Appendix E

Washington Department of Ecology

Fate and Effects Modeling

This page intentionally left blank.

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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suàrez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

List of Volumes

Volume I: Model Description, Approach, and Analysis
Volume II: Summary of Results for All Scenarios

Volume III: Model Inputs for Outer Coast (OC) Scenarios at Duntz Rock off Cape Flattery – Alaskan North Slope Crude
Volume IV: Stochastic Model Results for Outer Coast (OC) Scenarios at Duntz Rock off Cape Flattery – Alaskan North Slope Crude
Volume V: Results of Alternative Response Scenarios for Outer Coast (OC) Scenarios at Duntz Rock off Cape Flattery – Alaskan North Slope Crude
Volume VI: Model Inputs for Strait of Juan de Fuca – Bunker C
Volume VII: Stochastic Model Results for Strait of Juan de Fuca – Bunker C
Volume VIII: Results of Alternative Response Scenarios for Strait of Juan de Fuca – Bunker C
Volume IX: Model Inputs for Strait of Juan de Fuca – Diesel
Volume X: Stochastic Model Results for Strait of Juan de Fuca – Diesel
Volume XI: Results of Alternative Response Scenarios for Strait of Juan de Fuca – Diesel
Volume XII: Model Inputs for Strait of Juan de Fuca – Alaskan North Slope Crude
Volume XIII: Stochastic Model Results for Strait of Juan de Fuca – Alaskan North Slope Crude
Volume XIV: Results of Alternative Response Scenarios for Strait of Juan de Fuca – Alaskan North Slope Crude
Volume XV: Model Inputs for San Juan Islands – Alaskan North Slope Crude
Volume XVI: Stochastic Model Results for San Juan Islands – Alaskan North Slope Crude
Volume XVII: Results of Alternative Response Scenarios for San Juan Islands – Alaskan North Slope Crude

Volume XVIII: Model Inputs for Inner Straits/Puget Sound – Alaskan North Slope Crude
Volume XIX: Stochastic Model Results for Inner Straits/Puget Sound – Alaskan North Slope Crude
Volume XX: Results of Alternative Response Scenarios for Inner Straits/Puget Sound – Alaskan North Slope Crude
Volume XXI: Model Inputs for Lower Columbia River – Bunker C
Volume XXII: Stochastic Model Results for Lower Columbia River – Bunker C
Volume XXIII: Results of Alternative Response Scenarios for Lower Columbia River – Bunker C
Volume XXIV: Model Inputs for Upper Columbia River – Bunker C
Volume XXV: Stochastic Model Results for Upper Columbia River – Bunker C
Volume XXVI: Results of Alternative Response Scenarios for Upper Columbia River – Bunker C

Volume I: Table of Contents

Executive Summary 1

1. Introduction 14

2. SIMAP Model Description 20

2.1 Physical Fates Model 21
2.2 Biological Effects Model 25
2.2.1 Wildlife 26
2.2.2 Fish and Invertebrates 27
2.2.3 Validation of the Biological Effects Model 29
2.2.4 Quantification of Fish and Invertebrate Impacts as Lost Production 30
2.3 Stochastic Modeling 32
2.3.1 Approach 32

3. Model Input Data 35

3.1 Geographical and Model Grid 35
3.2 Environmental Data 37
3.3 Currents 38
3.3.1 Tidal and Other Currents 38
3.3.2 Wind-driven Surface Currents 40
3.4 Oil Properties, Toxicity, and Impact Thresholds 41
3.4.1 Whole oil 41
3.4.2 Low molecular weight aromatics 42
3.4.3 Toxicity Thresholds of Concern 42
3.5 Shoreline Oil Retention 43
3.6 Scenarios 44
3.7 Biological Abundance 45

4. Oil Fates Model Results 67

4.1 Explanation of Model Outputs 67
4.1.1 Stochastic Output to Estimate Probabilities and Degrees of Exposure 67
4.1.2 Summary of Exposure for the Sampled Range of Environmental Conditions 69
4.1.3 Exposure Results for Individual Runs 71
4.2 Stochastic Model Results 72
4.3 Results for Individual Scenarios 76

5. Biological Effects Model Results 78

5.1 Intertidal Habitats 78
5.2 Wildlife 81

5.3 Fish and Invertebrates 83
6. Potential Natural Resource Damages 86
6.1 NRD Based on Restoration Costs 86
6.1.1 Saltmarsh Restoration 88
6.1.2 Seagrass Bed Restoration 91
6.2 Washington State Compensation Schedule 93
7. Conclusions 97
8. References 98

Contents of Volume II

II.1. Introduction
II.2. Summary of the 13 Main Stochastic Scenarios
II.3. Comparison of Alternative Responses: Outer Coast at Duntz Rock off Cape Flattery – Alaskan North Slope Crude
II.4. Comparison of Alternative Responses: Strait of Juan de Fuca – Bunker C
II.5. Comparison of Alternative Responses: Strait of Juan de Fuca – Diesel
II.6. Comparison of Alternative Responses: Strait of Juan de Fuca – Alaskan North Slope Crude
II.7. Comparison of Alternative Responses: San Juan Islands – Alaskan North Slope Crude
II.8. Comparison of Alternative Responses: Inner Straits/Puget Sound – Alaskan North Slope Crude
II.9. Comparison of Alternative Responses: Lower Columbia River – Bunker C
II.10. Comparison of Alternative Responses: Upper Columbia River – Bunker C

Contents of Volumes III, VI, IX, XII, XV, XVIII, XXI, and XXIV

III.A. Introduction
III.B. Geographical Data
  III.B.1. Maps of the Vicinity of the Modeled Spill Locations
  III.B.2. Gridded Habitat Mapping
  III.B.3. Gridded Depth Data
  III.B.4. Areas Where Response Actions Assumed
III.C. Current Data
  III.C.1. Basis of Current Data
  III.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations
III.D: Oil Properties
III.E: Inputs to the SIMAP Physical Fates Model

Contents of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, and XXV

IV.A. Introduction
IV.B. Maps of Exposure Probability, Time First Exposed, and Maximum Possible Contamination
IV.C. Rank Order Distributions for All Model Runs
IV.D. Shoreline Areas Exposed by Shore Type
IV.E. Exposure for Representative Individual Model Runs
IV.F. Estimated Biological Impacts: Wildlife
IV.G. Estimated Biological Impacts: Fish and Invertebrates
IV.H. Estimated NRDA Costs: Habitat Restoration Costs
IV.I. Estimated NRDA Costs: Washington Compensation schedule

Contents for Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, and XXVI

V.A. Introduction
V.B. Exposure for Individual Model Runs
  V.B.1. No Removal
  V.B.2. State Mechanical Removal
  V.B.3. Federal Mechanical Removal
  V.B.4. 3rd Alternative Mechanical Removal
  V.B.5. State Mechanical Removal and dispersant
  V.B.6. Federal Mechanical Removal and dispersant
  V.B.7. 3rd Alternative Mechanical Removal and dispersant
  V.B.8. State Mechanical Removal and In-situ Burning
V.C. Estimated Biological Impacts: Wildlife
V.D. Estimated Biological Impacts: Fish and Invertebrates
V.E. Estimated NRDA Costs: Habitat Restoration Costs
V.F. Estimated NRDA Costs: Washington Compensation schedule

Volume I: List of Figures

Figure 1-1. Shipping route segments where the hypothetical spills are assumed to occur: Straits and outer coast scenarios. 18
Figure 1-2. Shipping route segments where the hypothetical spills are assumed to occur: Columbia River scenarios. 18
Figure 2-1. Simulated oil fates processes in open water 24
Figure 2-2. LC50 of dissolved PAH mixtures from oil, as a function of exposure duration and temperature 28

Volume I: List of Tables

Table E-1 Oil spill modeling scenarios. [St = main stochastic scenario; MR = mechanical removal capacities assumed; DSP = dispersant included; ISB = in situ burning included] ... 7
Table E-2. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass mechanically removed (%). ... 8
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). ... 8
Table E-4. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled. ... 9
Table E-5. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled. ... 9
Table E-6. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates. ... 10
Table E-7. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (clams). ... 10
Table E-8. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is wetland creation. ... 11
Table E-9. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (in millions of 2004$). ... 11
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$). ... 11
Table E-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of 2004$). ... 12
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$). ... 12
Table E-13. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of 2004$). ... 12
Table E-14. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total NRDA costs (in millions of 2004$). ... 13
Table E-15. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$). ... 13
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$). ... 13
Table 1-1 Oil spill modeling scenarios. [St = main stochastic scenario; MR = mechanical removal capacities assumed; DSP = dispersant included; ISB = in situ burning included] ... 17
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). ... 22
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. ... 27

Table 2-3. Biological resource types and exposure measure by which the resource is most affected. 34
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.) 36
Table 3-2. Default fringing intertidal habitat type, given adjacent subtidal or extensive intertidal habitat type. 37
Table 3-3. LC50s for fuel components and varying exposure times. 43
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). 44
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. 47
Table 3-6. Wildlife densities assumed for the outer coast of Washington, as seasonal means in number per km^2. 48
Table 3-7. Wildlife densities assumed for the lower Columbia River, as seasonal means in number per km^2. 50
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] 51
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. 53
Table 3-10. Fish and invertebrate densities (kg/km^2) assumed for the outer coast of Washington, as seasonal mean by habitat. 55
Table 3-11. Fish and invertebrate densities (kg/km^2) assumed for the lower Columbia River, as seasonal mean by habitat. 56
Table 3-12. Fish and invertebrate densities (kg/km^2) assumed for the upper Columbia River, as seasonal mean by habitat. 57
Table 3-13. Fish and invertebrate taxonomic grouping used in modeling. 59
Table 3-14. Fish and invertebrate taxa codes for species in Strait of Juan de Fuca and Puget Sound. 59
Table 3-15. Fish and invertebrate taxa codes for species for the outer coast of Washington. 60
Table 3-16. Fish and invertebrate taxa codes for species for the lower Columbia River. 60
Table 3-17. Fish and invertebrate taxa codes for species for the upper Columbia River. 61
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. 62
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. 63
Table 3-20. Fish and invertebrate young-of-the-year densities ($\#/km^2$) assumed for the lower Columbia River, as seasonal means by habitat. 64
Table 3-21. Fish and invertebrate young-of-the-year densities ($\#/km^2$) assumed for the upper Columbia River, as seasonal means by habitat. 65
Table 3-22. Intertidal invertebrate densities (kg/km^2) by location. 66
Table 4-1. Oil thickness (microns ~ g/m^2) and appearance on water (NRC, 1985). 68

Table 4-2. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass mechanically removed (%). 72
Table 4-3. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass coming ashore (%). 73
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). 74
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, %). 74
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 (%)... 75
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... 76
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. 76
Table 5-1. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (clams)... 79
Table 5-2. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to intertidal invertebrates (clams). 79
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). 79
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). 80
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). 80
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). 80
Table 5-7. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total impact (kg) to intertidal invertebrates (clams). 81
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). 81
Table 5-9. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled. 82
Table 5-10. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled. 82
Table 5-11. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates. 84
Table 5-12. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal and intertidal fish and invertebrates.................................... 85
Table 6-1. Assumed ecological efficiencies for one trophic step. 87
Table 6-2 Composite ecological efficiency relative to benthic invertebrate production by trophic group. 88
Table 6-3. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. 90

Table 6-4. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is wetland creation. 90
Table 6-5. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming seagrass bed creation. 92
Table 6-6. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is seagrass bed creation. 92
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. 94
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. 94
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. 95
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. 95
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. 95
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. 96
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. 96
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. 96

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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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

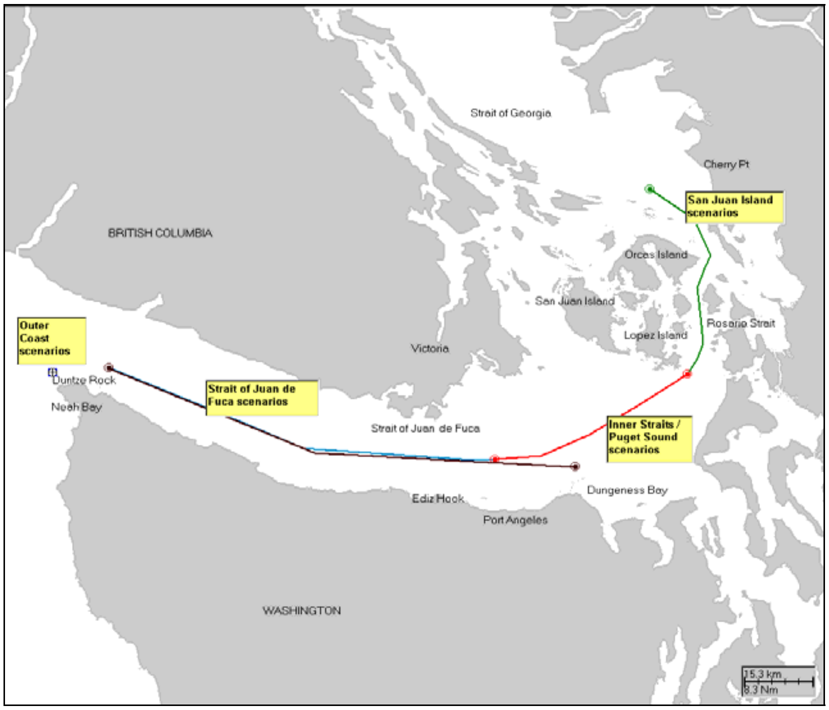


Figure 1-1. Shipping route segments where the hypothetical spills are assumed to occur: Straits and outer coast scenarios.

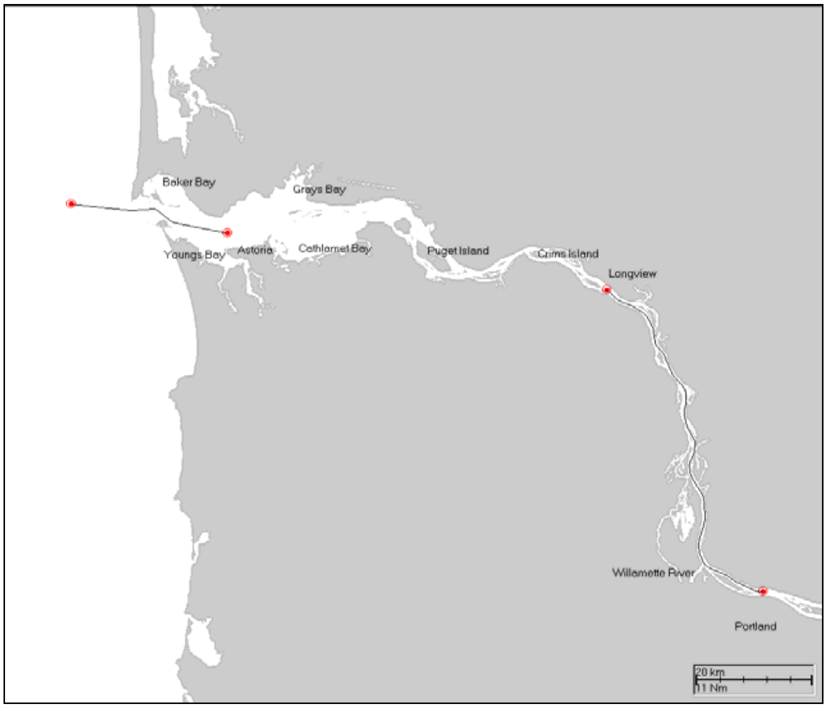


Figure 1-2. Shipping route segments where the hypothetical spills are assumed to occur: Columbia River scenarios.

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 (^oC)	< 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	≥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.

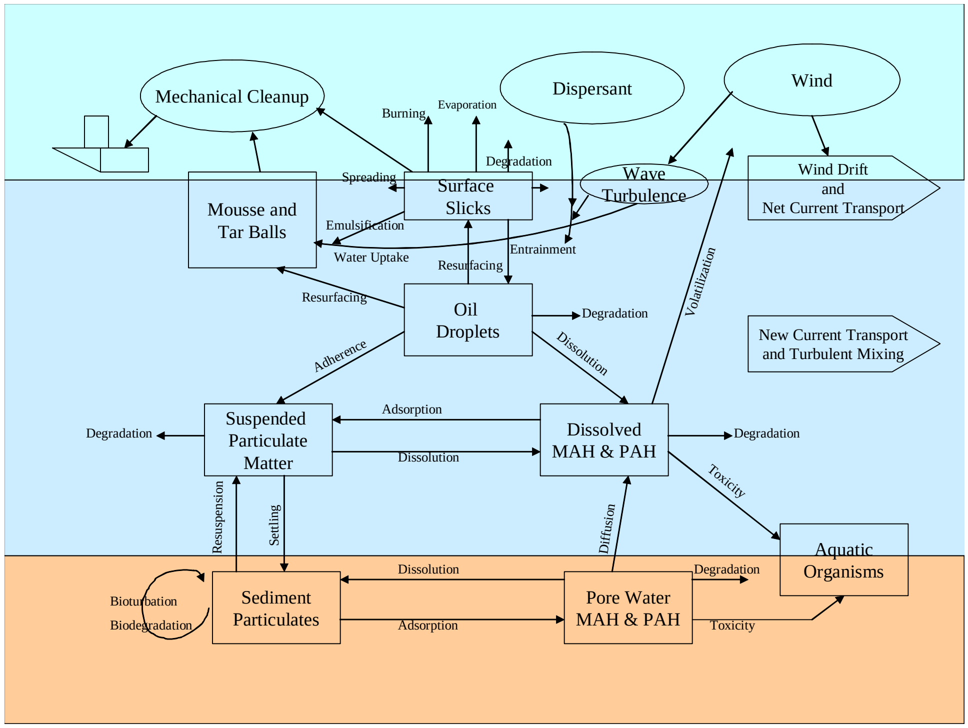


Figure 2-1. Simulated oil fates processes in open water

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.

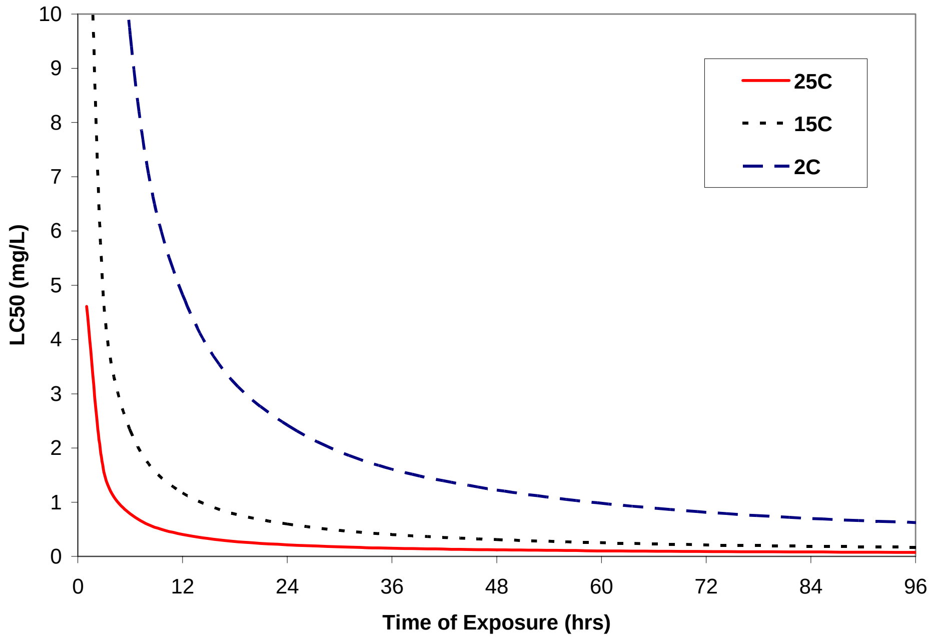


Figure 2-2. LC50 of dissolved PAH mixtures from oil, as a function of exposure duration and temperature.

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 50^{th} (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., 99^{th} percentile if 100 runs are made). The 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} percentile runs based on shoreline costs and the 5^{th}, 50^{th} and 95^{th} 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^o-30^o 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^o-30^o 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 (2.5th 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

For PAHs, the LC50 for six hours of exposure for the 2.5th 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 5^{th}, 50^{th} and 95^{th} 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 99^{th} 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 ($g\text{-}m^{-2}$-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 5^{th}, 50^{th} and 95^{th} percentile conditions (using the above impact measures) expected for that scenario. The runs producing the 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 3^{rd} 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 3^{rd} 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 3^{rd} 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.

8. REFERENCES

A.D. Little, 1996. Reference samples measured during North Cape damage assessment, (A.D. Little, personal communication)

Anderson, J.W., 1985. Toxicity of dispersed and undispersed Prudhoe Bay crude oil fractions to shrimp, fish, and their larvae. American Petroleum Institute Publication No. 4441, Washington, D.C., USA, August 1985, 52p.

ASCE Task Committee on Modeling Oil Spills, 1996. State-of-the-art Review of Modeling Transport and Fate of Oil Spills, Water Resources Engineering Division, ASCE, Journal of Hydraulic Engineering 122(11): 594-609.

Defant, A. (1961) Physical Oceanography. Vol. 2. Pergamon Press, New York.

DiToro, D.M., J.A. McGrath and D.J. Hansen, 2000. Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. I. Water and tissue. Environmental Toxicology and Chemistry 19(8): 1951-1970.

DiToro, D.M. and J.A. McGrath, 2000. Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. II. Mixtures and sediments. Environmental Toxicology and Chemistry 19(8): 1971-1982.

Egbert, G. D., A. F. Bennett, and M.G.G. Foreman, 1994. TOPEX/POSEIDON tides estimated using global inverse model. J. Geophys. Res. 99(C12): 24821-24852.

Etkin, D.S., D. French McCay, J. Rowe, N. Whittier, S. Sankaranarayanan, and L. Pilkey-Jarvis, 2005a. Modeling Impacts of Response Method and Capability on Oil Spill Costs and Damages for Washington State Spill Scenarios. Proceedings, 2005 International Oil Spill Conference, Paper 299, Miami, Florida, American Petroleum Institute, Washington, DC.

Etkin, D.S., 2005b. Response Cost Modeling For Washington State Oil Spill Scenarios: Part II. Submitted to Washington Department of Ecology, Lacey, WA, October 2005.

Etkin, D.S., 2005c. Socioeconomic Cost Modeling For Washington State Oil Spill Scenarios: Part II. Submitted to Washington Department of Ecology, Lacey, WA, October 2005.

Etkin, D.S. and D. French-McCay, 2005. Summary of Modeling Assumptions and Results For Washington State Oil Spill Scenarios Phases I and II. Submitted to Washington Department of Ecology, Lacey, WA, October 2005.

Fonseca, M. S., W. J., Kenworthy and G. W. Thayer, 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA's Coastal Ocean Program, Decision Analysis Series No. 12, November 1998.

French, D.P., S. Pavignano, A. Keller, D. Gifford, S. Puckett, S. Feng, M. Reed, M. Welsh and R. Bishop, 1993. Compensation formula for natural resource damage assessments under OPA: Oil spills into inland (freshwater) waters, Vol. I - Technical Documentation. Report to the National Oceanic and Atmospheric Administration, Rockville, MD, March 1993.

French, D.P., S. Pavignano, A. Keller and D. Gifford, 1993. Compensation formula for natural resource damage assessments under OPA: Oil spills into inland (freshwater) waters, Vol. II - Biological database: Inland waters other than the Great Lakes. Report to the National Oceanic and Atmospheric Administration, Rockville, MD, April 1993.

French, D., M. Reed, K. Jayko, S. Feng, H. Rines, S. Pavignano, T. Isaji, S. Puckett, A. Keller, F. W. French III, D. Gifford, J. McCue, G. Brown, E. MacDonald, J. Quirk, S. Natzke, R. Bishop, M. Welsh, M. Phillips and B.S. Ingram, 1996a. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), Technical Documentation, Vol. I - Model Description. Final Report, submitted to the Office of Environmental Policy and Compliance, U.S. Dept. of the Interior, Washington, DC, April, 1996, Contract No. 14-0001-91-C-11.

French, D., M. Reed, S. Feng and S. Pavignano, 1996b. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), Technical Documentation, Vol. III - Chemical and Environmental Databases. Final Report , Submitted to the Office of Environmental Policy and Compliance, U.S. Dept. of the Interior, Washington, DC, April, 1996, Contract No. 14-01-0001-91-C-11.

French, D., S. Pavignano, H. Rines, A. Keller, F.W. French III and D. Gifford, 1996c. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), Technical Documentation, Vol.IV - Biological Databases. Final Report , Submitted to the Office of Environmental Policy and Compliance, U.S. Dept. of the Interior, Washington, DC, April, 1996, Contract No. 14-01-0001-91-C-11.

French, D.P., and H. Rines, 1997. Validation and use of spill impact modeling for impact assessment. Proceedings, 1997 International Oil Spill Conference, Fort Lauderdale, Florida, American Petroleum Institute Publication No. 4651, Washington, DC, pp-829-834.

French, D., H. Schuttenberg, and T. Isaji, 1999. Probabilities of Oil Exceeding Thresholds of Concern: Examples from an Evaluation for Florida Power and Light.

In: Proceedings of the 22nd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, June 2-4, 1999, Calgary, Alberta, Environment Canada, pp.243-270.

French, D. P., C.A. Manen, M. Gibson, and J. Catena, 2001. Quantifying the scale of restoration required to compensate for the impacts of the North Cape oil spill on fish and invertebrates. Proceedings of the 2001 International Oil Spill Conference & Exposition, American Petroleum Institute, March 26-29, 2001, Tampa, Florida.

French McCay, D.P., 2002. Development and Application of an Oil Toxicity and Exposure Model, OilToxEx. Environmental Toxicology and Chemistry 21(10): 2080-2094.

French McCay, D.P., 2003. Development and Application of Damage Assessment Modeling: Example Assessment for the North Cape Oil Spill. Marine Pollution Bulletin, Volume 47, Issues 9-12, September-December 2003, pp. 341-359.

French McCay, D.P., 2004. Oil spill impact modeling: Development and validation. Environmental Toxicology and Chemistry 23(10): in press.

French McCay, D.P., and J.J. Rowe, 2003. Habitat restoration as mitigation for lost production at multiple trophic levels. Mar Ecol Prog Ser 264:235-249.

French McCay, D.P., and J.J. Rowe, 2004. Evaluation of Bird Impacts in Historical Oil Spill Cases Using the SIMAP Oil Spill Model. In Proceedings of the 27th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, pp. 421-452.

French McCay, D., N. Whittier, S. Sankaranarayanan, J. Jennings, and D. S. Etkin, 2002. Modeling Fates and Impacts for Bio-Economic Analysis of Hypothetical Oil Spill Scenarios in San Francisco Bay. In Proceedings of the Twenty Fifth Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Environment Canada, Calgary, AB, Canada, 2002, p. 1051-1074.

French McCay, D.P., C.H. Peterson, J.T. DeAlteris and J. Catena, 2003a. Restoration that targets function as opposed to structure: replacing lost bivalve production and filtration. Mar Ecol Prog Ser 264:197-212.

French McCay, D., N. Whittier, T. Isaji, and W.Saunders, 2003b. Assessment of the Potential Impacts of Oil Spills in the James River, Virginia. In Proceedings of the 26th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, p. 857-878.

French McCay, D., J. J. Rowe, and N. Whittier, 2003c. Final Report, Estimation of Natural Resource Damages for 23 Florida Cases Using Modeling of Physical Fates and Biological Injuries. (23 volumes). Prepared for Florida Department of Environmental Protection, May 2003.

French McCay, D., N. Whittier, S. Sankaranarayanan, J. Jennings, and D. S. Etkin, 2004a. Estimation of Potential Impacts and Natural Resource Damages of Oil. J. Hazardous Materials 107/1-2:11-25.

French McCay, D, J. Rowe, N. Whittier, S. Sankaranarayanan, C. Suàrez, and D. Schmidt Etkin, 2004b. Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters. Draft Report (26 volumes), Submitted to Washington Department of Ecology, Lacey, WA, July 8, 2004.

French-McCay, D.P, J. J. Rowe, N. Whittier, S. Sankaranarayanan, D. S. Etkin, and L. Pilkey-Jarvis, 2005a. Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA Costs of Oil Spills into Washington Waters. Proceedings, 2005 International Oil Spill Conference, Paper 395, Miami, Florida, American Petroleum Institute, Washington, DC.

French-McCay, D.P., J.J. Rowe, N. Whittier, R. Asch, S. Sankaranarayanan, A. Borowik, C. Suárez, and D. S. Etkin, 2005b. Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters, Phase II: Draft Report (23 Volumes), submitted to Washington Department of Ecology, Lacey, WA, October 2005.

Geise, B. S., and Jay, D. A. (1989) Modeling tidal energetic of the Columbia River Estuary, Estuarine, Coastal and Shelf Science, 29, pp.549-571.

Giesy, J.P., and R. Graney, 1989. Recent developments in and intercomparisons of acute and chronic bioassays and bioindicators. Hydrobiologia 188/189: 21-60.

Gobas, F.A.P.C. 1989. A model for exposure and toxicological impact assessment of aromatic hydrocarbon spills in the aquatic environment. Proceedings of the 12th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, June 7-9, 1989, Calgary, Alberta, p.279-296.

Gundlach, E.R., 1987. Oil Holding Capacities and Removal Coefficients for Different Shoreline Types to Computer Simulate Spills in Coastal Waters, in Proceedings of the 1987 Oil Spill conference, pp. 451-457.

Haines, J.R., and R.M. Atlas, 1982. In situ microbial degradation of Prudhoe Bay crude oil in Beaufort sea sediments. Marine Environmental Research 7:91-102.

Hodgins, D.O., 1998. Marine sewage outfall assessment for the capital regional district, British Columbia, using nested three-dimensional models. Water Science and Technology 38(10): 301–308.

Jokuty, P., S. Whiticar, Z. Wang, M. Fingas, P. Lambert, B. Fieldhouse, and J. Mullin, 1996. A catalogue of crude oil and oil product properties (1996 edition), Report # EE-157, Emergencies Science Division, Environment Canada, Ottawa, Canada (http://www.etcentre.org/spills)

Jokuty, P., S. Whiticar, Z. Wang, M. Fingas, P. Lambert, B. Fieldhouse, and J. Mullin, 1999. A catalogue of crude oil and oil product properties (1999 edition), Report # EE-165, Emergencies Science Division, Environment Canada, Ottawa, Canada.

Jones, R.K., 1997. A Simplified Pseudo-Component of Oil Evaporation Model, in Proceedings of the 20th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Environment Canada, pp. 43-61.

Kim, H.S. and J. C. Swanson, 2001. Modeling of double flood currents in the Sakonnet River. Submitted for publication in 7th Annual International Conference on Estuarine and Coastal Modeling (ECM 7), St. Petersburg Beach, Florida, November 5-7, 2001. American Society of Civil Engineers, Reston, Virginia, pp. 418-433.

Kolpack, R.L., Plutchak, N.B. and R. W. Stearns, 1977. Fate of oil in a water environment - Phase II, a dynamic model of the mass balance for released oil. University of Southern California, prepared for American Petroleum Institute, API Publication 4313, Washington, D.C.

Kullenberg, G. (ed.), 1982. Pollutant transfer and transport in the sea. Volume I. CRC Press, Boca Raton, Florida. 227 p.

Lee et al., 1992, Environ. Sci. Technol. 26:2104-2110.

Lehr, W.J., D. Wesley, D. Simecek-Beatty, R. Jones, G. Kachook and J. Lankford, 2000. Algorithm and interface modifications of the NOAA oil spill behavior model. Proceedings of the 23rd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Vancouver, BC, Environmental Protection Service, Environment Canada, pp. 525-539.

Lunel, T. 1993a. Dispersion: Oil droplet size measurements at sea. in Proceedings of the 16th Arctic Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada, Calgary, Alberta, June 7-9, 1993, pp. 1023-1056.

Lunel, T. 1993b. Dispersion: Oil droplet size measurements at sea. in Proceedings of the 1993 Oil Spill Conference, pp. 794-795.

Mackay, D.,S. Paterson and K. Trudel, 1980. A mathematical model of oil spill behavior, Department of Chemical and Applied Chemistry, University of Toronto, Canada, 39p.

Mackay, D., W.Y. Shiu, and K.C. Ma, 1992a. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. I, Monoaromatic Hydrocarbons, Chlorobenzenes, and PCBs. Lewis Publ., Chelsea, Michigan, 668p.

Mackay, D., W.Y. Shiu, and K.C. Ma, 1992b. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. II, Polynuclear Aromatic Hydrocarbons, Polychlorinated Dioxins, and Dibenzofurans. Lewis Publ., Chelsea, Michigan, 566p.

Mackay, D., W.Y. Shiu, and K.C. Ma, 1992c. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. III, Volatile Organic Chemicals. Lewis Publ., Chelsea, Michigan, 885p.

Mackay, D., W.Y. Shiu and D.C. Ma, 1992d. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals. Volume IV Oxygen, Nitrogen, and Sulfur containing compounds. Lewis Publishers, Inc. Chelsea, Michigan, 930p.

Malins, D.C. and H.O. Hodgins, 1981. Petroleum and marine fishes: a review of uptake, disposition, and effects. Envir. Science & Technology 15(11):1272-1280.

Markarian, R.K., J.P. Nicolette, T.R. Barber, and L.H. Giese, 1993. A critical review of toxicity values and evaluation of the persistence of petroleum products for use in natural resource damage assessments. Prepared by Entrix, Inc. for the American Petroleum Institute, Washington, DC, 126 pp plus appendices.

McAuliffe, C.D., 1987. Organism exposure to volatile/soluble hydrocarbons from crude oil spills – a field and laboratory comparison. Proceedings of the 1987 Oil Spill Conference, API, p. 275-288.

Mendelsohn, D., S. Peene, E. Yassuda, and S. Davie, 1999. A hydrodynamic model calibration study of the Savannah River Estuary with an examination of factors affecting salinity intrusion. Estuarine and Coastal Modeling 6 (ECM6), New Orleans, Louisiana, 3-5 November 1999. American Society of Civil Engineers, Reston, Virginia, pp. 663-685.

Mendelsohn, D.L., Yassuda, E.A., S.J. Peene, 2001. A simplified method for marsh inundation modeling in hydrodynamic and water quality models with application to the Cooper River Estuary (SC). Proceedings of the Seventh American Society of Civil Engineers (ASCE) International Estuarine and Coastal Modeling Conference. St. Petersburg (FL), November 5-7, 2001.

Morrison, J., M. Quick and M.G.G. Foreman, 2002. Climate change in the Fraser river watershed: flow and temperature projections. Journal of Hydrology 263: 230-244.

Muin, M., 1993. A Three-Dimensional Boundary Fitted Circulation Model in Spherical Coordinates, Ph.D. Dissertation, Department of Ocean Engineering, University of Rhode Island, Kingston, RI.

Muin, M. and M. Spaulding, 1997a. Three-dimensional boundary-fitted circulation model. Journal of Hydraulic Engineering, Vol. 123, No. 1, January 1997, p2-12.

Muin, M. and M. Spaulding, 1997b. Application of three-dimensional boundary-fitted circulation model to the Providence River. J. of Hydraulic Engineering, Vol. 123, No. 1, January 1997, p.13-20.

National Oceanic and Atmospheric Administration (NOAA), 2000. ADIOS Oil Database, NOAA HAZMAT, 2000 Version 2.0 (http://response.restoration.noaa.gov)

National Research Council, 1985. Oil in the Sea: Inputs, Fates and Effects, National Academy Press, Washington, D.C. 601p.

National Research Council, 2002. Oil in the Sea III: Inputs, Fates and Effects, National Academy Press, Washington, D.C. 446p.

Neff, J.M., J.W. Anderson, B.A. Cox, R.B. Laughlin, Jr., S.S. Rossi, and H.E. Tatem, 1976. Effects of petroleum on survival respiration, and growth of marine animals. p. 515-539 In: Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Am. Institute of Biological Sciences, Washington, DC.

Neff, J.M. and J.W. Anderson, 1981. Response of Marine Animals to Petroleum and Specific Petroleum Hydrocarbons. Applied Science Publishers Ltd., London and Halsted Press Division, John Wiley & Sons, NY. 177p.

Neff, J.M., and W. A. Burns, 1996. Estimation of polycyclic aromatic hydrocarbon concentrations in the water column based on tissue residues in mussels and salmon: an equilibrium partitioning approach, Environmental Toxicology and Chemistry 15: 2240-2253.

Nysewander,D. R., J. R. Evenson, B. L. Murphie, and T. A. Cyra. 2001. Status and trends for a suite of key diving marine bird species characteristic of Greater Puget Sound, as examined by the Marine Bird Component, Puget Sound Ambient Monitoring Program (PSAMP). Puget Sound Research 2001.

Odum, E.P., 1971. Fundamentals of Ecology, W.B. Saunders Co., Philadelphia, 574 p.

Okubo, A. 1971. Oceanic diffusion diagrams. Deep-Sea Research 8:789-802.

Okubo, A. and R.V. Ozmidov, 1970. Empirical dependence of the coefficient of horizontal turbulent diffusion in the ocean on the scale of the phenomenon in question atmospheric and ocean physics 6(5):534-536.

Ostazeski, S.A., S.C. Macomber, L.G. Roberts, A.D. Uhler, and K.R. Bitting, 1997. The environmental behavior of Orimulsion spilled on water, In: Proceedings of the 1997 International Oil Spill Conference, American Petroleum Institute, Fort Lauderdale, Florida, Publication No. 4651, pp. 469-478.

Payne, J.R., B.E. Kirstein, G.D. McNabb, Jr., J.L. Lambach, R. Redding R.E. Jordan, W. Hom, C. deOliveria, G.S. Smith, D.M. Baxter, and R. Gaegel, 1984. Multivariate analysis of petroleum weathering in the marine environment – sub Arctic , Environmental Assessment of the Alaskan Continental Shelf, OCEAP, Final Report of Principal Investigators, Vol. 21 and 22, Feb. 1984, 690p.

Payne, J.R., B.E. Kirstein, J.R. Clayton, Jr., C. Clary, R. Redding, G.D. McNabb, Jr., and G. Farmer, 1987. Integration of suspended particulate matter and oil transportation study. Final Report. Minerals Management Service, Environmental Studies Branch, Anchorage, AK. Contract No. 14-12-0001-30146, 216 p.

