher than dB_{rms}. Thus, the estimated source levels for oil/chemical carriers in Bassett et al. (2012), even if adjusted to peak levels, would be well below NMFS propose TTS criterion for peak received level.

The SEL_{cum} measurement is indeterminate in this case because it requires knowing how long an animal is exposed to a sound level. In the case of whale/vessel interactions, whales are likely to

begin moving away from the vessel when they hear the vessel (Richardson et al. 1995), reducing the whale's exposure to sound both in time and intensity. Given the source level of vessel calling at the BP Marine Terminal is considerably below the TTS peak criterion and whales are unlikely to remain in the vicinity or vessels for an extended period of time, the SEL_{cum} criterion is not likely to be violated either. Even though these proposed criteria currently have no regulatory effect, consideration of them indicate that the incremental increase in exposure to vessels calling at the BP North Wing is not likely to result in TTS or level "B" harassment. . And as discussed in section 3.1.2 and 3.2.2 the overall increase in sound energy contributed to the sound budget by the increase in vessels calls at the BP terminal is expected to be minimal and likewise is not likely to adversely affect killer whales.

4.1.2.2 Operations of the Marine Terminal

Effects to killer whales from operations of the BP Marine Terminal would be similar to those described above in Section 4.1.1.2. The effects would be limited in duration and magnitude, and would not be expected to result in population-level effects to Southern Resident killer whales.

4.1.2.3 Effects to Critical Habitat

Vessel traffic moving to and from the BP Marine Terminal would transit through Southern Resident killer whale critical habitat and would increase mixing of the surface and subsurface layers of the water column in the area immediately surrounding the vessel path and wake. This mixing of the layers would not be expected to affect water quality since the increase in vessel traffic attributable to the Proposed Action would be very small and those vessels would stay within the Coast Guards VTS, which is an area that is already disturbed by vessel traffic; therefore increased vessel traffic would not be expected to have an effect on killer whale critical habitat. Fish and marine mammals as prey species would also avoid areas where vessels are present, but would otherwise be unaffected by vessels in terms of sufficient quantity, quality and availability.

An accidental spill of oil during oil transfer from the vessel to the refinery could threaten killer whale critical habitat by decreasing prey population, thereby reducing food availability. However, the probability of a spill of oil or other hazardous material at the dock is slight (small spills occurring less than once per year), and would not be expected to affect killer whale critical habitat.

The primary constituent element of passage conditions to allow for migration, resting, and foraging would be affected by the passage of vessels. Whales would move away from the source of the noise, temporarily displacing them from the area. However, the passage of watercraft in the area is an existing, temporary and common occurrence. Overall, the Proposed Action may affect, but is not likely to adversely affect, designated critical habitat for the Southern Resident killer whale.

4.1.2.4 Conclusion

The ongoing operation and maintenance activities of the BP Marine Terminal would be unlikely to result in increased collisions with killer whales in the shipping lanes, or increased effects due to noise exposure or water pollution. Because ongoing operation and maintenance of the terminal would be unlikely to adversely affect killer whales or their critical habitat, the Proposed Action may affect, but is not likely to adversely affect killer whales.

The Action Area includes killer whale critical habitat occurring in the Strait of Juan de Fuca and the Summer Core Area (Haro Strait and San Juan Islands). The effects of vessel traffic on the primary constituent elements Southern Resident killer whale critical habitat would be limited to temporary displacement of whales and their prey species. In addition, these critical habitat units could be impacted by the Proposed Action if there is a discharge of oil or other hazardous material into the aquatic environment that leads to a decrease in prey population, thereby reducing food availability. As discussed above, such incidents would not be expected to occur in a large enough magnitude or frequent enough to affect killer whale critical habitat.

4.2 Fish Species

There are nine fish species listed as threatened or endangered under the federal ESA that could be affected by ongoing operations at the BP Marine Terminal and associated increases in vessel traffic. ESA-listed fish, species that could be affected include bocaccio, canary and yelloweye rockfish, green sturgeon, Pacific eulachon, bull trout, Chinook salmon, chum salmon, and Puget Sound steelhead. Effects to these species and their critical habitat from the Proposed Action are described below.

4.2.1 Rockfish

4.2.1.1 Effects of Vessel Traffic

Noise

Adult fish are able to detect vessel noise over a large range of frequencies, ten to several hundred Hz, when the noise level is greater than about 30 dB above their hearing threshold (Mitson 1995). Fish within a few hundred meters of passing ships (e.g., tankers) may exhibit avoidance behaviors (Mitson 1995). A study on the behavior of larval fish in response to exposure to varying levels of sound found no significant effect on behavior or fish tissue (Jorgensen et al. 2005 as cited in Popper and Hastings 2009). An increase in vessel traffic due to the operation of the BP Marine Terminal would lead to a small incremental increase in noise; the increase in noise would be unlikely to affect larval rockfish as sound does not have a negative effect on larval fish, or adult rockfish as they are a deepwater assemblage that would not commonly occur within the vicinity of transiting vessels. Since the overall increase in noise, relative to background conditions, would be relatively small, and rockfish would not be likely to occur in the vicinity of vessel traffic, the Proposed Action would result in an insignificant effect to fish present in the Action Area.

Entrainment

Adverse effects to listed fish species from increased vessel traffic would primarily be limited to larval stages of rockfish, as they have limited swimming capability, may occupy the nekton layer of the water column for several months (primarily in the spring) and are therefore subject to currents and unable to avoid vessel traffic.

Vessel traffic of all types and sizes presents a persistent, if small, risk to larval rockfish populations. All rockfish species, including the three distinct population segments present in Puget Sound are viviparous giving birth to well-developed larvae with limited abilities to swim, maintain buoyancy in the water column, and feed. These larvae are pelagic for several months and occur in the water column from near the surface to depths of 100 meters (328 feet) or more.

Those near the surface and in the shipping lanes may to be injured or killed by encounters with vessel traffic. In addition, those near docks and mooring facilities may be subject to entrainment in vessel engine cooling systems.

A literature review, including NMFS' status review, listing documents, and several relevant biological opinions, did not reveal any analysis of the level of risk vessel traffic presents to the survival and abundance of rockfish populations. For example, vessel traffic or interactions with vessels is not identified as a threat in the Status review document NMFS relied upon in considering its decision to list the Georgia Strait/Puget Sound DPSs of bocaccio, canary, and yelloweye rockfish. Presumably, this is related to the view that reduction in adult population levels due to overfishing by commercial and recreational anglers has been the major driver in the decline of rockfish along the Pacific Coast (Zabel et al. 2011) and in Puget Sound in particular (NMFS 2010b; Palsson et al. 2009). Other risk factors considered in the NMFS status review include habitat loss, water quality, predation, competition, derelict fishing gear, climate change, and hatcheries. Of those, loss of habitat and competition from other rockfish and hatchery fish were identified as factors that could be impeding recovery of the listed DPSs of rockfish, but even those impacts are discussed in the context of effects on juvenile rather than larval rockfish.

Several biological opinions (NMFS 2011d-f; 2012) cover the effects of in-water construction and in-water dredge disposal; NMFS analyzed the effects of sound, habitat destruction, and sedimentation, however, there has been no analysis of the effect of vessel operations associated with those actions on larval fish. In each of these opinions NMFS concluded that although larval fish were likely to be killed by exposure to the effects of the actions, the numbers of mortalities were small compared to the number of larvae produced by these species. Given that recruitment of larvae to settled juvenile is an infrequent event and that larval rockfish experience high natural mortality, the NMFS's conclusion in the biological opinion (NMFS 2011d) was that the loss of larval rockfish was not likely to jeopardize the continued existence of the species.

A similar analysis is appropriate to determine the effect of the Proposed Action on rockfish. No studies examining the effects of vessel traffic on larval rockfish where found, however, two studies were identified that examine the effect of commercial vessel traffic on larval and juvenile assemblages or riverine species. Huckstorf et al. (2011) reported that effects of intense commercial navigation in large low land river system in Germany affected fish assemblages primarily through the hydraulic disturbances along the banks. Roach (*Rutilus rutilus*) larvae, which tend to remain in the littoral zone declined as traffic increase, but perch (*Perca fluviatilis*) larvae did not. They also reported the total zooplankton biomass was highest in the high traffic intensity reach. Odom et al. (1992) investigated barge-associated mortality of larval fishes in Kanawha River (a tributary to the Ohio River) and found the percent of live larvae in samples taken before and after barge passage did not differ significantly for either sampling period.

While these studies were conducted on different species in different environments, they demonstrate that adverse effects of commercial barge traffic on pelagic larval fish in large riverine transportation corridors may be minimal. Even if these studies are not considered relevant, information on distribution of rockfish larvae in the water column indicates most larvae are likely to escape an encounter.

Moser and Boehlert (1991) reviewed the ecology of pelagic larvae and juveniles of the genus Sebastes. They reported vertical larval distribution of at two CalCofi sampling sites of Southern California: one 2.4 nautical miles offshore over a bottom depth of 350 meters (1,148 feet) and one 38.4 nautical miles offshore over a bottom depth of 1,200 meters (4,000 feet). About 90 percent of the larvae occurred at depths shallower than 80 meters (262 feet) at both stations. The largest proportion of the larvae occurred in the 20 to 30 meter (66 to 98 foot) depth at the nearshore site and at 30 to 40 meters (98 to 130 feet) at the offshore site. They attribute the difference to the deeper depth of the thermocline at the offshore site. Relatively small numbers of larvae occurred in the 0 to 20 meter (0 to 66 foot) range at both sites. They suggest that the relative rarity of larvae in the shallow Ekman layer (that layer subject to wind generated currents) may be a mechanism to reduce offshore transport during periods of upwelling keeping larvae closer to benthic habitat where juveniles will ultimately settle. Ross and Larson (2003) examined vertical distribution of pelagic juveniles in 15 species of rockfishes off central California. In depth-stratified midwater trawls made at night, pelagic juveniles of most species were equally distributed throughout the water column. Notable exceptions were bocaccio, which was significantly more abundant in 10 meter and 30 meter (33 to 98 foot) deep tows. For most species examined (13 of 15), increased stratification of the water column led to a tendency for deeper centers of density and smaller rockfishes (≤25 mm standard length) occurred primarily below the thermocline. Since Puget Sound is estuarine in character, its waters stratify according to salinity and temperature. Assuming rockfish larvae behave like larvae in central California, they likely will be distributed below the depths of transiting vessel traffic. The draft of a millennium tanker, the type likely to call on the BP Marine Terminal is about 17 meters (56 feet), and tugs and barges have shallower drafts generally less than 10 meters (33 feet). In addition, larvae are widely distributed in low densities by currents in Puget Sound (Weiss 2004), so even those that are at a shallow depth are likely to escape an encounter with a vessel. Therefore, even though the effect of vessel traffic on larval fish cannot be quantified, most larvae would be likely to escape encounters; the few that do not would not affect the recruitment dynamics of these three species of rockfish.

Larval rock fish are also susceptible to entrainment (the direct uptake of aquatic organisms by the suction field generated by water intakes) in the vessel sea water intakes for engine cooling, fire suppression units, other ship board uses of sea water, and ballast water management. Adverse effects to listed fish species from entrainment would primarily be limited to larval stages of rockfish, as they have limited swimming capability, may occupy the nekton layer of the water column for several months (primarily in the spring), and are therefore subject to currents and unable to avoid the approach velocities near intake structures. Puget Sound wide assessments of larval rockfish are rare. Greene and Godersky (2012) documented seasonal trends in abundance with peaks in spring and summer, and geographic trends with lower densities in northern basins compared Central and South Sound. Waldron (1972, cited in Greene and Godersky 2012) sampled only in the spring and found a different distribution with Central and Rosario Basins having higher densities than Whidbey basin and South Sound. Weis (2004) was limited to only sampling around San Juan Island, but documented the seasonality observed by Greene and Godersky (2012). While none of these studies included Cherry Point, they do document the wide distribution both vertically and horizontally (Weis 2004) indicating that only a small fraction of the larval population is likely to be exposed to the risk of entrainment in vessel cooling systems during spring and summer.. All other life stages of rockfish inhabit deeper water and would avoid the vessels intakes.

There have been a number of studies of coastal power plants in California that use sea water in cooling systems to condense steam. The largest of these is the Diablo Canyon nuclear plant in central California. When operating at full capacity it uses about 3.8 Kcfs in its cooling system (Tetra Tech 2008). Ehrler et al. (2002) and Steinbeck et al. (2007) estimated the number of kelp, gopher, and black rockfish complex larvae entrained in the vicinity of the power plant annually for two periods. Their estimates, adjusted to the long-term average intake cove surface plankton tow index, were:

- October 1996 through September 1997 – 275,000,000 (Standard Error [SE] = 24,700,000) larvae; and
- October 1997 through September 1998 – 222,000,000 (SE = 28,900,000) larvae.

Based on three impact assessment approaches, in conjunction with additional adult abundance data, Ehrler et al. (2002) concluded that kelp, gopher, and black rockfish in the vicinity of Diablo Canyon Power Plant were not adversely impacted by power plant entrainment, and the results supported a conclusion that potential impacts to rockfish were relatively small. Combining these results with the observation of a fairly stable adult rockfish population confirms the conclusion of no adverse environmental impact to kelp, gopher, and black rockfish.