Pacific Estuarine Research Laboratory, 1990. A manual for assessing restored and natural coastal wetlands with examples from southern California. California Sea Grant Report No. T-CSGCP-021. La Jolla, California.

Parker, B. B., 1977. Tidal hydrodynamics in the Straits of Juan de Fuca – Strait of Georgia, NOAA Tech. Rep. TR-NOS 69, U.S. Dept. of Commerce, Washington, DC, 56pp.

Peene, S.J., E.A. Yassuda, and D.L. Mendelsohn, 1997. Development of a waste load allocation model within the Charleston Harbor Estuary. Part I: Barotropic circulation. Proceedings of the Fifth American Society of Civil Engineers (ASCE) International Estuarine and Coastal Modeling Conference. Alexandria, Virginia, October 22nd to 24th, 1997.

Rice, S.D., J.W. Short and J.F. Karinen, 1977. Comparative oil toxicity and comparative animal sensitivity. p. 78-94 In: D.A. Wolfe (ed.)., Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. Pergamon Press, NY.

Ricker, W.E., 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.

Sankaranarayanan, S. and D. French McCay, 2003. Three-dimensional modeling of tidal circulation in Bay of Fundy. Journal of Waterway, Port, Coastal, and Ocean Engineering, ASCE, Vol. 129(3), May/June 2003, p.114-123.

Sankaranarayanan, S., and M. L. Spaulding, 2003. A study of the effects of grid non-orthogonality on the solution of shallow water equations in boundary-fitted coordinate systems. Journal of Computational Physics 184(1):299-320.

Seneca, E. D. And S. W. Broome, 1992. Restoring tidal marshes in North Carolina and France. Chapter 2 In: G.W. Thayer (editor), Restoring the Nation's Marine Environment. Maryland Sea Grant, College Park, MD, p. 53-78.

Spaulding, M.L., 1984. A vertically averaged circulation model using boundary-fitted coordinates, J. Phys. Oceanography, 14, 973.

Spaulding, M. L., D. Mendelsohn, and J. C. Swanson, 1999a. WQMAP: An integrated three-dimensional hydrodynamic and water quality model system for estuarine and coastal applications, Marine Technology Society Journal, invited paper, Special issue on state of the art in ocean and coastal modeling, Vol. 33, No. 3, p. 38-54.

Spaulding, M., J.C. Swanson, and D. Mendelsohn, 1999b. Application of quantitative model – data calibration measures to assess model performance. Estuarine and Coastal Modeling 6 (ECM6), New Orleans, Louisiana, 3-5 November 1999. American Society of Civil Engineers, Reston, Virginia, pp. 843-867.

Swanson, J.C., D. Mendelsohn, H. Rines, and H. Schuttenberg, 1998. Mount Hope Bay hydrodynamic model calibration and confirmation. Report to New England Power Company, Applied Science Associates, Narragansett, Rhode Island, Project No. ASA-96-076.

Stiver, W. and D. Mackay, 1984. Evaporation rate of oil spills of hydrocarbons and petroleum mixtures. Environmental Science and Technology 18: 834-840.

Swartz, R.C., D.W. Schults, R.J. Ozretich, J.O. Lamberson, F.A. Cole, T.H. DeWitt, M.S. Redmond, and S.P. Ferraro, 1995. ∑PAH: A Model to Predict the Toxicity of Polynuclear Aromatic Hydrocarbon Mixtures in Field-Collected Sediments, Journal of Environmental Toxicology and Chemistry 14(11): 1977-1987.

Thompson, C.W., 1999. Distribution and Abundance of Marbled Murrelets and Common Murres on the Outer Coast of Washington – Summer 1998 through Winter 1998-1999. Washington Department of Fish and Wildlife, Wildlife Research. http://wdfw.wa.gov/wlm/research/papers/murrelet/murrelets.pdf

Wang, Z., M.F. Fingas, M. Landriault, L. Sigouin, and N. Xu, "Identification of Alkyl Benzenes and Direct Determination of BTEX and (BTEX + C3-Benzenes) in Oils by GC/MS", in Proceedings of the Eighteenth Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Edmonton, AB, Canada, pp. 141-164, 1995.

Whiticar, S., M. Bobra, M. Fingas, P. Jokuty, P. Liuzzo, S. Callaghan, F. Ackerman and J. Cao, 1992. A catalogue of crude oil and oil product properties 1992 (edition), Report # EE-144, Environment Canada, Ottawa, Canada, 643p.

Youssef, M., 1993. The behavior of the near ocean surface under the combined action of waves and currents in shallow water. PhD Dissertation, Department of Ocean Engineering, University of Rhode Island, Narragansett, RI, 212p.

Youssef, M. and M. L. Spaulding, 1993. Drift current under the action of wind waves, Proceedings of the 16th Arctic and Marine Oil Spill Program Technical Seminar, Calgary, Alberta, Canada, pp. 587-615.

Youssef, M. and M.L. Spaulding, 1994. Drift Current Under the Combined Action of Wind and Waves in Shallow Water, in Proceedings of the 17th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Vancouver, British Columbia, June 8-10, 1994, pp. 767-784.

Zedler, J. B., 1992. Restoring cordgrass marshes in Southern California. Chapter 1 In: G.W. Thayer (editor), Restoring the Nation's Marine Environment. Maryland Sea Grant, College Park, MD, p.7-52.

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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suàrez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

II.1. Introduction 1
II.2. Summary of the 13 Main Stochastic Scenarios 9
II.3. Comparison of Alternative Responses: Outer Coast at Duntz Rock off Cape Flattery – Alaskan North Slope Crude 36
II.4. Comparison of Alternative Responses: Strait of Juan de Fuca – Bunker C 62
II.5. Comparison of Alternative Responses: Strait of Juan de Fuca – Diesel 83
II.6. Comparison of Alternative Responses: Strait of Juan de Fuca – Alaskan North Slope Crude 97
II.7. Comparison of Alternative Responses: San Juan Islands – Alaskan North Slope Crude 123
II.8. Comparison of Alternative Responses: Inner Straits/Puget Sound – Alaskan North Slope Crude 149
II.9. Comparison of Alternative Responses: Lower Columbia River – Bunker C 175
II.10. Comparison of Alternative Responses: Upper Columbia River – Bunker C 189

List of Tables

Table II.1-1 Oil spill modeling scenarios: Scenario/response and number scheme. 3
Table II.1-2 Oil spill modeling scenarios: Scenario abbreviations.................................... 8
Table II.2-1. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass coming ashore (%). 10
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, %). 11
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 (%).. 12
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 (%). 13
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.. 14
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....................... 15
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). 16
Table II.2-8. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 100 g/m^2. 17
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). 18
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). 19
Table II.2-11. Summary of results for all stochastic scenarios of 100 runs each: Cost (2003$) for shoreline cleanup (per area costs only).. 20
Table II.2-12. Summary of results for all stochastic scenarios of 100 runs each: Total number of waterfowl oiled... 21
Table II.2-13. Summary of results for all stochastic scenarios of 100 runs each: Total number of seabirds oiled.. 22
Table II.2-14. Summary of results for all stochastic scenarios of 100 runs each: Total number of wading birds and shorebirds oiled.. 23
Table II.2-15. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled.. 24
Table II.2-16. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled. 25
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.. 26
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)... 27

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). 28
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). 29
Table II.2-21. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. 30
Table II.2-22. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. 31
Table II.2-23. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming eelgrass bed creation. 32
Table II.2-24. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. 33
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. 34
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. 37
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. 38
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. 39
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. 40
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. 41
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. 42
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. 43
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. 44
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. 45

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........................ 46
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. 47
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.. 48
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.. 49
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. 50
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.. 51
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.. 52
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.. 53
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.. 54
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. 55
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. 56
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. 57
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. 58
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. 59

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.. 60
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. 61
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. 63
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. 64
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.. 64
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.. 65
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... 66
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................ 67
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. 67
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. 68
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.. 69
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. 70
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.................... 70

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. 71
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. 71
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. 72
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.. 72
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. 73
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. 74
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.. 75
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.. 76
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. 77
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. 78
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$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.. 79
Table II.4-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 80
Table II.4-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 81

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. 82
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. 84
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. 85
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... 85
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.. 86
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.. 86
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................ 87
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........................ 87
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. 88
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. 88
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. 89
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. 89
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. 90
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... 90

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. 91
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. 91
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. 92
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. 92
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. 93
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. 93
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. 94
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. 94
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$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs. 95
Table II.5-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 95
Table II.5-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 96
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. 96
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. 98

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. 99
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........ 100
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........ 101
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........ 102
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........ 103
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........ 104
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. 105
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. 106
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. 107
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. 108
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........ 109
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........ 110
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........ 111

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. 112
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........ 113
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. 114
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. 115
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........ 116
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. 117
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. 118
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$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs........ 119
Table II.6-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 120
Table II.6-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 121
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. 122
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. 124
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........ 125

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.. 126
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.............. 127
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. 128
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. 129
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................................ 130
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. 131
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............ 132
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............ 133
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. 134
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. 135
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. 136
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. 137
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.. 138
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. 139
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........ 140
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........ 141
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........ 142
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. 143
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. 144
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$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs........ 145
Table II.7-23. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 146
Table II.7-24. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 147
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. 148
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. 150
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........ 151
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........ 152
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. 153

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. 154
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. 155
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. 156
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. 157
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...................... 158
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...................... 159
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. 160
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... 161
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... 162
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. 163
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... 164
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... 165
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... 166
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... 167
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. 168
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. 169
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. 170
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$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs. 171
Table II.8-23. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 172
Table II.8-24. Summary of results for alternate response scenarios for Inner Straits spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs... 173
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. 174
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. 176
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. 177
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... 177
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.178
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.. 178
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.............. 179

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. 179
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. 180
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........ 180
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. 181
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........ 181
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. 182
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. 182
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. 183
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. 183
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. 184
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. 184
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........ 185
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. 185
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. 186
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. 186
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$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs.. 187
Table II.9-23. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 187
Table II.9-24. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 188
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. 188
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. 190
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. 191
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.. 191
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.192
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.. 192
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.............. 193
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. 193

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. 194
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.. 194
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. 195
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.................. 195
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. 196
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. 196
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. 197
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. 197
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. 198
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. 198
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.. 199
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. 199
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... 200

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. 200
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$), assuming compensatory restoration is wetland creation. Note: data for shaded cells are based only on 3 runs... 201
Table II.10-23. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 201
Table II.10-24. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. Note: data for shaded cells are based only on 3 runs. 202

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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th} to 95^{th} percentile run by shore cost. The actual 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} or 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} or 95^{th} 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 5^{th}, 50^{th} or 95^{th} percentile result for that index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5^{th}, 50^{th} or 95^{th} *runs based on shore costs*. The results for 5^{th}, 50^{th} or 95^{th} *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 5^{th}, 50^{th} or 95^{th} *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	5^{th} Percentile	50^{th} Percentile	95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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/m².

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	5^{th} Percentile	50^{th} Percentile	95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th} or 95^{th} 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 5^{th}, 50^{th} or 95^{th} 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 5^{th}, 50^{th} or 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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

by

Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

XII.A. Introduction 1
XII.B. Geographical Data 2
XII.B.1. Maps of the Vicinity of the Modeled Spill Locations 2
XII.B.2. Gridded Habitat Mapping 3
XII.B-3. Gridded Depth Data.. 4
XII.B-4. Areas Where Response Actions Assumed 5
XII.C. Current Data.. 8
XII.C.1. Basis of Current Data... 8
XII.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations........ 9
XII.D: Oil Properties.. 12
XII.E: Inputs to the SIMAP Physical Fates Model... 15

List of Figures

Figure XII.B.1-1 Map of the vicinity of the potential spill locations. 2
Figure XII.B.2-1 Habitat grid used for modeling the potential spills. 3
Figure XII.B.2-2 Habitat grid used for modeling the potential spills (closer view). 3
Figure XII.B.3-1 Depth grid used for modeling the potential spills. 4
Figure XII.B.3-2 Depth grid used for modeling the potential spills (closer view). 4
Figure XII.B.4-1 Jurisdictions in the area of the potential spills. 5
Figure XII.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 5
Figure XII.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 6
Figure XII.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 6
Figure XII.B.4-5 Areas where dispersant application was assumed to occur in modeling the potential spills. 7
Figure XII.B.4-6 Areas where in situ burning (ISB) was assumed to occur in modeling the potential spills. 7
Figure XII.C.1-1 Grid used for the hydrodynamic model-generated current data. 8
Figure XII.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC). 9
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. 10
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. 10
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. 11
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. 11
Figure XII.E-1 Varied range of spill site, shipping lane from Neah Bay to Port Angeles. 18
Figure XII.E-2 Wind Station Locations. 22

List of Tables

Table XII.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling. 12
Table XII.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil. ... 13
Table XII.E-1. Inputs to the Fates Model for Stochastic Scenarios................................ 15
Table XII.E-2. Time, date and location inputs for each of the 100 stochastic runs.......... 19
Table XII.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 21
Table XII.E-4. Water temperature by month of the year (from French et al., 1996b)..... 21
Table XII.E-5. Wind data sources and records used... 22

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

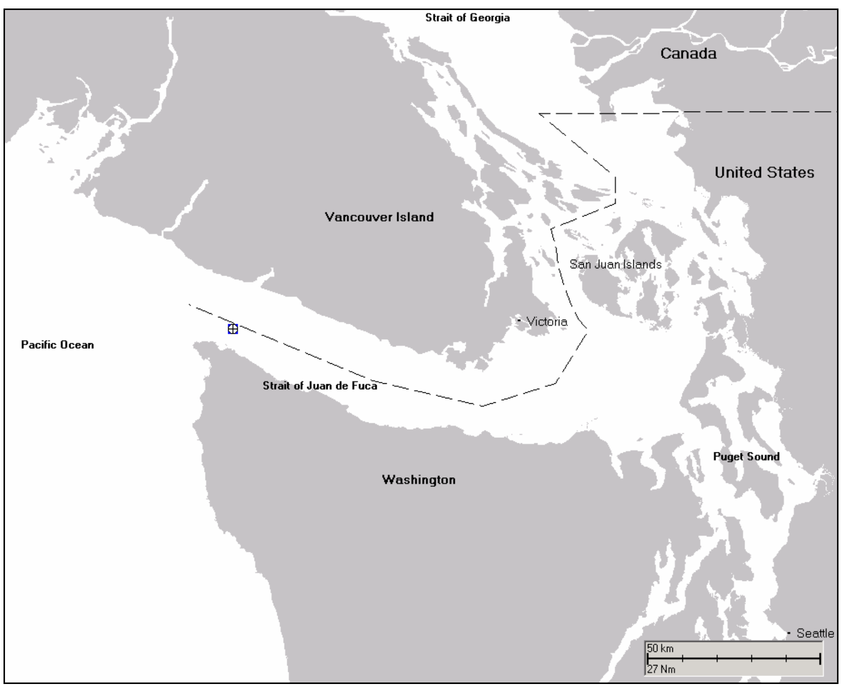


Figure XII.B.1-1 Map of the vicinity of the potential spill locations.

XII.B.2. Gridded Habitat Mapping

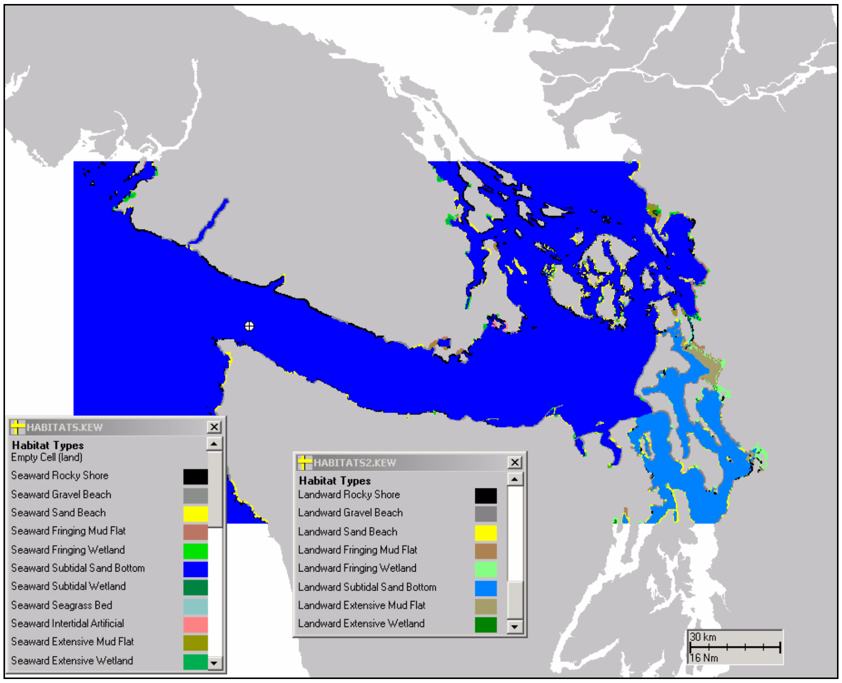


Figure XII.B.2-1 Habitat grid used for modeling the potential spills.

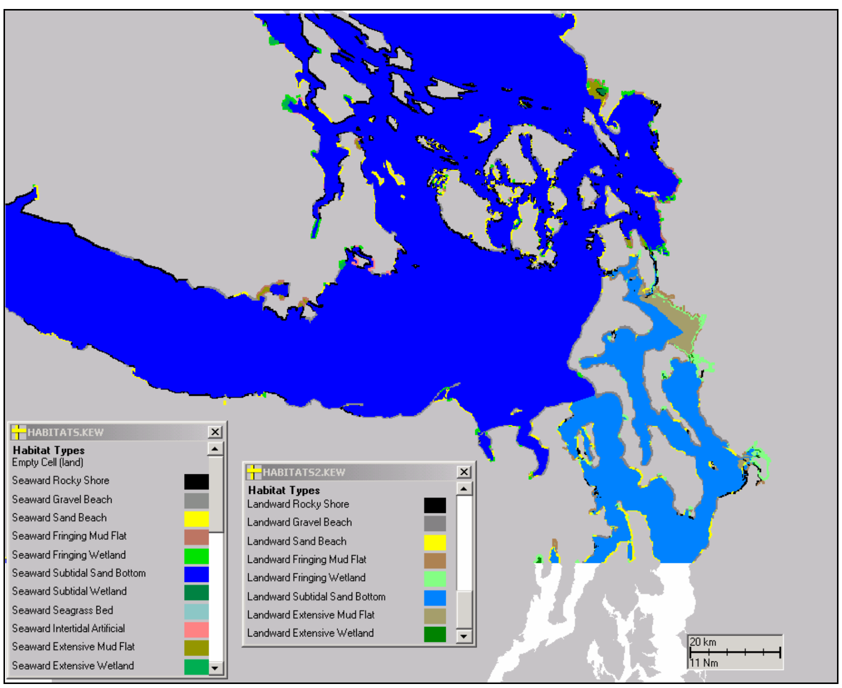


Figure XII.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XII.B-3. Gridded Depth Data

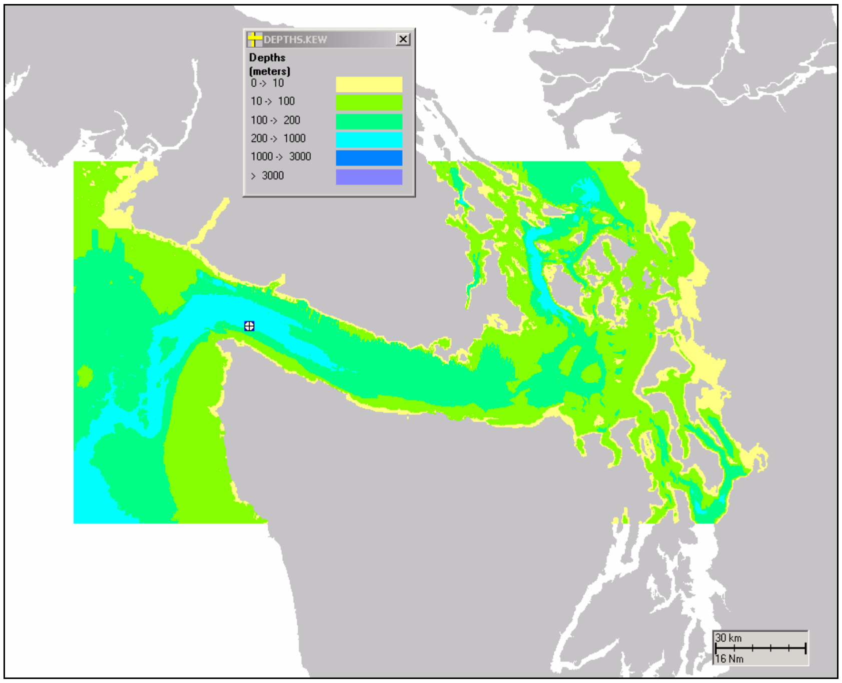


Figure XII.B.3-1 Depth grid used for modeling the potential spills.

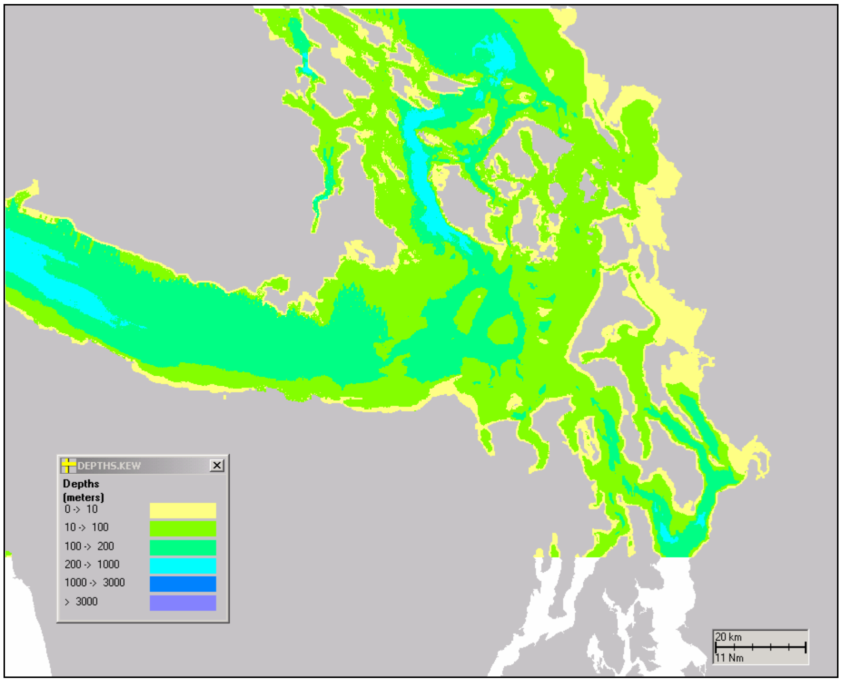


Figure XII.B.3-2 Depth grid used for modeling the potential spills (closer view).

XII.B-4. Areas Where Response Actions Assumed

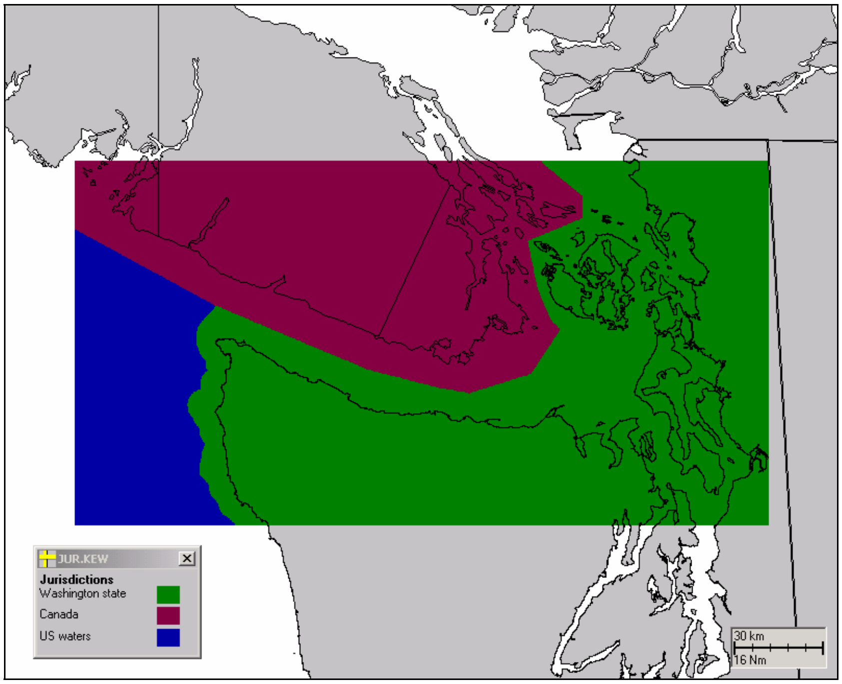


Figure XII.B.4-1 Jurisdictions in the area of the potential spills.

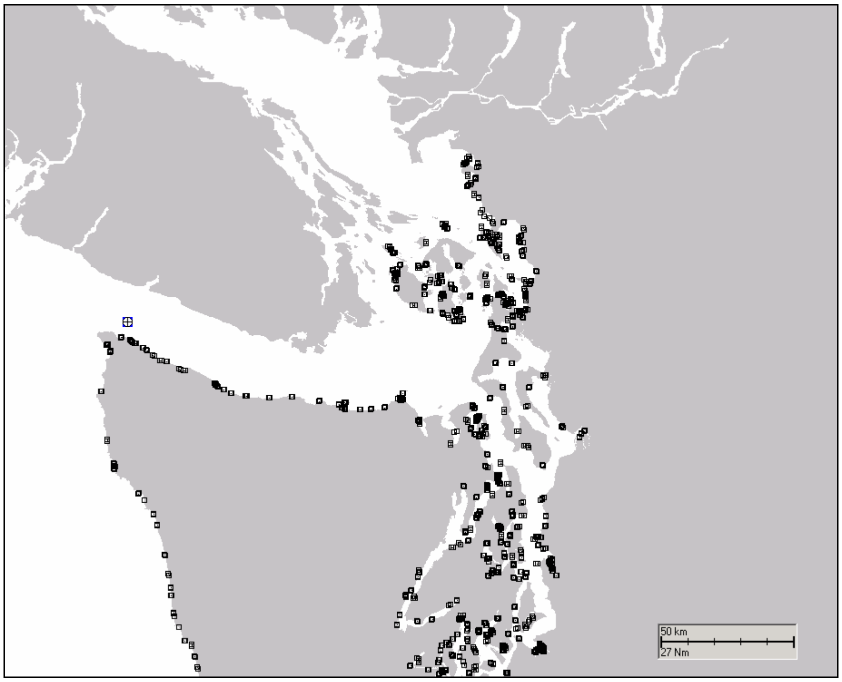


Figure XII.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

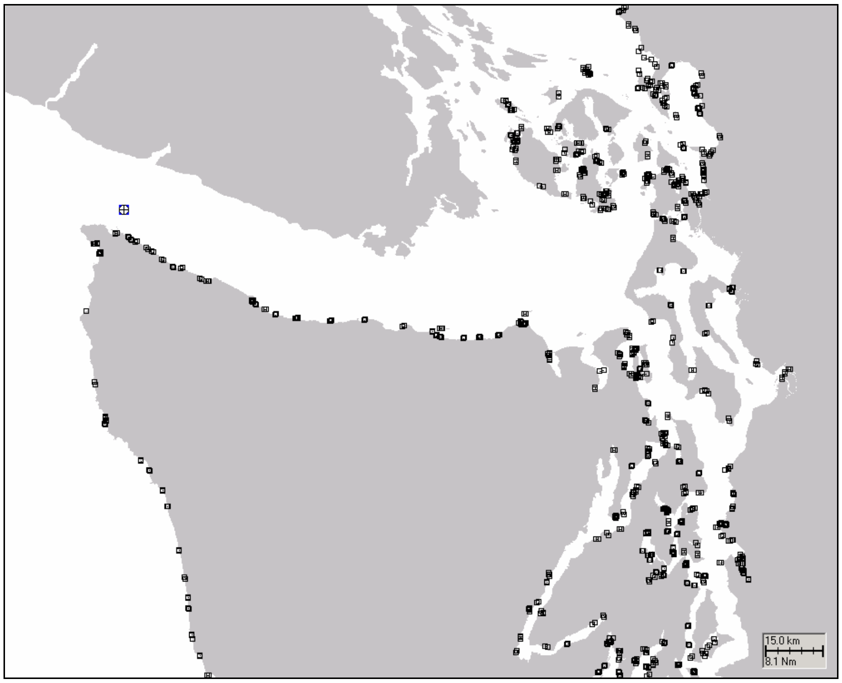


Figure XII.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

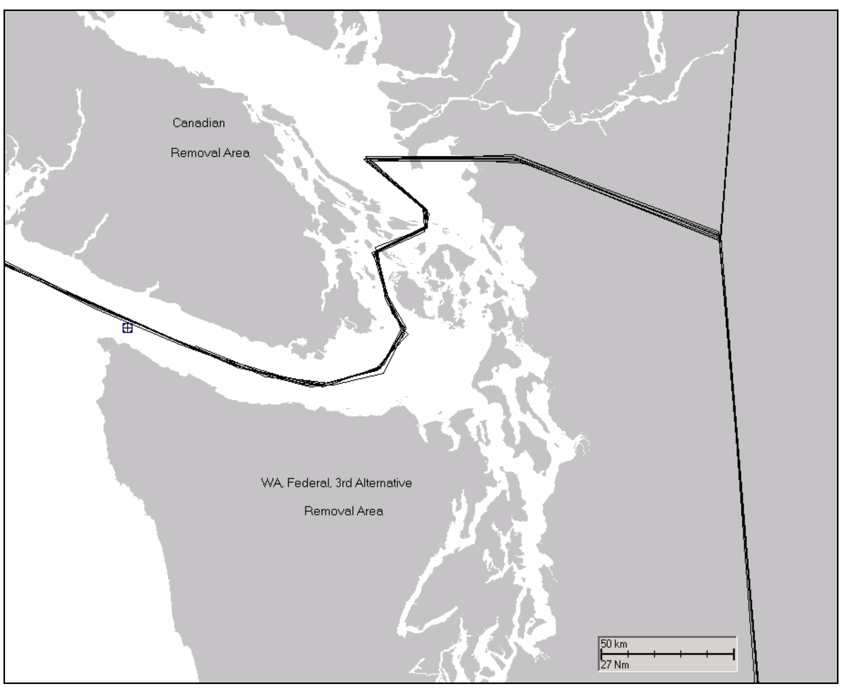


Figure XII.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

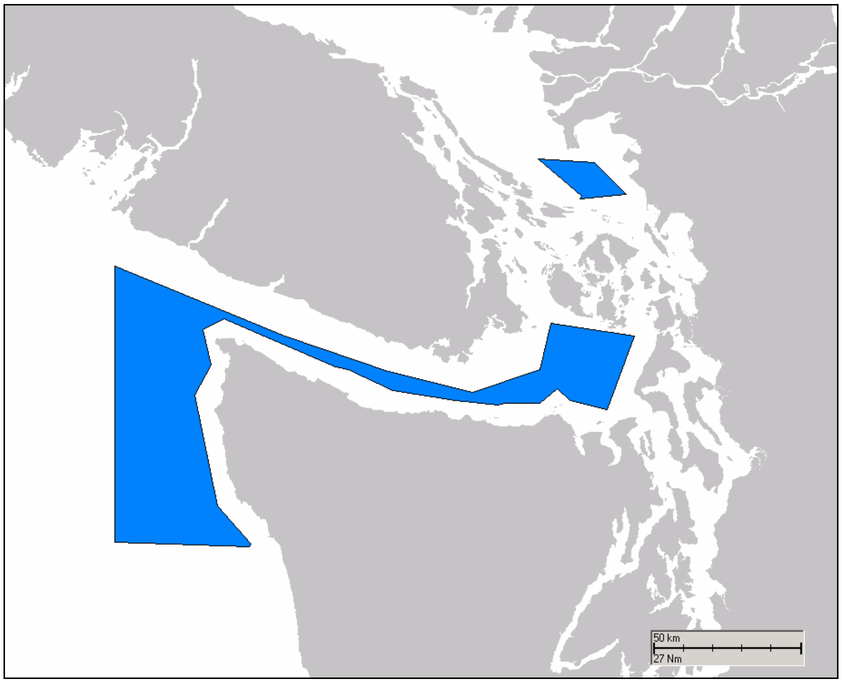


Figure XII.B.4-5 Areas where dispersant application was assumed to occur in modeling the potential spills.

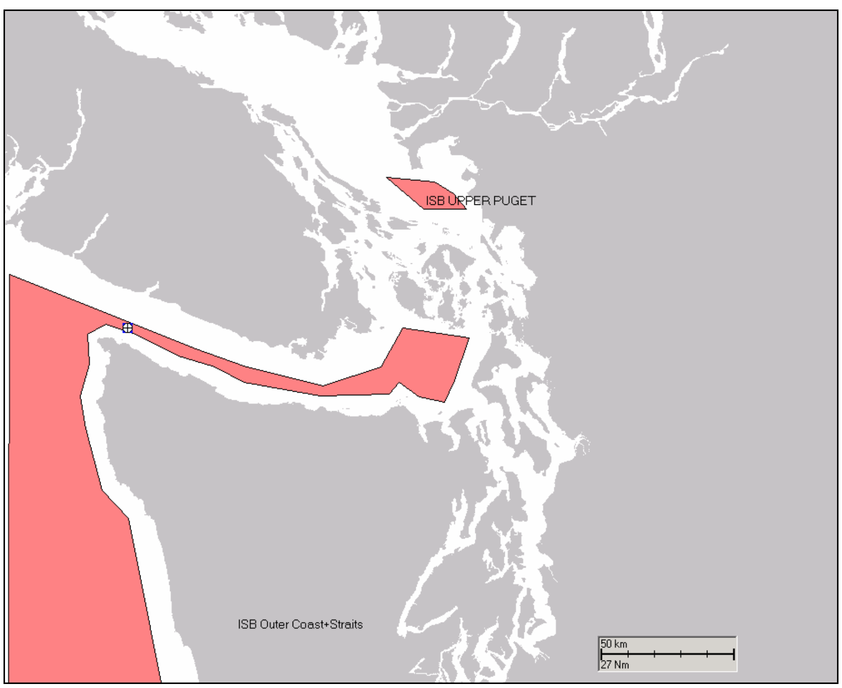


Figure XII.B.4-6 Areas where in situ burning (ISB) was assumed to occur in modeling the potential spills.

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).

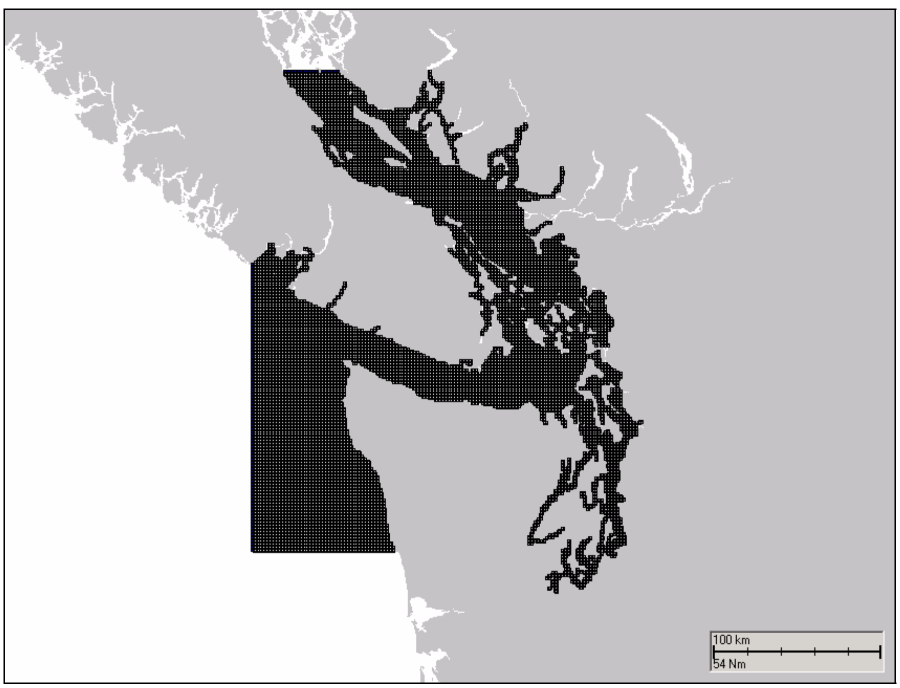


Figure XII.C.1-1 Grid used for the hydrodynamic model-generated current data.

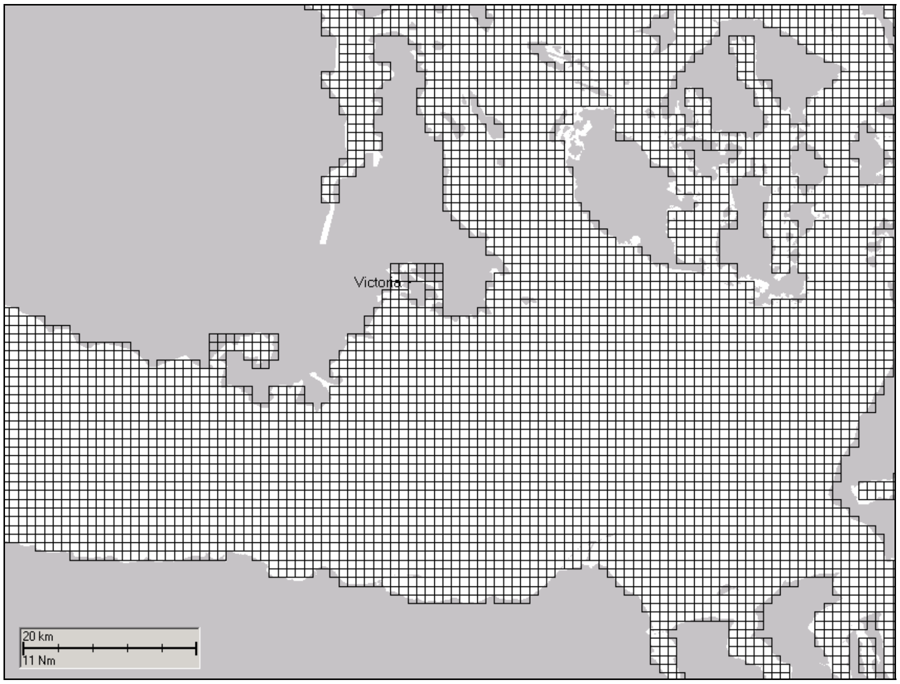


Figure XII.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC).

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.

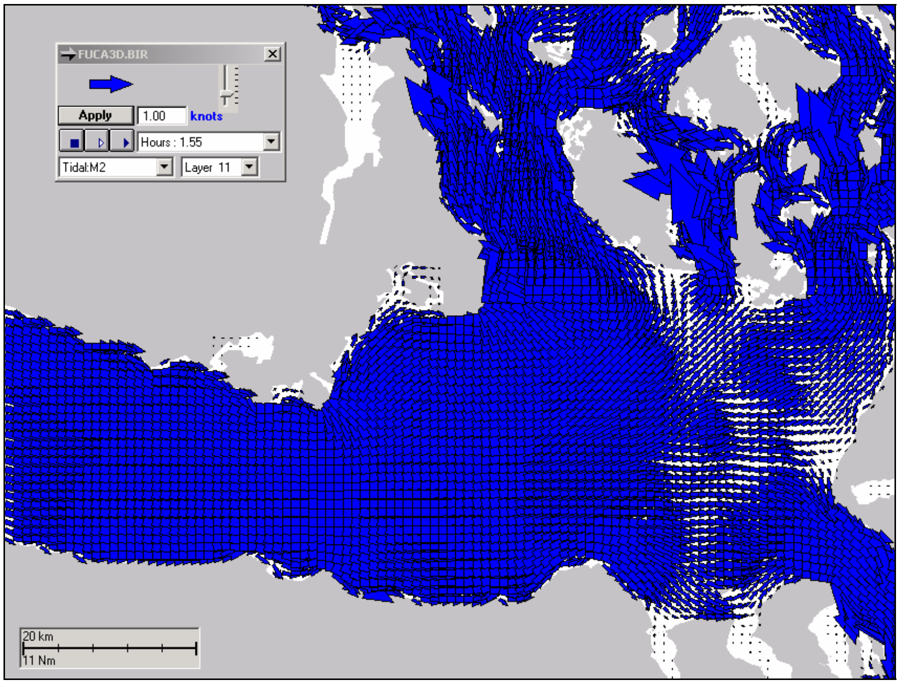


Figure XII.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Victoria, BC.

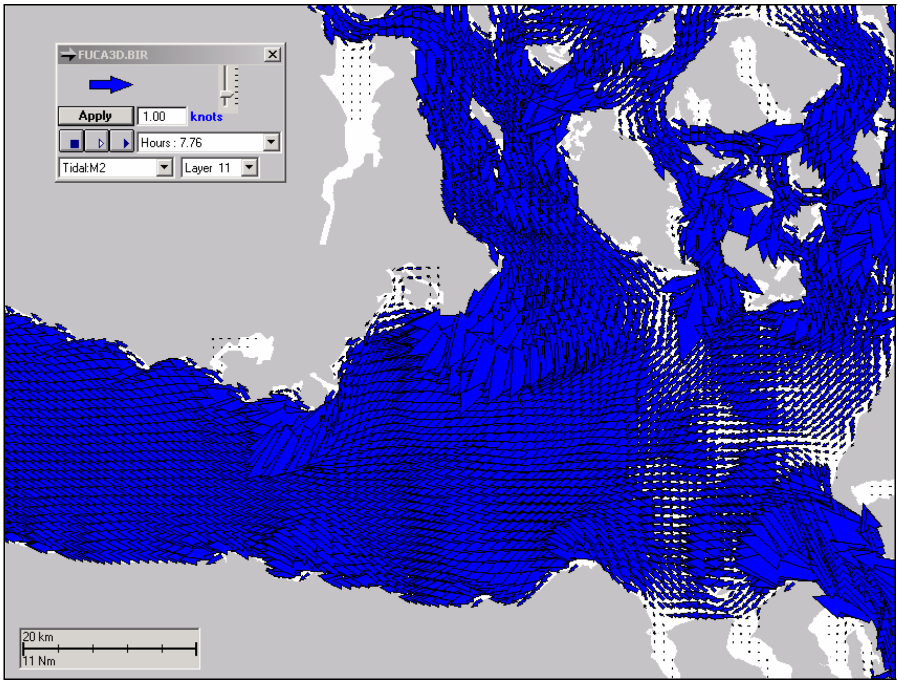


Figure XII.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Victoria, BC.

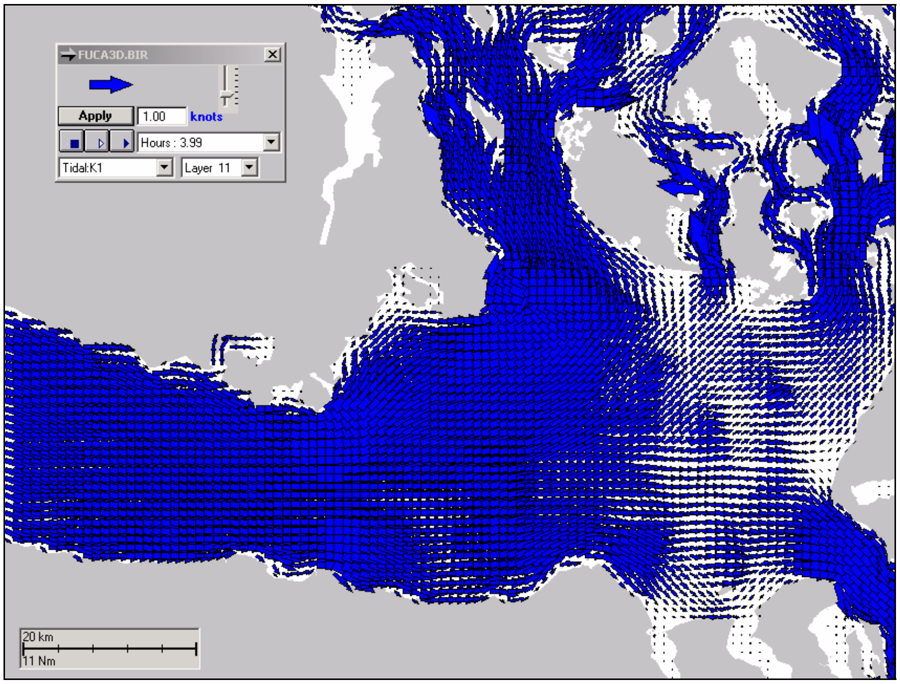


Figure XII.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Victoria, BC.

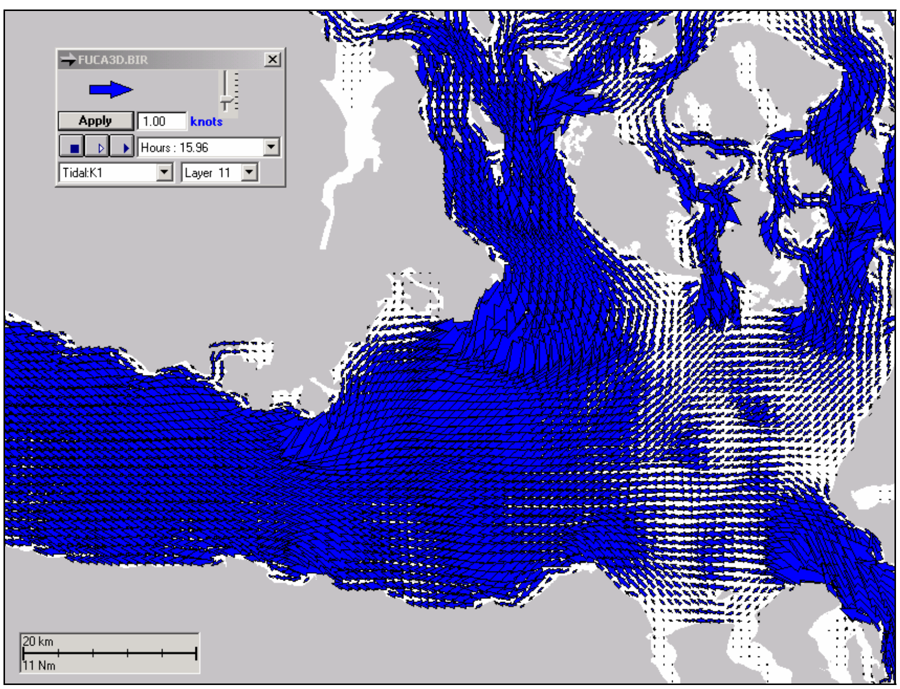


Figure XII.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Victoria, BC.

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	$\text{Log}(K_{ow})$*	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 = $\mu g/L$ = 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 = $\mu g/L$ = 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

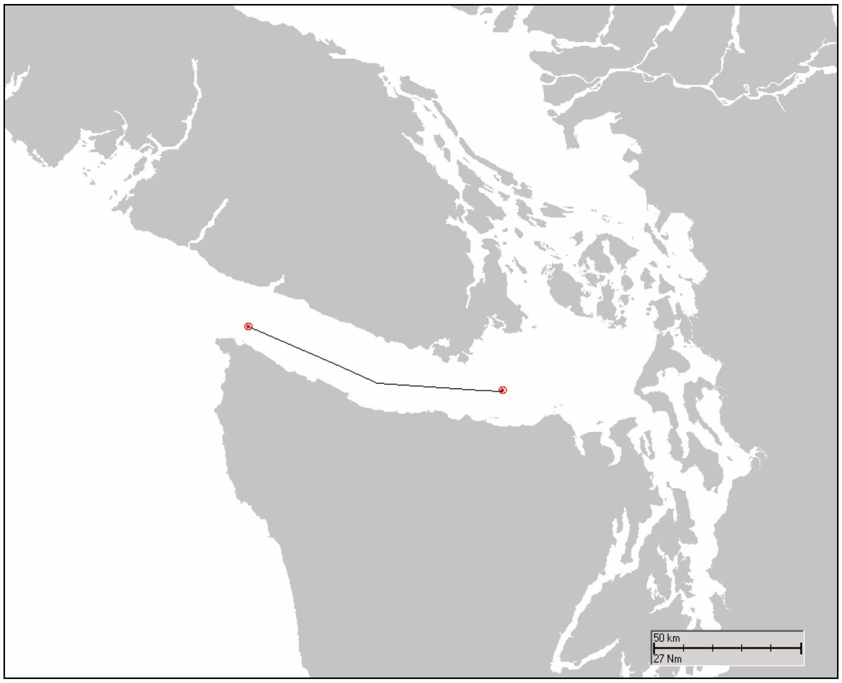


Figure XII.E-1 Varied range of spill site, shipping lane from Neah Bay to Port Angeles.

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^{o} 23.40180'W
Grid S edge	47^{o} 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.

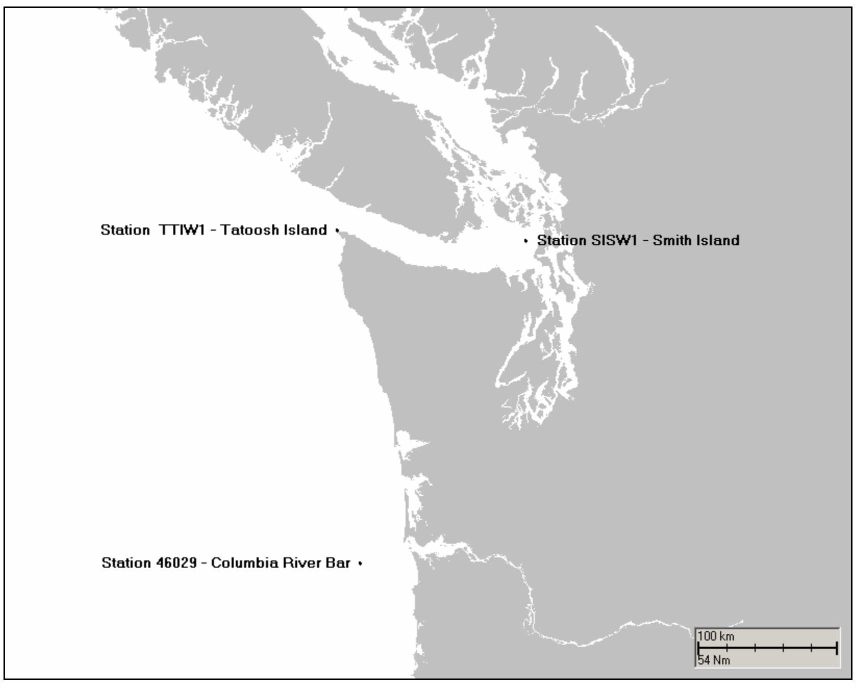


Figure XII.E-2 Wind Station Locations.

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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suàrez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

XIII.A. Introduction 1
XIII.B. Maps of Exposure Probability, Time First Exposed, and Maximum Possible Contamination 1
XIII.C. Rank Order Distributions for All Model Runs 9
XIII.D. Shoreline Areas Exposed by Shore Type 22
XIII.E. Exposure for Representative Individual Model Runs 26
XIII.F. Estimated Biological Impacts: Wildlife 34
XIII.G. Estimated Biological Impacts: Fish and Invertebrates 37
XIII.H. Estimated NRDA Costs: Habitat Restoration Costs 40
XIII.I. Estimated NRDA Costs: Washington Compensation schedule 45

List of Figures

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). 2
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.......... 3
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). 3
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.......... 4
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).......... 4
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).......... 5
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). 5
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. 6
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). 6
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. 7
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).......... 7
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).. 8
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............................. 9
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).. 10
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).. 10
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).. 11
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).. 11
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)... 12
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. 12
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.. 13
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... 13
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). 14
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 (%).. 14
Figure XIII.C-12. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass mechanically removed. 15
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... 15
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)... 16

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). 16
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). 17
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). 17
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). 18
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. 18
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. 19
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. 19
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). 20
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 (%). 20
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. 21
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. 26
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. 27
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. 27
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. 28
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. 28
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. 29
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. 29
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. 30
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. 30
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. 31
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. 31
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. 32
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. 32
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. 33

List of Tables

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). XIII-22
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). XIII-23
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). XIII-23
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).. XIII-23
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). XIII-24
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). XIII-24
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). XIII-24
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). XIII-25
Table XIII.F-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost)....... XIII-35
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). XIII-36
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)....... XIII-38
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). XIII-39
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....... XIII-41
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. XIII-42

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. XIII-43
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$) for compensatory restoration. XIII-44
Table XIII.I-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. XIII-45
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. XIII-45

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)

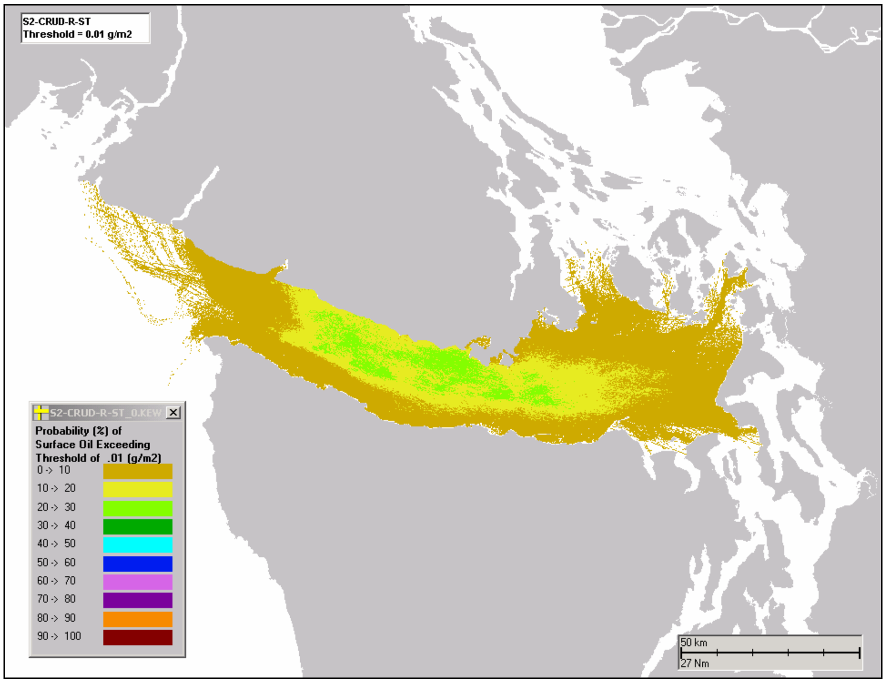


Figure XIII.B-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

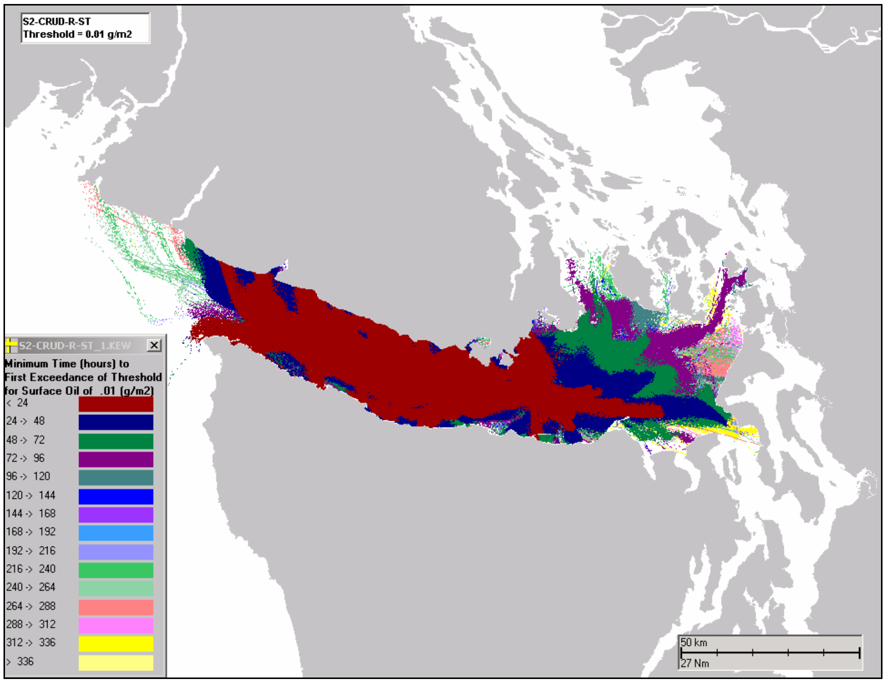


Figure XIII.B-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

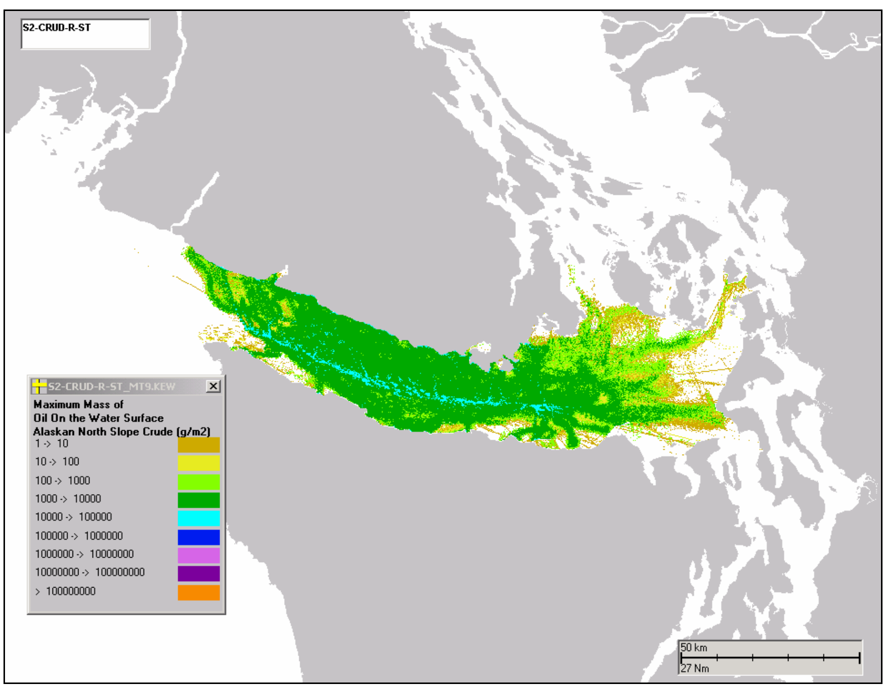


Figure XIII.B-3. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

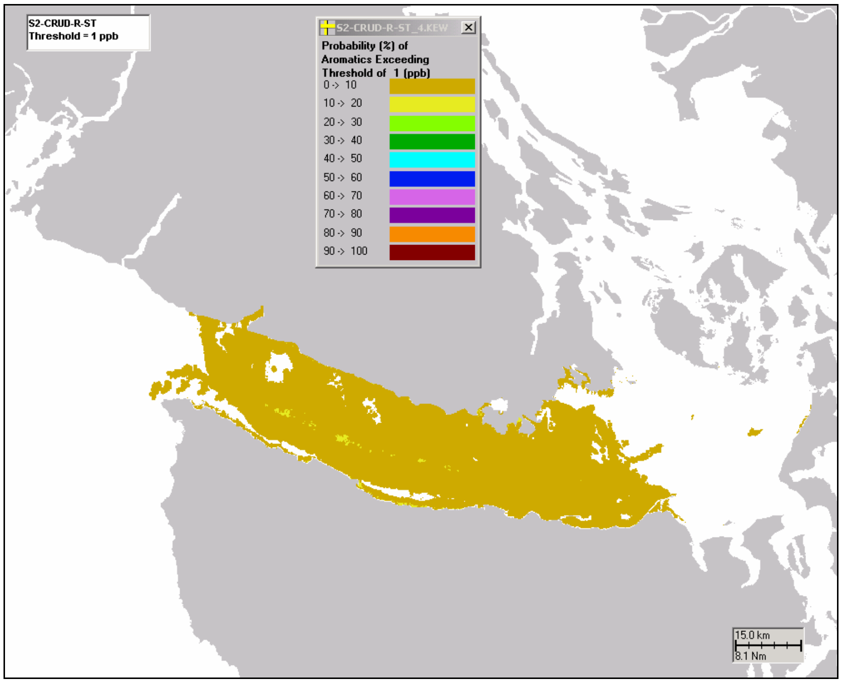


Figure XIII.B-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

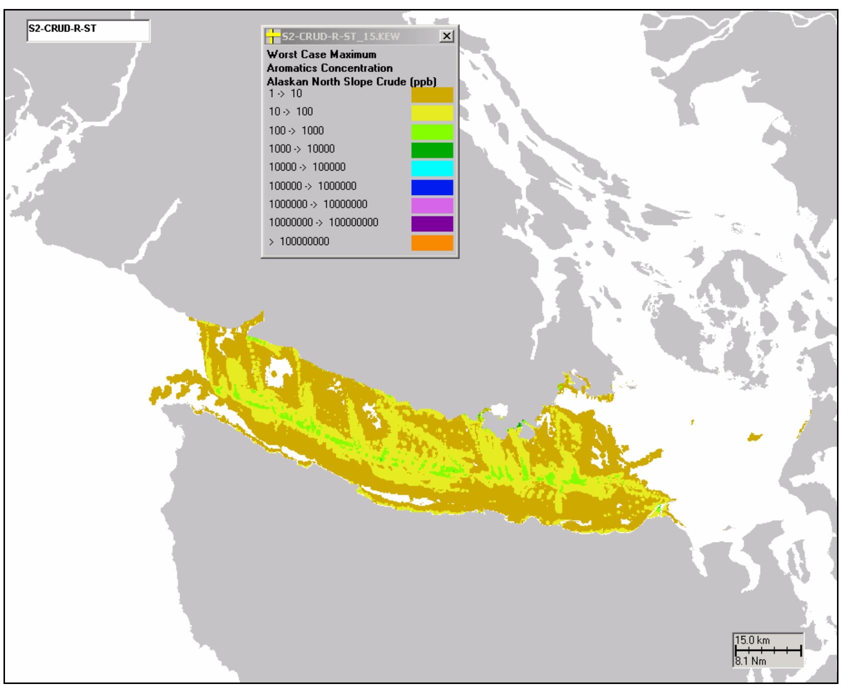


Figure XIII.B-5. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any 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).

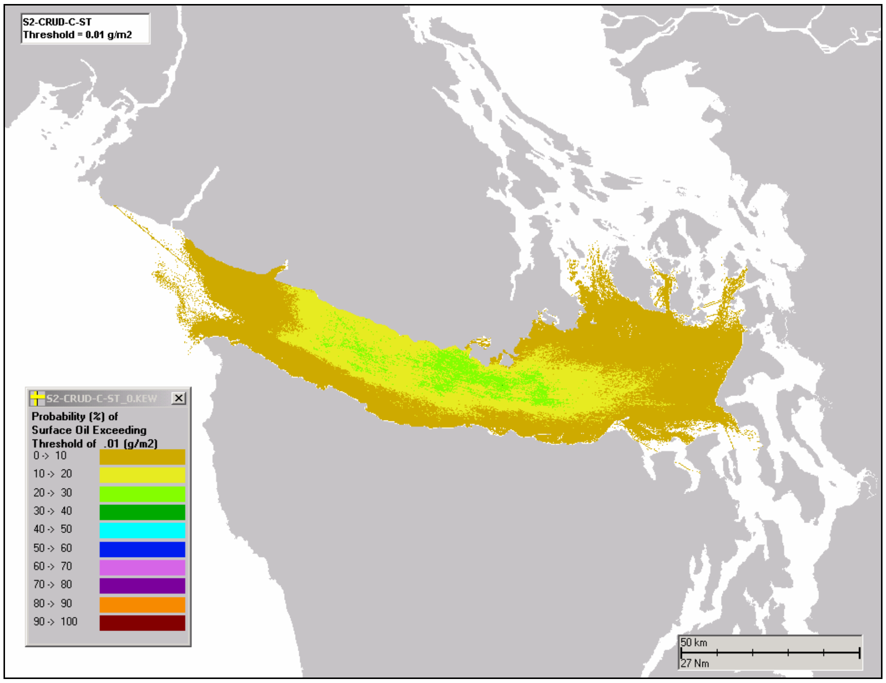


Figure XIII.B-7. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

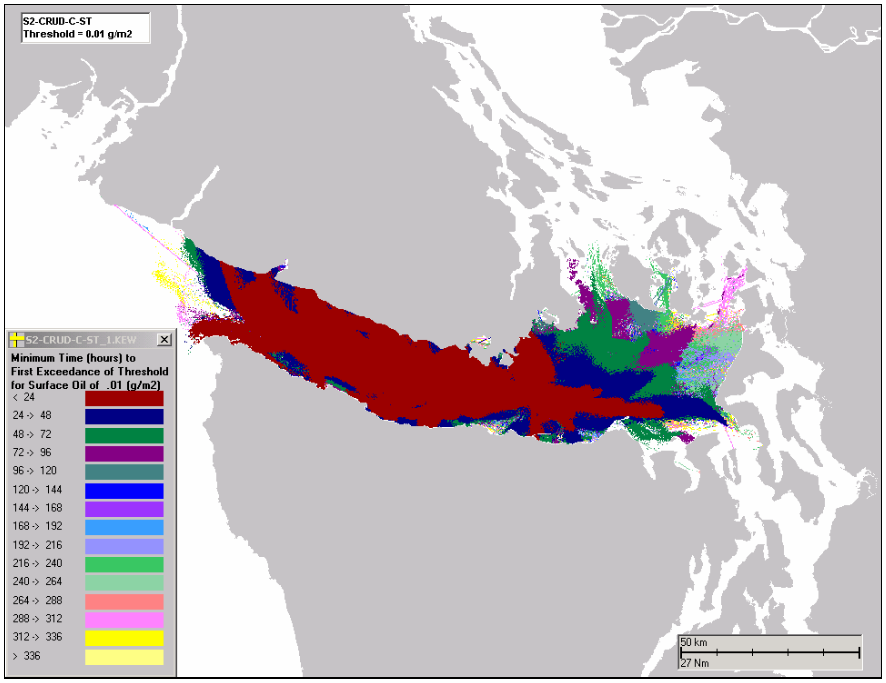


Figure XIII.B-8. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

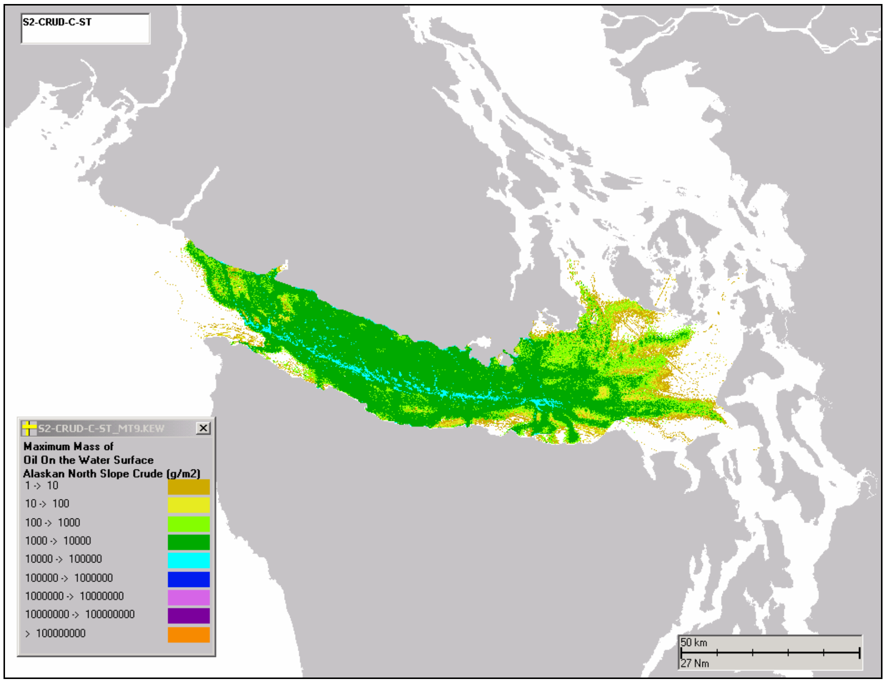


Figure XIII.B-9. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

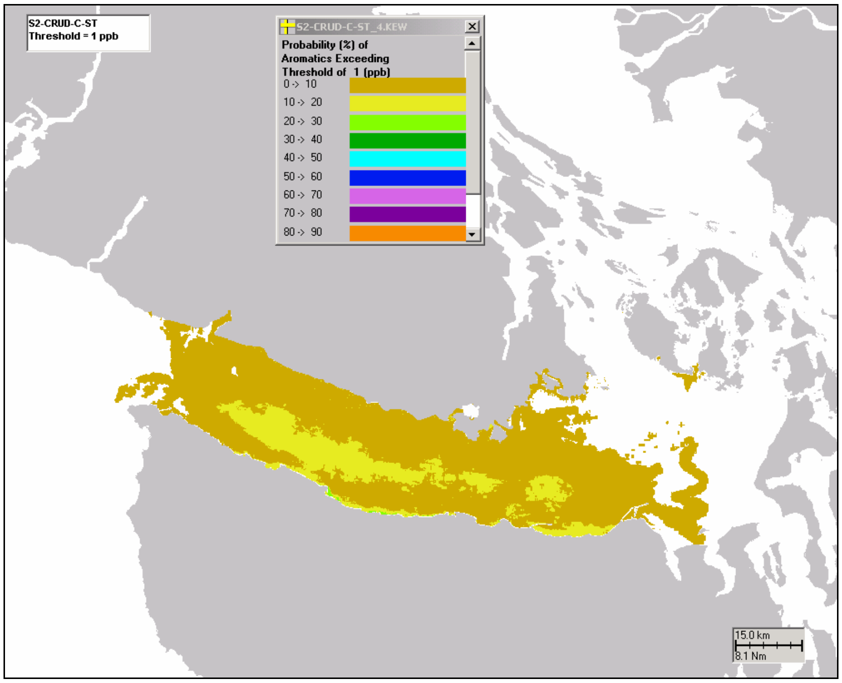


Figure XIII.B-10. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

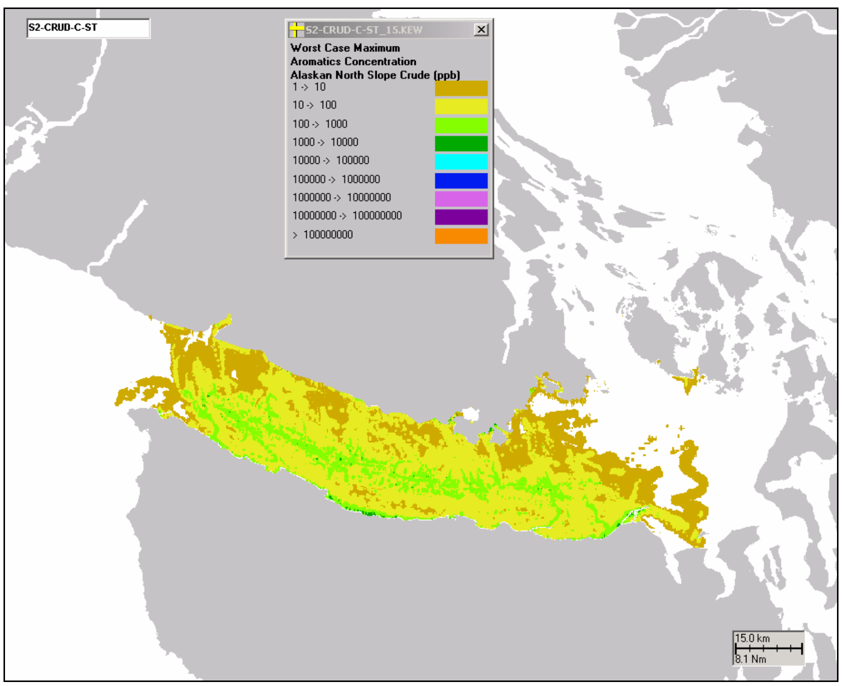


Figure XIII.B-11. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum 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).