The Diablo Canyon study was performed on thriving rockfish populations compared to the listed Puget Sound rockfish, and demonstrates that populations can sustain high levels of larval mortality without adverse environmental impact. The capacity of vessel cooling systems is orders of magnitude smaller than the capacity of a coastal power plant (10cfs v. 1000s of cfs) and although the amount of larval rock fish entrainment associated with the incremental increase in vessel traffic associated with this action cannot be meaningfully measured, detected, or evaluated, it would not likely adversely affect the reproduction, population size, or distribution on the three listed rockfish populations.

In years when larval production is good, climatic conditions are just right, and currents deliver larval fish to juvenile rearing habitat, a strong cohort recruit to the juvenile and adult populations would be expected. For bocaccio this generally occurs on the frequency once every 13 years (Tolimieri and Levin 2005). Canary and yelloweye rockfish likely have similar patterns of mostly poor years interspersed with occasional good years of larval production and survival. The increment of larval mortality that occurs in those years is unlikely to be large enough to reduce the production of a strong cohort, which will contribute to recovery. Therefore, vessel traffic (including entrainment) would not likely have an adverse effect on the reproduction, numbers, or distribution of these three rockfish populations. And, in any case, any impact would be so negligible it could not be meaningfully measured, detected or evaluated.

4.2.1.2 Operation of the Marine Terminal

Effects to rockfish from the operation of the BP Marine Terminal include increased lighting, accidental release of ballast water, and minor releases of oil and other contaminants.

Most fish utilize vision to orient and perform activities such as foraging, breeding, and avoiding predators. Fish behavior can be affected by artificial light stimuli; a common reaction of fish groups in the presences of artificial light is to school and move towards the light source. Levels

of aggregation and attraction to light varies by species (Marchesan et al. 2004). Artificial lighting at the dock may facilitate nocturnal predation by visual aquatic predators and piscivorous birds.

BP records, from 1971 to 2005, indicate that ballast water from cargo tanks has been spilled twice (<1 percent occurrence). While these accidents are outside the scope of Coast Guard regulations, they are a rare event and of such a size to not create an additional risk of invasive species introduction. Vessels calling at BP's Marine Terminal would comply with Coast Guard regulations. Should vessels require discharge of ballast from their cargo tanks, the BP Marine Terminal has reception facilities available. Any cargo ballast water received by the BP Marine Terminal would go through laboratory testing to ensure it contains no chemicals or toxins which could not be appropriately treated in the on-site wastewater treatment plant prior to treatment and subsequent discharge into the marine environment. The BP Marine Terminal would not accept ballast containing MTBE. NMFS has consulted with the Coast Guard on the implementation of the ballast water management regulations and concluded that the minimal potential for introduction on invasive species is not likely to jeopardize the existence of listed species (NMFS 2012c).

Ongoing operation and maintenance activities at the BP Marine Terminal could result in accidental spills of oil or other hazardous materials (e.g., hydraulic fluid). Spill records at the dock for the period from 1990 through 2010 indicate that incidents are infrequent (typically average 3.5 per year), and the volume of spills is usually very small. Many of the incidents reported were in quantities of drops or sheen on the water, and with an average spill volume of 37 liters (9.8 gallons). Between 2001 (when the North Wing became operational) and 2010, the average spill volume at the BP Marine Terminal decreased to 2.5 liters (0.65 gallons).If an accidental spill of oil or other hazardous material were to occur, a small number of individual rockfish larvae near the dock could be adversely affected. Such incidents are not part of the normal operations and maintenance activities, and would not be expected to occur in a large enough magnitude or enough frequency to adversely affect rockfish.

4.2.1.3 Effects to Critical Habitat

Critical habitat for adult canary and bocaccio and adult and juvenile yelloweye rockfish is designated in waters deeper than 30 meters (98 feet) within the Action Area. The draft of a millennium tanker is about 17 meters (56 feet) which would not impact deepwater habitat. Vessels transiting through the Action Area would increase mixing of the surface and subsurface layers of the water column in the area immediately surrounding the vessel path and wake which could have a minor impact on surface water quality including DO, however, these impacts at the surface would be unlikely to affect deepwater habitat.

Juvenile canary rockfish and bocaccio critical habitat is designated in nearshore areas where increased vessel traffic could increase water turbidity, however this would be a temporary and localized effect. Minor shading of the nearshore habitat in the vicinity of the dock could impact aquatic vegetation present in the area which could alter physical habitat conditions; however, shading would be minimal and would not be expected to result in lasting habitat alterations. Rockfishes primary prey species include sand lance and surf smelt and other species that spawn in intertidal areas. Intertidal areas are located outside of the vessel traffic routes, and would not be affected by vessels transiting to the BP Marine Terminal. Overall, vessels transiting through

the Action Area would not likely have an adverse effect on the primary constituent elements identified for rockfish.

An accidental spill of oil during oil transfer from the vessel to the refinery poses the greatest potential threat to rockfish critical habitat because a release is likely to affect nearshore areas or sensitive habitats. Impacts could include alteration of habitat complexity (e.g., loss of aquatic vegetation providing cover) and destruction of prey organisms. However, the probability of a spill of oil or other hazardous material at the dock is slight (small spills occurring less than once per year), and would not be expected to affect rockfish critical habitat. Overall, the Proposed Action may affect, but is not likely to adversely affect, proposed critical habitat for canary rockfish, yelloweye rockfish and bocaccio.

4.2.1.4 Conclusion

All three of the listed rockfish species are deep dwelling species associated with rocky habitat, which is extremely limited in Puget Sound. Only about 10 km^2 (6 mi^2) of such habitat occurs in Puget Sound (i.e., south of Admiralty Inlet), and about 207 km^2 (129 mi^2) is present in Northern Puget Sound (Palsson et al. 2009). There is no adult rockfish habitat in the vicinity of the BP Marine Terminal. Because adults of these species are distributed in habitats at some distance (likely hundreds of meters to tens of kilometers), they are not likely to be exposed the effects of routine operations of the BP Marine Terminal, including occasional small (a few spoonfuls to a few gallons) oil spills. Nor are they likely to be affected by vessel encounters (collisions) as their depth ranges are well below the draft of any tanker or tug and barge likely to transit in the Sound and call at the terminal. Effects to rockfish would be limited to the larval stage. While the Proposed Action may have some negligible effect on the species' abundance at the larval stage, it would be unlikely to kill juveniles using the nearshore or benthic habitats of the Action Area, or kill any adults, and thus it would not likely have an appreciable effect on the survival and recovery of the species due to effects on their productivity, diversity, or structure within the Puget Sound/Georgia Basin. Because effects from the ongoing operation and maintenance of the terminal would be limited to the larval stage and, in any case, could not be meaningfully measured, detected or evaluated, the Proposed Action may affect, but is not likely to adversely affect bocaccio, canary, and yelloweye rockfish.

The Action Area includes proposed critical habitat for canary, bocaccio and yelloweye rockfish. The effects of vessel traffic on the primary constituent elements of canary, bocaccio and yelloweye rockfish critical habitat would be limited to increased water turbidity and shading in nearshore areas, although these effects would be minimal and would not be expected to result in lasting habitat alterations. Impacts could also occur from an accidental spill of oil, although this is unlikely. The Proposed Action may affect, but is not likely to adversely affect bocaccio, canary, and yelloweye rockfish critical habitat.

4.2.2 Green Sturgeon

Southern DPS green sturgeon were first determined to occur in Oregon and Washington waters in the late 1950s when tagged San Pablo Bay green sturgeon were recovered in the Columbia River estuary (CDFG 2002). A few green sturgeon have been recovered in Puget Sound as incidental harvest from trawl fishers. Lindley et al. (2008) tagged 213 subadult and adult green sturgeon in spawning rivers and summer aggregation areas with uniquely coded ultrasonic pingers and observed their coastal movements with arrays of automated hydrophones deployed

along the West Coast of North America from southeast Alaska to Monterey Bay, California. Based on the pattern of detections, they suggest that important overwintering grounds for green sturgeon may occur north of Vancouver Island and south of Cape Spencer, Alaska. Although they reported that during this migration a few sturgeon were detected at the San Juan de Fuca station, based on apparent migration rates between detection locations they hypothesize that most green sturgeon migrating between Canadian and U.S. waters cross the Strait of Juan de Fuca over deep water to the west of the Strait of Juan de Fuca line. Lindley et al. 2008 and Lindley et al. 2011 are consistent with a view that green sturgeon presence in Puget Sound is transitory and more likely to occur in the western part of the Action Area.

4.2.2.1 Effects of Vessel Traffic

Noise

Adult fish are able to detect vessel noise over a large range of frequencies, tens to several hundred Hz, when the noise level is greater than about 30 dB above their hearing threshold (Mitson 1995). Fish within a few hundred meters of passing ships (e.g., tankers) may exhibit avoidance behaviors (Mitson 1995). An increase in vessel traffic due to the operation of the BP Marine Terminal would lead to a small incremental increase in noise, which could cause green sturgeon to avoid areas where vessels are present. Since the overall increase in noise, relative to background conditions, would be relatively small, it would result in an insignificant effect to fish present in the Action Area.

Entrainment

Entrainment or the direct uptake of aquatic organisms by the suction field generated by water intakes on the vessels could occur. Sources of potential entrainment could include engine cooling, ballast water, and utility water used at the terminal. Potential impacts from entrainment could include physical stress due to pressure changes and/or abrasions or contact with screens and pump impellers. The change in pressure may burst swim bladders.

The potential for entrainment would primarily affect larval fish as larger adult fish have been found to escape by avoiding large vessels (Dettmers et al. 1998). Young sturgeons utilize freshwater habitat and would not be present in the Action Area. Adult and subadult green sturgeon could be present in the Action Area; however occurrence is rare (Lindley et al. 2011). Therefore, entrainment would not pose a hazard to this species because the presence of green sturgeon in the Action Area would be limited to subadults and adults and green sturgeon would be large enough during these life stages to avoid large vessels.

4.2.2.2 Operation of the Marine Terminal

Effects related to ongoing operation of the BP Marine Terminal would be similar to those described above in Section 4.2.1.2, would be limited in duration and magnitude, and would not be expected to result in population-level effects to southern DPS green sturgeon.

4.2.2.3 Effects to Critical Habitat

Green sturgeon critical habitat occurs along the Strait of Juan de Fuca and the southern portion of Rosario Strait, it does not extend north to the BP Marine Terminal. Therefore, effects to green sturgeon critical habitat from the Proposed Action would be limited to the increase in vessel traffic transiting to the BP Marine Terminal.

Vessel traffic transiting to the BP Marine Terminal would move through green sturgeon critical habitat. Transiting vessels could cause fish to temporarily move away from the source of the noise until the vessel has passed through the area. The overall increase in noise, relative to background conditions, would be relatively small; it would result in an insignificant effect to green sturgeon migration routes in the Action Area.

Increased vessel traffic would increase mixing of the surface and subsurface layers of the water column in the area immediately surrounding the vessel path and wake. This mixing of the layers would not be expected to affect water quality since the increase in vessel traffic attributable to the Proposed Action would be very small and those vessels would stay within the designated shipping lanes, which is an area that is already disturbed by vessel traffic. Therefore, the incremental increase in vessel traffic would not be expected to have an effect on water quality in designated critical habitat.

Green sturgeon generally are benthic feeders, and their critical habitat is located in coastal waters less that 60 fathoms (109.7 m) deep along the U.S. coast of the San Juan de Fuca Strait to the entrance of Rosario Strait. Given the general deep bathymetry of the strait, vessel transits would avoid most of the critical habitat; where they do cross critical habitat, vessels underway would not be likely to affect the benthic communities sturgeon may use for forage. Overall, the Proposed Action may affect, but is not likely to adversely affect, designated critical habitat for southern DPS green sturgeon.

4.2.2.4 Conclusion

Southern DPS green sturgeon would not likely experience long term effects as a result of ongoing operation of the BP Marine Terminal. As described above, individuals of these species could potentially experience habitat disturbance related to maintenance activities at the BP Marine Terminal, as a consequence of tanker vessels in transit to the docking facilities, and while unloading and loading cargo. Green sturgeon present in the Action Area would not be spawning, rearing, or foraging and project activities are limited in duration and magnitude; therefore, the likelihood of population effect from the Proposed Action is remote and is considered insignificant. Because ongoing operation and maintenance of the terminal would be unlikely to adversely impact southern DPS green sturgeon, the Proposed Action may affect, but is not likely to adversely affect southern DPS green sturgeon.

The Action Area includes critical habitat for green sturgeon. Given the location of critical habitat, effects from the Proposed Action would be limited to the increase in vessel traffic transiting through the Strait of Juan de Fuca to the BP Marine Terminal. Migratory corridors and water quality would not be expected to be affected by the Proposed Action because the increase in vessel traffic attributable to the Proposed Action would be very small and those vessels would stay within the designated shipping lanes, which is an area that is already disturbed by vessel traffic. Since green sturgeon do not forage within the Action Area, there would be no effects from the Proposed Action on prey availability. The Proposed Action may affect, but is not likely to adversely affect, designated critical habitat for southern DPS green sturgeon.

4.2.3 Pacific Eulachon

In its status review report, NMFS reviewed available literature on the distribution and abundance of eulachon in Puget Sound (Gustafson et al. 2010). Historically, there was confusion over the

identification of species and several early references to eulachon were subsequently determined to be longfin or surf smelt (See discussion of historical references in Gustafson et al. 2010). This is the case for the reported run in the Nooksack River (G. Bargmann, WDFW, and Olympia, Washington. Pers. com., June 2008; cited in NMFS' status review [Gustafson et al. 2010]). WDFW and ODFW (2008) indicate there is virtually no life history information within the Puget Sound Basin available for eulachon, nor is there evidence of spawning stocks of eulachon in Puget Sound Rivers. However, an irregular but apparently persistent run was documented in the Elwha River in 2005.