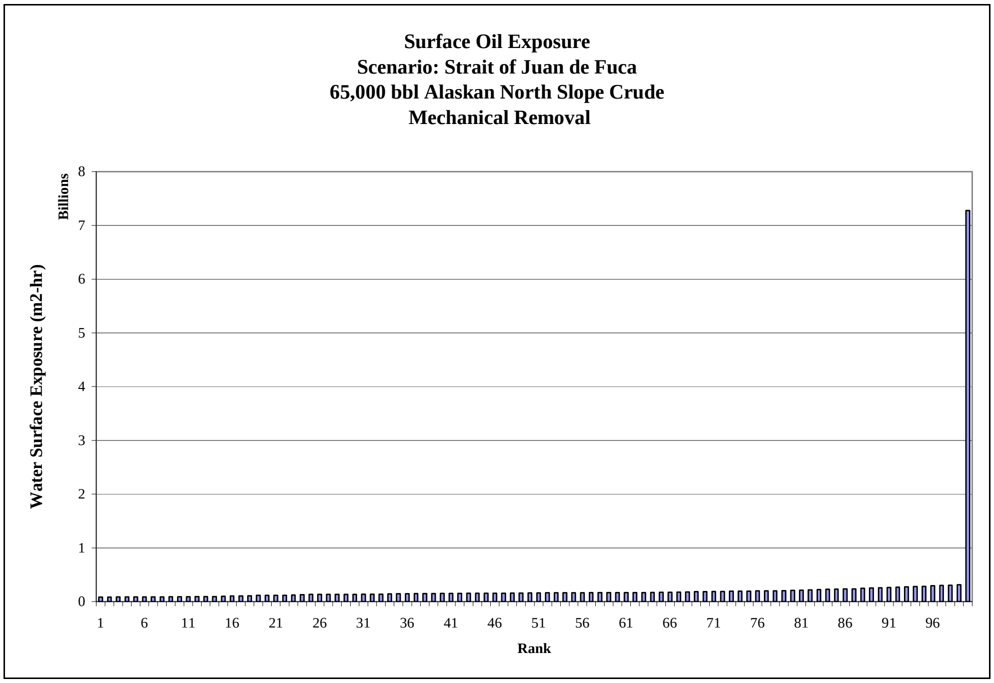


Figure XIII.C-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

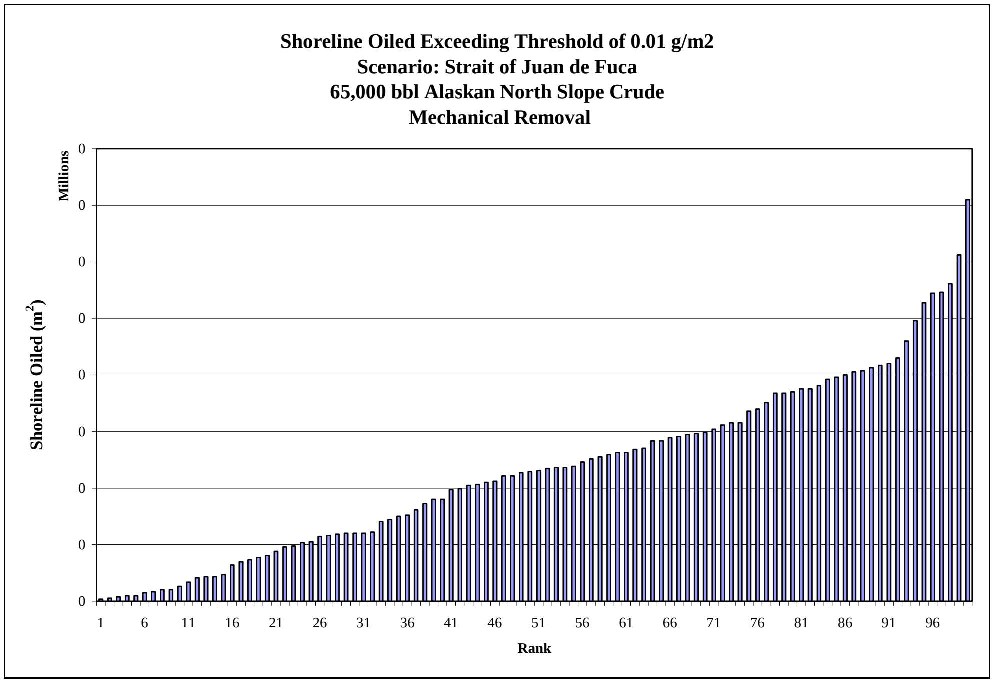


Figure XIII.C-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

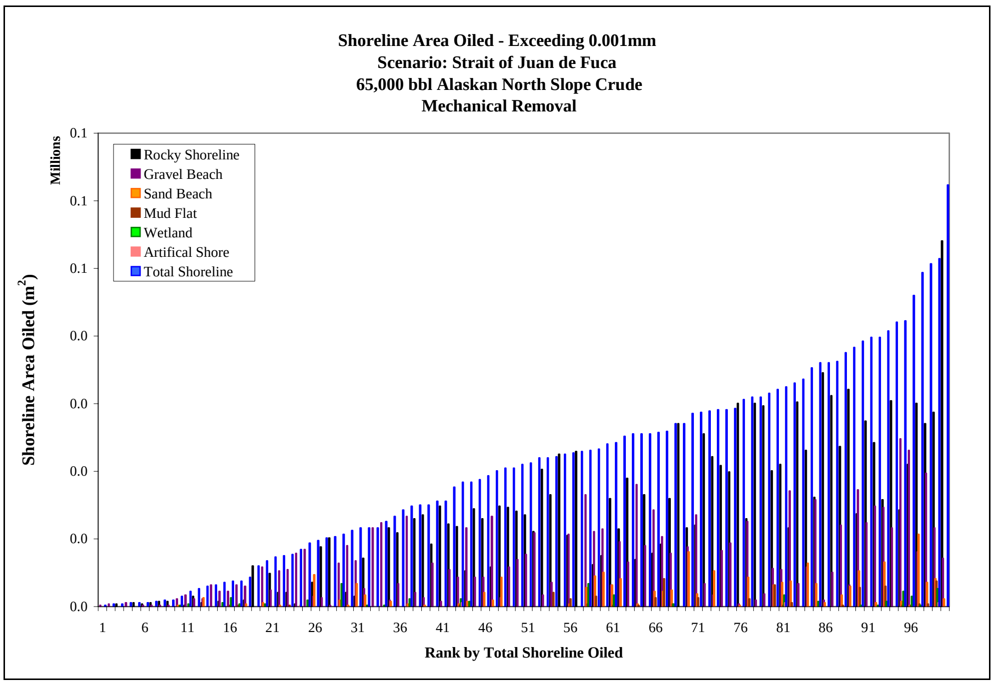


Figure XIII.C-3. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

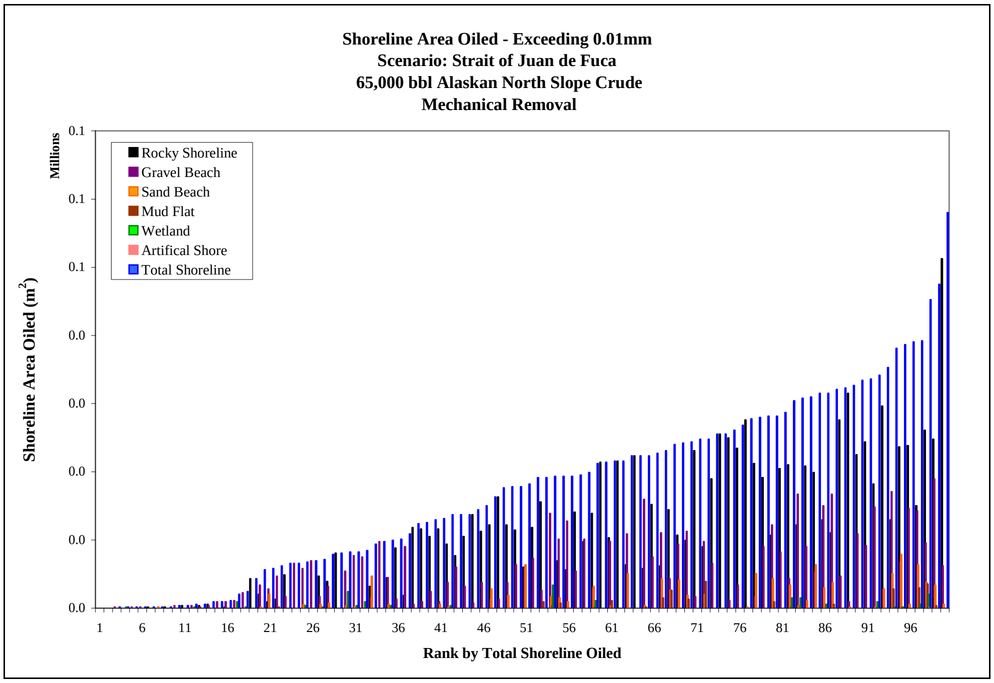


Figure XIII.C-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

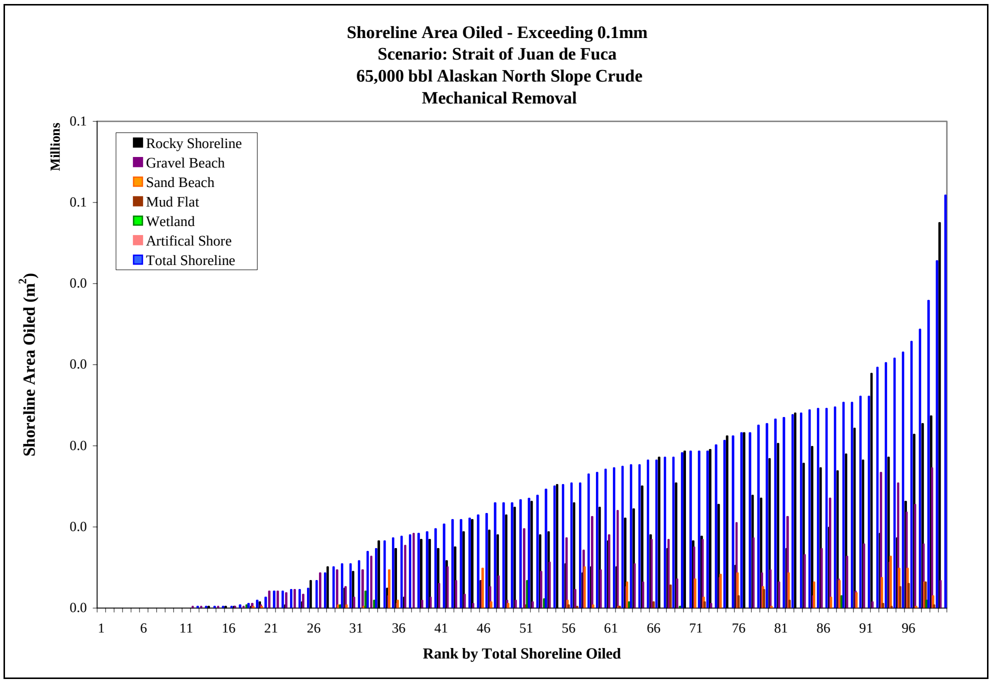


Figure XIII.C-5. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

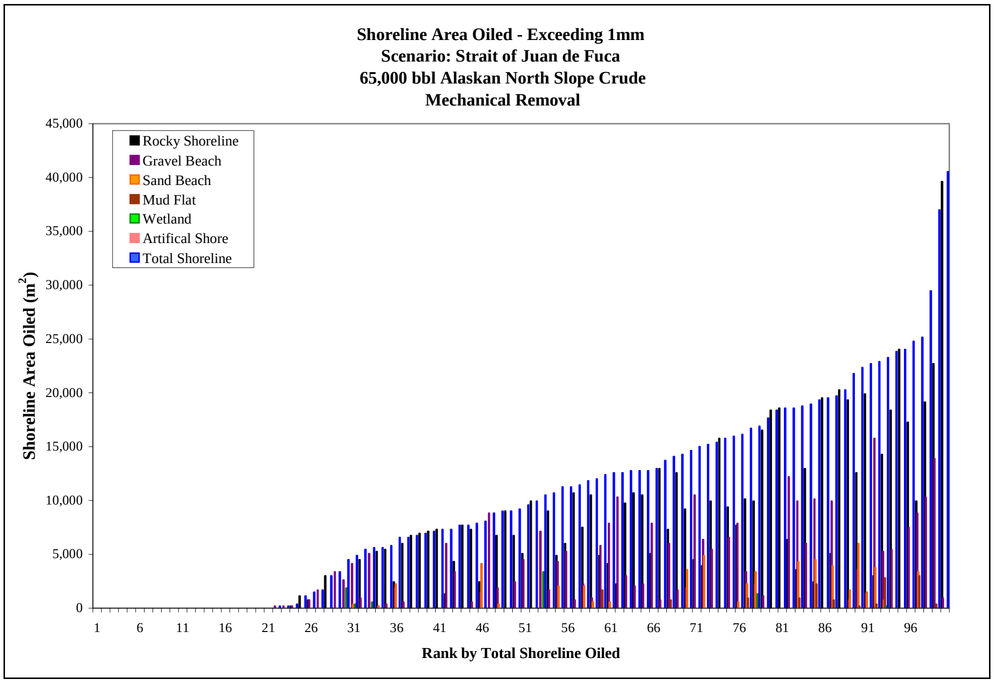


Figure XIII.C-6. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

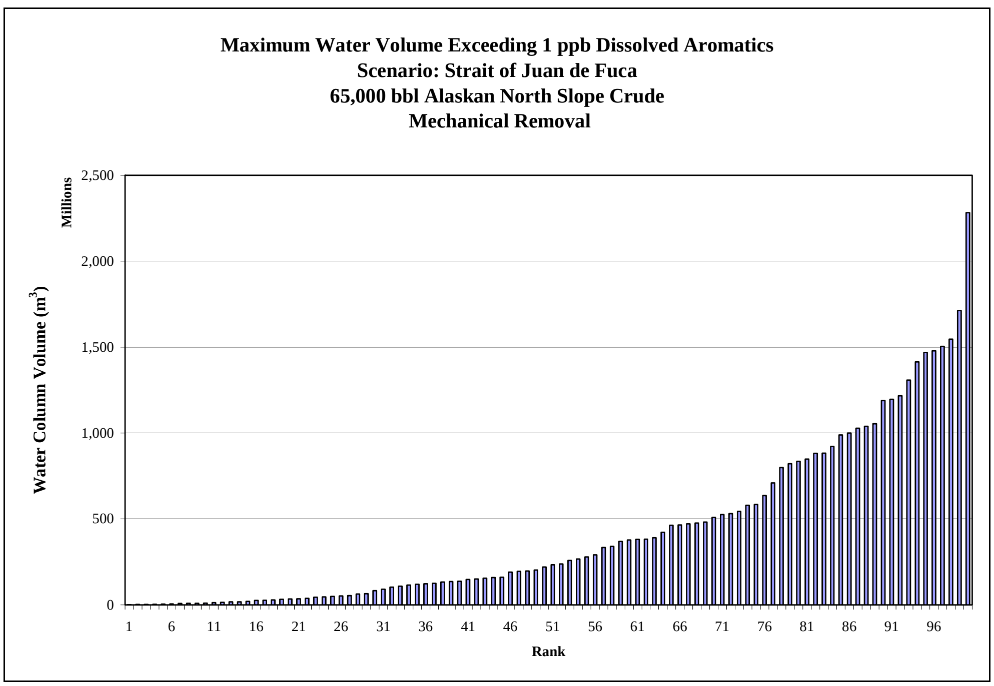


Figure XIII.C-7. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

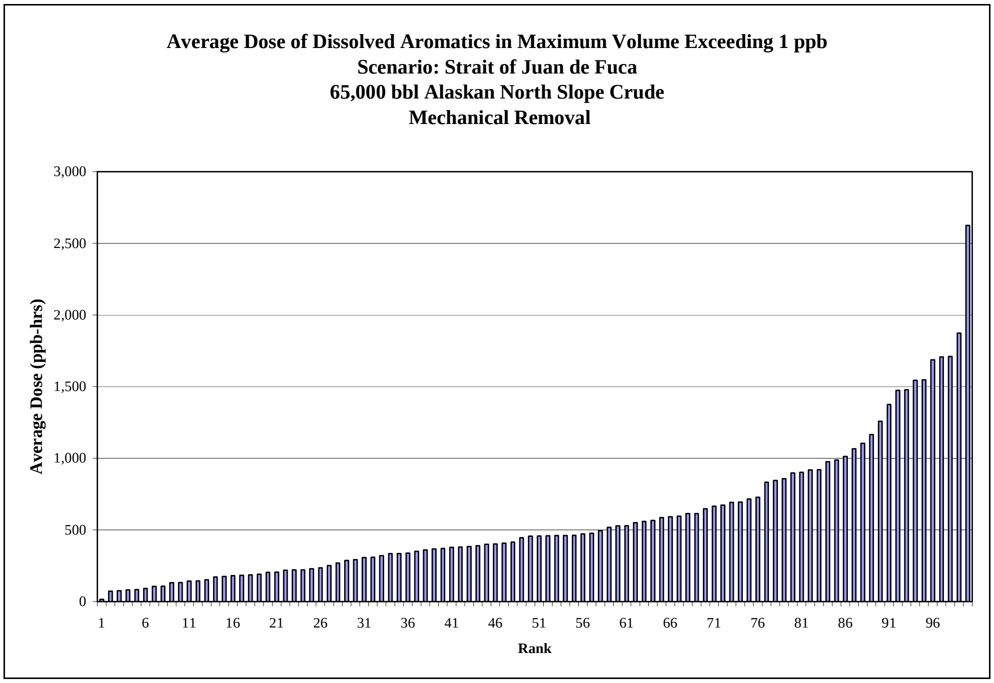


Figure XIII.C-8. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

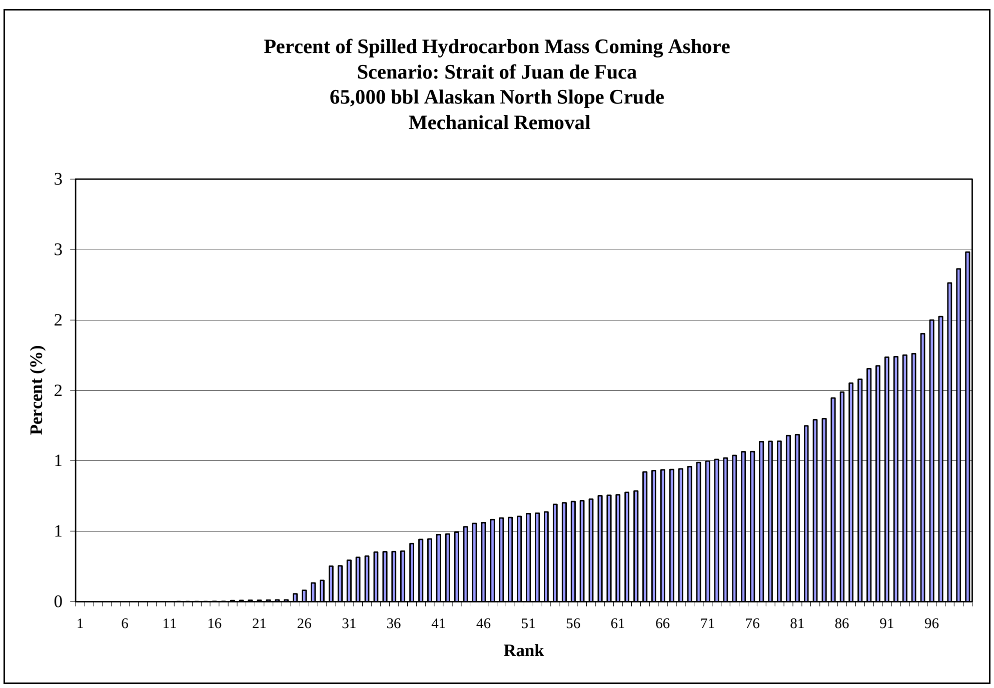


Figure XIII.C-9. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

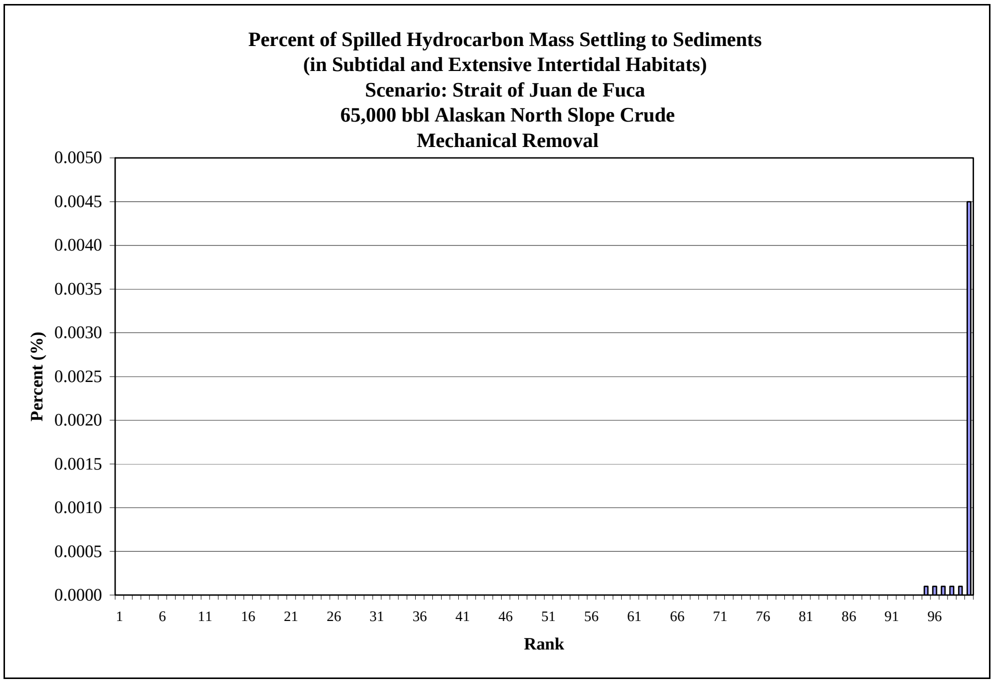


Figure XIII.C-10. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

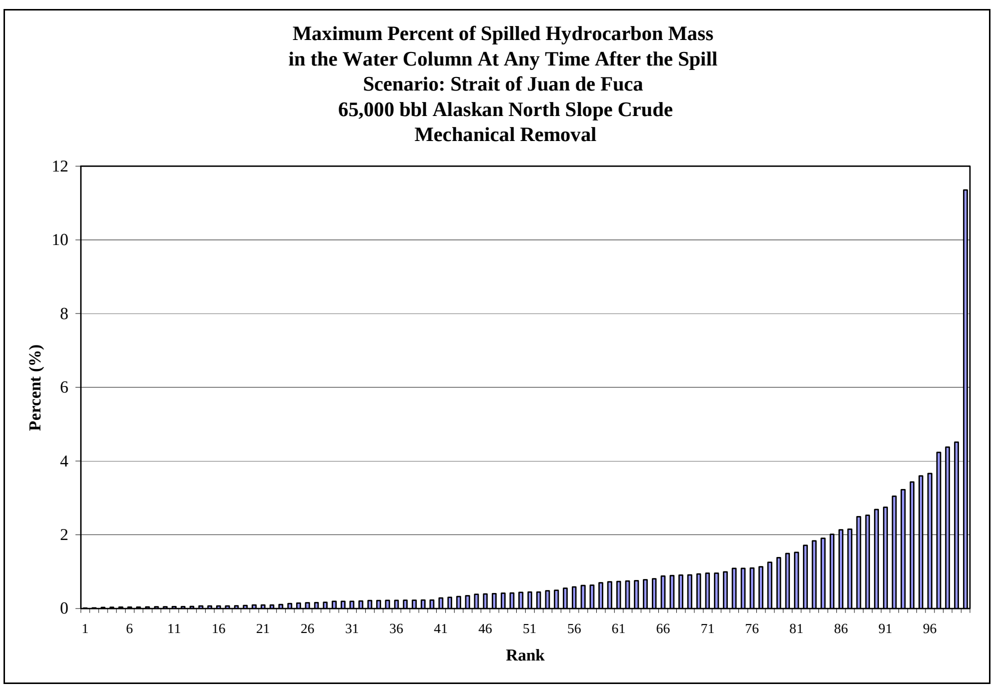


Figure XIII.C-11. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

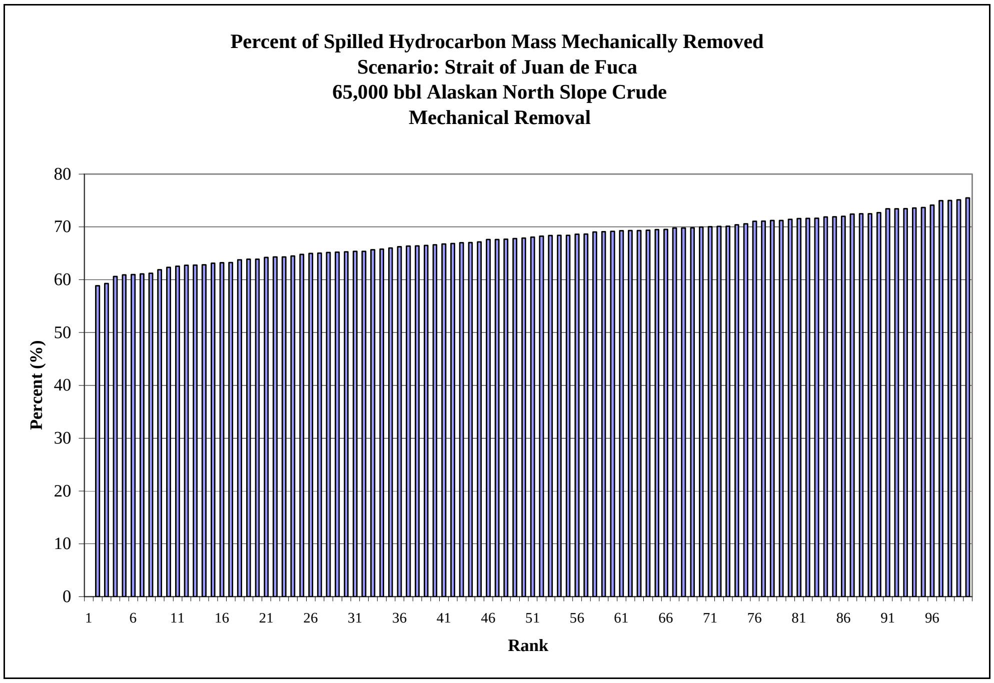


Figure XIII.C-12. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass mechanically removed.