4.2.3.1 Effects of Vessel Traffic

Noise

Adult fish are able to detect vessel noise over a large range of frequencies, tens to several hundred Hz, when the noise level is greater than about 30 dB above their hearing threshold (Mitson 1995). Fish within a few hundred meters of passing ships (e.g., tankers) may exhibit avoidance behaviors (Mitson 1995). An increase in vessel traffic due to the operation of the BP Marine Terminal would lead to a small incremental increase in noise, which could cause eulachon to avoid areas where vessels are present. Since the overall increase in noise, relative to background conditions, would be relatively small, it would result in an insignificant effect to fish present in the Action Area.

Entrainment

Once juvenile eulachon enter the ocean, they move from shallow nearshore areas to deeper areas over the continental shelf where they are typically found near the ocean bottom in waters 20 to 150 meters (65 to 490 feet) deep (NMFS 2011c). There is currently little information available about eulachon movements in nearshore marine areas and the open ocean. Eulachon could be present in the Action Area but would generally occur at depths greater than the draft a millennium tanker (17 meters [56 feet]) so that entrainment would not be an issue.

4.2.3.2 Operation of the Marine Terminal

Effects related to ongoing operation of the BP Marine Terminal would be similar to those described above in Section 4.2.1.2, would be limited in duration and magnitude, and would not be expected to result in population-level effects to Pacific eulachon.

4.2.3.3 Conclusion

Eulachon are not likely to be adversely affected by the Proposed Action because relative to their distribution and abundance they are rare visitors to Puget Sound and its tributaries. The irregular but persistent run in the Elwha River is an exception, but it is protected by its remoteness from the BP Marine Terminal with respect to any effects associated with those operations. Since there are so few eulachon in the Action Area and the interaction with the small increase in vessel traffic would likely be discountable, the Proposed Action may affect, but is not likely to adversely affect eulachon.

Pacific eulachon critical habitat does not occur within the Action Area and therefore would not be affected by the Proposed Action.

4.2.4 Bull Trout, Chinook Salmon, and Chum Salmon

Bull trout use the nearshore marine ecosystem during the spring and late summer months. Juvenile bull trout rear in the nearshore ecosystem with preference for unconsolidated habitats that may include eelgrass and kelp beds, which is found in the vicinity of Cherry Point. The nearshore area is critical foraging habitat for this species group. Adults also feed in this area and then migrate into freshwater rivers and streams to spawn. Critical habitat has been designated for bull trout within the Action Area in the Coastal Puget Sound and the Olympic Peninsula that extends from the line of extreme high tide to a depth of 10 meters (33 feet).

Adult and juvenile Chinook and chum migrate through the Action Area en route to spawning tributaries and when they are headed out to sea, respectively. Critical habitat for Chinook salmon has been designated within the Action Area for nearshore marine areas of the Strait of Georgia, Puget Sound, Hood Canal and the Strait of Juan de Fuca from the line of extreme high tide to a depth of 30 meters (98 feet). Critical habitat has been designated for chum salmon within the Action Area for the Strait of Juan de Fuca from the line of extreme high tide to a depth of 30 meters (98 feet).

4.2.4.1 Effects of Vessel Traffic

Noise

Adult fish are able to detect vessel noise over a large range of frequencies, ten to several hundred Hz, when the noise level is greater than about 30 dB above their hearing threshold (Mitson 1995). Fish within a few hundred meters of passing ships (e.g., tankers) may exhibit avoidance behaviors (Mitson 1995). An increase in vessel traffic due to the operation of the BP Marine Terminal would lead to a small incremental increase in noise, which could cause salmon to avoid areas where vessels are present. Since the overall increase in noise, relative to background conditions, would be relatively small, it would result in an insignificant effect to fish present in the Action Area.

Entrainment

Chinook salmon, chum salmon and bull trout present in the Action Area would be large enough and possess swimming capabilities so that entrainment would not be an issue (Dettmers et al. 1998).

4.2.4.2 Operation of the Marine Terminal

Effects related to the ongoing operation of the BP Marine Terminal would be similar to those described above in Section 4.2.1.2; they would be limited in duration and magnitude, and would not be expected to result in long term effects to Chinook salmon, chum salmon and bull trout. Fish could potentially experience habitat disturbance related to maintenance activities at the terminal dock, as a consequence of tanker vessels in transit to the docking facilities, and while unloading and loading cargo.

Chinook and chum salmon are generally only present in the Action Area as they migrate to their natal streams while bull trout could be present in the nearshore habitat around the BP Marine Terminal, particularly in the patches of eelgrass found in the sandy patches in the vicinity of the dock. Should an accidental spill occur, a small number of individual fish near the BP Marine Terminal could be adversely affected. However, such incidents are not part of the normal

operations and maintenance activities, and would not be expected to occur in a large enough magnitude or enough frequency to result in population level effects to bull trout, Chinook salmon or chum salmon.

4.2.4.3 Effects to Critical Habitat

Many of the primary constituent elements of Pacific salmon and bull trout critical habitat are relevant to freshwater and estuarine environments and as such are not discussed further. Those applicable to the Action Area include migration habitats with minimal impediments, nearshore marine areas, water quality, natural cover and an abundant food base including aquatic macroinvertebrates and forage fish.

Vessel traffic moving to and from the BP Marine Terminal would not transit through bull trout critical habitat and would therefore have no impact. However, vessels would pass through critical habitat designated for Chinook and chum salmon. Transiting vessels could cause these fish to temporarily move away from the source of the noise until the vessel has passed through the area, however it would not directly block migration routes. Increased vessel traffic could increase water turbidity, which could affect nearshore aquatic habitat and macroinvertebrates. However, vessels would move at low speeds which would minimize this temporary and localized effect. Moving vessels would also increase mixing of the surface and subsurface layers of the water column in the area immediately surrounding the vessel path and wake. This mixing of the layers would not be expected to affect water quality since the increase in vessel traffic attributable to the Proposed Action would be very small and those vessels would stay within the Coast Guards VTS, which is an area that is already disturbed by vessel traffic.

Increased lighting at the Marine Terminal would be associated with vessels unloading at night and would not affect nearshore critical habitat due to its temporary nature as lights would only be on during unloading. Minor shading of the nearshore habitat in the vicinity of the dock could impact natural aquatic vegetation cover in the area; however, shading would be minimal and would not be expected to result in lasting habitat alterations. Ongoing operation and maintenance activities at the BP Marine Terminal could result in accidental spills of oil or other hazardous materials (e.g., hydraulic fluid or contaminated ballast) which may affect nearshore critical habitat including its food base. However, given the spill history at the BP Marine Terminal and BP's oil spill avoidance and response measures (Section 3.2.1), it is unlikely the that operation of the BP Marine Terminal would have long-term impacts to Pacific salmon and bull trout critical habitat. Overall, the Proposed Action may affect, but is not likely to adversely affect, designated critical habitat for bull trout, Chinook salmon and chum salmon.

4.2.4.4 Conclusion

Chinook, chum salmon and bull trout would not be likely to experience long term effects as a result of ongoing operation of the BP Marine Terminal. As described above, individuals of these species could potentially experience habitat disturbance related to maintenance activities at the terminal dock, as a consequence of tanker vessels in transit to the docking facilities, and while unloading and loading cargo. The accidental release of oil or hazardous materials at the dock would have the greatest potential effect to these fish, however such incidents are not part of the normal operations and maintenance activities, and would not be expected to occur in a large enough magnitude or enough frequency to adversely affect bull trout, Chinook salmon or chum salmon. The likelihood of effects at a population level from the Proposed Action would be

remote and are considered insignificant. Because ongoing operation and maintenance of the terminal would be unlikely to adversely impact bull trout, Chinook salmon and chum salmon, the Proposed Action may affect, but is not likely to adversely affect bull trout, Chinook salmon and chum salmon.

The Action Area includes critical habitat for all three species. The effects of vessel traffic on the primary constituent elements of bull trout, Chinook salmon and chum salmon critical habitat would be limited to increased water turbidity and shading in nearshore areas, although these effects would be minimal and would not be expected to result in lasting habitat alterations. These critical habitat areas could also be impacted by the Proposed Action if there is a discharge of oil or other hazardous material into the aquatic environment that leads to a decrease in prey population, thereby reducing food availability. As discussed above, such incidents would not be expected to occur in a large enough magnitude or frequently enough to affect critical habitat. The Proposed Action may affect, but is not likely to adversely affect critical habitat for bull trout, Chinook salmon or chum salmon.

4.2.5 Puget Sound Steelhead

Out-migrating smolts of this species use the intertidal and nearshore marine habitats for early rearing and to adjust to the saline environment. In addition to smolts occurring in the vicinity of the BP Marine Terminal, steelhead migrate through the Strait of Juan de Fuca en route to spawning tributaries throughout Washington's north coast. It is possible that this species would be present within the Action Area.

4.2.5.1 Effects of Vessel Traffic

Noise

Adult fish are able to detect vessel noise over a large range of frequencies, tens to several hundred Hz, when the noise level is greater than about 30 dB above their hearing threshold (Mitson 1995). Fish within a few hundred meters of passing ships (e.g., tankers) may exhibit avoidance behaviors (Mitson 1995). An increase in vessel traffic due to the operation of the BP Marine Terminal would lead to a small incremental increase in noise, which could cause Puget Sound steelhead to avoid areas where vessels are present. Since the overall increase in noise, relative to background conditions, would be relatively small, it would result in an insignificant effect to fish present in the Action Area.

Entrainment

Entrainment or the direct uptake of aquatic organisms by the suction field generated by water intakes on the vessels could occur. Sources of potential entrainment could include engine cooling, ballast water, and utility water used at the terminal. Potential impacts from entrainment could include physical stress due to pressure changes and/or abrasions or contact with screens and pump impellers. The change in pressure may burst swim bladders.

The potential for entrainment would primarily affect larval fish as larger adult fish have been found to escape by avoiding large vessels (Dettmers et al. 1998). The presence of Puget Sound steelhead in the Action Area would be limited to smolts in the nearshore area and adults migrating through on their way to their natal streams. Puget Sound steelhead would be large enough during these life stages to avoid large vessels and entrainment would not pose a hazard.

4.2.5.2 Operation of the Marine Terminal

Effects related to ongoing operation of the BP Marine Terminal would be similar to those described above in Section 4.2.1.2, would be limited in duration and magnitude, and would not be expected to result in population-level effects to Puget Sound steelhead. Puget Sound steelhead smolts could be present in the nearshore habitat around the dock, and should an accidental spill occur, a small number of individual fish in the area could be adversely affected. However, such incidents are not part of the normal operations and maintenance activities, and would not be expected to occur in a large enough magnitude or enough frequency to result in population level effects.

4.2.5.3 Conclusion

Puget Sound steelhead would not likely experience long term effects as a result of ongoing operation of the BP Marine Terminal. As described above, individuals of these species could potentially experience habitat disturbance related to maintenance activities at the BP Marine Terminal, as a consequence of tanker vessels in transit to the docking facilities, and while unloading and loading cargo. Project activities are limited in duration and magnitude; therefore the likelihood of population effect from the Proposed Action is remote and is considered insignificant. Because ongoing operation and maintenance of the terminal would be unlikely to adversely impact Puget Sound steelhead, the Proposed Action may affect, but is not likely to adversely affect Puget Sound steelhead.

Proposed critical habitat for Puget Sound steelhead does not occur within the Action Area and therefore would not be affected by the Proposed Action.

4.3 Birds

4.3.1 Marbled Murrelet

There are six marbled murrelet conservation zones (WDFW 2014), one of which occurs in the Action Area. Zone 1 includes the Strait of Juan de Fuca, Hood Canal, and the San Juan Islands and is monitored by the Pacific Northwest Research Station, and the United States Department of Agriculture Forest Service. The most recent murrelet population estimate for Zone 1 is 4,393 birds, with the majority occurring around the south end of the San Juan Islands and along the northern coast of the Olympic Peninsula (WDFW 2014). Primary fish prey of marbled murrelets include Pacific sand lance, Pacific herring, northern anchovy, and smelts. Documented smelt and sand lance spawning locations occur throughout the Strait of Juan de Fuca and in the vicinity of the BP Marine Terminal. Herring and smelt spawning occur along the shoreline from Blaine, WA south to Bellingham and the BP Marine Terminal falls within these areas (WDFW 2014b). Sand lance spawning occurs within the Action Area, but has not been documented in close proximity to the terminal (WDFW 2014b). While the presence of forage fish suggests that marbled murrelets may feed within the Action Area, nesting habitat is limited by a lack of the required old-growth forests. No critical habitat has been designated for marbled murrelet within the Action Area (USFWS 2013). Therefore, it is possible that marbled murrelets will be present within the Action Area, but likely only for foraging.

4.3.1.1 Effects of Vessel Traffic

Disturbance by ships can be a threat to birds through effects on behavior, reproduction, and fitness of individuals in colonies as well as on foraging or resting habitats (Schwemmer et al.

2011). Increased vessel traffic could result in increased noise and physical disturbance of marbled murrelets present in the Affected Area. Some evidence suggests that marbled murrelets are capable of habituating to heavy vessel traffic, such as that near Juneau, Alaska and around the San Juan Islands (Ralph et al. 1995; Speckman et al. 2004). Flushing (avoidance behavior) is energetically costly to birds and increased vessel traffic could affect marbled murrelets; however, the relatively small increase in vessels (<1 per day) at the maximum forecast is not expected to increase the disruptions to the behavior of marbled murrelets in a biologically meaningful way.

Increased habitat disturbance for marbled murrelets could occur with the presence of additional vessels, although the effect would be temporary. Ships would continue to follow established shipping lane pathways and marbled murrelets would likely avoid these areas or become habituated, thus reducing potential disturbance effects. Fish (including prey fish for piscivorous birds) are unlikely to be affected by the small increase in vessel traffic; therefore, effects to birds via food chain disturbance are expected to be minimal and discountable.

Marbled murrelets sometimes respond to vessel disturbance by swallowing prey held in their beaks (Speckman et al. 2004). This behavior could result in starvation of chicks if the adults cannot return with fish; however, murrelet foraging areas lie outside of established shipping lanes so disturbance to feeding is expected to be minimal. Although marbled murrelets may forage within the Action Area, the incremental increase in vessel traffic attributed to the Proposed Action would not be expected to have an effect on marbled murrelet distribution, abundance, or reproduction.

Vessel Strikes

Marbled murrelet typically forage in relatively shallow waters between 20 and 80 meters (66 to 131 feet) in depth within 2 km (1.24 mile) of the shoreline (Ralph et al 1995). Vessels transiting through the Action Area would stay within the designated shipping lanes, outside of known spawning areas and prey species habitat; therefore, murrelets would be unlikely to forage in their path. Since vessel traffic calling at the BP Marine Terminal represents only a portion of all shipping traffic (approximately one percent), and murrelets would be able to move out of the vessel's path, the likelihood of a vessel collision with marbled murrelets attributed to BP Marine Terminal vessel traffic would be expected to be very low.

Noise

Vessel movement to and from the BP Marine Terminal would occur within existing designated shipping lanes, which are characterized by high levels of use by both commercial and recreational vessels. Noise associated with BP bound traffic would likely be indistinguishable from baseline levels. Vessel sounds associated with traffic traveling to the BP Marine Terminal traffic would be attributed to large ships, tankers, and tugs.

Birds are very sensitive to sound, but little is known about the effects of underwater noise on diving birds. Some species of birds are more sensitive to noise than others (SAIC 2011). Rapid changes in underwater sound pressure levels can cause a range of effects to birds including physical injury in the form of sublethal injuries, lethal injuries, and auditory effects, as well as non-physical behavioral effects (SAIC 2011). There is a wide variability in susceptibility to noise-related injury among bird species and the effects to marbled murrelets are unknown. The USFWS considers the cumulative sound exposure level (SEL) of 183 dB re 1µPa2-sec and the

single-strike criterion of 206 dB re 1µPa2 (peak) to be the thresholds for inner ear hair cell damage, which is the point at which injury occurs. Large commercial vessels such as crude oil tankers produce relatively loud and predominately low frequency sound that is unlikely to exceed the injury thresholds for birds or forage fish. For example, at a distance of 3 km SELs for bulk carriers traveling at 7.4 ms-1 were 127 dB re 1 µPa2 s (McKenna et al. 2012). An increase in vessel traffic due to the operation of the BP Marine Terminal could lead to a slight increase in low-frequency noise associated with the project but would be unlikely to adversely affect marbled murrelets due to the transient nature of the vessels, which would not cause long-term alteration of background noise levels.

4.3.1.2 Operations of the Marine Terminal

Effects to marbled murrelet from operation of the BP Marine Terminal include accidental release of ballast water, interruption of feeding activities, and minor releases of oil and other contaminants.

Ongoing operation and maintenance activities at the BP Marine Terminal could result in accidental spills of oil or other hazardous materials (e.g., hydraulic fluid). If an accidental spill of oil or other hazardous material were to occur, prey species such as herring and smelt which spawn near the dock could be adversely affected. Such incidents are not part of the normal operations and maintenance activities, and would not be expected to occur in a large enough magnitude or enough frequency to adversely affect marbled murrelet.

Vessels approaching the BP Marine Terminal would pass through a documented herring pre-spawning holding area located just offshore from the BP Marine Terminal (WDFW 2014b) which could disrupt murrelet feeding opportunities. Vessels approaching the terminal would be travelling slowly and foraging murrelets are expected to move away. The area of disturbance from approaching vessels is small relative to the herring habitat and minimal impact to marbled murrelets foraging would be expected from disturbance near the terminal.

Birds could be affected if prey items become more or less abundant due to the presence of invasive species through accidental release of ballast water. BP records, from 1971 to 2005, indicate that ballast water from cargo tanks has been spilled twice (<1 percent occurrence). In addition, NMFS has consulted with the Coast Guard on the implementation of the ballast water management regulations and concluded that the minimal potential for introduction on invasive species is not likely to jeopardize the existence of listed species (NMFS 2012b).

4.3.1.3 Conclusion

Marbled murrelets may forage within the Action Area because established populations of their prey fish species occur throughout the area. Marbled murrelets typically forage in shallow water outside of established shipping lanes and tend to move away when approached by vessels. Increased vessel traffic and operations of the BP Marine Terminal associated with the Proposed Action may affect, but are not likely to adversely affect marbled murrelets.

4.4 Reptiles

4.4.1 Leatherback Turtle

Adult leatherbacks turtles could be present in the Action Area during the summer and fall when jellyfish aggregate, however, this species is more common in waters off the coast of Washington, outside the Action Area.

4.4.1.1 Effects of Vessel Traffic

Vessel Strikes

Vessel traffic calling to the BP Marine Terminal have the potential to strike or disturb leatherback turtles feeding or swimming at or below the surface of the water. However, vessels would be moving at low speeds and leatherbacks would be able to detect them and move out of their path (Hazel 2007). Vessel traffic calling at the BP Marine Terminal currently comprise about 1 percent of the commercial traffic in the Action Area and the increase in vessel traffic attributable to the Proposed Action is very small. The low likelihood that leatherback turtles would be present it the Action Area, combined with the small potential increase in vessel traffic calling at the BP Marine Terminal, makes a measurable increase in the probability of a vessel strike over baseline conditions unlikely.

Noise

Leatherback auditory sensitivity is not well studied, but would likely follow that of other sea turtles. A few investigations suggest that their hearing is limited to low frequency bandwidths (Lenhardt 1994 and Moein et al. 1994). Sea turtles respond to low-frequency sounds, but with less sensitivity than mammals (McCauley et al. 2000 and URI 2013), It is currently believed that the range of maximum sensitivity for sea turtles is 0.20 to 0.80 kHz, with hearing below 0.080 kHz being less sensitive but potentially usable to the animal (Lenhardt 1994 and Moein et al. 1994). Vessel sounds attributed to large ships, tankers, and tugs traveling to the BP Marine Terminal would generate low frequency sound in the 0.005 to 0.5 kHz range (NOAA 2008). The role of underwater hearing in sea turtles is unclear (URI 2013); however, it is possible that noise from increased traffic associated with the Proposed Action could mask biologically significant sounds. Should leatherback turtles be present in the Action Area, the increase in vessel traffic due to the ongoing operation of the BP Marine Terminal would not significantly alter the background noise level (sea state -139-159 dB; ConocoPhillips 2007). The incremental increase in vessel traffic due to the operation of the BP Marine Terminal could lead to a slight increase in low-frequency noise associated with the project but would be unlikely to adversely affect leatherback turtles due to the transient nature of the vessels, which would not cause long-term alteration of background noise levels.

4.4.1.2 Operations of the Marine Terminal

Ongoing operation and maintenance activities at the BP Marine Terminal could result in accidental spills of oil or other hazardous materials (e.g., hydraulic fluid). Instances of spills associated with the operation of the BP Marine terminal, described in Section 3.2, is very small and unlikely to adversely affect leatherback turtles.

It is possible that leatherback turtles could be present in the vicinity when ships are arriving or departing from the BP Marine Terminal. The low likelihood that they will be present in the Action Area combined with the small potential increase in vessel traffic calling at the BP Marine

Terminal makes a measurable increase in the probability of a vessel strike over baseline conditions unlikely.

4.4.1.3 Effects to Critical Habitat

Vessel traffic moving to and from the BP Marine Terminal would transit through a small portion of leatherback critical habitat in the vicinity of J Buoy. This area contains the Juan de Fuca Eddy, which develops offshore of northern Washington and the mouth of the Strait of Juan de Fuca as a result of wind-driven current interaction with the continental slope (NMFS 2009). Leatherbacks could be using this eddy current for migration as well as foraging. As vessels pass though designated critical habitat turtles could move away from the source of the noise, temporarily displacing them from the area. However, the passage of watercraft in the area is an existing, temporary and common occurrence. Overall, the Proposed Action may affect, but is not likely to adversely affect, designated critical habitat for leatherback turtles.

4.4.1.4 Conclusion

Should leatherback turtles occur in the Action Area, the ongoing operation and maintenance activities of the BP Marine Terminal would be unlikely to result in increased collisions in the shipping lanes, or increased effects due to noise exposure or water pollution. Because ongoing operation and maintenance of the terminal is unlikely to adversely affect leatherback turtles, the Proposed Action may affect, but is not likely to adversely affect leatherback turtles.

The Action Area includes leatherback turtle critical habitat in the vicinity of J Buoy. The effects of vessel traffic on the primary constituent elements leatherback turtle critical habitat would be limited to temporary displacement of turtles and their prey species. However, the passage of watercraft in the area is an existing, temporary and common occurrence, the Proposed Action may affect, but is not likely to adversely affect, designated critical habitat for leatherback turtles.

4.5 Cumulative Effects

Cumulative effects under the ESA are the effects of non-federal actions (i.e., future state, tribal, local, or private actions) that are reasonably certain to occur in the Action Area. At this time, no actions have been identified that are considered cumulative with the Proposed Action. The proposed Gateway Pacific Terminal would be located in Whatcom County, and may affect similar fish and wildlife species as the BP Marine Terminal; however, the Gateway Pacific Terminal will require federal authorizations and will undergo separate Section 7 consultation. Therefore, the proposed Gateway Pacific Terminal is not a “cumulative effect” as defined by the Service’s consultation regulations and is not evaluated here.

Chapter 5

Summary and Conclusion of Effects on Federally-Listed Species

In fulfilling its obligations under Section 7(a)(2) of the ESA, the information presented in this BE represents the best data currently available to assess the potential effect of effects of ongoing operations of the North Wing of the BP Marine Terminal on fifteen listed species which occur within the Action Area.

Table 5.1-1 provides a summary of the listing status and the determination of the potential project effect for each species based on a review of the current status of the listed species, the environmental baseline for each, including past and present impacts of all federal, state, or private actions and other human activities in the Action Area; the anticipated future impacts of all proposed federal projects in the Action Area that have undergone consultation; and the cumulative effects of non-federal actions (i.e., future state, tribal, local, or private actions that are reasonable certain to occur in the Action Area) contemporaneous to this consultation.

Table 5.1-1 Conclusion of effects of the Proposed Action on Federally listed species within the Action Area

Species Common Name	Species Scientific Name	Status	Critical Habitat Status	Project Effect
Mammals				
Humpback Whale	*Megaptera novaeangliae*	E	None	May Affect; Not Likely to Adversely Affect
Blue Whale	*Balaenoptera musculus*	E	None	May Affect; Not Likely to Adversely Affect
Fin Whale	*Balaenoptera physalus*	E	None	May Affect; Not Likely to Adversely Affect
Southern Resident DPS Killer Whale	*Orcinus orca*	E	Designated	May Affect; Not Likely to Adversely Affect
Bird				
Marbled Murrelet	*Brachyramphus marmoratus*	T	Designated	May Affect; Not Likely to Adversely Affect
Reptiles				
Leatherback Turtle	*Dermochelys coriacea*	E	Designated	May Affect; Not Likely to Adversely Affect
Fish				
Bull trout	*Salvelinus confluentus*	T	Designated	May Affect; Not Likely to Adversely Affect
Chinook salmon (Puget Sound ESU)	*Oncorhynchus tshawytscha*	T	Designated	May Affect; Not Likely to Adversely Affect
Chum salmon (Hood Canal summer-run)	*Oncorhynchus keta*	T	Designated	May Affect; Not Likely to Adversely Affect
Puget Sound steelhead	*Oncorhynchus mykiss*	T	Proposed	May Affect; Not Likely to Adversely Affect
Eulachon (Southern DPS)	*Thaleichthys pacificus*	T	Designated	May Affect; Not Likely to Adversely Affect
Green sturgeon (Southern DPS)	*Acipenser medirostris*	T	Designated	May Affect; Not Likely to Adversely Affect
Groundfish				
DPS Bocaccio	*Sebastes paucispinis*	E	Proposed	May Affect; Not Likely to Adversely Affect
DPS Canary rockfish	*Sebastes pinniger*	T	Proposed	May Affect; Not Likely to Adversely Affect
DPS Yelloweye rockfish	*Sebastes ruberrimus*	T	Proposed	May Affect; Not Likely to Adversely Affect

T – Threatened

E - Endangered

Chapter 6

Magnuson Stevens Fishery Conservation and Management Act

The Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) established a management system for national marine and estuarine fishery resources. Pursuant to section 305(b)(2), all federal agencies are required to consult with National Marine Fisheries Service (NMFS) regarding any action permitted, funded, or undertaken that may adversely affect "essential fish habitat" (EFH). Effects on habitat managed under any relevant Fishery Management Plans must also be considered. EFH is defined as "waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." This includes migratory routes to and from anadromous fish spawning grounds. The phrase "adversely affect" refers to the creation of any impact that reduces the quality or quantity of essential fish habitat. Federal activities that occur outside of an EFH but that may, nonetheless, have an impact on EFH waters and substrate must also be considered.