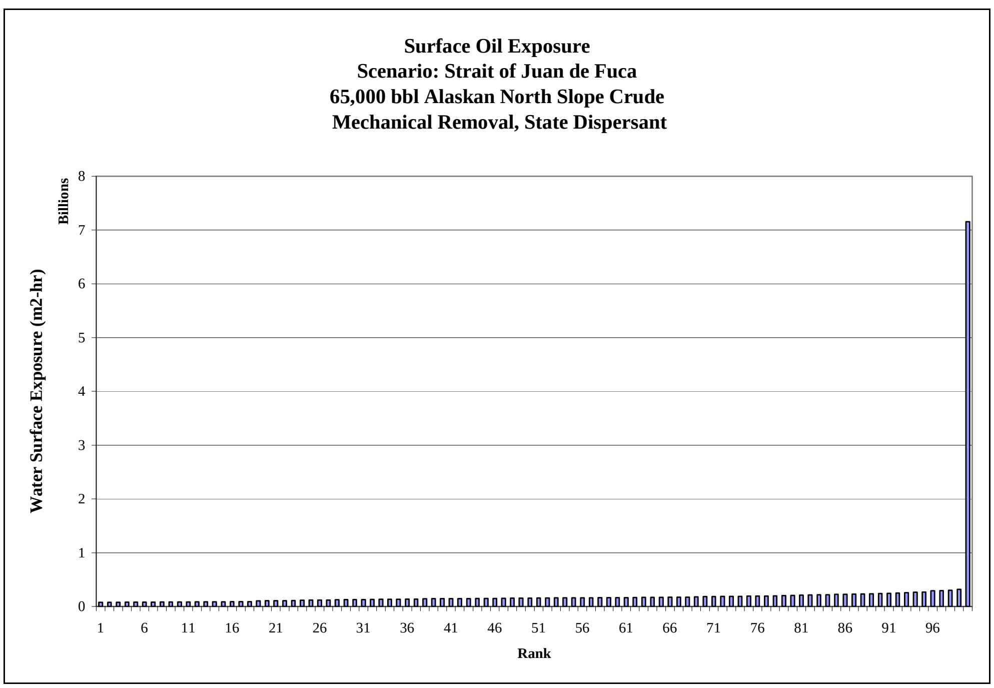


Figure XIII.C-13. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

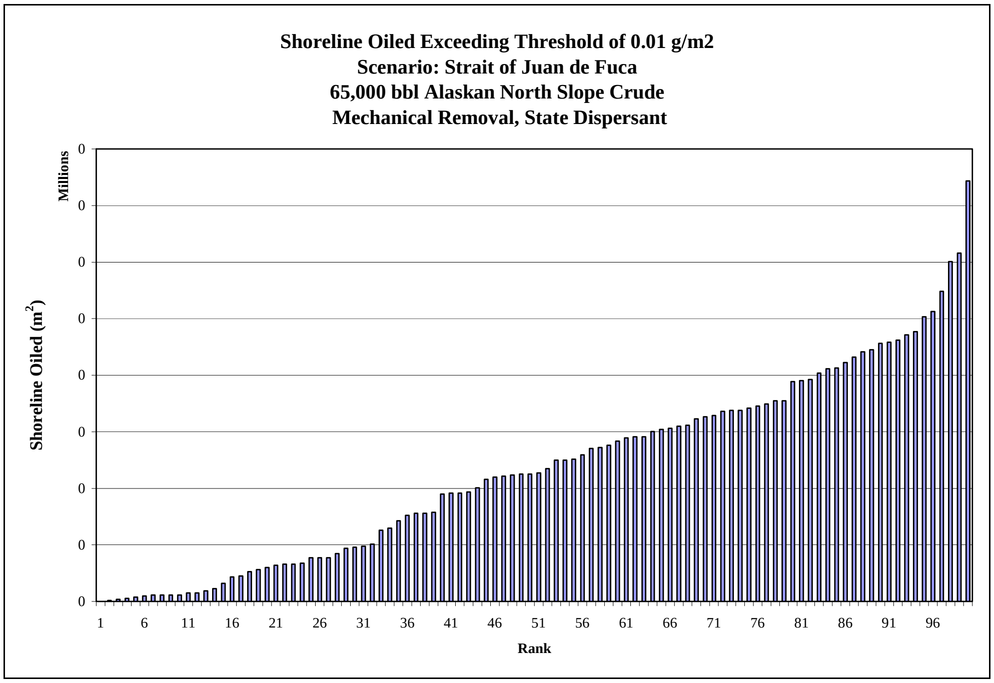


Figure XIII.C-14. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

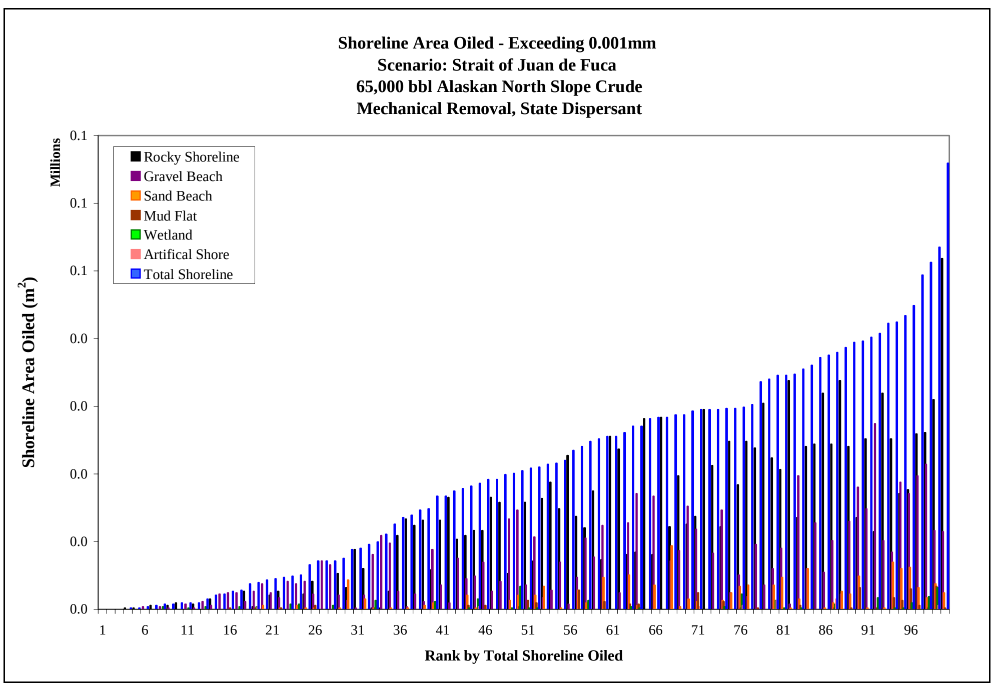


Figure XIII.C-15. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

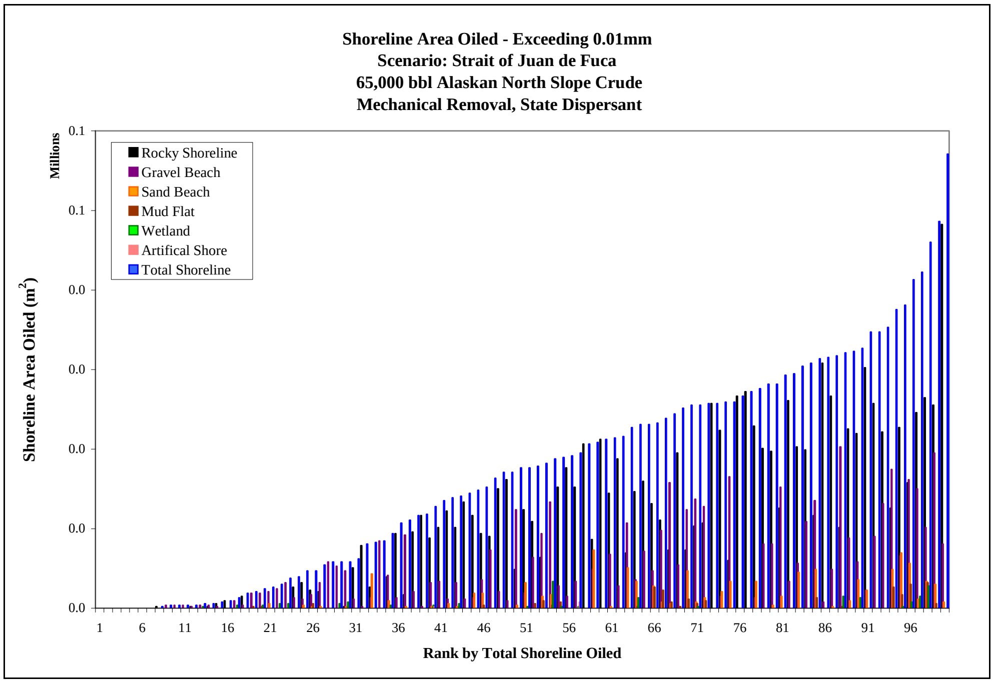


Figure XIII.C-16. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

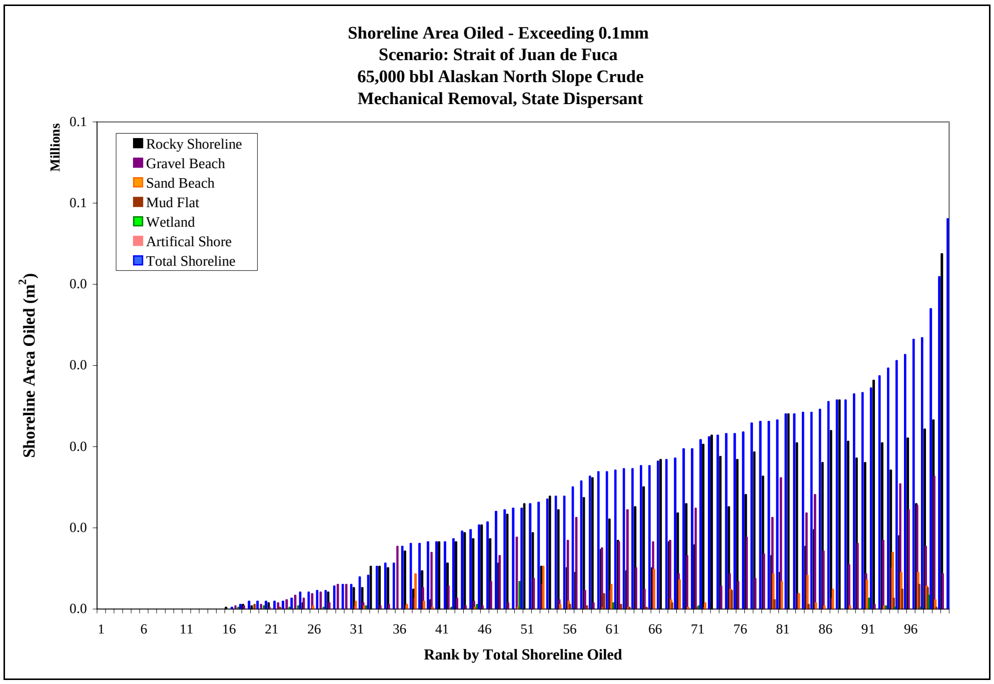


Figure XIII.C-17. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

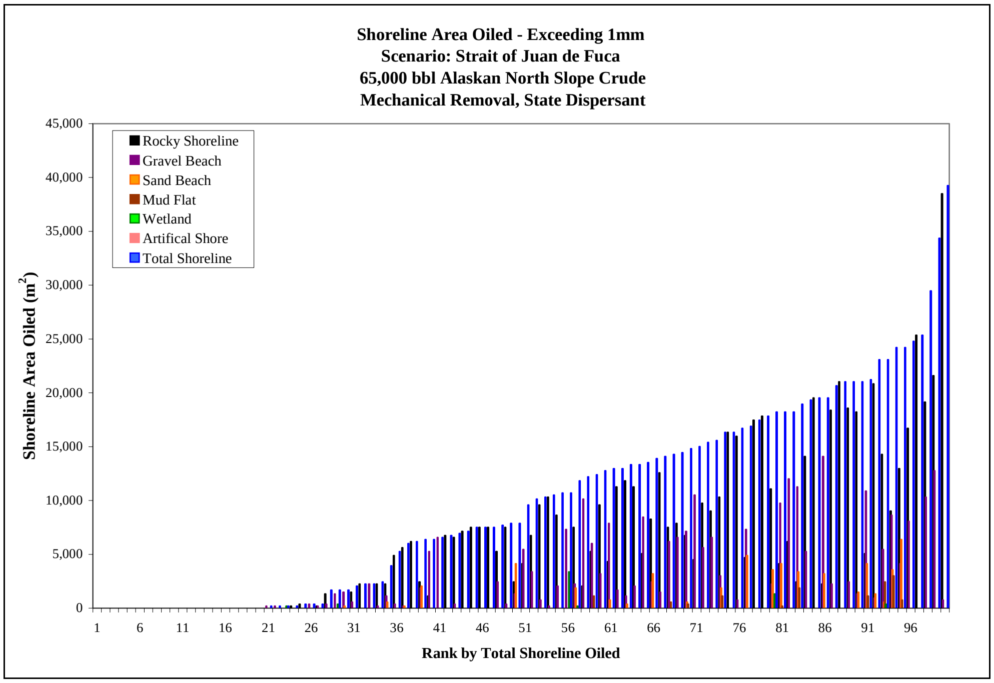


Figure XIII.C-18. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

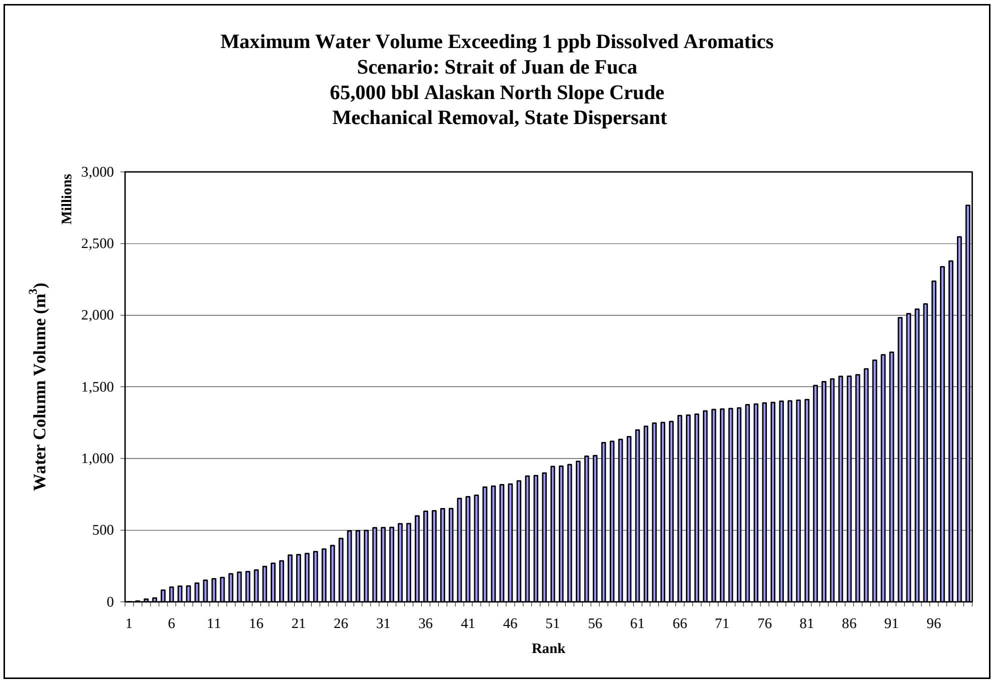


Figure XIII.C-19. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

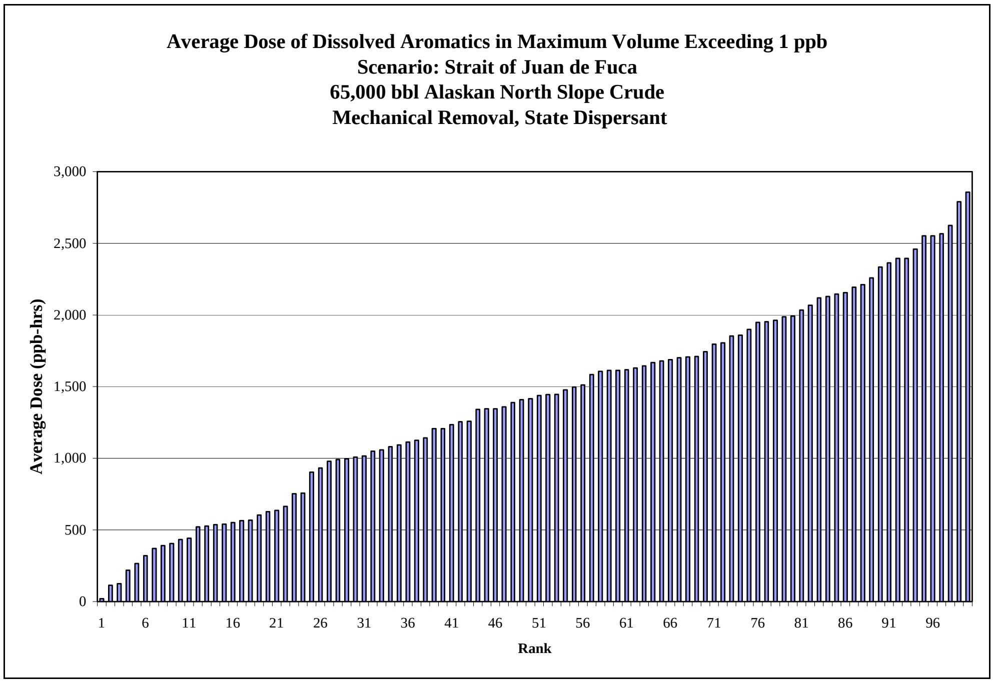


Figure XIII.C-20. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

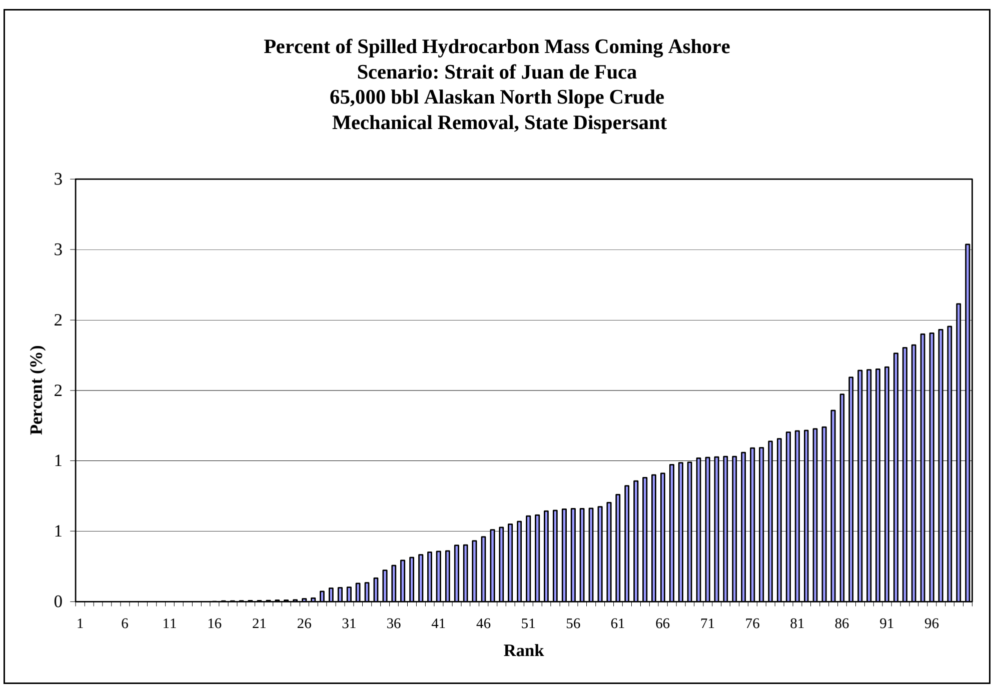


Figure XIII.C-21. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

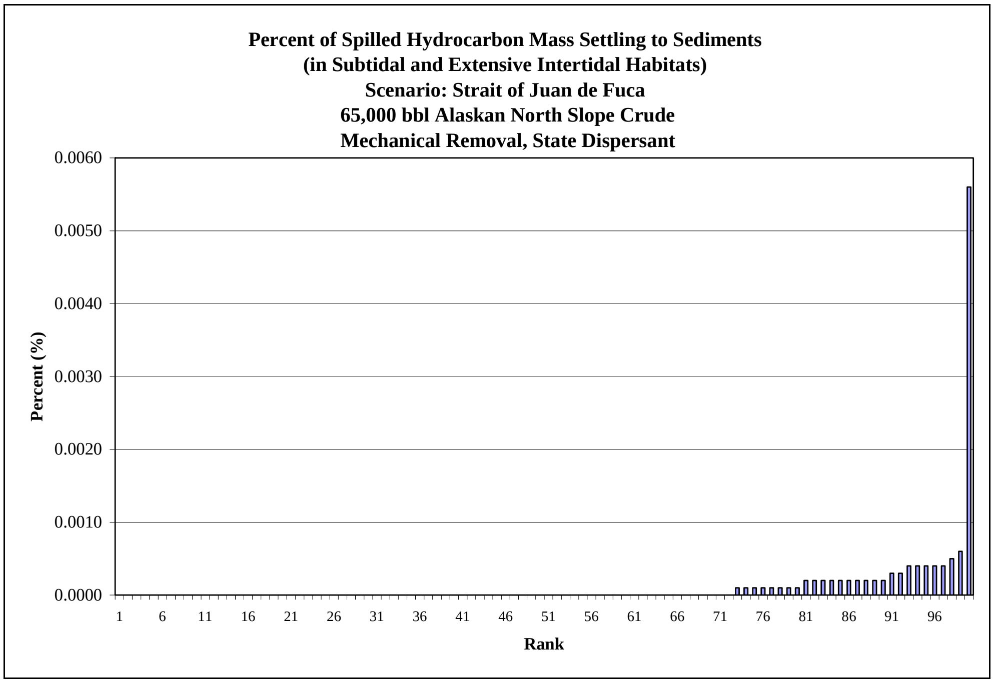


Figure XIII.C-22. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

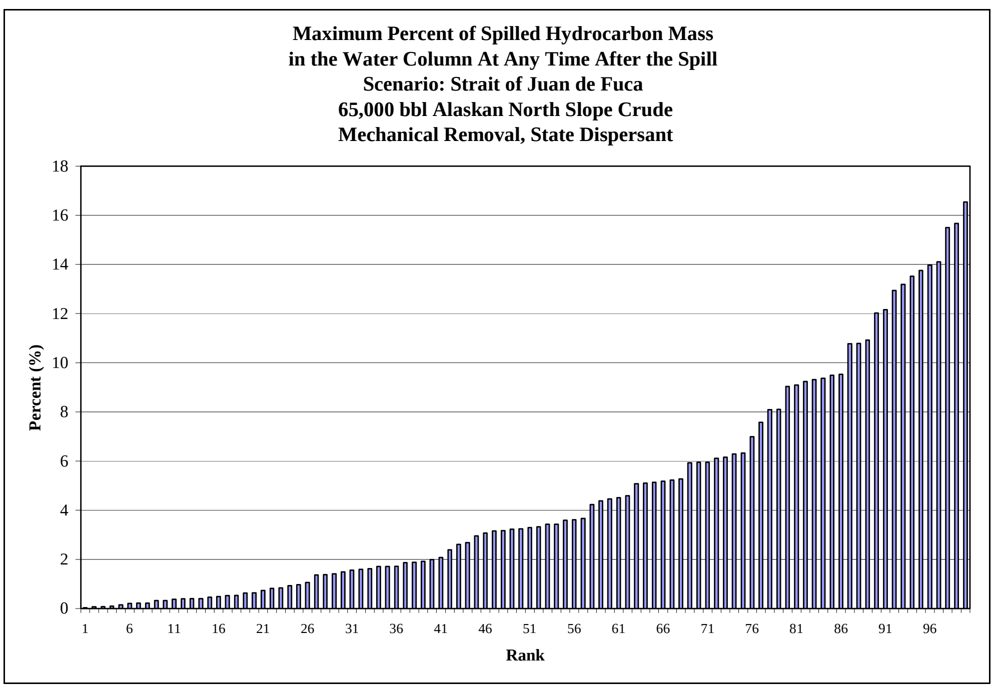


Figure XIII.C-23. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

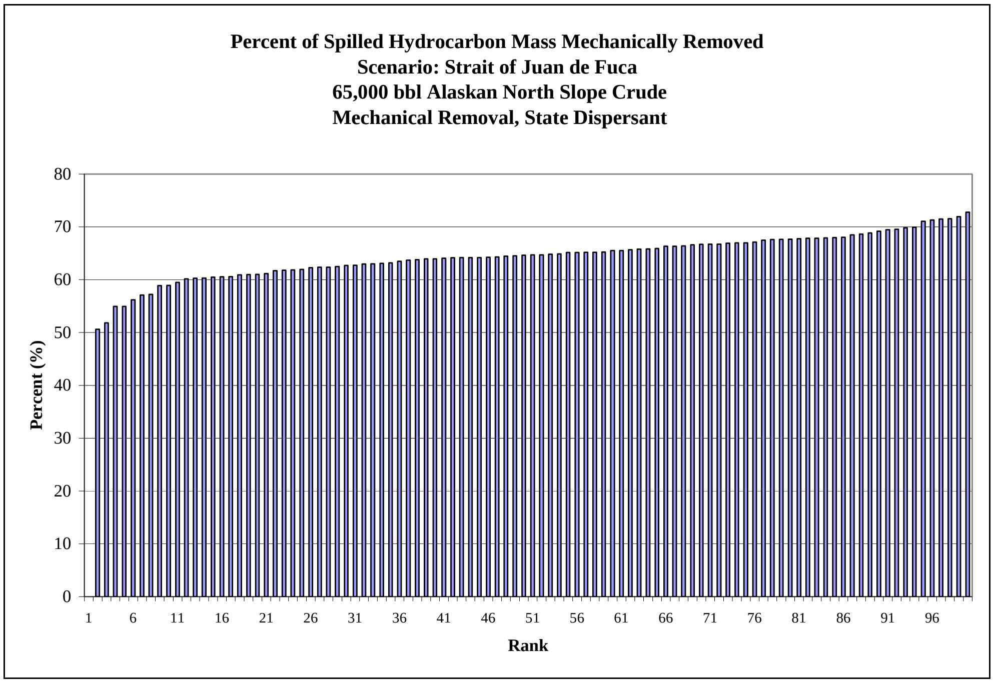


Figure XIII.C-24. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass mechanically removed.

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

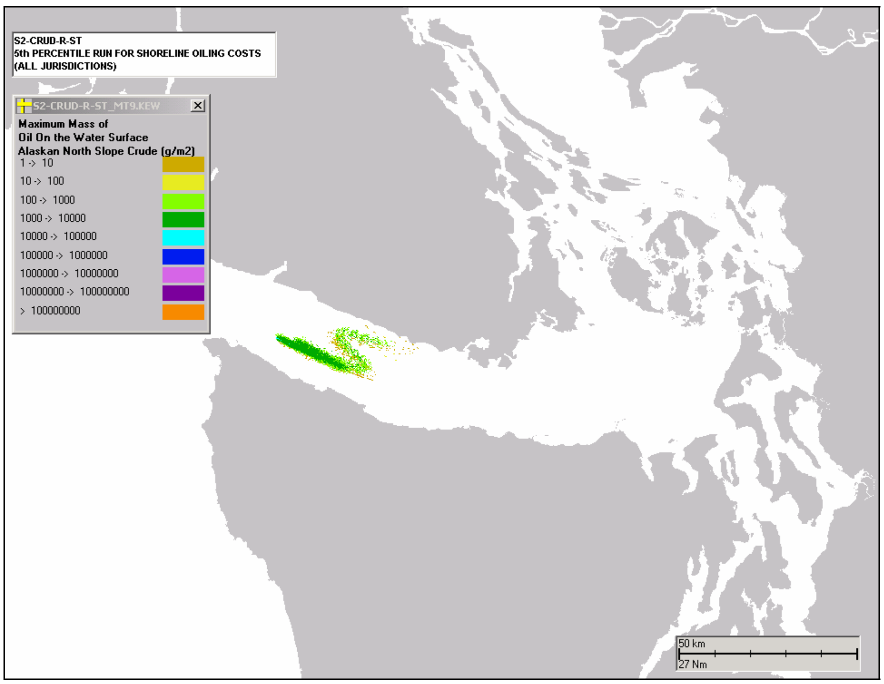


Figure XIII.E-1. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

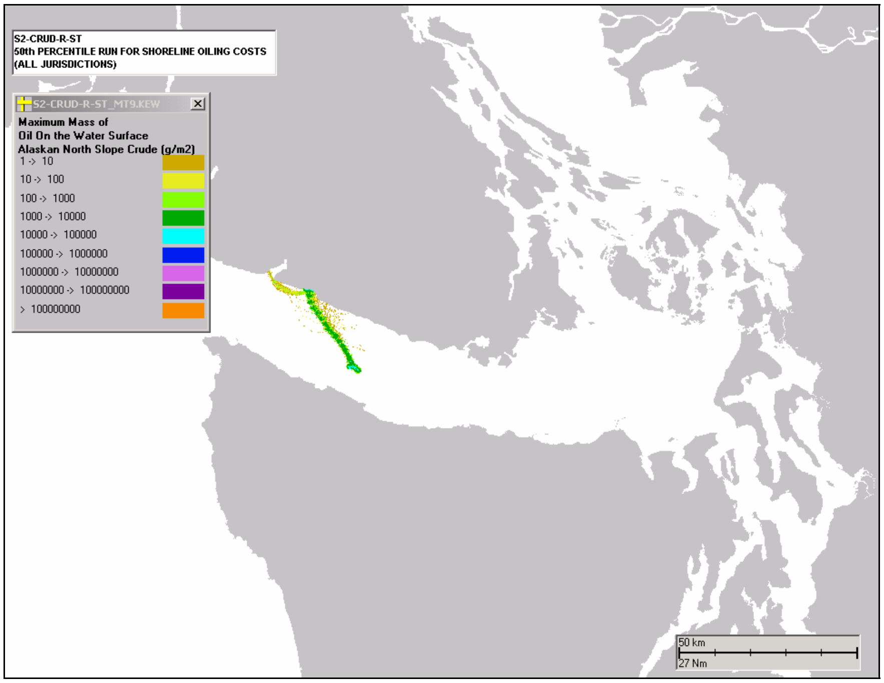


Figure XIII.E-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

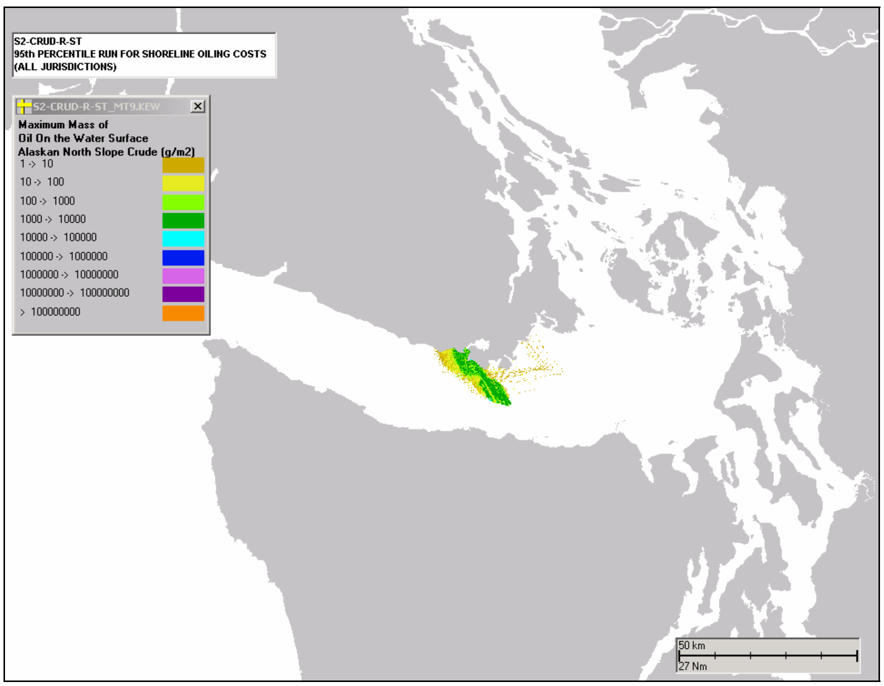


Figure XIII.E-3. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

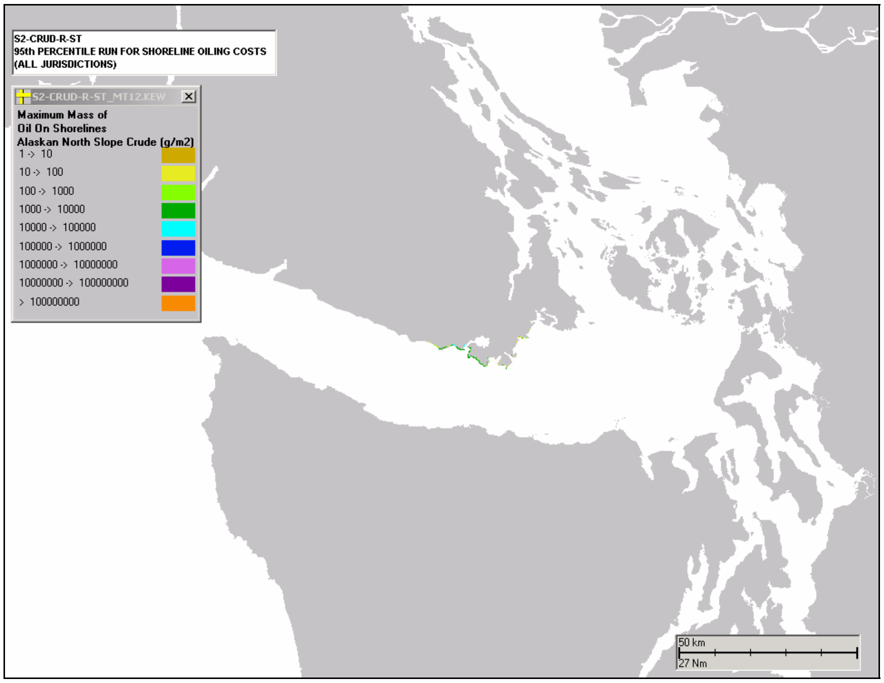


Figure XIII.E-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

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.

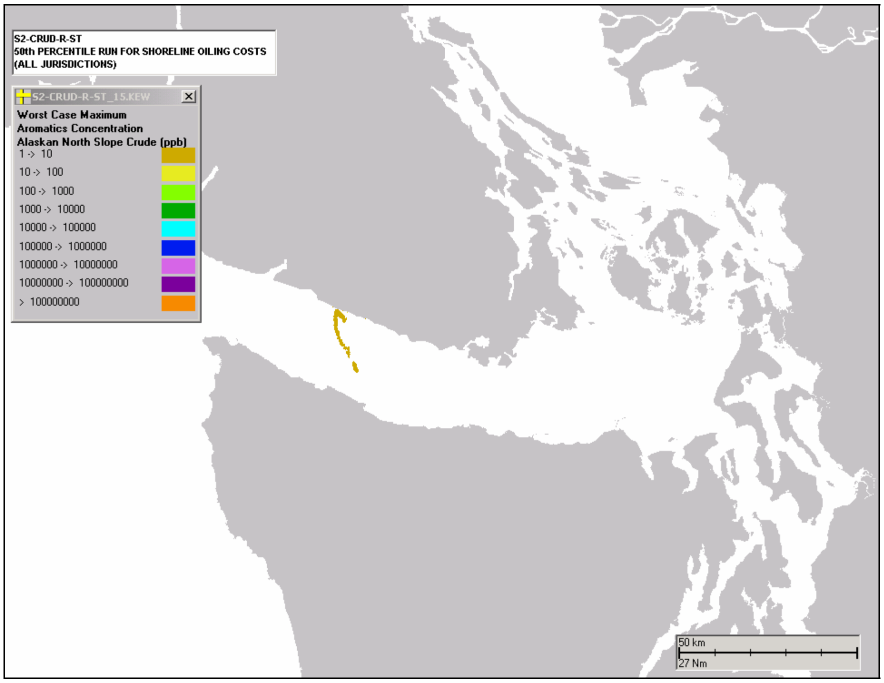


Figure XIII.E-6. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

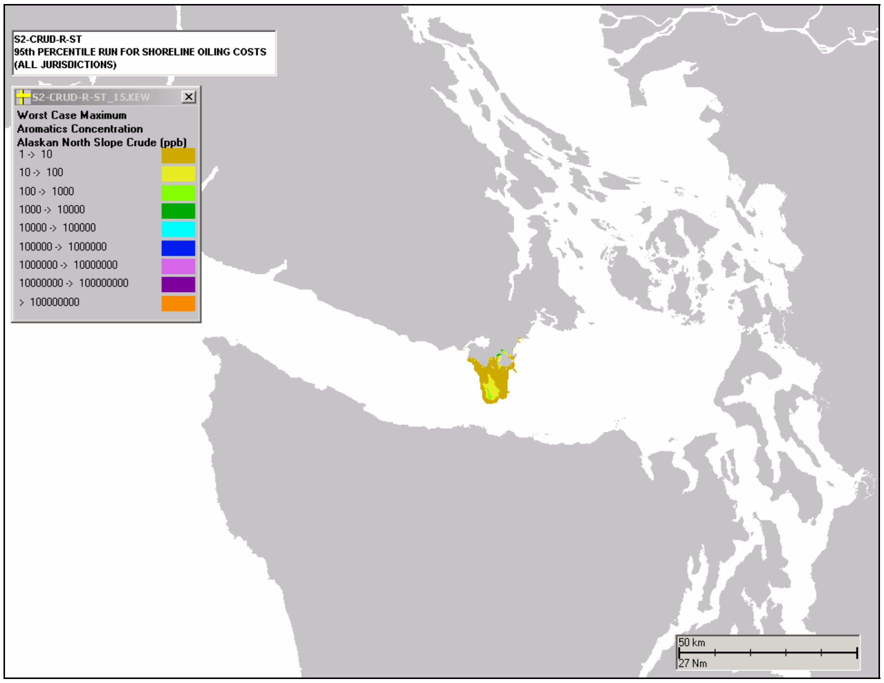


Figure XIII.E-7. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

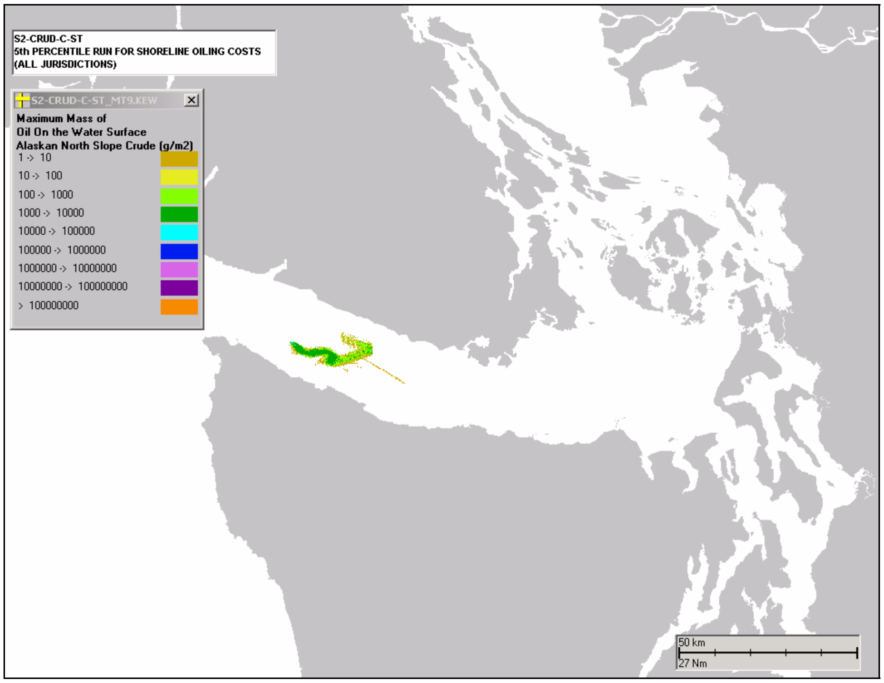


Figure XIII.E-8. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

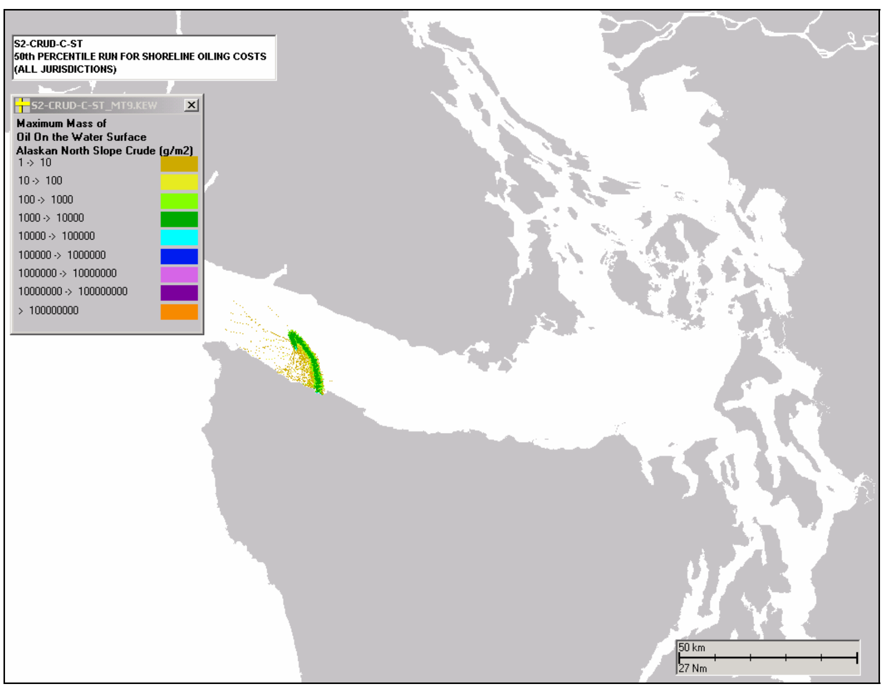


Figure XIII.E-9. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

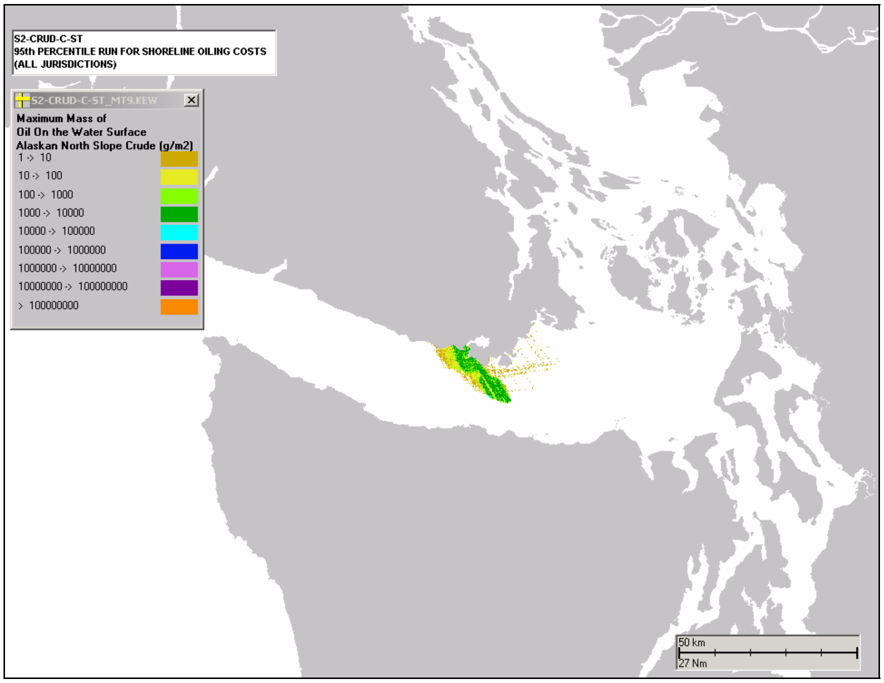


Figure XIII.E-10. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

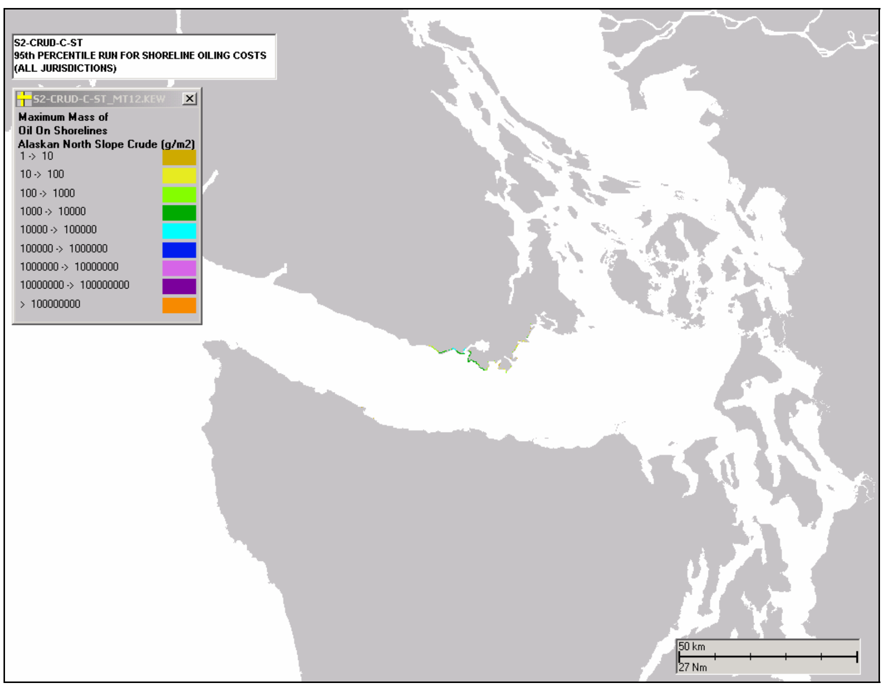


Figure XIII.E-11. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

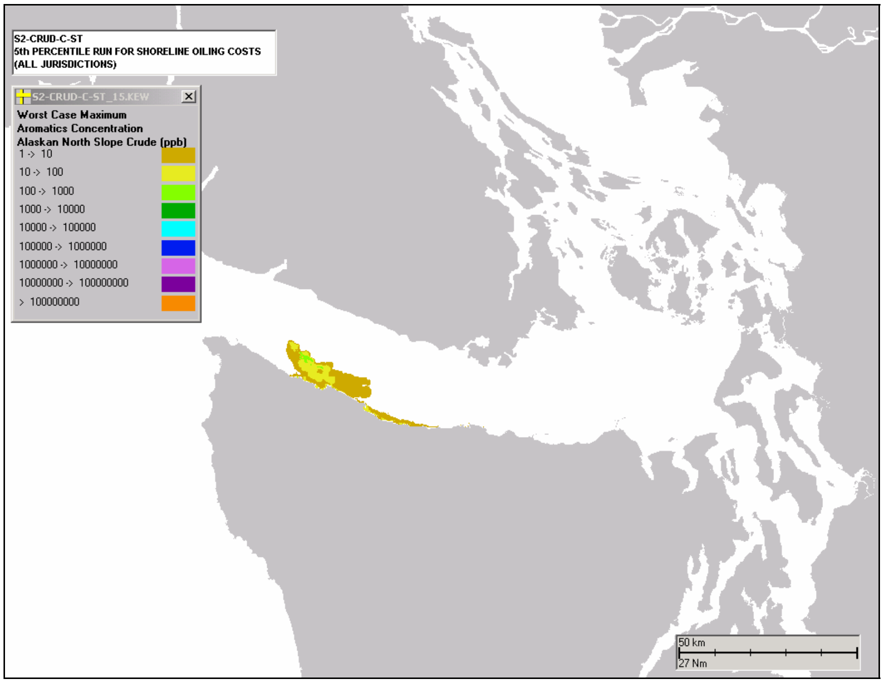


Figure XIII.E-12. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

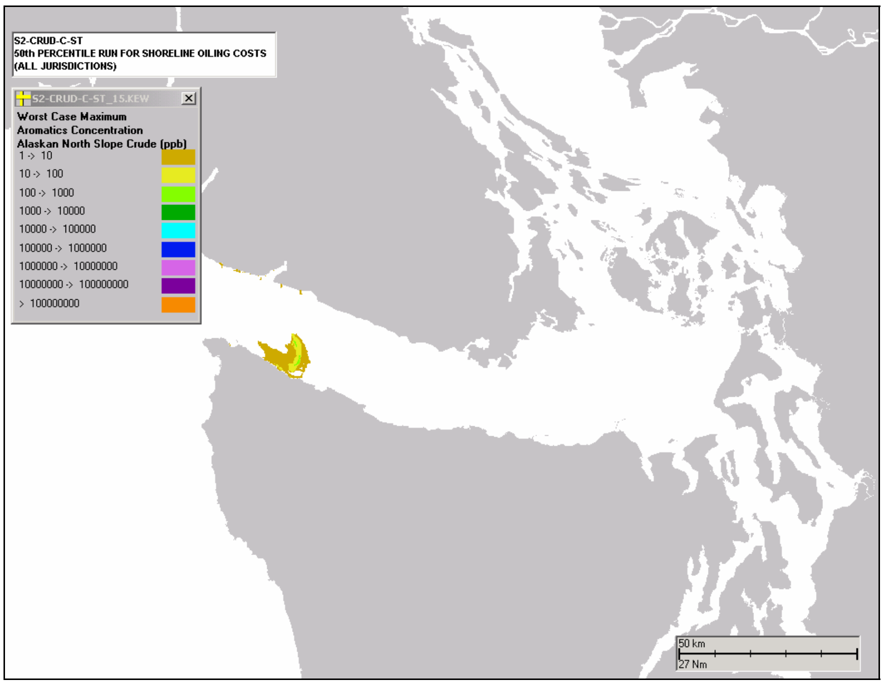


Figure XIII.E-13. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

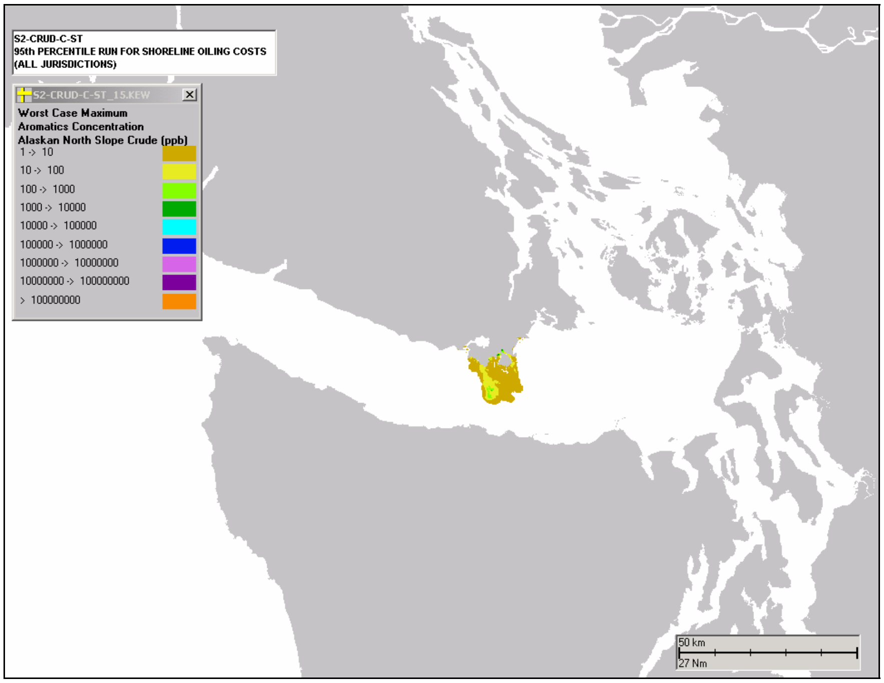


Figure XIII.E-14. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIII.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated for the 5^{th}, 50^{th} and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} or 95^{th} 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 5^{th}, 50^{th} or 95^{th} percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5^{th}, 50^{th} or 95^{th} *runs based on shore costs*. The results for 5^{th}, 50^{th} or 95^{th} *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 5^{th}, 50^{th} or 95^{th} *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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

XIV.A. Introduction 1
XIV.B. Exposure for Individual Model Runs 3
XIV.B.1. No Removal, Scenario S2-Crud-N 3
XIV.B.2. State Mechanical Removal, Scenario S2-Crud-R-ST 7
XIV.B.3. Federal Mechanical Removal, Scenario S2-Crud-R-Fed 11
XIV.B.4. 3rd Alternative Mechanical Removal, Scenario S2-Crud-R-3 15
XIV.B.5. State Mechanical Removal and dispersant, Scenario S2-Crud-C-ST 19
XIV.B.6. Federal Mechanical Removal and dispersant, Scenario S2-Crud-C-Fed 23
XIV.B.7. 3rd Alternative Mechanical Removal and dispersant, Scenario S2-Crud-C-327
XIV.B.8. State Mechanical Removal and In-situ Burning, Scenario S2-Crud-R-ISB . 31
XIV.B.9 Oil Fate Over Time 35
XIV.C. Estimated Biological Impacts: Wildlife 65
XIV.D. Estimated Biological Impacts: Fish and Invertebrates 73
XIV.E. Estimated NRDA Costs: Habitat Restoration Costs 81
XIV.F. Estimated NRDA Costs: Washington Compensation schedule 90

List of Figures

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. 3
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 50^{th} percentile run based on shoreline costs. 4
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. 4
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. 5
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 50^{th} percentile run based on shoreline costs. 5
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. 6
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. 7
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 50^{th} percentile run based on shoreline costs. 8
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. 8
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. 9
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 50^{th} percentile run based on shoreline costs. 9
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. 10
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. 11
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 50^{th} percentile run based on shoreline costs. 12
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. 12

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. 13
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. 13
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. 14
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.. 15
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.. 16
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.. 16
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. 17
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. 17
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. 18
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.. 19
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.. 20
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.. 20
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. 21
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. 21
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. 22
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.. 23
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.. 24
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.. 24
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. 25
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. 25
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. 26
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.. 27
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.. 28
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.. 28
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. 29
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. 29
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. 30

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. 31
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 50^{th} percentile run based on shoreline costs. 32
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. 32
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. 33
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 50^{th} percentile run based on shoreline costs. 33
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. 34
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). 36
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). 36
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). 37
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). 37
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). 38
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). 38
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). 39
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). 39

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). 40
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). 40
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). 41
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)................................... 41
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)................................... 42
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)................................... 42
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).. 43
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). 43
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). 44
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). 44
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)................................... 45
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)................................... 45
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)................................... 46
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. 47
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 5^{th} percentile run (based on shore cost). Part b is a subset of Part a. 48
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 5^{th} percentile run (based on shore cost). Part b is a subset of Part a... 49
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 5^{th} percentile run (based on shore cost). Part b of this figure is a subset of Part a. 50
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 5^{th} percentile run (based on shore cost). Part b of this figure is a subset of Part a. 51
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 5^{th} percentile run (based on shore cost). Part b of this figure is a subset of Part a. 52
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 50^{th} percentile run (based on shore cost). Part b is a subset of Part a. 53
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 50^{th} percentile run (based on shore cost). Part b is a subset of Part a. 54
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 50^{th} percentile run (based on shore cost). Part b is a subset of Part a.. 55
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 50^{th} percentile run (based on shore cost). Part b is a subset of Part a. 56
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 50^{th} percentile run (based on shore cost). Part b is a subset of Part a. 57
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 50^{th} percentile run (based on shore cost). Part b is a subset of Part a. 58
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 95^{th} percentile run (based on shore cost). Part b of this figure is a subset of Part a. 59
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. 60
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. 61
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. 62
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. 63
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. 64

List of Tables

Table IXIV.C-1 Strait of Juan de Fuca – Alaskan North Slope Crude, no removal: Wildlife injury (as numbers lost). 65
Table IXIV.C-2 Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost). 66
Table IXIV.C-3 Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal: Wildlife injury (as numbers lost). 67
Table IXIV.C-4 Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal: Wildlife injury (as numbers lost). 68
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). 69
Table IXIV.C-6 Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal and dispersant application: Wildlife injury (as numbers lost). 70
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). 71
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). 72
Table XIV.D-1. Strait of Juan de Fuca – Alaskan North Slope Crude, no removal: Fish and invertebrate injury (as biomass lost in kg). 73
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). 74
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). 75
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). 76
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). 77
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). 78
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). 79
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). 80
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. 82
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. 82

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. 83
Table XIV.E-4. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 83
Table XIV.E-5. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 84
Table XIV.E-6. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 84
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. 85
Table XIV.E-8. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 85
Table XIV.E-9. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 86
Table XIV.E-10. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration. 86
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. 87
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$) for compensatory restoration. 87
Table XIV.E-13. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 88
Table XIV.E-14. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration. 88
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. 89
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$) for compensatory restoration. 89
Table XIV.F-1. Strait of Juan de Fuca – Alaskan North Slope Crude, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 90

Table XIV.F-2. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 90
Table XIV.F-3. Strait of Juan de Fuca – Alaskan North Slope Crude, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 90
Table XIV.F-4. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 91
Table XIV.F-5. Strait of Juan de Fuca – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 91
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$) based on the Washington state compensatory schedule. 91
Table XIV.F-7. Strait of Juan de Fuca – Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 91
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. 92

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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th}, and 95^{th} 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.