6.1 Essential Fish Habitat Background

EFH is designated for commercially-fished species managed under the Magnuson-Stevens Act. The Magnuson-Stevens Act requires federal fishery management plans developed by NMFS and the Pacific Fisheries Management Council to describe the habitat essential to the fish species being managed and describes threats to that habitat from both fishing and non-fishing activities. To protect EFH, federal agencies are required to consult with the NMFS on activities that may adversely affect EFH.

The purpose of this EFH assessment is to determine whether the Proposed Action may adversely affect designated EFH for relevant federally-managed commercial fisheries species within the Action Area (Figure 6.1-1). EFH designated for 3 species of salmon, 83 groundfish species, and six pelagic species is described below.

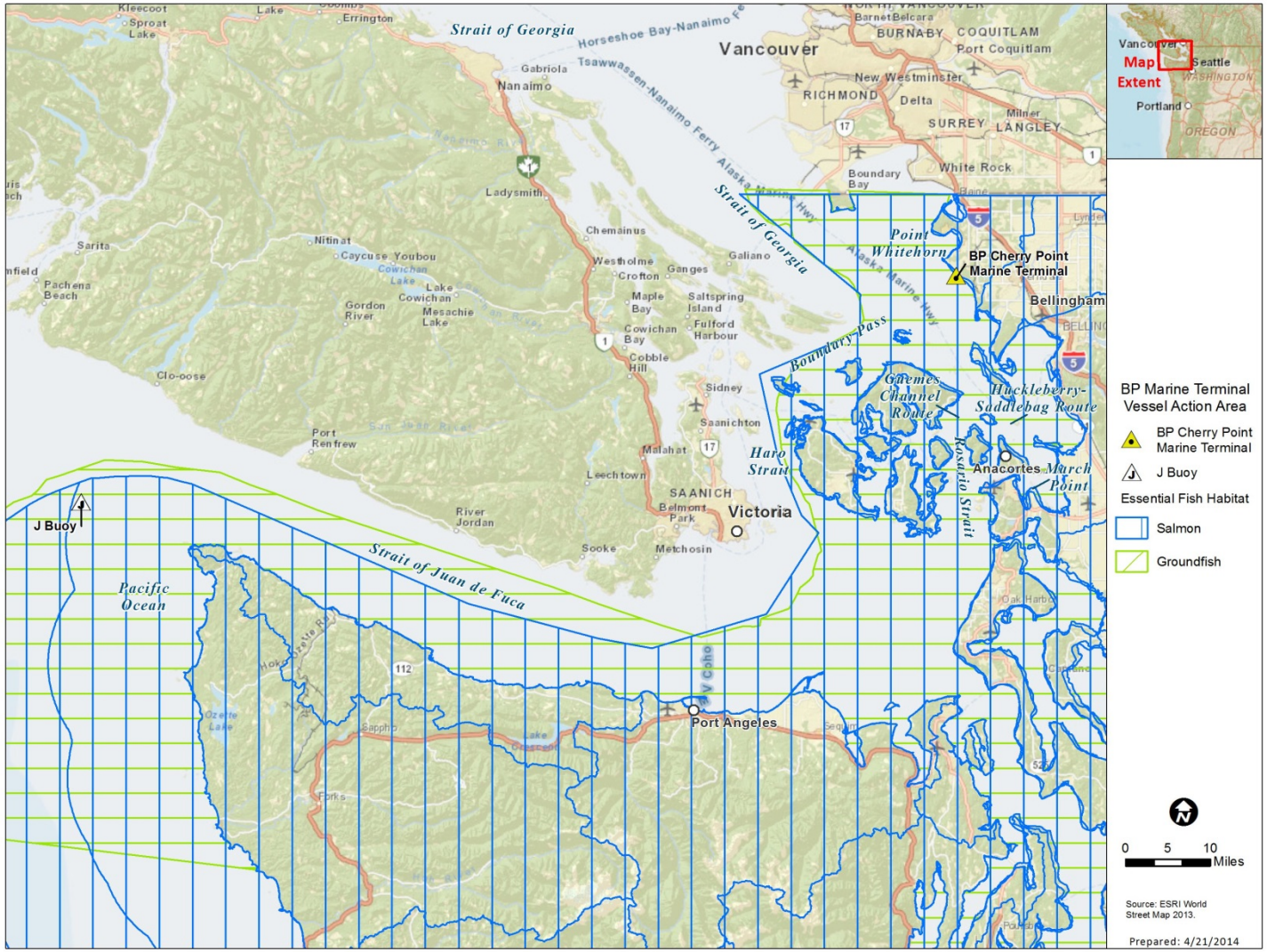

Figure 6.1-1 Essential Fish Habitat (EFH) in the BP Cherry Point Action Area

Source: NMFS 2013

Note: Data was unavailable for pelagic EFH.

6.1.1 Pacific Salmon (Chinook, Coho and Pink)

EFH for the Pacific coast salmon includes all streams, lakes, ponds, wetlands, and other currently viable water bodies and most of the habitat historically accessible to salmon in Washington, Oregon, Idaho, and California. In the estuarine and marine areas, salmon EFH extends from the nearshore and tidal submerged environments within state territorial waters out to the full extent of the EEZ (370.4 km) offshore of Washington, Oregon, and California north of Point Conception. Freshwater EFH for Pacific salmon includes all those streams, lakes, ponds, wetlands, and other water bodies currently, or historically accessible to salmon in Washington, Oregon, Idaho, and California, except areas upstream of certain impassable man-made barriers (as identified by the Pacific Fishery Management Council Fishery Management Plan [PFMC 1999a]), and longstanding, naturally-impassable barriers (i.e., natural waterfalls in existence for several hundred years).

6.1.2 Groundfish

NMFS defined EFH for Pacific groundfish (CFR 660.395; 5/11/2006) to include those waters and substrate necessary to groundfish for spawning, breeding, feeding or growth to maturity (16 U.S.C. 1802 (10)). EFH for Pacific Coast groundfish includes all waters and substrate within areas with a depth less than or equal to 3,500 meters (11,483 feet) shoreward to the mean higher high water level or the upriver extent of saltwater intrusion (defined as upstream and landward to where ocean-derived salts measure less than 0.5 parts per thousand (ppt) during the period of average annual low flow).

6.1.3 Pelagic Species

EFH for coastal pelagic species including finfish (northern anchovy, Pacific sardine, Pacific (chub), mackerel, and jack mackerel) and market squid occurs from the shorelines of California, Oregon, and Washington westward to the exclusive economic zone and above the thermocline where sea surface temperatures range between 10°C (50°F) and 26°C (79°F). During colder winters, the northern extent of EFH for coastal pelagic species may be as far south as Cape Mendocino (California), and during warm summers it may extend into Alaska's Aleutian Islands (PFMC 1998). In 2006, the Coastal Pelagic Species: Fishery Management Plan (FMP) was amended to include all krill species, to prohibit their harvest, and to identify EFH for them. EFH for *Thysanoessa spinifera* includes waters from the baseline from which the shoreline is measured to the 500 fm (914 meters [3,000 feet]) isobath, from the U.S.- Mexico north to the U.S.-Canada border, from the surface to 100 meters deep. EFH for *Euphausia pacifica* and other krill species includes waters from the baseline from which the shoreline is measured seaward to the 1000 fm (1,829 meters [6,207 feet]) isobath, from the U.S.- Mexico north to the U.S.-Canada border, from the surface to 400 meters (1,312 feet) deep.

6.2 Description of the Proposed Action

Refer to Section 1.2 for a description of the Proposed Action

6.3 Essential Fish Habitat Requirements

6.3.1 Pacific Salmon (Chinook, Coho and Pink)

The Pacific salmon management unit includes Chinook, coho, and pink salmon. EFH for Pacific salmon in the Action Area include those elements associated with adult migration pathways and marine habitat. Important marine elements of Pacific salmon EFH include adequate water quality, water temperature, prey species and forage base, and adequate depth, cover, marine vegetation, and algae in estuarine and near-shore habitats.

Limited information exists on Chinook and coho salmon habitat use in marine waters (PFMC 1999a). Ocean-type juvenile Chinook appear to utilize different marine areas for rearing than stream-type juvenile Chinook and are believed to migrate to ocean waters further offshore early in their ocean residency. Many stream-type Chinook populations do not appear to be as heavily exploited as ocean-type Chinook, indicating that stream-type fish may be vulnerable to costal fisheries for a short period during their spawning migrations (PFMC 1999a). In the open ocean, juvenile and maturing coho are found in the highest concentrations in more productive waters associated with the continental shelf within 60 km of the Washington coastline (PFMC 1999a). The essential marine habitat for Chinook and coho includes all marine waters within the EEZ north of point Conception, CA and the marine areas off Alaska designated as salmon EFH by the North Pacific Fishery Management Council. Puget Sound is critical to the early marine survival of pink salmon. Therefore, essential marine habitat for pink salmon includes all nearshore marine waters north and east of Cape Flattery, Washington, including Puget Sound, the Strait of Juan de Fuca and Strait of Georgia. (PFMC 1999a)

6.3.2 Groundfish

The 83 groundfish species managed under the federal FMP occupy diverse habitats at all stages of their life histories (PFMC 1999b). Some species are widely distributed during certain life stages, particularly those with pelagic eggs and larva, therefore the EFH for these species is correspondingly large. However, some species/life stages occupy comparatively small habitat ranges (i.e., adults of nearshore groundfish) as they show affinity to particular substrates and/or locations. Consequently, the large number of species and diverse habitat association of the entire EEZ becomes EFH when individual EFHs for all species are combined.

EFH for Pacific coast groundfish includes all waters from the mean higher water line, and the upriver extent of saltwater intrusion in river mouths, along the coasts of Washington, Oregon, and California seaward to the boundary of the U.S. EEZ. Groundfish EFH is grouped into seven units (called composites) which are defined below:

- **Estuarine**: Those waters, substrates and associated biological communities within bays and estuaries of the coasts of Washington, Oregon, and California, seaward from the high tide line or extent of upriver saltwater intrusion
- **Rocky Shelf**: Those waters, substrates and associated biological communities living on or within ten meters (33 feet) overlying rocky areas, including reefs, pinnacles, bounders and cobble, along the continental shelf, excluding canyons, from the high tide line to the shelf break.

- **Non-Rocky Shelf**: Those waters, substrates, and associated biological communities living on or within ten meters (33 feet) overlying the substrates of the continental shelf, excluding the rocky shelf and canyon composites, from the high tide line to the shelf break.
- **Canyon**: Those waters, substrates, and associated biological communities living within submarine canyons, including the walls, beds, sea floor, and any outcrops or landslide morphology, such as slump scarps and debris fields.
- **Continental Slope/Basin**: Those waters, substrates, and associated biological communities living on or within 20 meters (66 feet) overlying the substrate of the continental slope and basin below the shelf break and extending to the westward boundary of the EEZ.
- **Neritic Zone**: Those waters and biological communities living in the water column more than 20 meters (66 feet) above the continental shelf.
- **Oceanic Zone**: Those waters and biological communities living in the water column more than 20 meters (66 feet) above the continental slope and abyssal plain, extending to the westward boundary of the EEZ.

6.3.3 Pelagic Species

Coastal pelagic species EFH accommodates the fact that the geographic range of covered species varies widely over time and in response to temperature of the upper mixed layer of the ocean, particularly in areas north of Point Arena, California. Adult finfish are generally not found at temperatures colder than 10°C (50°F) or warmer than 26°C (79°F). Preferred temperatures and minimum spawning temperatures are generally above 13°C (55°F), with spawning most commonly occurring at 14°C to 16°C (57°F to 59°F). The geographic boundary is defined to be all marine and estuarine waters from the shoreline along the coasts of California, Oregon, and Washington offshore to the limits of the EEZ and above the thermocline. Table 6.3-1identifies species and life stages that could be present in the Action Area.

Table 6.3-1 Coastal Pelagic Species Potentially Present in the Action Area

Common Name (Scientific Name)	Lifestage
Northern anchovy (*Engraulis mordax*)	Eggs/Larvae/Juveniles/Adults
Pacific sardine (*Sardinops sagax*)	Eggs/Larvae/Juveniles/Adults (warm environment/high abundance)
Pacific mackerel (*Scomber japonicus*)	Eggs/Larvae/Juveniles/Adults (warm environment/high abundance)
Jack mackerel (*Trachurus symmetricus*)	Adults
Market squid (*Loligo opalescens*)	Adults (no information available for Eggs/Larvae/Juveniles)

Source: PFMC 1998

6.4 Potential Adverse Effects of Proposed Action

The EFH implementing regulations, 50 CFR 6000.810(a), define "adverse effect" as:

> "any impact that reduces the quality and/or quantity of EFH. Adverse effects may include direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of, or injury to, benthic organisms, prey species and their habitat, and other ecosystem components, if such modifications reduce the quality and/or quantity of EFH. Adverse effects to EFH may result from actions occurring within EFH or outside of EFH and may include site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions."