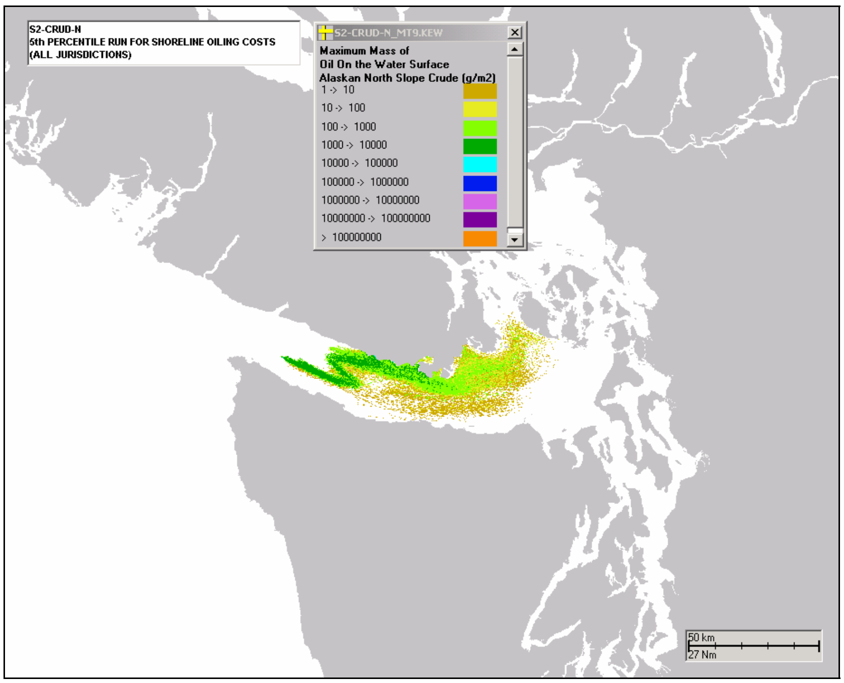


Figure XIV.B.1-1. Strait of Juan de Fuca, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

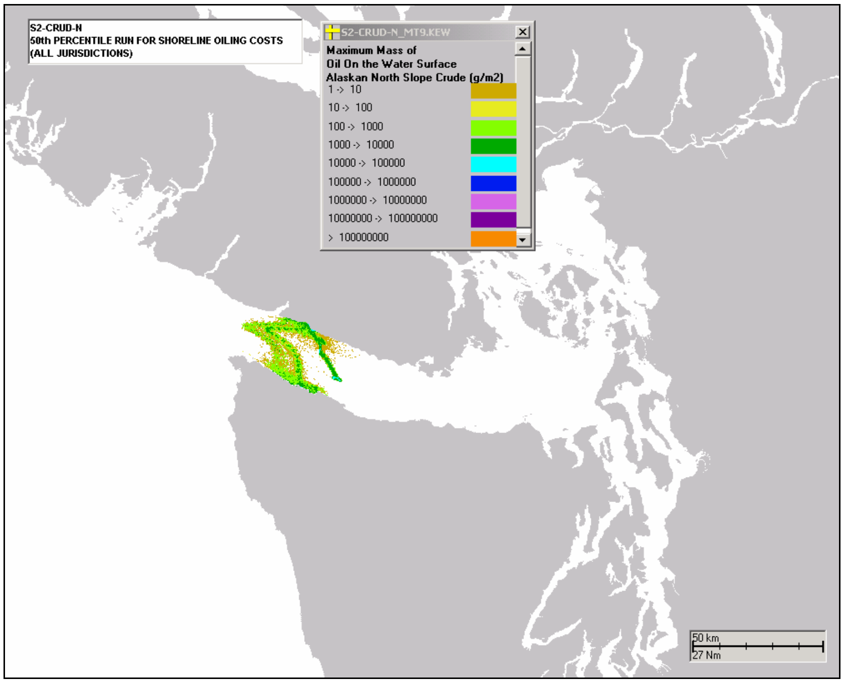


Figure XIV.B.1-2. Strait of Juan de Fuca, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

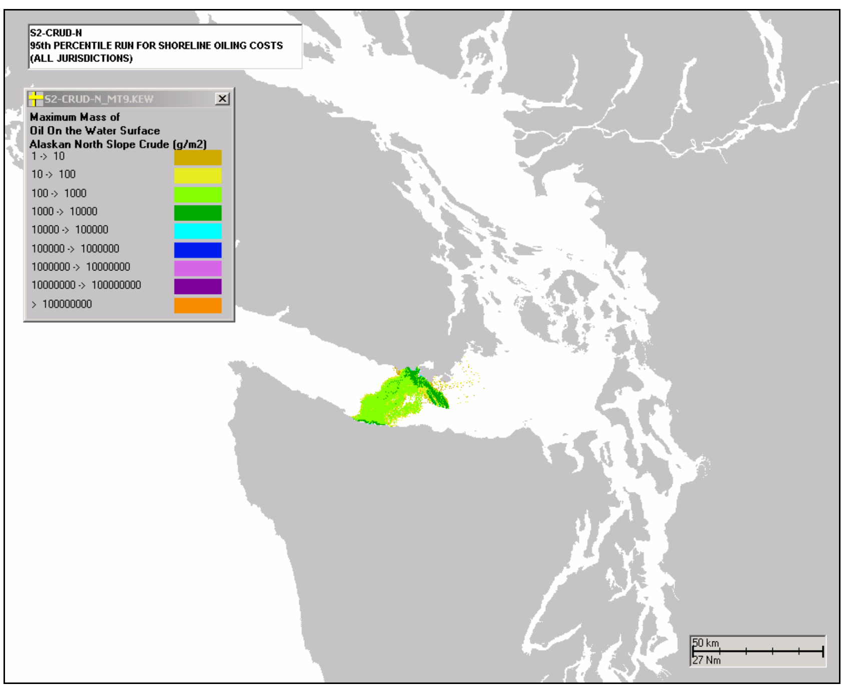


Figure XIV.B.1-3. Strait of Juan de Fuca, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

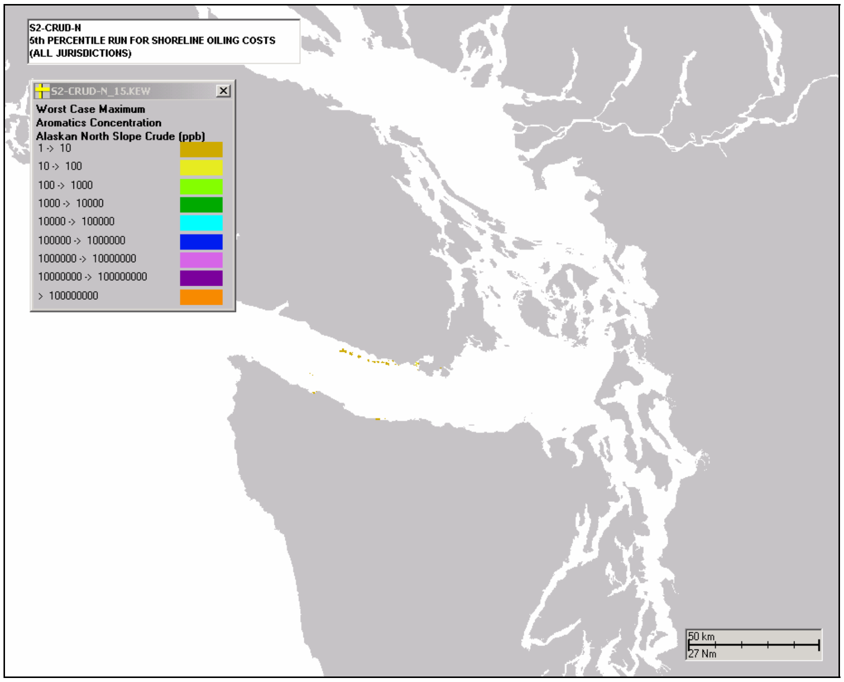


Figure XIV.B.1-4. Strait of Juan de Fuca, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

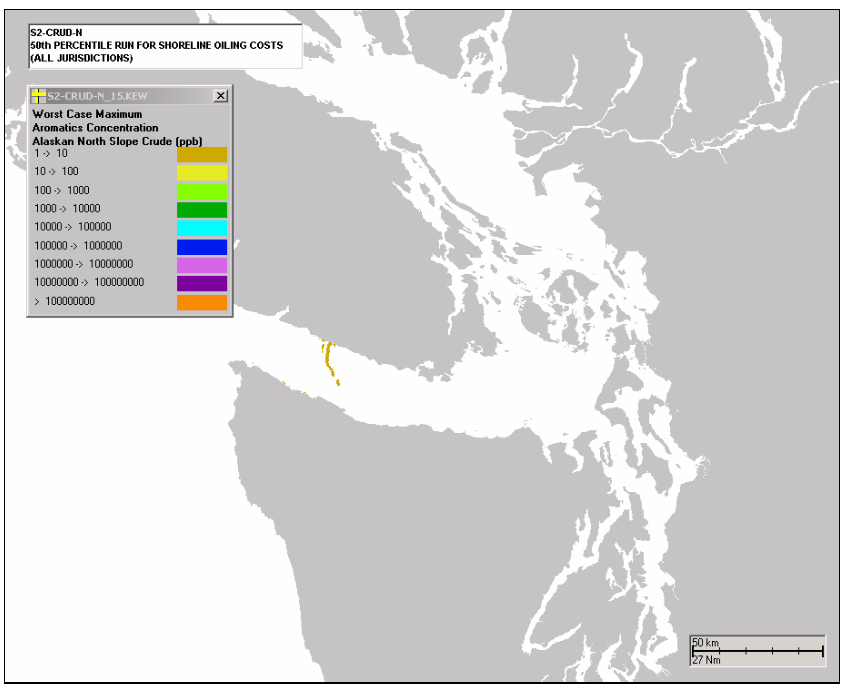


Figure XIV.B.1-5. Strait of Juan de Fuca, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

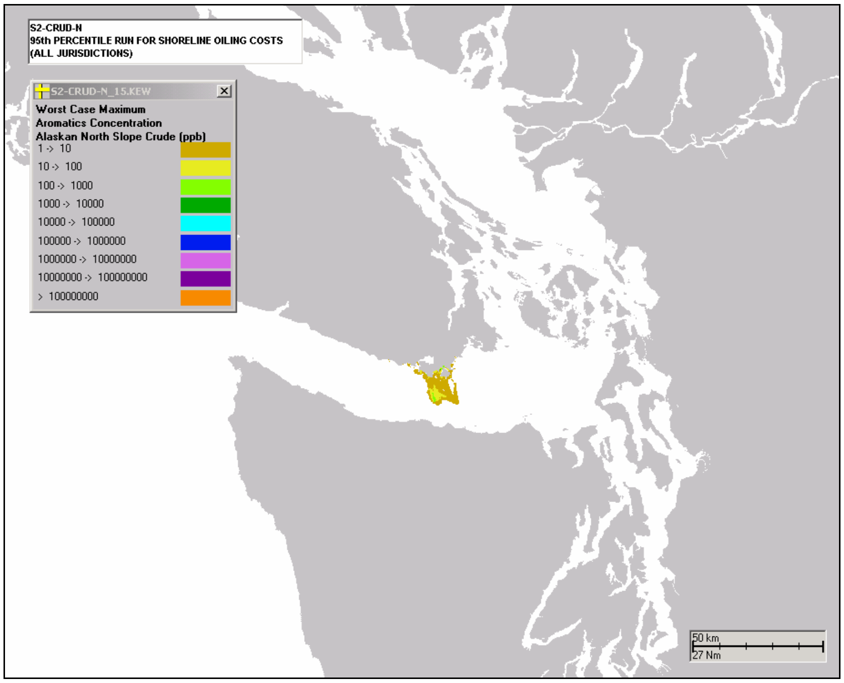


Figure XIV.B.1-6. Strait of Juan de Fuca, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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".

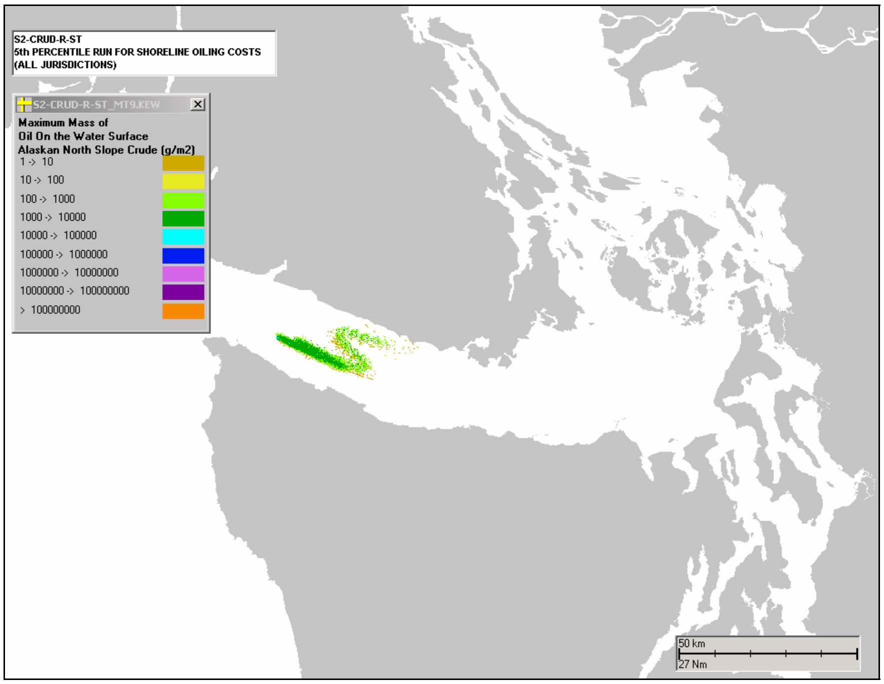


Figure XIV.B.2-1. Strait of Juan de Fuca, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

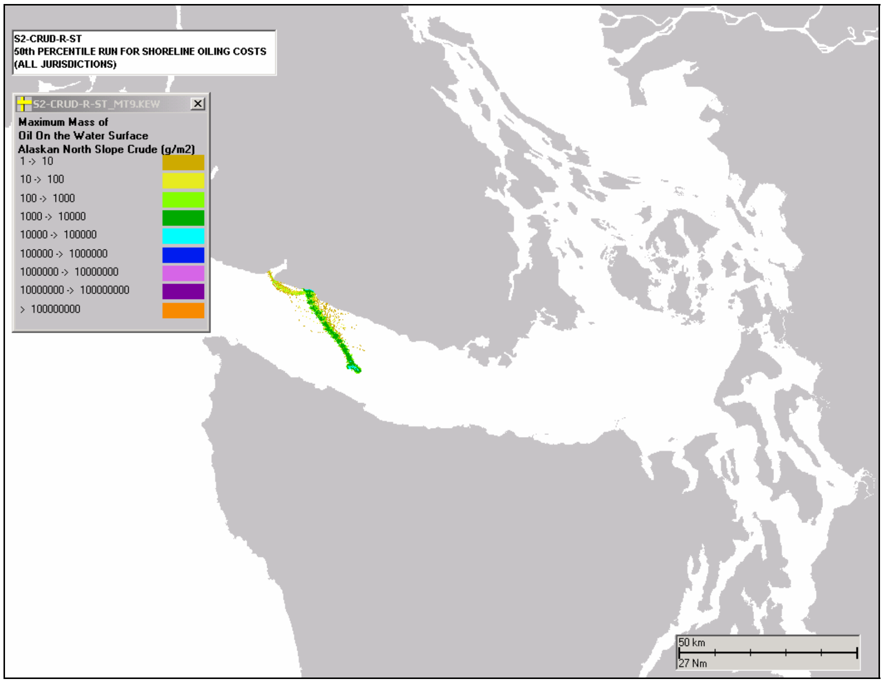


Figure XIV. B.2-2. Strait of Juan de Fuca, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

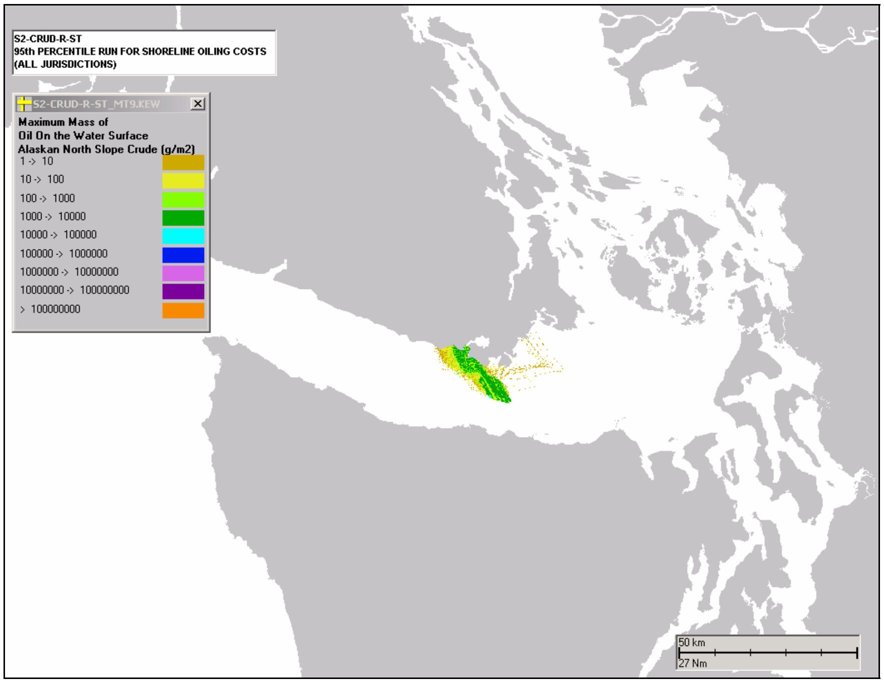


Figure XIV. B.2-3. Strait of Juan de Fuca, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

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.

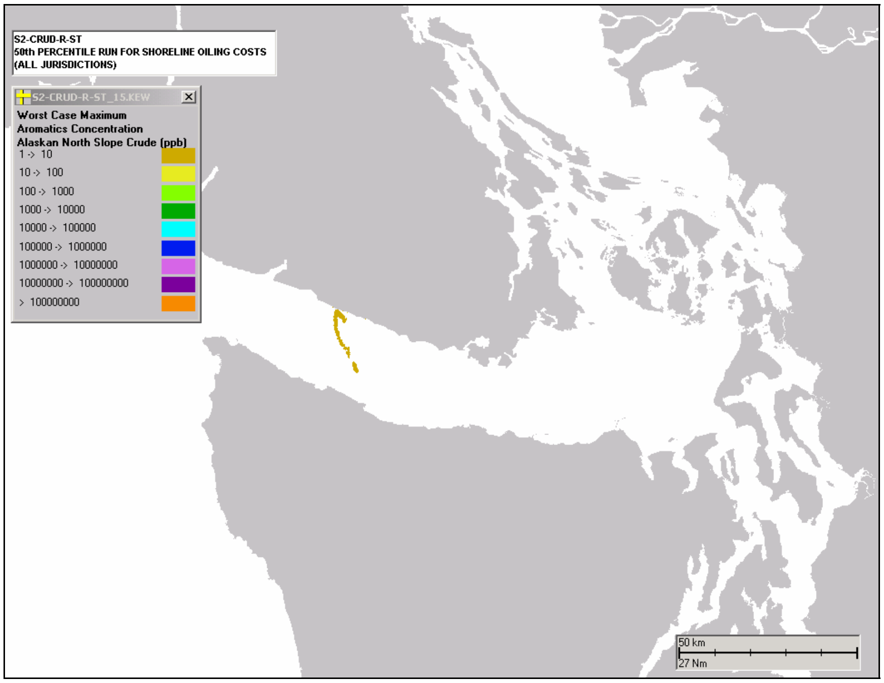


Figure XIV. B.2-5. Strait of Juan de Fuca, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

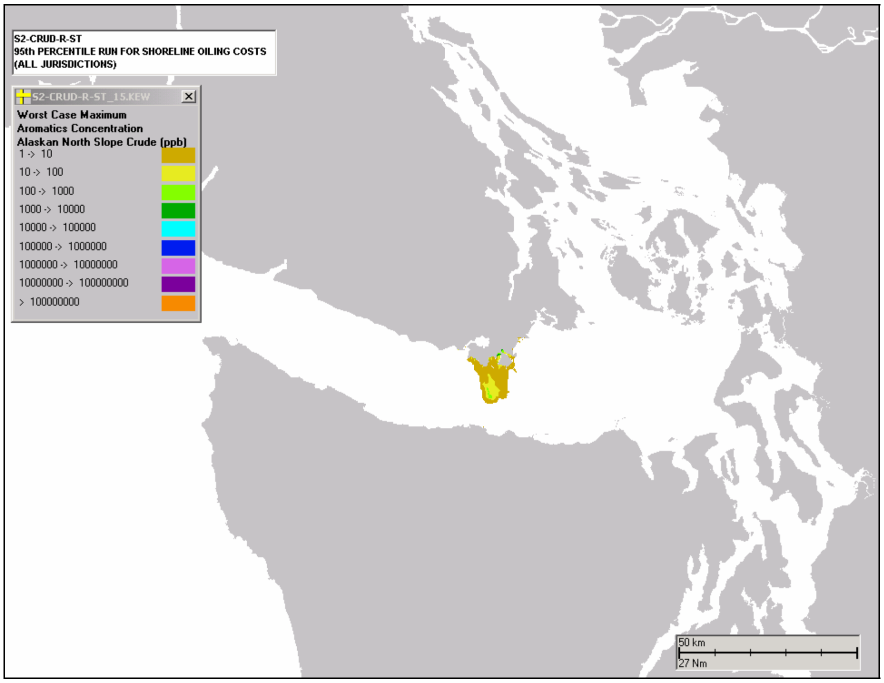


Figure XIV. B.2-6. Strait of Juan de Fuca, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

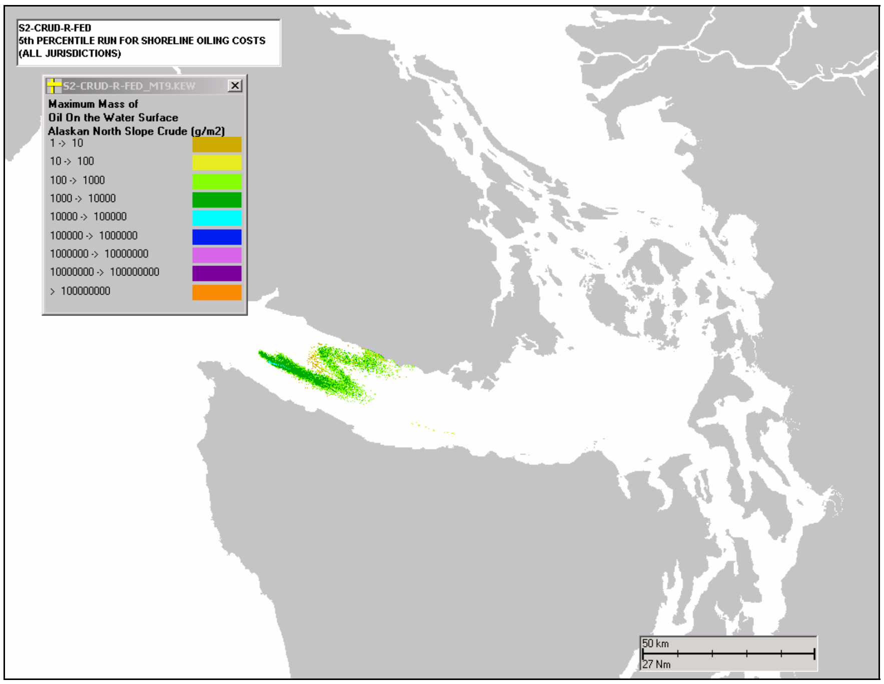


Figure XIV.B.3-1. Strait of Juan de Fuca, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

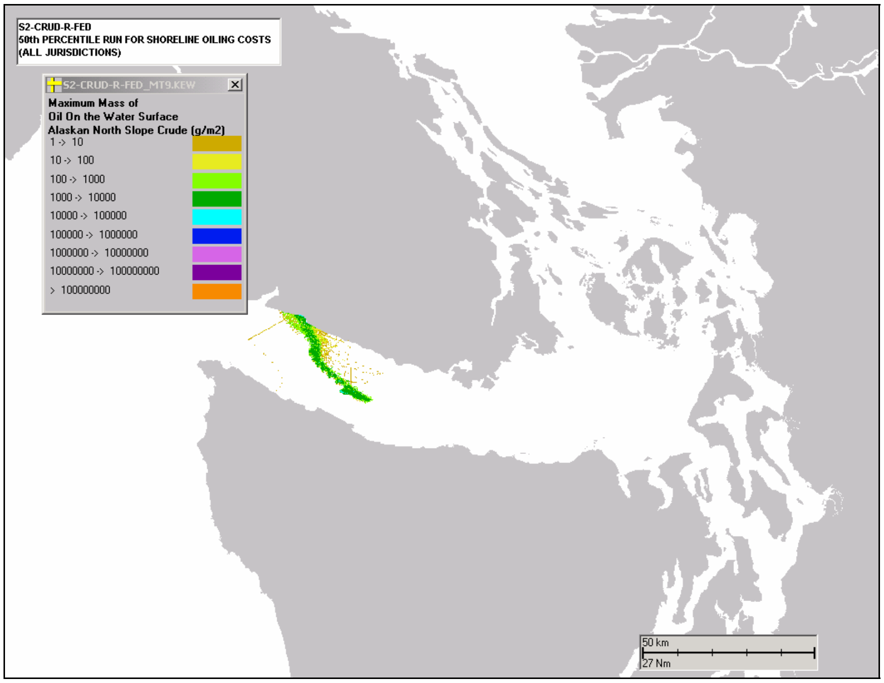


Figure XIV. B.3-2. Strait of Juan de Fuca, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

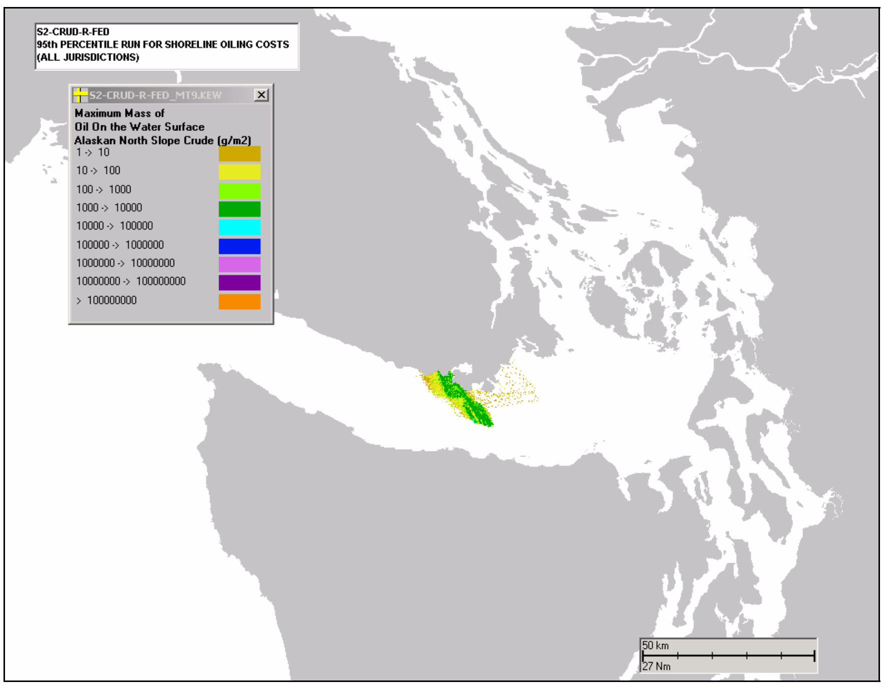


Figure XIV. B.3-3. Strait of Juan de Fuca, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

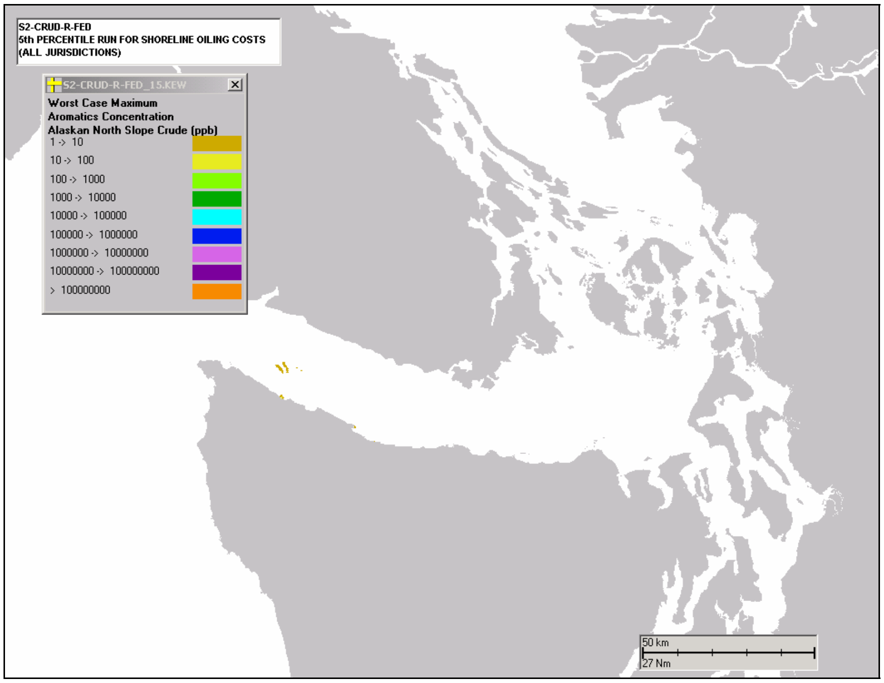


Figure XIV.B.3-4. Strait of Juan de Fuca, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

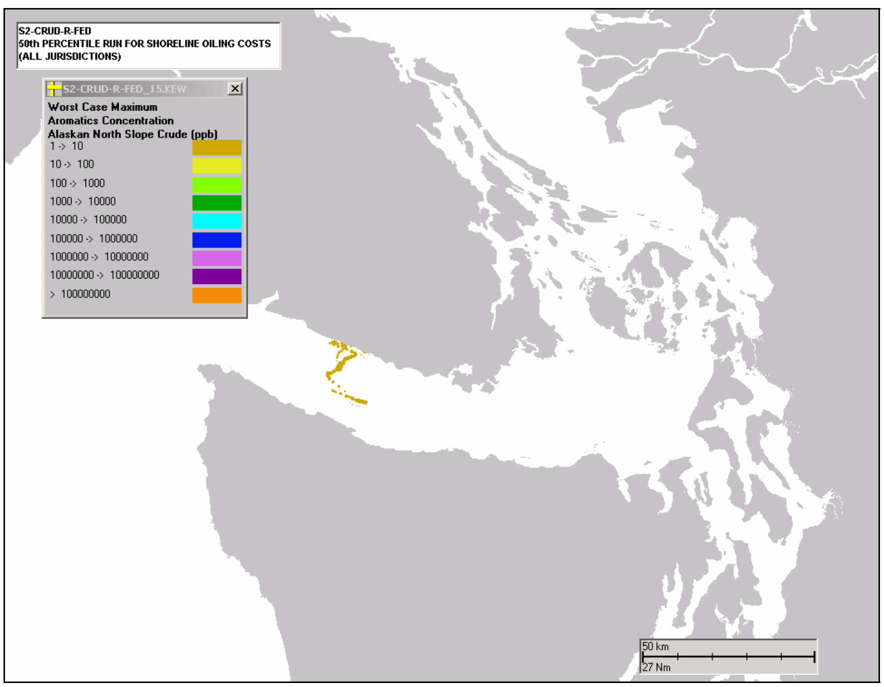


Figure XIV.B.3-5. Strait of Juan de Fuca, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

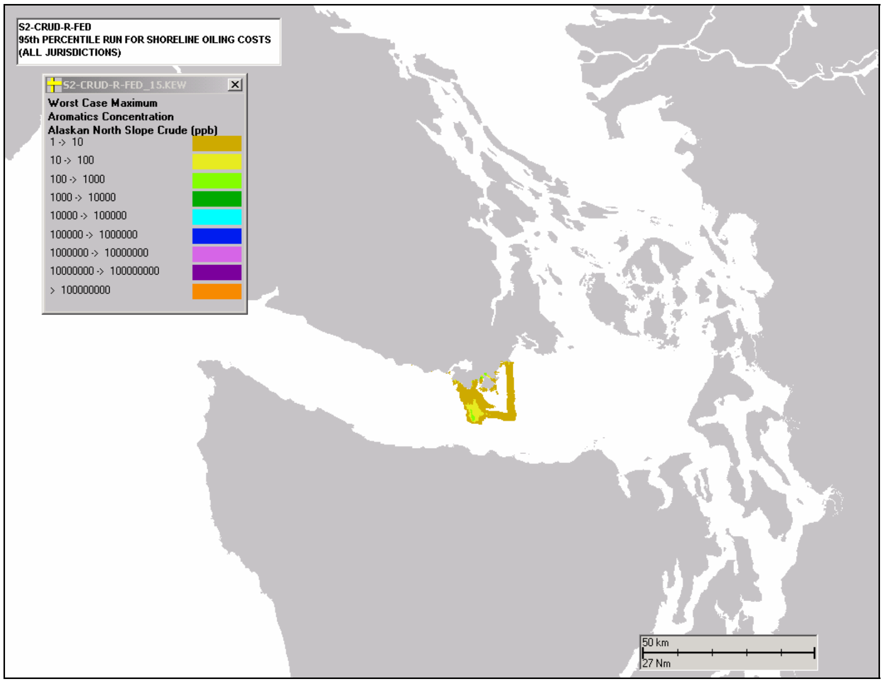


Figure XIV.B.3-6. Strait of Juan de Fuca, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