6.4.1 Pacific Salmon (Chinook, Coho and Pink)

Pacific salmon EFH occurs throughout the Action Area. The primary threat to the habitat for these species from the ongoing operation and maintenance of the North Wing could result from an increase in vessel traffic in the shipping lanes (a potential increase of 15 to 85 vessel calls/year) and operation of the BP Marine Terminal. The effects to Pacific salmon EFH from these activities are described below.

6.4.1.1 Effects of Vessel Traffic

Vessels transiting to the Marine Terminal at Cherry Point enter the USCG VTS at J buoy, travel through the Strait of Juan de Fuca into Rosario Strait, and then into the southern reach of the Strait of Georgia and then onto the BP Marine Terminal at Cherry Point. Increased vessel traffic could increase water turbidity, which could affect nearshore aquatic habitat. However, due to the controlled route and low speeds of the moving vessels, no long-term impacts are anticipated to occur to EFH from vessel traffic.

Noise

An increase in vessel traffic due to the operation of the BP Marine Terminal could adversely affect Pacific salmon EFH by temporarily increasing noise levels near the transiting vessels. As a consequence of increased noise, salmon near the vessel may move away temporarily displacing them from an area they would otherwise occupy. Fish are able to detect vessel noise over a large range of frequencies, tens to several hundred Hz (Mitson 1995). Fish may alter their behavior in response to the noise; typically, they would move away from the source of the noise (Mitson 1995). Avoidance reactions in fish occur at a distance of approximately 100-200 meters (328-656 feet) from the vessel, but could occur at distances up to 400 meters (1,312 feet) in louder vessels (Mitson 1995). Due to the short magnitude and duration of noise created by a moving vessel the adverse effects to Pacific salmon EFH that would be created by the Proposed Action would be temporary and minimal.

6.4.1.2 Operation of the Marine Terminal

Effects of operation of the Marine Terminal include increased lighting, minor shading of shallow water nearshore habitat, accidental release of ballast water, and minor releases of oil and other contaminants. Increased lighting at the Marine Terminal would be associated with vessels unloading at night and could temporarily attract fish to the area, however, there would be no affect to EFH from increased lighting . Minor shading of the nearshore habitat in the vicinity of

the dock could affect primary production and impact aquatic vegetation present in the area, however, shading would be minimal and would not be expected to result in lasting habitat alterations.

Ongoing operation and maintenance activities at the BP Marine Terminal could result in accidental spills of oil or other hazardous materials (e.g., hydraulic fluid or contaminated ballast). If an accidental spill of oil or other hazardous material where to occur water quality near the BP Marine Terminal could be affected. Records at the dock for the period from 1971 through 2005 indicate that incidents are infrequent (typically less than one per year), and the volume of spills is usually small. Many of the incidents reported were in quantities of drops or a sheen on the water, and some of them were 1-2 gallons. If a spill were to occur, the BP Marine Terminal is equipped with containment booms and clean-up equipment, which can be readily deployed.

Eelgrass beds occur within the vicinity of the Marine Terminal and could be impacted by an accidental spill, however, given the spill history at the BP Marine Terminal and BP's oil spill avoidance and response measures (Section 3.2.1); it is unlikely the that operation of the BP Marine Terminal would have long-term impacts to Pacific salmon EFH.

6.4.1.3 Conclusion

Habitat concerns associated with the Proposed Action would primarily be centered on effects to water quality. The Proposed Action is not expected to result in an increase in sedimentation or result in a decrease in water quality. No permanent adverse effects on Pacific salmon EFH would occur as a result of this project. Therefore, the project will not adversely affect EFH for Pacific salmon.

6.4.2 Groundfish

Groundfish species are widely distributed and could potentially occur in the shipping lanes throughout the Action Area (Figure 6.4-1). The primary threat to these species from the ongoing operation and maintenance of the North Wing could result from an increase in vessel traffic in the shipping lanes (a potential increase of 15 to 85 vessel calls/year). This increase in traffic could potentially cause an increase in the probability of an oil spill and increased noise. The effects to groundfish EFH from these activities are described below.

6.4.2.1 Effects of Vessel Traffic

Vessels anchoring over hard bottom substrates could crush, remove or bury substrate used by groundfish for feeding or shelter. Vessels approaching the BP Marine Terminal at Cherry Point may be required to come to anchor at the designated temporary anchorage offshore of Vendovi Island if the docks are in use. This area does not contain rocky substrate (Figure 6.4-1) and would therefore not be affected by anchorage. No impacts are anticipated to occur to groundfish EFH from increased vessel traffic.

Noise

The effects of noise to groundfish EFH would be the same as those described in Section 6.4.1.1.

6.4.2.2 Operation of the Marine Terminal

Effects of operation of the BP Marine Terminal include increased lighting, minor shading of shallow water near shore habitat, accidental release of ballast water, and minor releases of oil and other contaminants. Increased lighting at the Marine Terminal would be associated with vessels unloading at night and could temporally attract fish to the area, however there would be no affect to EFH from temporary lighting. Minor shading of the nearshore habitat in the vicinity of the dock could affect primary production thereby affecting aquatic vegetation present in the area; however, the shading would be minimal and would not be expected to result in lasting habitat alterations. If an accidental spill of oil or other hazardous material where to occur submerged aquatic vegetation sites including eelgrass and kelp beds, which are utilized by groundfish and other fish species for food, shelter and protection from predators could be impacted.

Accidental spills of oil or other hazardous material at the BP Marine Terminal is infrequent and the volume of spills is usually small; additional spill history information for the BP Marine Terminal is provided in Section 6.4.1.2.

Give the spill history at the BP Marine Terminal, BP's oil spill avoidance and response measures (Section 3.2.1), and the lack of groundfish habitat (rocky relief and deeper waters), it is unlikely that the operation of the BP Marine Terminal would have a long-term impacts on groundfish EFH.

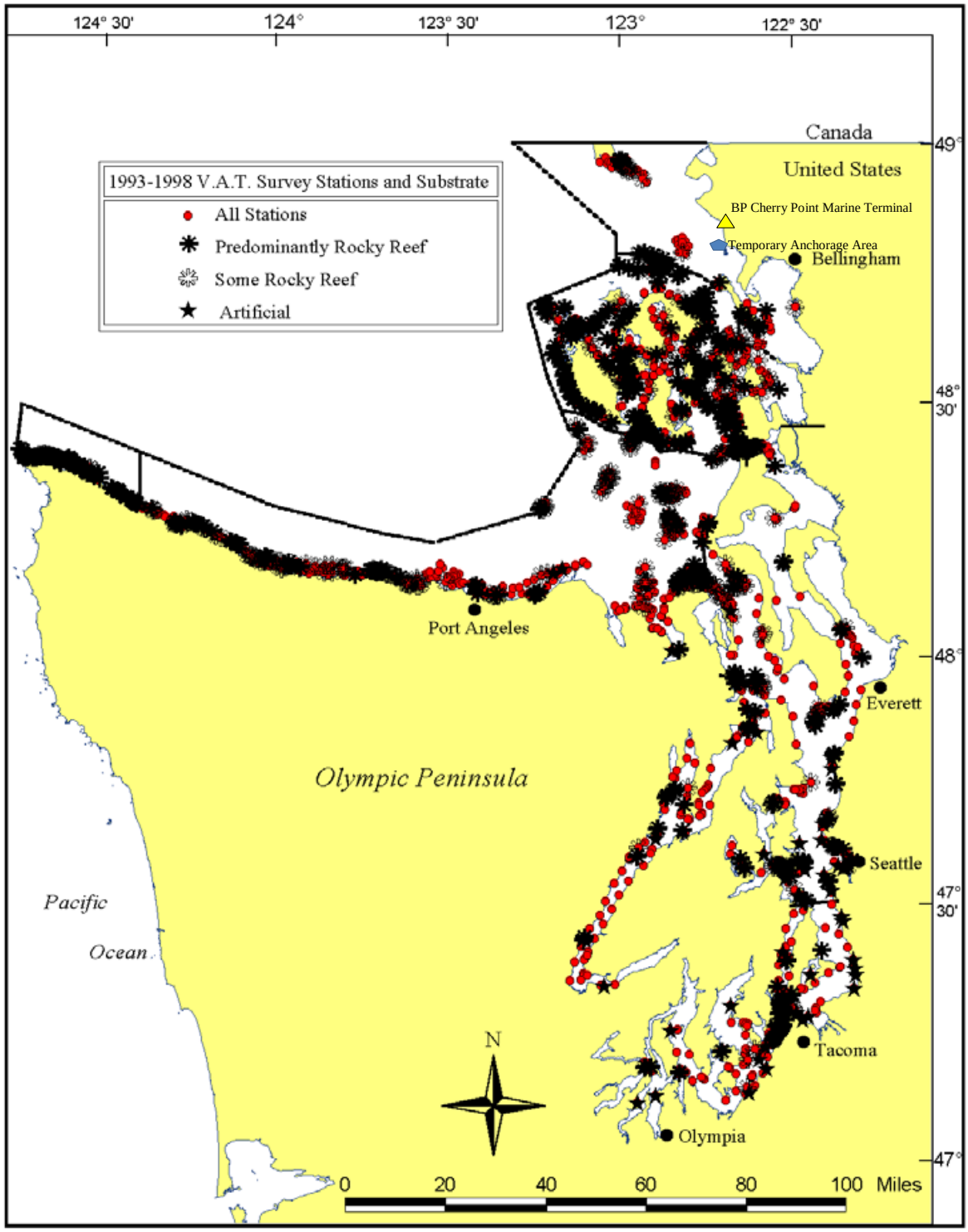

Figure 6.4-1 BP Cherry Point Temporary Anchorage and the Distribution of Nearshore Rocky Habitats in Puget Sound

Source: Palsson et al. 2009

6.4.2.3 Conclusion

The Proposed Action is not expected to adversely affect the seven groundfish composites (Section 6.3.2) and therefore would not adversely affect EFH for groundfish.

6.4.3 Pelagic Species

Coastal pelagic species generally live nearer the surface than the seafloor and could potentially occur in the shipping lanes throughout the Action Area. Anchovies are the only species in the Coastal and Pelagic Species Fishery Management Plan report that are common in Puget Sound and may be associated with the neritic portion of the nearshore environment, in spite of their pelagic habitat (Penttila 2007 and Burke Museum 2013). The primary threat to these species EFH from the ongoing operation and maintenance of the North Wing could result from an increase in vessel traffic in the shipping lanes (a potential increase of 15 to 85 vessel calls/year). This increase in traffic could potentially cause an increase in the probability of exposure to noise and an oil spill. The effects to pelagic species from these activities are described below.

6.4.3.1 Effects of Vessel Traffic

Vessels transiting to the Marine Terminal at Cherry Point enter the USCG VTS at J buoy, travel through the Strait of Juan de Fuca into Rosario Strait, and then into the southern reach of the Strait of Georgia and then onto the BP Marine Terminal at Cherry Point. The transiting of vessels would not be expected to affect the EFH of coastal pelagic species given their transient nature. Therefore, no long-term effect to coastal pelagic EFH would be expected as a result of increased vessel traffic.

Noise

The effects of noise to coastal pelagic EFH would be the same as those described in Section 6.4.1.1.

6.4.3.2 Operation of the Marine Terminal

Effects from operation of the Marine Terminal include the accidental release of ballast water and minor releases of oil and other contaminants. Accidental release of ballast water, oil and other contaminants could introduce a localized source of pollutants detrimental to estuarine and marine habitats utilized by coastal pelagic species near the BP Marine Terminal.

Accidental spills of oil or other hazardous material at the BP Marine Terminal is infrequent and the volume of spills is usually small; additional spill history information for the BP Marine Terminal is provided in Section 6.4.1.2.

Give the spill history at the BP Marine Terminal, and BP's oil spill avoidance and response measures (Section 3.2.1); it is unlikely that the operation of the BP Marine Terminal would have a long-term impact on pelagic species EFH.

6.4.3.3 Conclusion

Since the overall increase in traffic is relatively small (one percent of Puget Sound traffic) and the probability of a spill of oil or other hazardous material at the dock is slight (small spills occurring less than once per year), the Proposed Action would not adversely affect EFH for coastal pelagic species.

Chapter 7

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Appendix H

Magnuson Amendment Discussion

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1. INTRODUCTION AND BACKGROUND

The BP Cherry Point facility, previously owned and operated by Atlantic Richfield Company (ARCO), was built in 1971 as a petroleum refinery and marine terminal. Although the Department of the Army (DA) Section 10 permit (NWS-1992-00435) issued by the U.S. Army Corps of Engineers (USACE) in 1969 authorized ARCO to construct a two-wing (North Wing and South Wing) marine terminal, only the South Wing was constructed and was placed in operation in 1971. The South Wing consists of a single ship berth connected to the shore by a trestle that includes a causeway and pipelines for transfer of crude oil and refined petroleum products between the dock and the refinery. The South Wing was used for both unloading of crude oil and loading of refined petroleum products. In addition to marine transportation, ARCO used the Olympic pipeline to transport product from the refinery. In 1977, ARCO requested re-issuance of the 1969 DA Section 10 permit to allow for construction of the North Wing, as originally permitted. This request was withdrawn and a new application was submitted in 1992 for construction of the North Wing. On March 1, 1996, ARCO obtained the DA Section 10 permit to construct the North Wing.