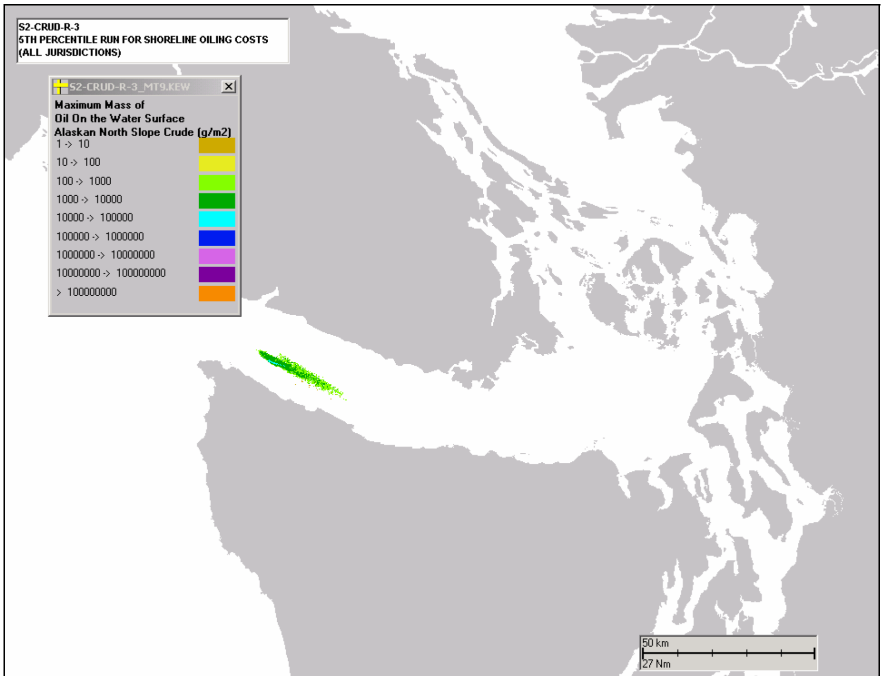


Figure XIV.B.4-1. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

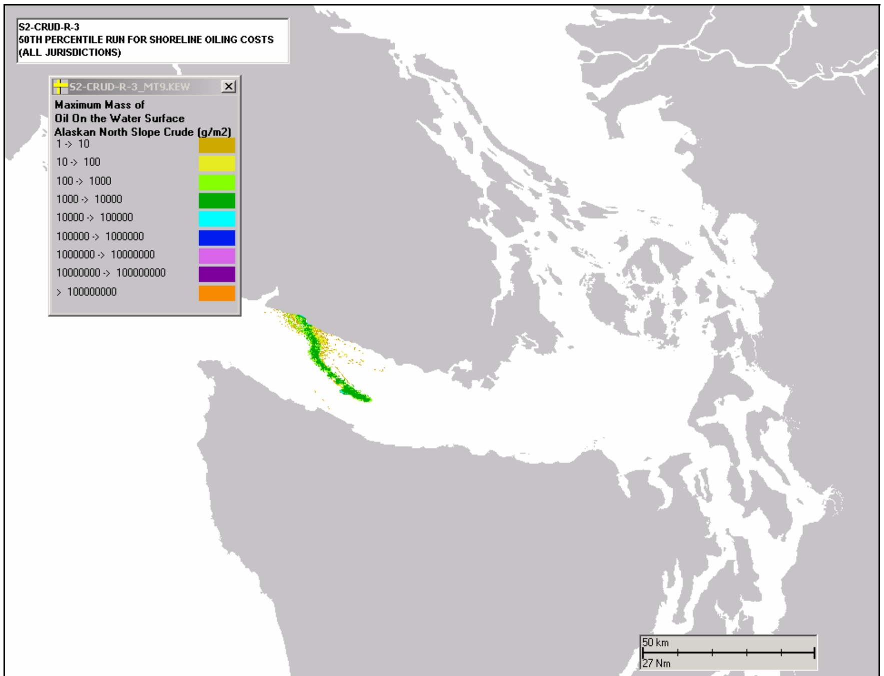


Figure XIV.B.4-2. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

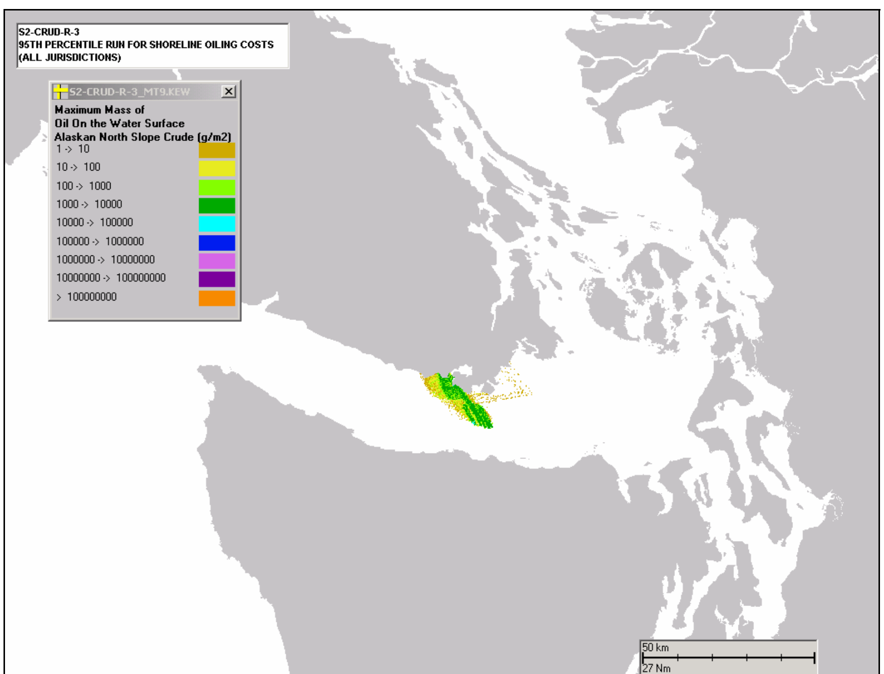


Figure XIV.B.4-3. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

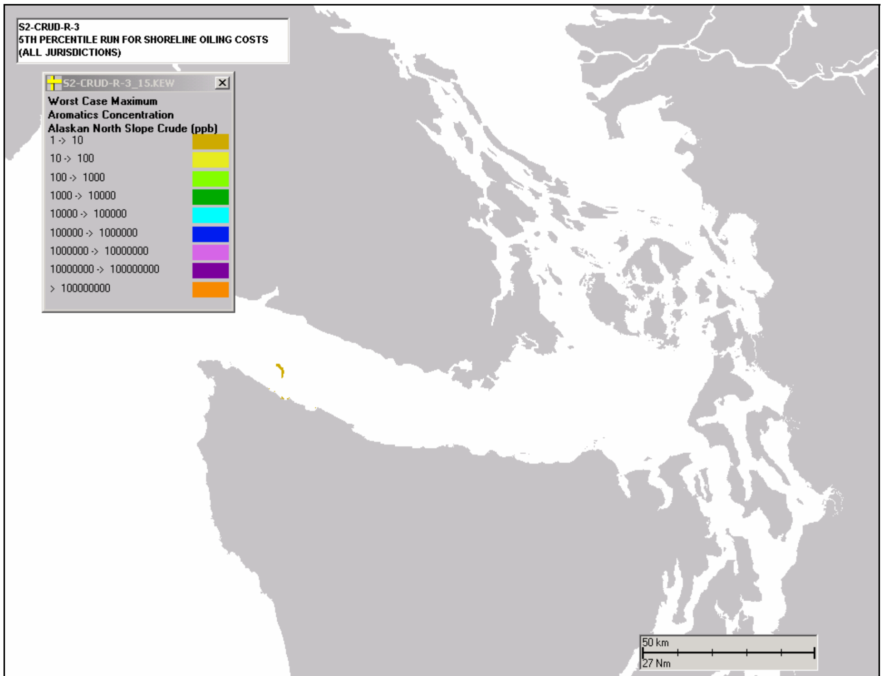


Figure XIV.B.4-4. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

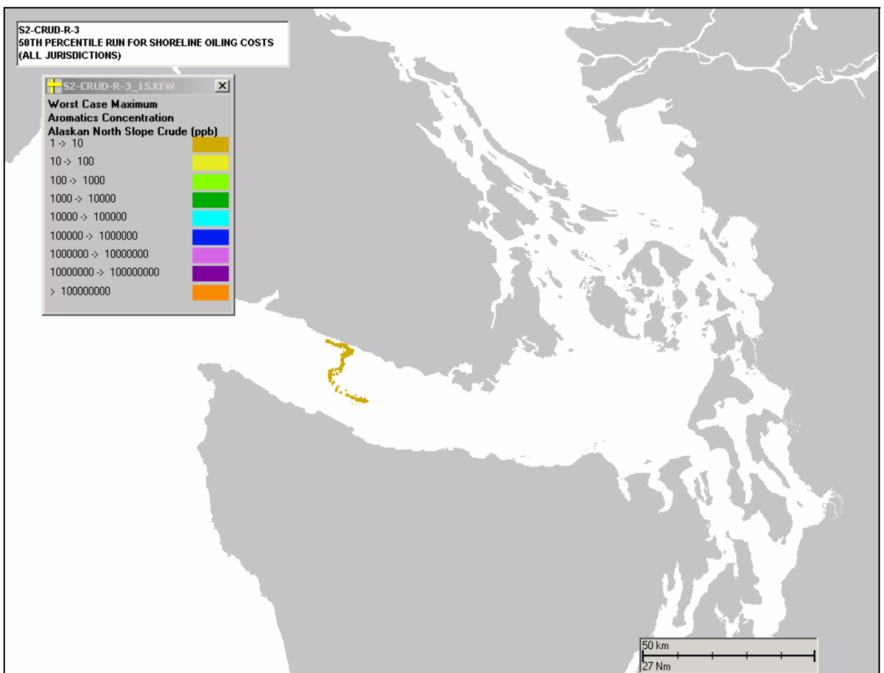


Figure XIV.B.4-5. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

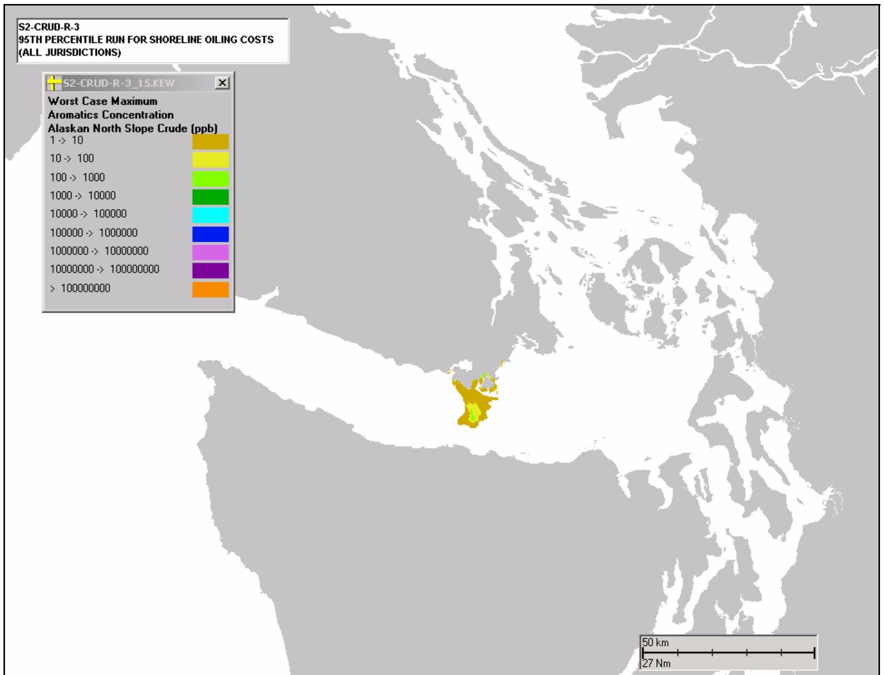


Figure XIV.B.4-6. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

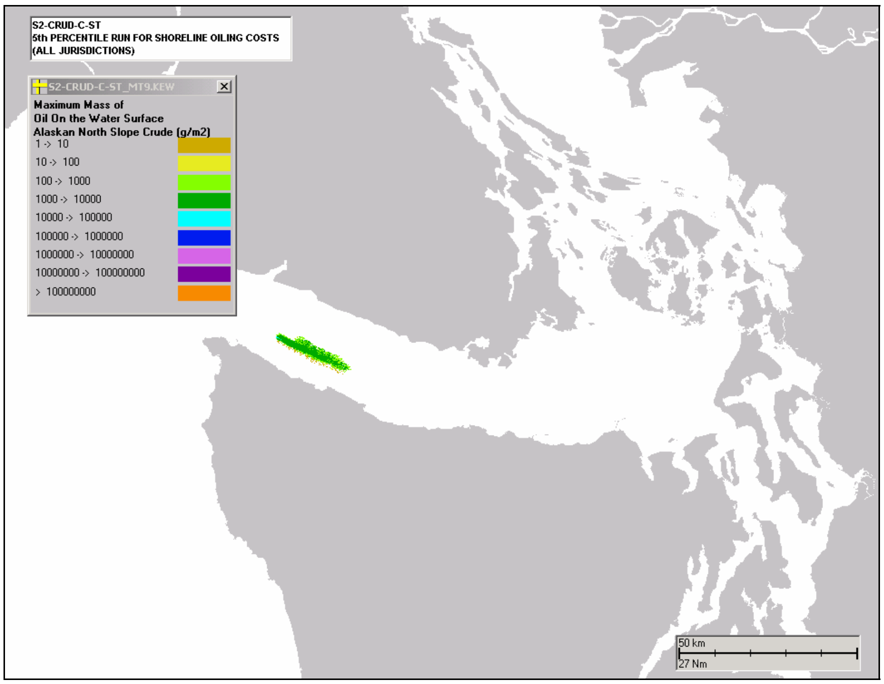


Figure XIV.B.5-1. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

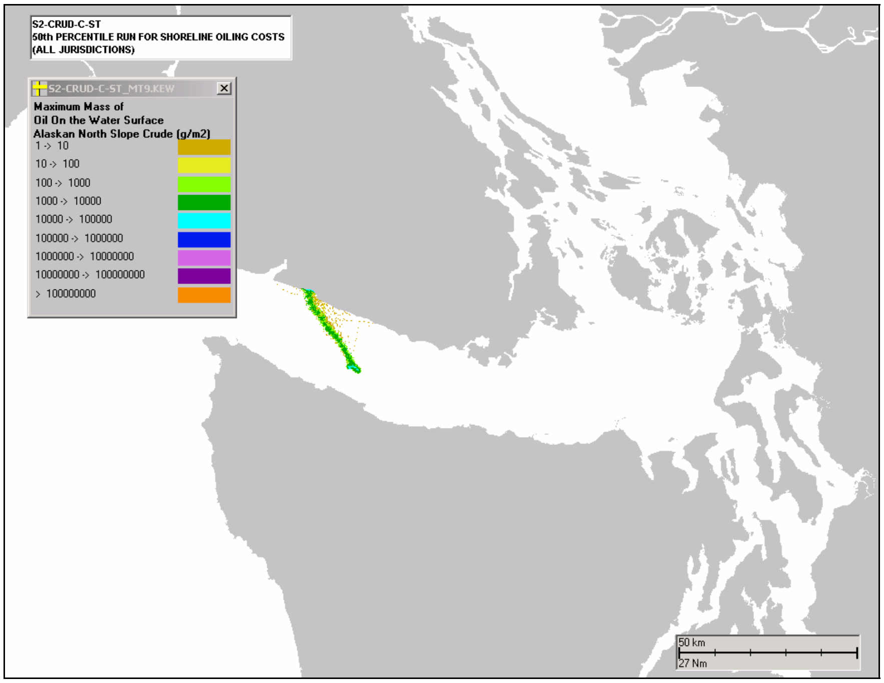


Figure XIV.B.5-2. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

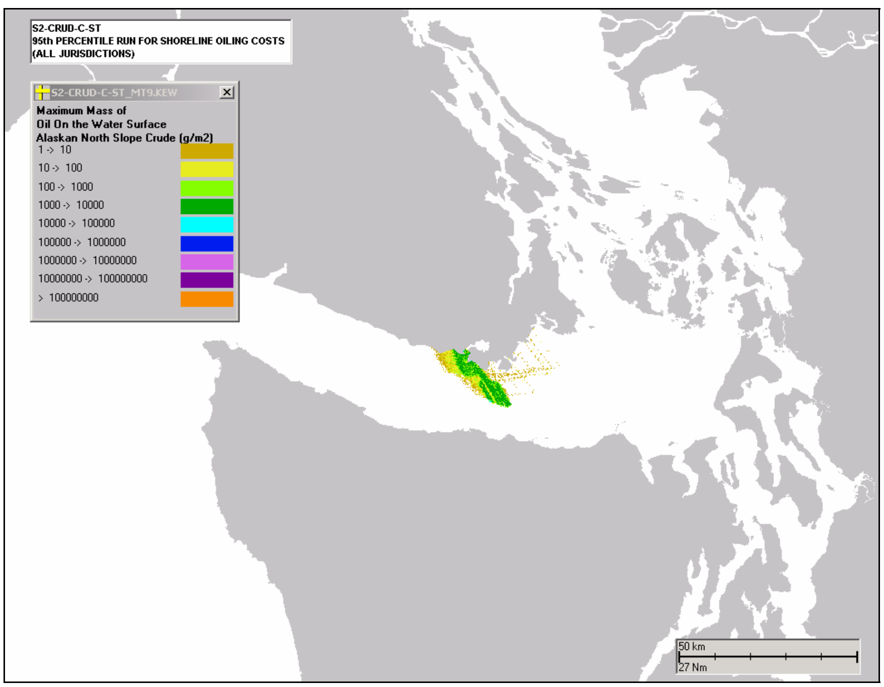


Figure XIV.B.5-3. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

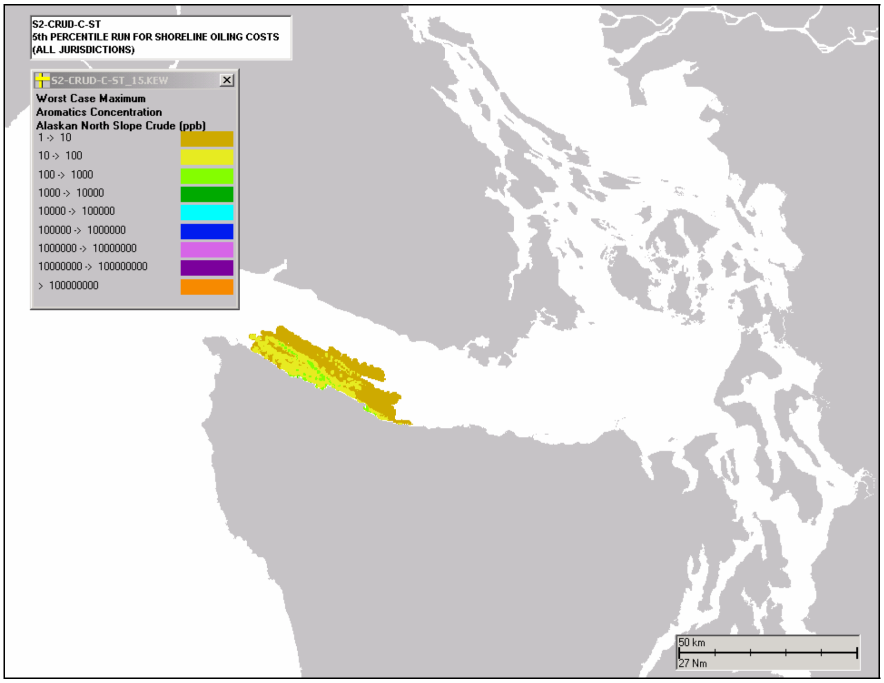


Figure XIV.B.5-4. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

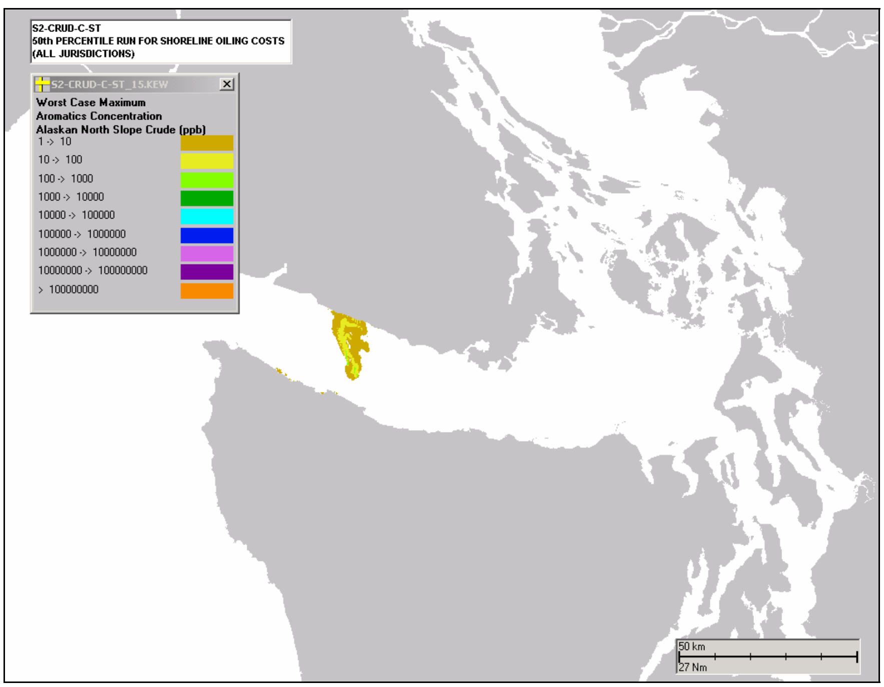


Figure XIV.B.5-5. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

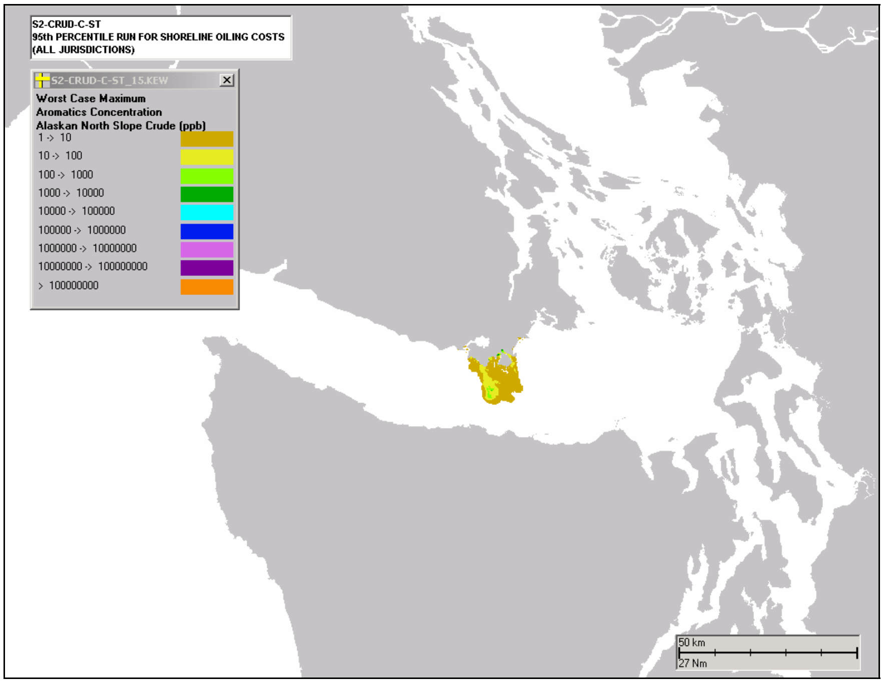


Figure XIV.B.5-6. Strait of Juan de Fuca, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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 5^{th}, 50^{th} and 95^{th} percentile in the base case where no dispersant was applied.

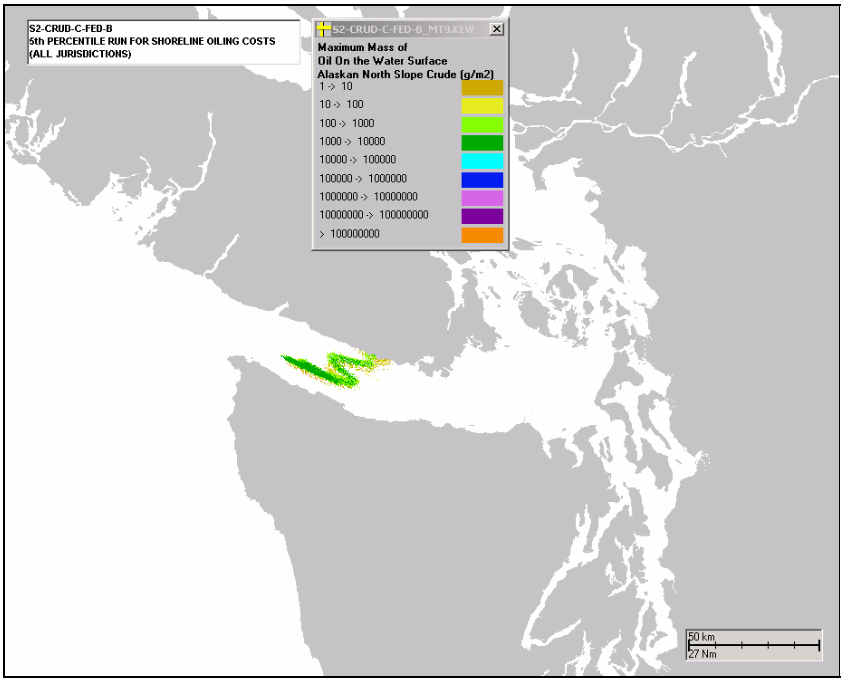


Figure XIV.B.6-1. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

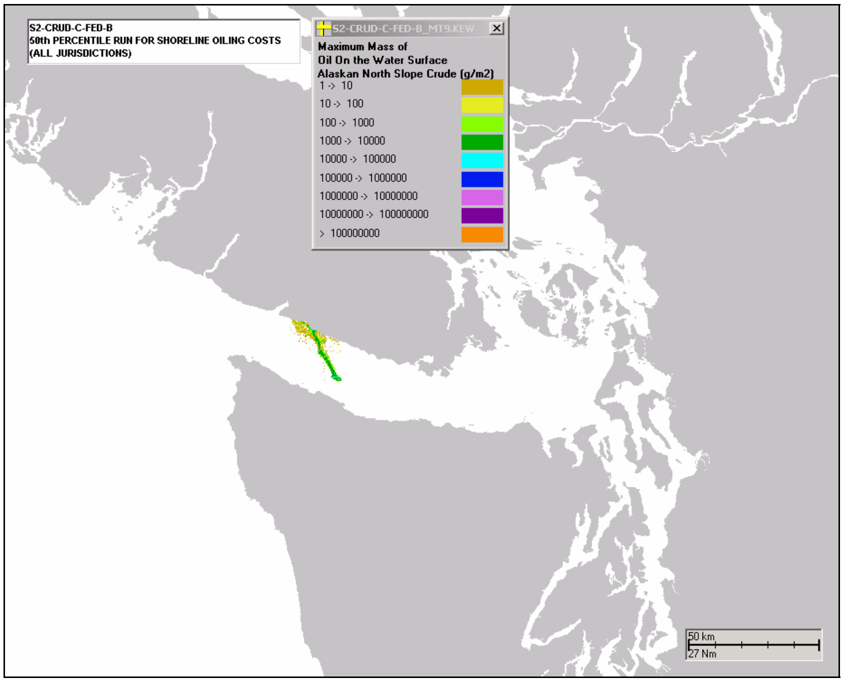


Figure XIV.B.6-2. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50^{th} percentile run based on shoreline costs.

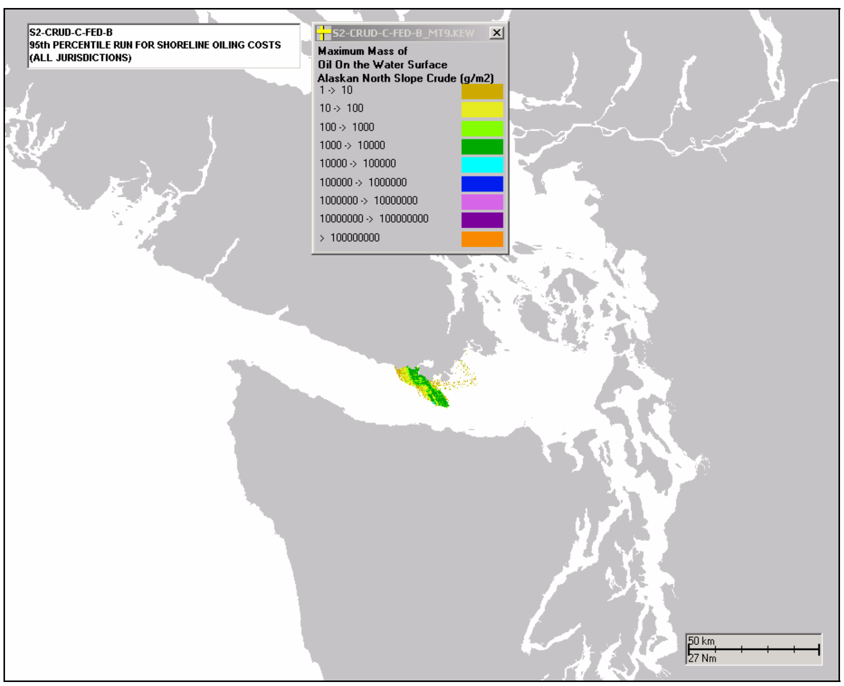


Figure XIV.B.6-3. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

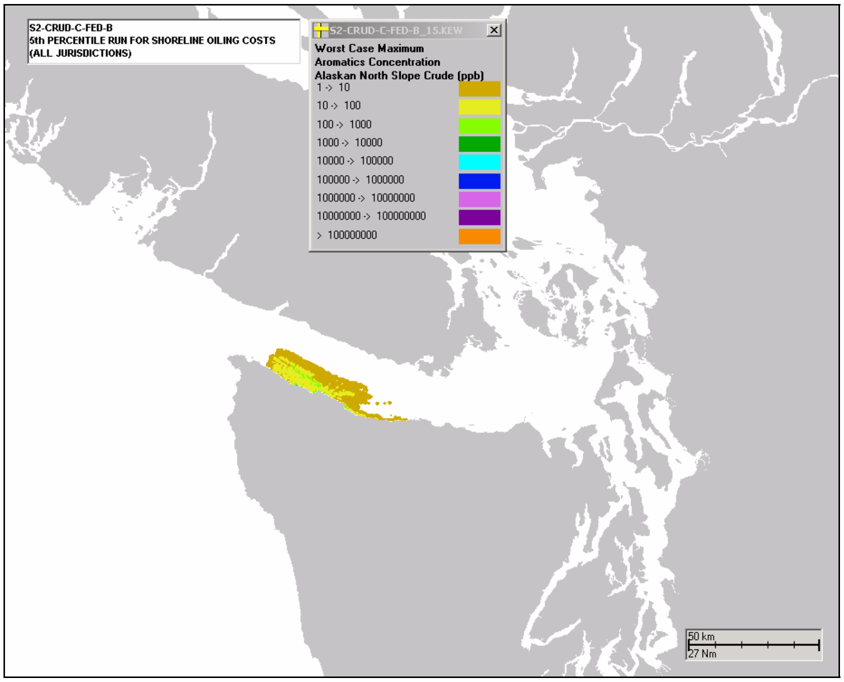


Figure XIV.B.6-4. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

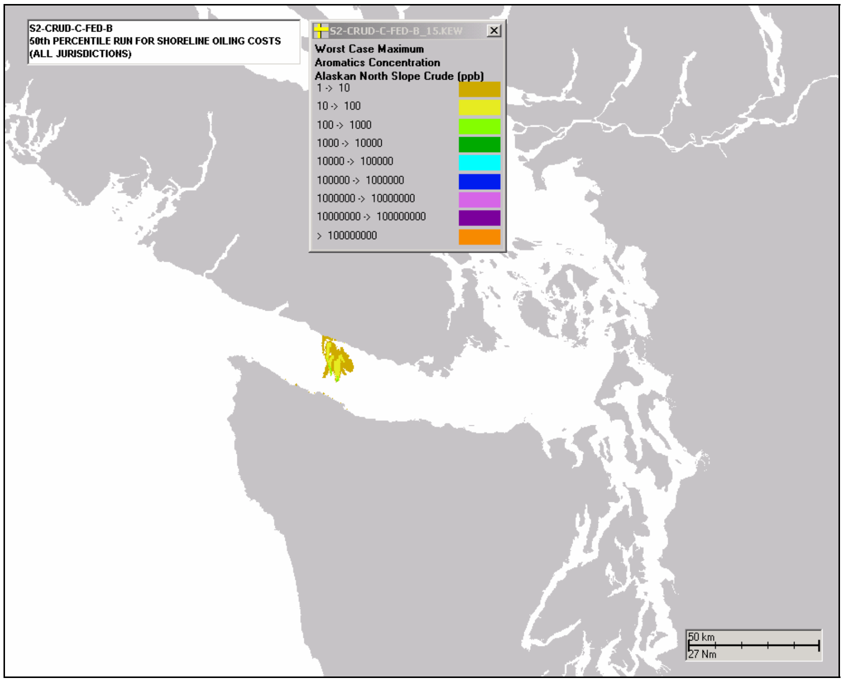


Figure XIV.B.6-5. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

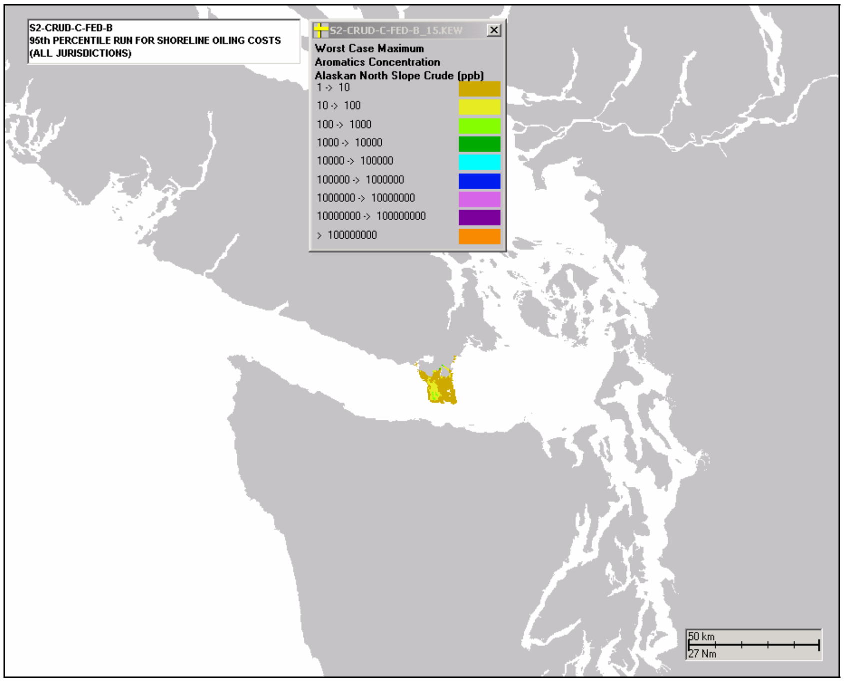


Figure XIV.B.6-6. Strait of Juan de Fuca, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