In April 2000, BP West Coast Products, LLC (BP) purchased the ARCO refinery and marine terminal (dock**).** On June 19, 2000, a 1-year time extension of the DA permit was granted to ARCO to complete construction of the North Wing. Construction of the North Wing was completed in 2001, and it went into service in September 2001. Both wings are currently in operation. The North Wing is dedicated to loading and occasional unloading of refined petroleum products, and the South Wing is used primarily for unloading crude oil and the occasional loading of refined petroleum products when vessel loading requirements are better met by use of the equipment on the South Wing. Figure 2-2 on page 2-3 of the Draft Environmental Impact Statement (EIS) illustrates the BP Cherry Point dock configuration.

In November 2000, Ocean Advocates filed a lawsuit in the U.S. District Court challenging the issuance of the 1996 DA permit. The District Court ruled in favor of the USACE's finding that an EIS was not required and the DA permit issued did not violate the Magnuson Amendment (33 U.S. Code [USC] 476). Ocean Advocates filed an appeal at the U.S. Court of Appeals for the Ninth Circuit (9th Circuit Court). As part of its ruling in Ocean Advocates v. U.S. Army Corps of Engineers, 402 F. 3d 846 (9th Cir. 2005), the 9th Circuit Court required the USACE to reevaluate the dock extension's (the North Wing) potential violation of the Magnuson Amendment (33 USC 476[b]).

The Magnuson Amendment provides, in relevant part:

> *Notwithstanding any other provision of law, on and after October 18, 1977, no officer, employee, or other official of the Federal Government shall, or shall have authority to, issue, renew, grant, or otherwise approve any permit, license, or other authority for constructing, renovating, modifying, or otherwise altering a terminal, dock, or other facility in, on, or immediately adjacent to, or affecting the navigable waters of Puget Sound, or any other navigable waters in the State of Washington east of Port Angeles, which will or may result in any increase in the volume of crude oil capable of being handled at any such facility (measured as of October 18, 1977), other than oil to be refined for consumption in the State of Washington.*

Congress's stated purpose in adopting the Magnuson Amendment was to restrict crude oil "tanker traffic in Puget Sound." Thus, if the Amendment applies to a particular request for a federal permit, license, or other authority, the pertinent inquiry is whether the proposed action "will or may result in any increase in the volume of crude oil capable of being handled" at the marine facility in question, beyond the amount of crude oil the facility was capable of handling as of October 18, 1977.

In Ocean Advocates v. U.S. Army Corps of Engineers, the 9th Circuit Court had interpreted that, in analyzing capacity, one should not look to the capacity of the refinery, but rather to the capacity of the terminal. In evaluating whether the permit issued in 1996 may have resulted in any increase in the volume of crude oil capable of being handled at the BP Cherry Point dock, the 9th Circuit Court asked for a determination on the following three questions:

(1) Is it physically possible for the new platform to handle crude oil today?

(2) Is it physically possible to modify the new platform such that it could handle crude oil, without requiring additional permitting?

(3) Did the modifications authorized by the permit increase the potential berthing capacity of the terminal for tankers carrying crude oil?

These questions are discussed in sequential order below.

2. Is it physically possible for the new platform (North Wing) to handle crude oil today?

2.1 North Wing's Capability to Handle Crude Oil

The North Wing was designed and constructed specifically to handle only loading and unloading of refined petroleum products. The North Wing has no crude oil unloading arms, only refined petroleum product loading arms. These refined petroleum product loading arms are too short to offload crude oil from crude tankers that call at the terminal. All pipeline sizes on the North Wing are specific to lines that service refined petroleum products and are connected to refined petroleum product tanks and associated pumps as well as headers that are exclusive to refined petroleum product service. Various refined petroleum product pipelines that lead to the North Wing originate from refined petroleum product tanks designed and/or permitted for specific refined petroleum product types. These pipelines feed into a common manifold located on the North Wing, where a series of valves and pipes that compose the header allow the Storage and Handling Technicians to direct refined petroleum products into a specific loading arm(s) on the North Wing planned for loading that specific product to a vessel. Loading arms are not designed or designated for specific refined petroleum products—any refined petroleum product may be loaded through any loading arm other than the vapor arm, which is used exclusively to capture vapors displaced from tankage and route them to the vapor combustor located on the North Wing.

To ensure product quality from one product loading to the next, it is standard industry practice to flush the refined petroleum product line, header, and loading arm with the next refined petroleum product to be loaded. Flush volumes typically range from 1,500 to 4,300 barrels (bbl), depending on the previous product loaded, the following product, and how much flush volume of the following product is required to ensure that the product, when loaded, will meet all quality assurance parameters in the shipboard product tank. This off-specification flush material is routed through the 6-inch Flush Line, which connects the North Wing manifold to the existing 30-inch-diameter crude Marine Line that runs from the South Wing up to the crude oil tankage (onshore), allowing the flush material to be recycled.

The Flush Line is an industry-standard design requirement and can be found on virtually all modern marine transfer facilities that load multiple products, which are subject to the requirements under 33 Code of Federal Regulations (CFR) § 154. The Flush Line configuration serves two key purposes to ensure safe and compliant operation of the marine terminal and refinery: (1) the Flush Line ensures product safety and quality from load to load; and (2) the Flush Line allows the flushed material to be sent back to crude tankage for re-processing. The Flush Line is used exclusively for transporting the volume of two

different refined petroleum products that mix in the pipeline when switching from loading of one type of product to loading of another type of product. This volume of mixed products is returned to the refinery for recycling through the Flush Line.

Because the 6-inch Flush Line on the North Wing connects the North Wing manifold to the 30-inch crude oil Marine Line, the Flush Line theoretically could be used to transfer crude oil to the crude tankage. However, this theoretical application is not possible because the loading arms on the North Wing are designed to load refined petroleum product only and do not have the sufficient size and height to connect to crude oil tankers. In addition, the flow rate of the 6-inch Flush Line would make this theoretical crude oil transfer commercially unsustainable and would disrupt the normal, approved, safe operation of the North Wing. Offloading crude oil from a tank vessel through the 6-inch Flush Line would take approximately 180 hours or 7.5 days, making the North Wing unavailable to load refined petroleum product during that entire period.

The 30-inch crude oil Marine Line exclusively services the South Wing and does not extend to the North Wing. When the North Wing was designed and constructed, tie-ins were designed allowing the refined petroleum product lines that extended down the main causeway and to the existing South Wing to branch off and to continue on to the North Wing. No such tie-in was designed or installed for the 30-inch-diameter crude oil Marine Line to service the North Wing, and no crude oil offloading arms were specified or installed on the North Wing. The North Wing has no capability to handle crude oil today (BP 2013).

2.2 South Wing's Capability to Handle Crude Oil

The current South Wing was designed and constructed to handle both crude oil and refined petroleum products at a single berth. Pipelines connect the South Wing to both the refinery's crude oil storage tanks and the refined petroleum products storage tanks. The South Wing has both crude oil tanker unloading arms and refined petroleum product loading arms. The South Wing's 30-inch Marine Line can offload a crude tanker in about 24 hours. At its current production rate, the refinery requires a tanker load of crude oil approximately every 3.5 days. The South Wing's capability to handle crude oil has not changed since its construction in 1971.

3. Is it physically possible to modify the new platform (North Wing) such that it could handle crude oil without requiring additional permitting?

The USACE conducted a site visit of the BP Cherry Point dock on August 7, 2007. The USACE project manager toured the North Wing to better understand how the North Wing operates in relation to South Wing. The USACE also requested BP provide a detailed description of the North Wing, its operation, and what modifications to the North Wing would be needed to unload crude oil (BP 2013).

Based on the existing design and construction of the North Wing, including the lack of crude oil unloading arms and the existing Flush Line (with a pipe diameter of 6 inches), the North Wing cannot handle the volume of crude oil needed by the refinery for production. To use the existing Flush Line, new crude oil unloading arms and a new connection to the existing Flush Line would be required to offload crude oil from a tank vessel. Furthermore, offloading crude oil through the 6-inch Flush Line would take approximately 180 hours or 7.5 days. The use of the Flush Line to unload crude oil would prevent loading of refined petroleum products at the North Wing during this period.

To modify the North Wing to allow unloading crude oil would require extensive modification of the piping configuration from the "Y"-shaped area to the North Wing in order to unload crude oil at a rate similar to the South Wing's rate. The "Y" shaped area is where the North and South Wings split off from

the main causeway. A new tie-in from the existing 30-inch-diameter crude oil Marine Line to the North Wing would be required. A new 30-inch line would need to be installed through the "Y" area and added to the existing pipe rack on the North Wing causeway to the North Wing loading platform. Taller and larger diameter crude oil loading arms would need to be installed on the North Wing loading platform. In addition, modifications to the manifold and piping configuration on the North Wing loading platform would be required to allow routing of crude oil from the 30-inch crude oil Marine Line to any new crude oil loading arms.

The modifications described above would require authorization by the USACE and other regulatory agencies. A DA permit modification from the USACE is required for a change in the usage of the North Wing (from handling refined petroleum products only to handling both crude oil and refined petroleum products), for installation of new crude oil loading arms, and adding a new 30-inch crude oil pipeline from the "Y" area to new crude oil loading arms on the North Wing and tie-in from the Marine Line to the North Wing. See 33 CFR § 325.7.

4. Did the modifications authorized by the permit increase the potential berthing capacity of the terminal for tankers carrying crude oil?

4.1 Berthing Capacity of the North Wing

The North Wing has a single berth and loading arms designed to handle loading of refined petroleum products. The North Wing became operational in 2001. A review of Table 2- 1, *Monthly and Annual Vessel Calls at BP Cherry Point Dock (1998–2010)* [Draft EIS page 2-11]; Table 2-2, *Total Annual Material Transfer at BP Cherry Point Dock (1998–2010)(bbl)* [Draft EIS page 2-12]; and Table 2-3, *Annual Volume and Vessel Calls at BP Cherry Point Dock (1998–2010) Compared to 1998-2010 Average Values* [Draft EIS page 2-13] shows that the amount of refined petroleum products and number of vessels serviced at the North Wing varies from year to year. The lowest volume of refined petroleum product loaded occurred in 2004; a total of 25,404,183 bbl were loaded on 150 vessels. The highest volume of refined petroleum product loaded occurred in 2007, when a total of 37,787,207 bbl were loaded on 225 vessels. Since the North Wing became operational, the average number of calls per year is 176 refined petroleum products vessels (for the period from 2002 to 2010). Refined petroleum products also are transported by pipeline, truck, and train from the refinery. The North Wing's maximum annual capacity for unloading crude oil cannot be calculated, because the North Wing cannot handle unloading of crude oil. The North Wing has reduced utilization of the South Wing for loading refined petroleum products (BP 2011).

4.2 Berthing Capacity of the South Wing

From 1971 to April 2001, the South Wing handled both crude oil unloading and refined petroleum product loading. Historical utilization of the South Wing for unloading crude oil vessels varied from a low of 100 crude oil vessels in 1991 to a high of 125 crude oil vessels in 1996 (see Table 1 below). In June 1999, a section of the Olympic Pipeline ruptured, and deliveries of refined petroleum product by pipeline were disrupted. The pipeline was out of service from June 1999 to April 2001. During this period from June 1999 to April 2001, loading of refined petroleum product increased at the South Wing. A total of 303 vessels used the South Wing in 2000, including loading of 195 refined petroleum product vessels and unloading of 108 crude oil vessels.

The maximum capacity of the South Wing is presented in Table 2-4, *Calculation of Maximum Single-Wing Dock Capacity for the BP Cherry Point Dock* (Draft EIS page 2-15) and is discussed in Section 2.2.9, *Maximum Dock Capacity of the South Wing* (Draft EIS page 2-15) of the Draft EIS.

The most accurate measurement of berthing capacity at the South Wing is hours that the berth is available for vessel operations. Berth availability allows for an accurate measure of capacity, including known and demonstrated values for parameters that preclude dock availability, while excluding those variables that are cargo- or vessel-specific, such as vessel size, cargo size, and pumping rate. Factors that reduce dock availability, and thus berthing capacity, are based on historical averages which show that the berth is not available 2.1 days per year due to weather restrictions and that the berth is not available 5.5 days per year due to regulatory requirements for annual pressure testing of the dock lines and mechanical availability. When averaged across the year, and then translated into meaningful availability measures, these data reflect that the maximum berthing capacity of the South Wing is 23.5 hours per day. Based on assumptions shown in Table 2-4 of the Draft EIS, the annual capacity of the South Wing for both refined petroleum product and crude oil vessels is 335 calls. This annual capacity includes adequate time for all of the normal elements of operation required for continued dock availability and safe and effective operation for unloading crude oil and loading refined petroleum products.

Using the same assumptions shown in Table 2-4 of the Draft EIS, the maximum annual capacity of the South Wing for crude oil vessels only can be calculated, as follows.

Dock Time Available for Operations
8,760 hours per year total time
- 132 hours dock out of service for maintenance (5.5 days)
- 50.4 hours dock out of service for weather (2.1 days)
= 8,577.6 hours per year dock available

Dock Time Required per Vessel Call
5.2 hours – Maneuvering, docking and departure
+22.06 hours – Average crude oil unloading time (620,000 bbl average cargo size divided by 28,100 bbl per hour unloading rate = 22.06 hours.)
= 27.26 hours/call

The calculation above was used to determine the maximum number of crude oil vessel calls that could be served at the South Wing: 8,577.6 hours dock available divided by 27.26 hours per vessel call = 314.66 calls of crude oil vessels.

Based on the above calculation, up to 315 crude oil vessel calls per year could occur at the South Wing. Actual berth utilization of the South Wing is expected to be well below the calculated 315 crude oil vessel calls per year. Between 2002 and 2010, after the North Wing became operational, the number of crude oil vessel calls at the South Wing ranged between 140 and 191 vessels per year. The annual crude oil vessel calls at the South Wing have been well below the annual berthing capacity of 315 calls per year for crude oil vessels only and below the annual berthing capacity of 335 vessels per year for both crude oil and refined petroleum product vessels.

The refinery production rate has been stable at 225,000 bbl per day, or 82,125,000 bbl per year, for the period from 2001 through 2010 (EIS page 2-12). If the entire year of crude oil was delivered by ship with an average cargo volume of 624,626 bbl, 131 vessels per year would be required to deliver 82,125,000 bbl per year. The refinery also receives crude oil deliveries by pipeline and will begin receiving deliveries by train in the near future; these other modes of crude oil deliveries would reduce the volume of crude oil delivered to the refinery over the South Wing.

Table 1 shows the number of crude oil vessel calls that occurred at the South Wing from 1990 to 2010 and the annual volume of crude oil unloaded. The overall annual volume of crude oil unloaded at the South Wing remained within a range of 60,721,943 to 76,431,762 bbl per year over this 20-year period.

In 2007, a total of 191 vessels called at the South Wing and unloaded a total volume of 71,840,417 bbl of crude oil. This is the highest number of crude oil vessel calls to occur at the South Wing in the 20-year period. It is important to note that the total volume of crude oil unloaded in 2007 is less than the total volume unloaded in 1997. In 1997, a total volume of 75,591,500 bbl of crude oil was unloaded from 107 vessels. The comparison of the number of crude vessels and amount of crude oil unloaded over the past 9 years (2002 through 2010) shows a trend to smaller volume crude oil cargoes per vessel being unloaded. This trend to smaller volumes being unloaded has resulted in the increase in the total number of crude oil vessels calling at the South Wing during this period.

Table 1. Annual Crude Oil Vessels/Crude Oil Volume at South Wing from 1990 through 2010

Year	Annual Crude Oil Vessels	Crude Oil Volume (barrels)
1990	108	61,028,000
1991	100	63,692,500
1992	111	68,839,000
1993	112	68,948,500
1994	114	66,685,500
1995	123	73,328,500
1996	125	72,671,500
1997	107	75,591,500
1998	114	71,207,327
1999	110	60,721,943
2000	108	64,624,712
2001	119	70,976,481
2002	140	71,495,998
2003	165	72,991,103
2004	137	68,749,545
2005	143	62,368,592
2006	141	74,346,487
2007	191	71,840,417
2008	188	76,431,762
2009	162	71,153,897
2010	174	64,215,057

Sources: 1990 – 1997 data, ARCO May 2000;
1998 – 2010 data, BP 2011.

5. Volume of Crude Oil Handled at South Wing

The South Wing has not been modified since its construction in 1971. Therefore, its handling capacity for crude oil has not changed. Figure 1 is a graph showing the barrels of crude oil per year unloaded at the South Wing from 1990 to 2010. The amount of crude oil unloaded varies from a low of 61,028,000 bbl to a high of 76,431,762 bbl. The average volume of crude oil that moved across the South Wing was 69,138,491 bbl for the period from 1990 to 2010. A review of the information in Table 2-1, *Monthly and Annual Vessel Calls at BP Cherry Point Dock (1998–2010)* [page 2-11 of the Draft EIS] and Table 2-3, *Annual Volume and Vessel Calls at BP Cherry Point Dock (1998–2010) Compared to 1998–2010 Average Values* [pages 2-13 and 2-14 of the Draft EIS] shows that the average cargo size of crude oil has declined from 624,626 bbl in 1998 to 369,052 bbl in 2010. The overall average cargo size for the entire period was 474,776 bbl, indicating that crude oil cargo size has declined while the refinery production has been stable at approximately 225,000 bbl per day for the period from 2001 through 2010. Fully loaded crude oil vessels are arriving at the South Wing, but only a portion of the overall cargo is

unloaded at the South Wing. Some of these crude oil vessels continue to other refineries located in the general area. Figure 1 shows that crude oil volumes have remained within the same range from 1990 to 2010.

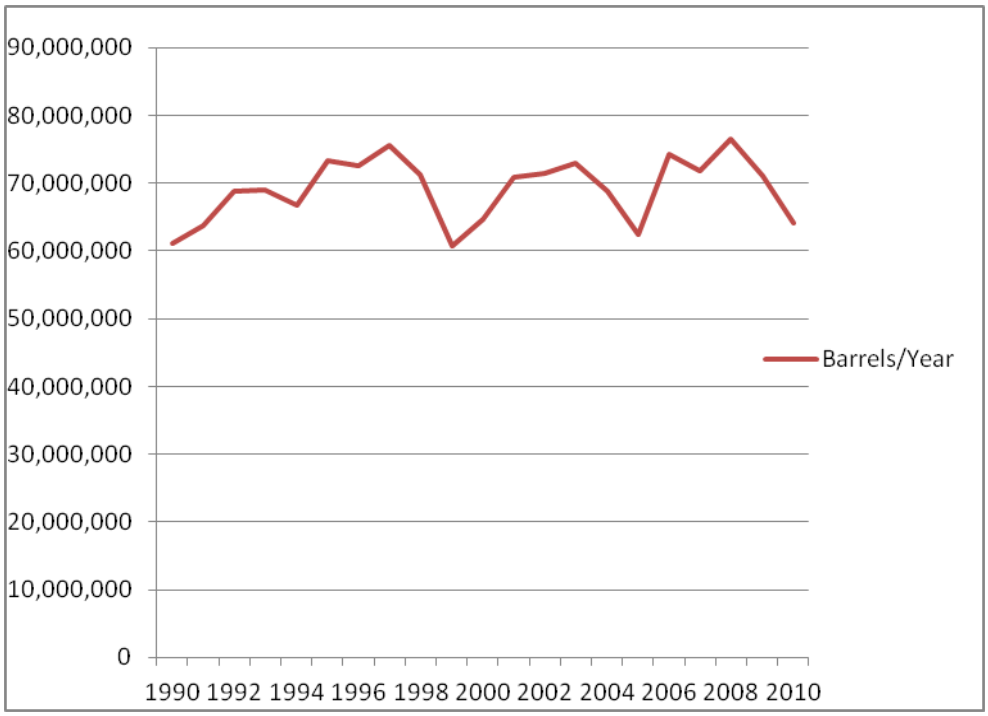

Figure 1. Annual Crude Oil Volumes from 1990 through 2010

Figure 2 is a graph that compares the barrels of crude oil per year (in million barrels) unloaded at the BP Cherry Point dock and the number of calls per year at the South Wing from 1990 to 2010. This graph shows that the volume of crude oil per year has remained within the same range over the past 20 years while the number of vessel calls per year has increased, beginning in 2001.

In 1998, the average monthly number of crude oil vessel calls was 9.5; in 2010, the average monthly number of crude oil vessel calls was 14.5. However, the volume of crude oil received by the BP Cherry Point dock from 1998 through 2010 remained relatively consistent, with an average of 69,317,256 bbl annually both before and after construction of the North Wing. It appears that starting in 2002 the number of vessels delivering crude oil to the South Wing increased, but the average load of the crude oil vessels has declined from 624,626 bbl in 1998 to approximately 369,052 bbl in 2010 (EIS Chapter 2). BP indicated that this change is a result of the refinery's declining reliance on Alaska North Slope (ANS) crude oil. The increase in number of vessels and decrease in cargo size is attributed to the declining ANS crude production, the historical source of crude oil for the Cherry Point Refinery, and the associated change in crude oil sourcing strategy brought about by the purchase of the Refinery by BP in April 2000. In 1977, with the completion of the Trans-Alaska Pipeline System, the Cherry Point Refinery began operating on 100 percent ANS crude. In 2014, BP anticipates that ANS will constitute less than 40 percent of the Refinery's crude deliveries (BP 2014).

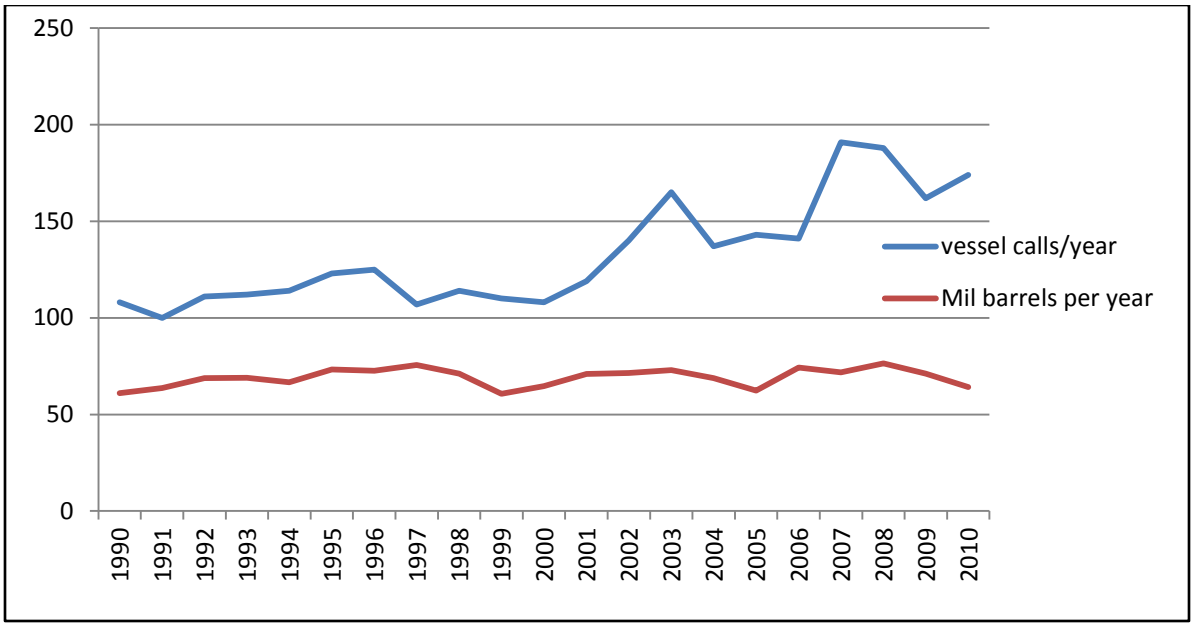

Figure 2. Comparison of Annual Vessel Calls to Annual Crude Oil Volume

The BP Cherry Point Refinery operates most efficiently on a crude oil feedstock that is very similar chemically to ANS crude. Due to the decline in ANS production and the increase in ANS prices relative to other available crude oil, BP chose to augment ANS deliveries with a variety of domestic crude oil, including North Dakota crude, Canada tar sands oil, and internationally sourced crude. These varieties of crude oil, when combined for processing, yield a range of refined petroleum products very similar to ANS. BP has chosen this strategy of using various sources of crude oils and maintaining the complex management of storage tank contents and volumes, in lieu of building additional crude oil storage tanks. The use of this business strategy has resulted in an increase in the average annual number of crude oil vessel calls and a decrease in the average cargo volume per crude oil delivery since 2002.

6. Legal Restriction That Limits the Crude Oil Capability of the North Wing

According to 33 CFR § 320.2(b), Section 10 of the Rivers and Harbors Act of 1899 prohibits the unauthorized obstruction or alteration of any navigable water of the United States; furthermore, construction of any structure in or over any navigable water of the United States requires a permit from the USACE. The March 1996 permit issued to ARCO (predecessor to BP) was granted under this authority. The USACE has the authority to re-evaluate the circumstances and conditions of any permit and initiate action to modify, suspend, or revoke a permit as may be necessary by considerations of the public interest. See 33 CFR § 325.7. As stated in the EIS, under the Proposed Action, the USACE would modify the DA permit for continued operation and maintenance of the dock, with the added condition that the North Wing could not be used for unloading or loading crude oil. If at a later date BP wishes to make any change to the operations of the North Wing or change to the piping configuration or equipment on that wing, BP would be required to submit a permit application to seek DA approval for such changes. The USACE would process such a request for permit modification, including an evaluation of the proposed modification with respect to requirements of the Magnuson Amendment.

7. Crude Oil Refined for Consumption in the State of Washington

Analysis of product shipment data by BP for the period from January 1, 2007, through December 31, 2012—the only time period for which data are available,[1] indicates that approximately 26 percent of the crude oil delivered to the BP Cherry Point dock during this period was refined for consumption in Washington State (BP 2013).

This analysis of crude oil delivered to the BP Cherry Point dock for consumption within Washington State is based on an extrapolation from product delivery data during the identified time frame. Product placement over any given time period is driven by market forces and is not a reflection of any limitation of the terminal where crude oil is delivered. Under different market conditions, up to 100 percent of the crude oil delivered to the BP Cherry Point Refinery could be refined for consumption in Washington State.

8. Literature Cited

ARCO. 2000. Annual Crude Oil Vessels/Crude Oil Volume at South Wing from 1990 through 1997. May.

BP. 2011. Updated Response to USACE Data Requests 3a and 3b. August 18, 2011.

BP. 2013. Response to USACE Magnuson Evaluation Data Request Items 9 and 10. October 26, 2013.

BP. 2014. Email from Scott McCreery (BP) to Olivia Romano (USACE) regarding crude vessel numbers. January 15, 2014.

[1] BP's ability to access the Cherry Point Refinery data before 2007 has become difficult due to a change in accounting tools that has resulted in older data being incompatible with newer software.

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