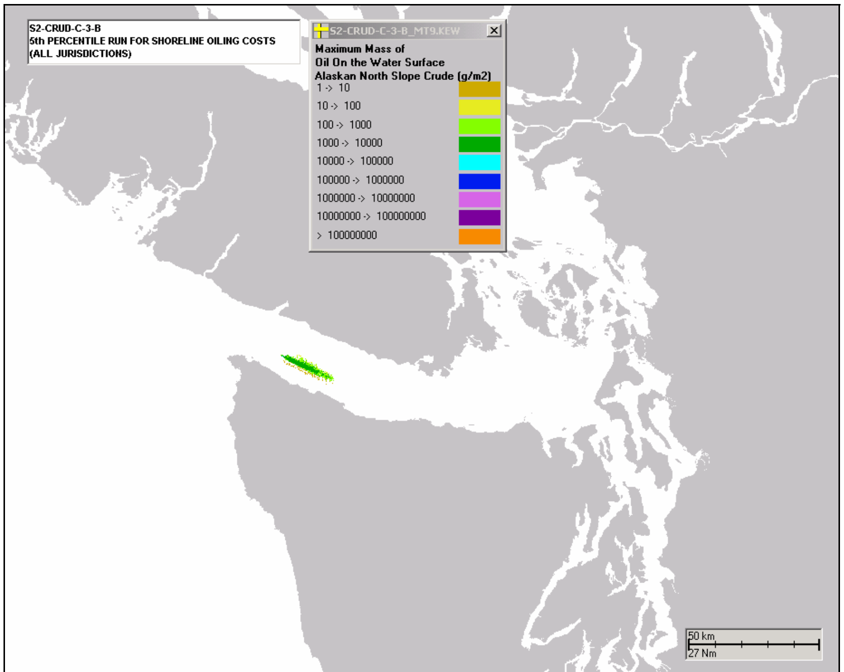


Figure XIV.B.7-1. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

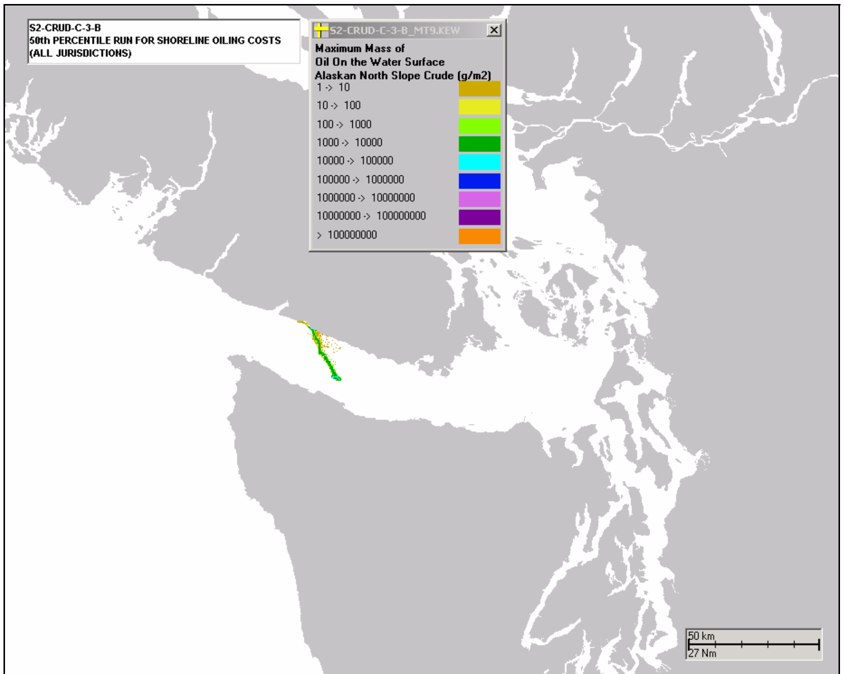


Figure XIV.B.7-2. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

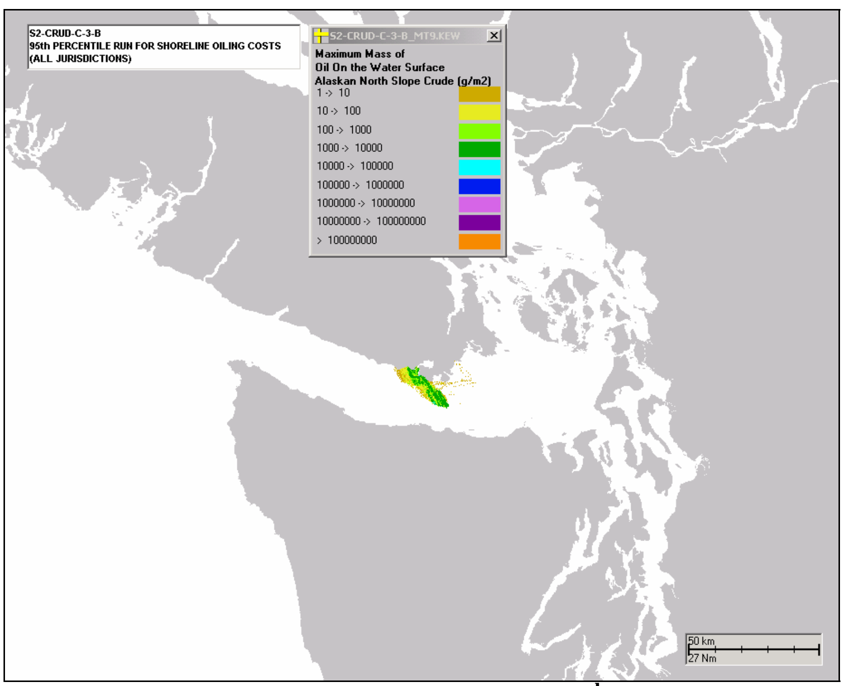


Figure XIV.B.7-3. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

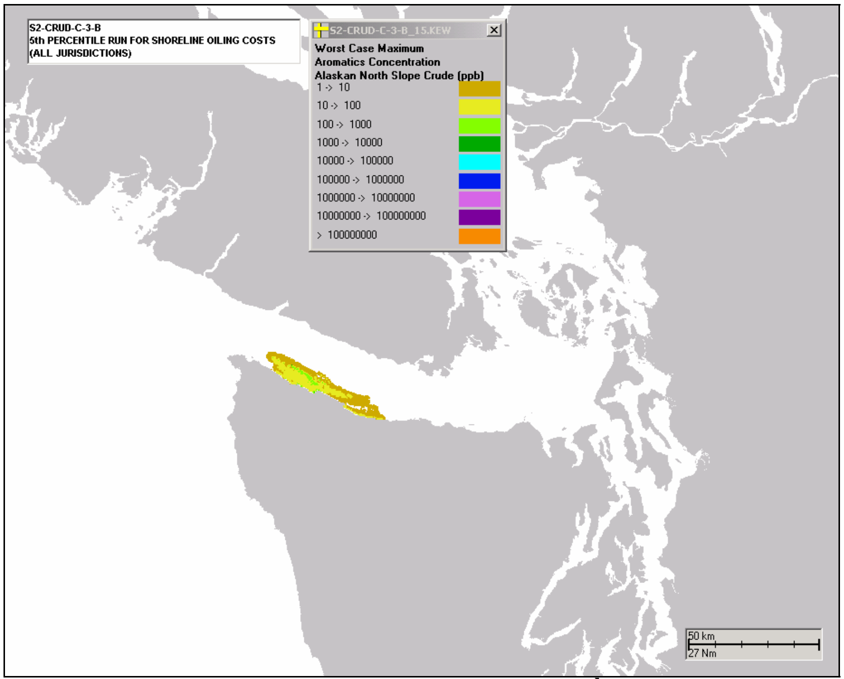


Figure XIV.B.7-4. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

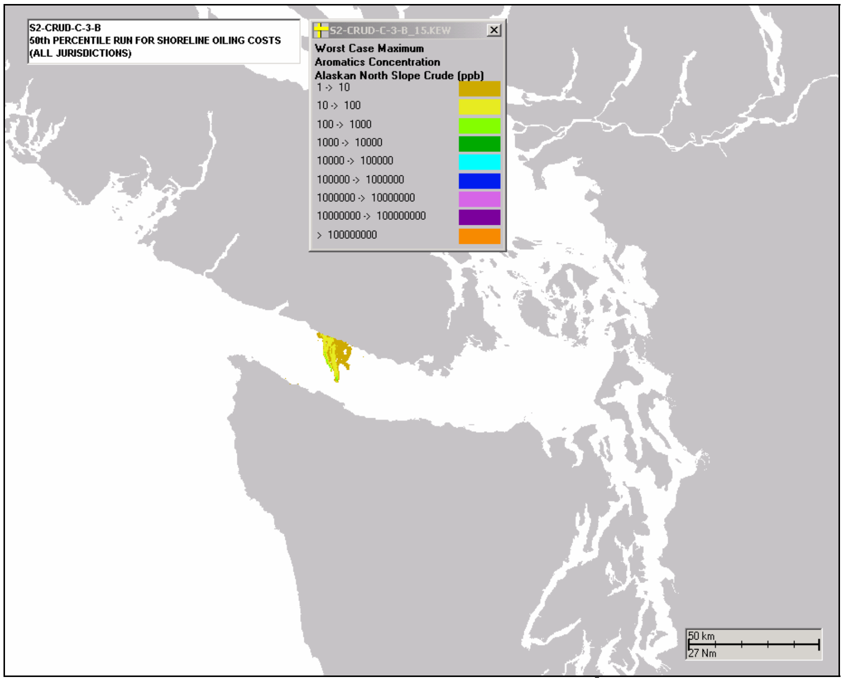


Figure XIV.B.7-5. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

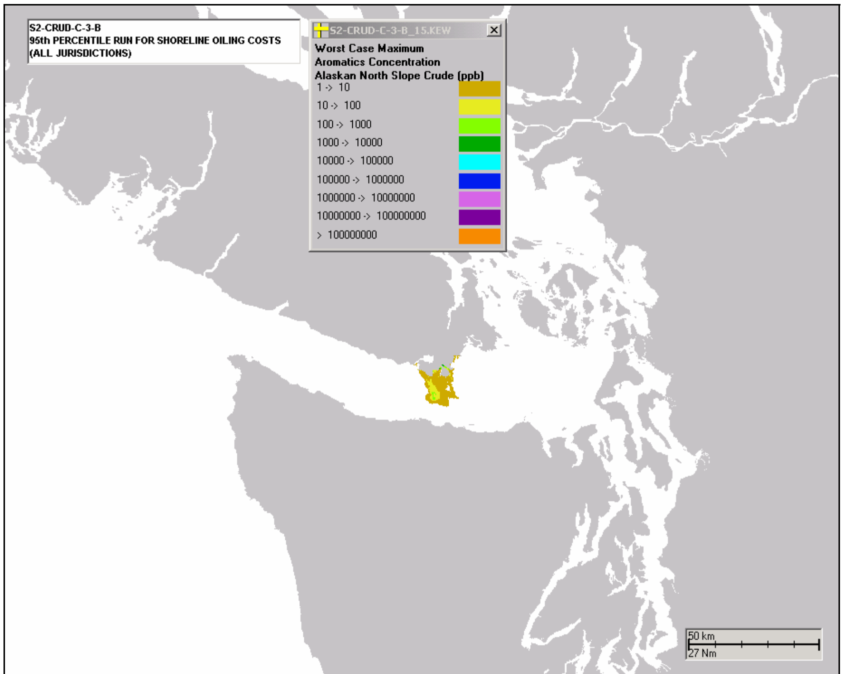


Figure XIV.B.7-6. Strait of Juan de Fuca, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

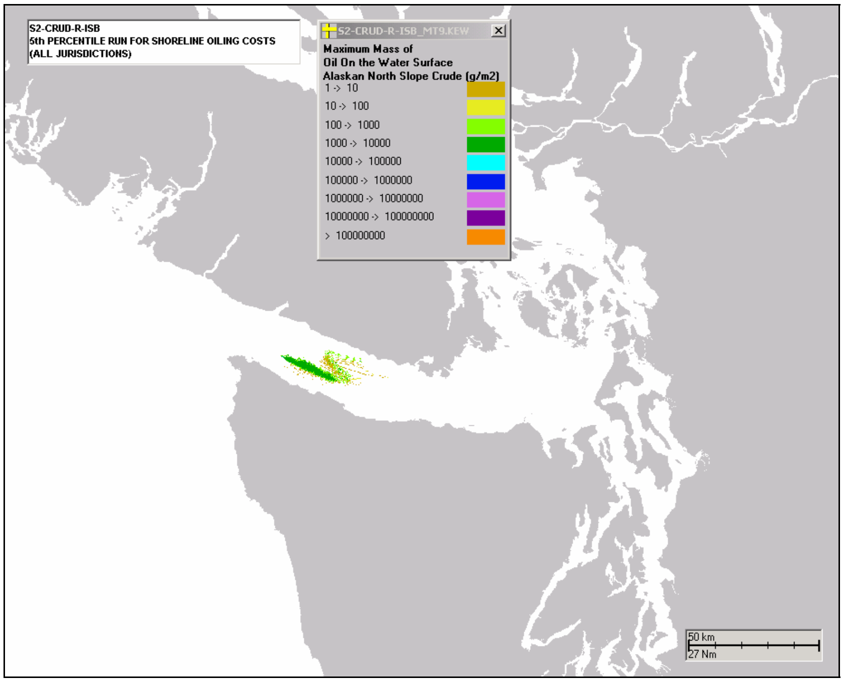


Figure XIV.B.8-1. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Water surface exposure to floating hydrocarbons (g/m²) for the 5th percentile run based on shoreline costs.

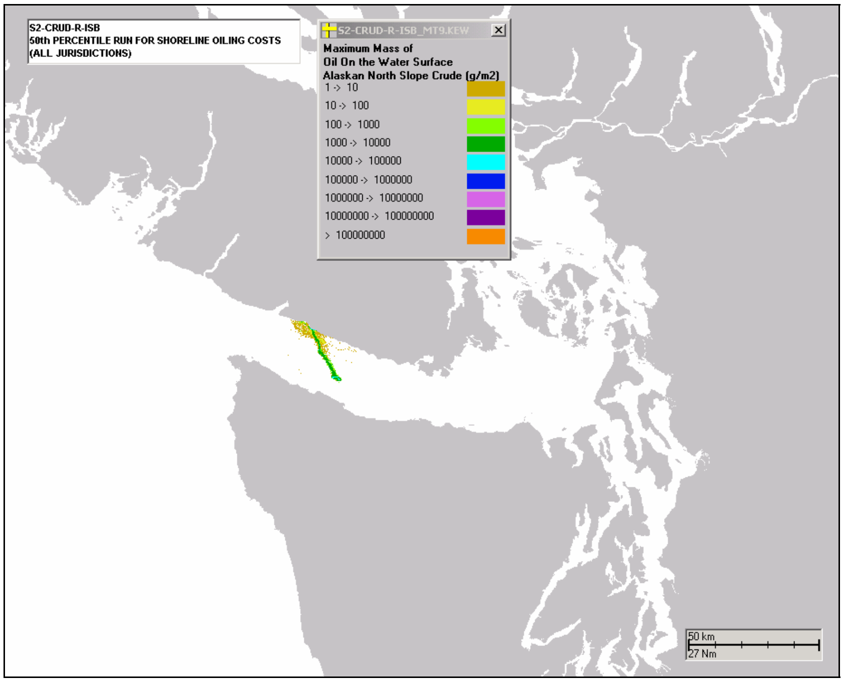


Figure XIV.B.8-2. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

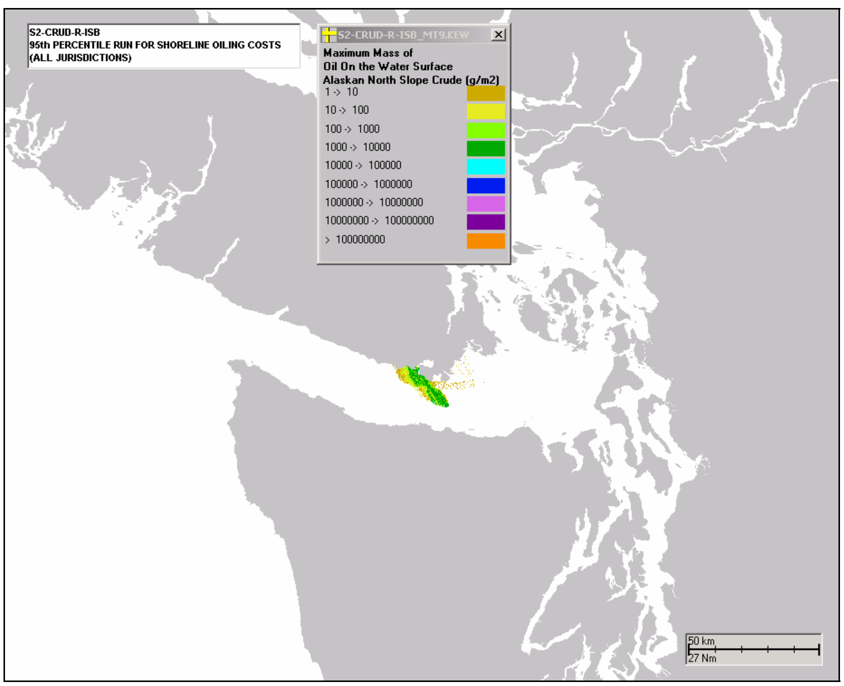


Figure XIV.B.8-3. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

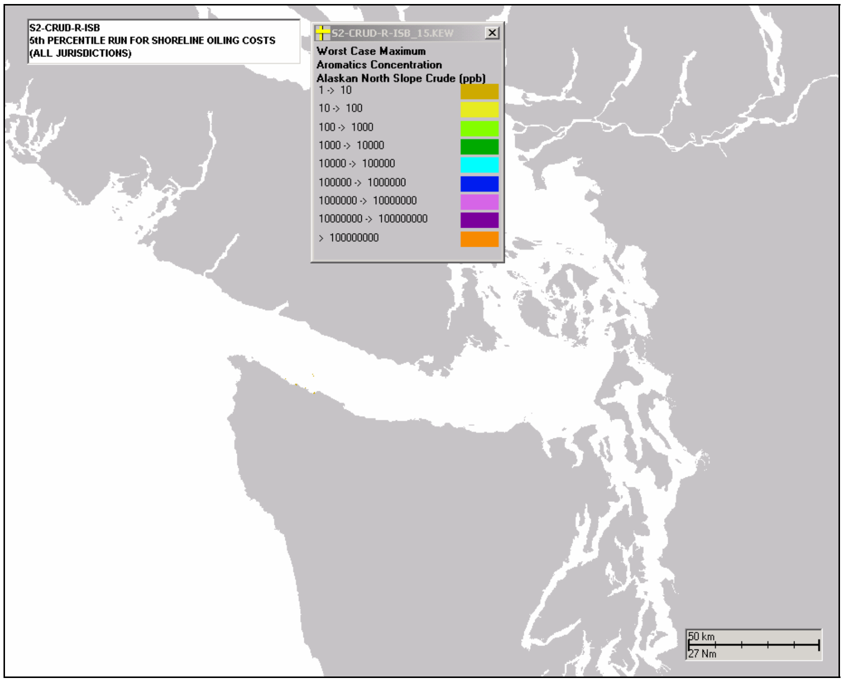


Figure XIV.B.8-4. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

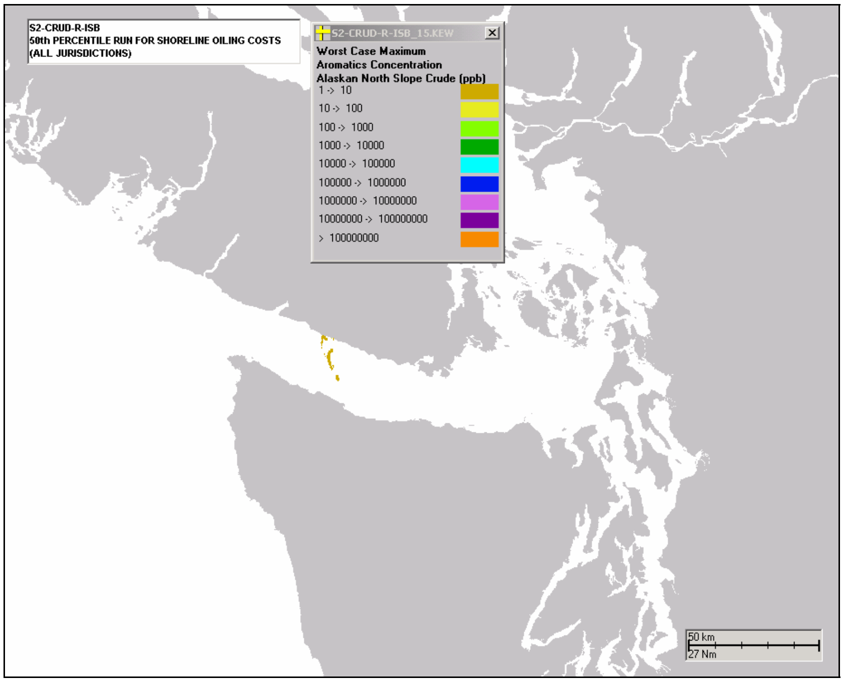


Figure XIV.B.8-5. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

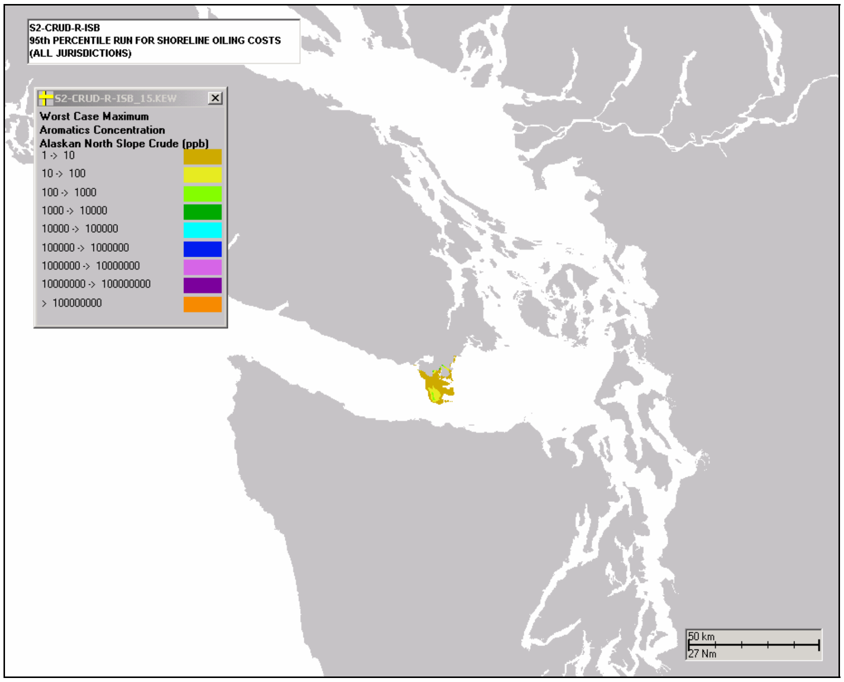


Figure XIV.B.8-6. Strait of Juan de Fuca, crude oil, state mechanical removal, in situ burning: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

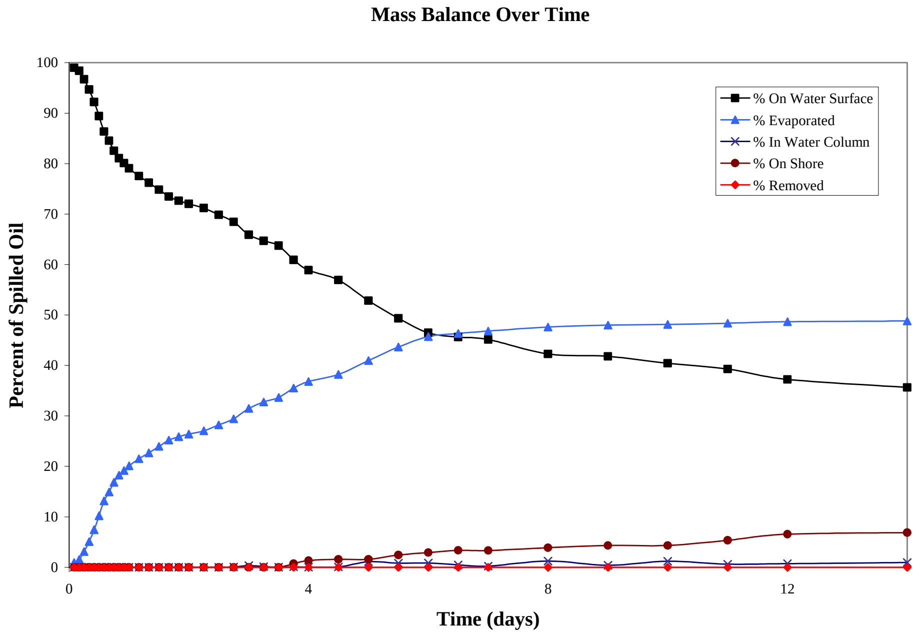


Figure XIV.B.9-1 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

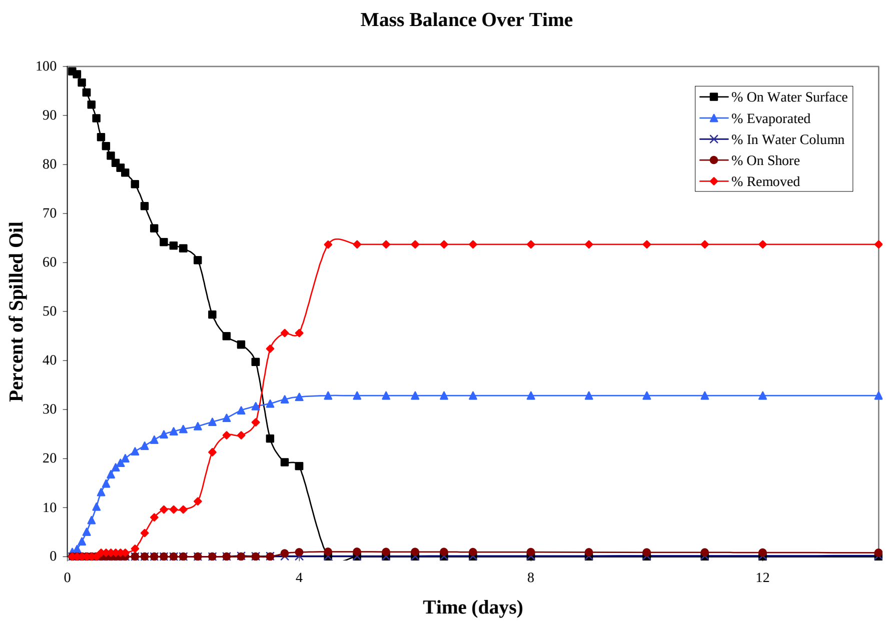


Figure XIV.B.9-2 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

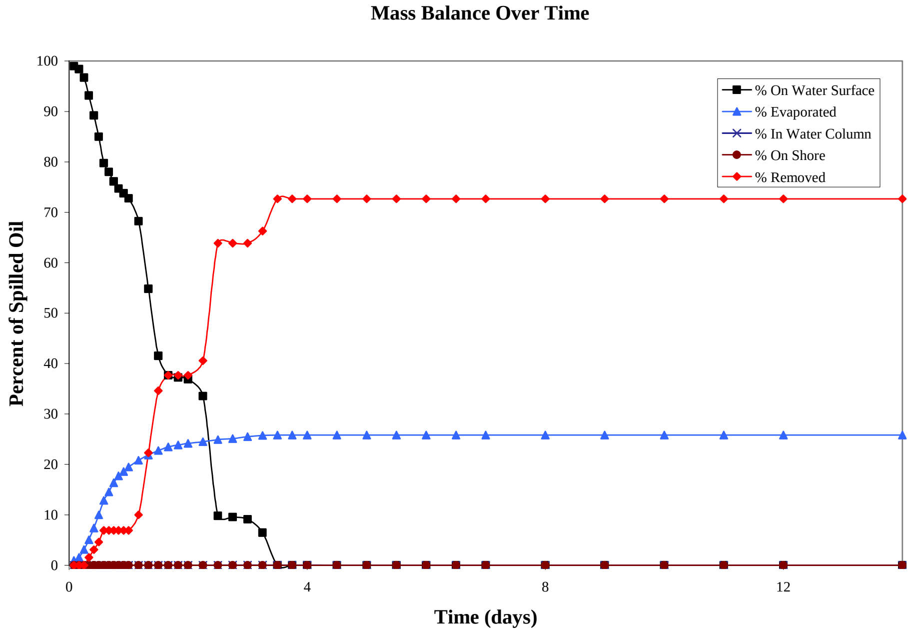


Figure XIV.B.9-3 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

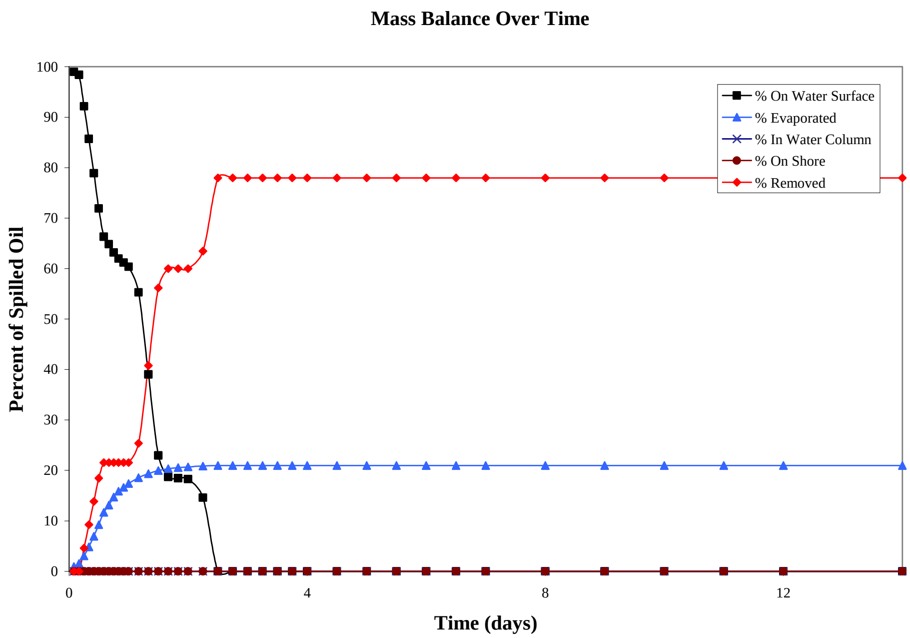


Figure XIV.B.9-4 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

Mass Balance Over Time

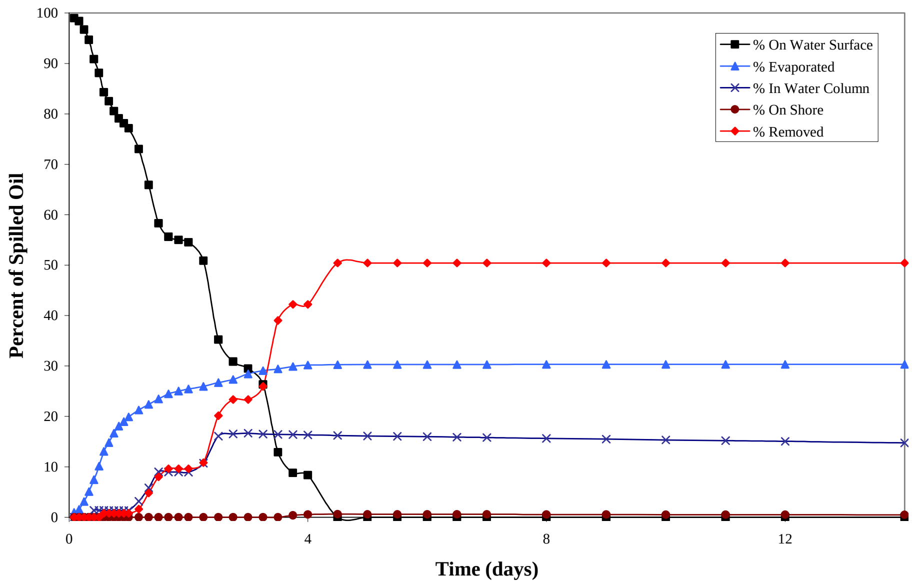


Figure XIV.B.9-5 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

Mass Balance Over Time

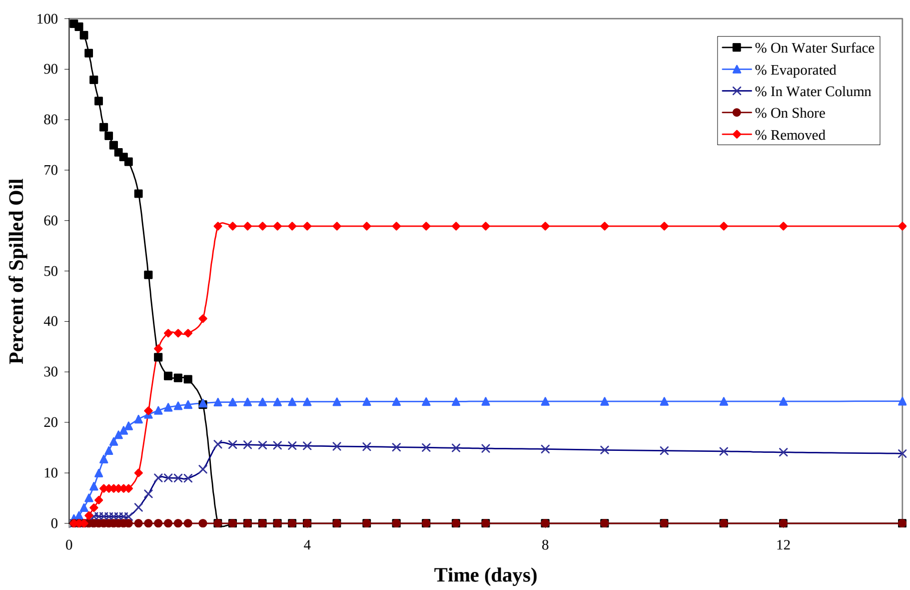


Figure XIV.B.9-6 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

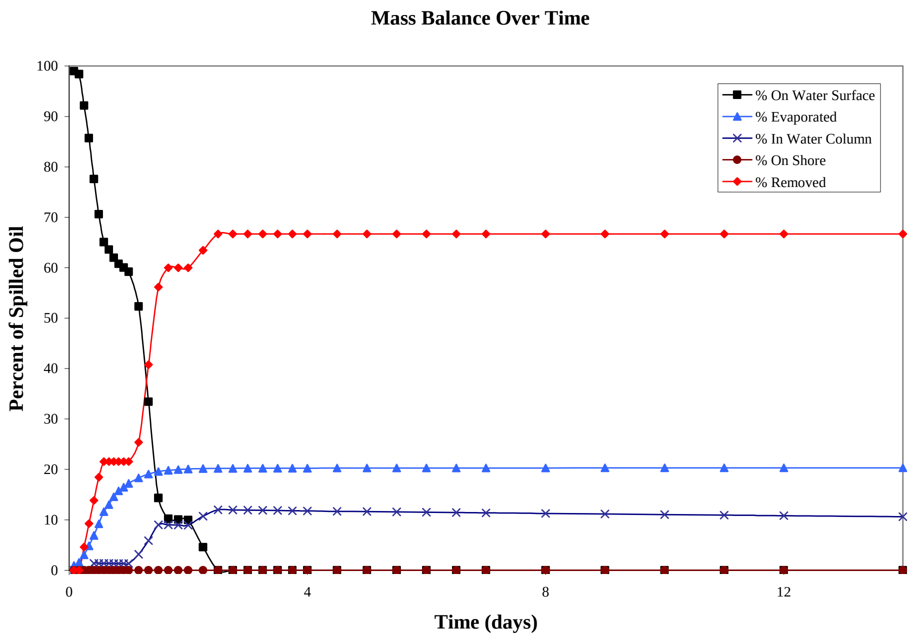


Figure XIV.B.9-7 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

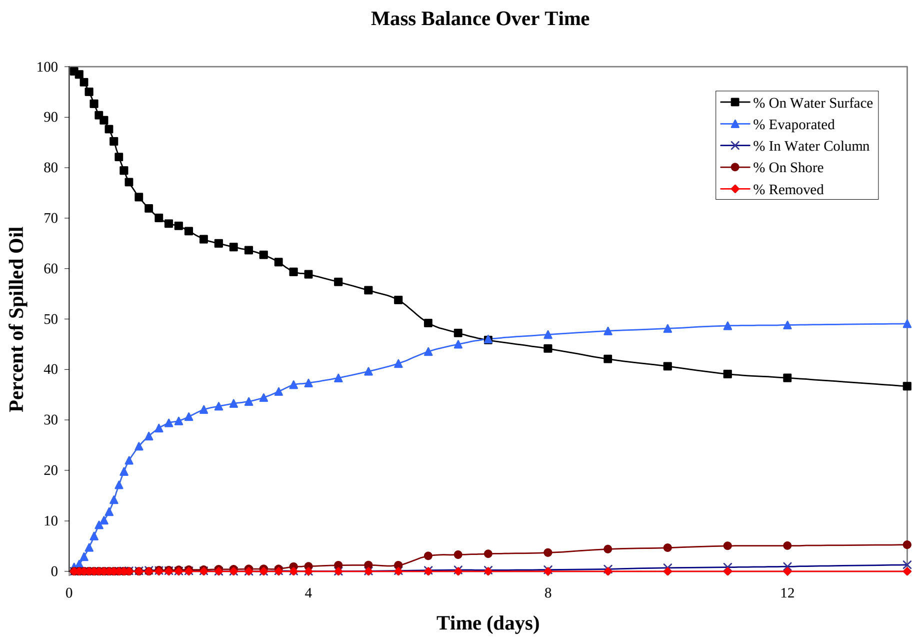


Figure XIV.B.9-8 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Mass Balance Over Time

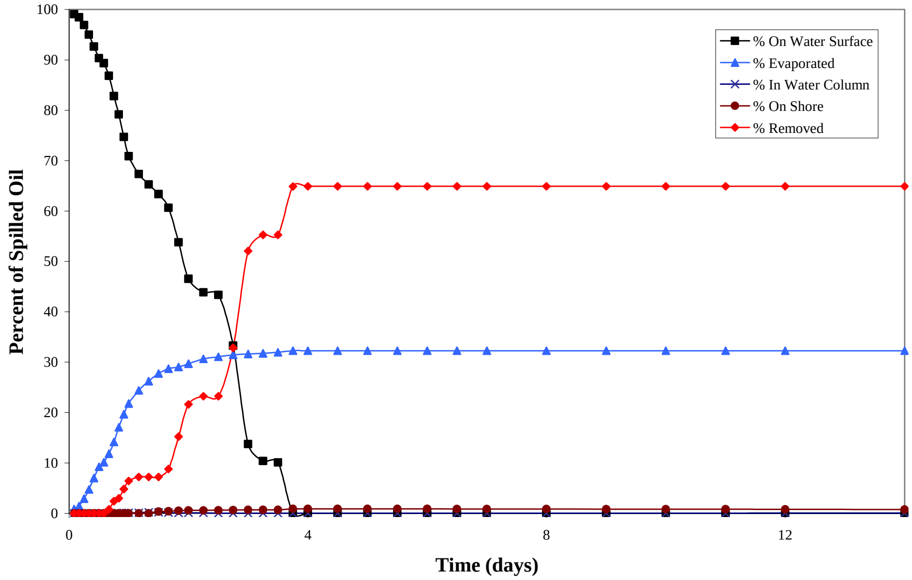


Figure XIV.B.9-9 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Mass Balance Over Time

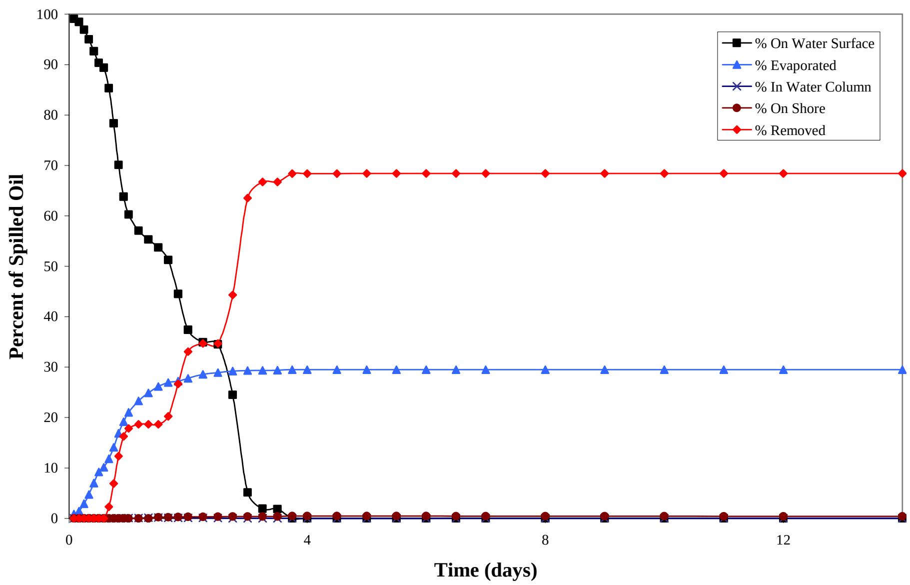


Figure XIV.B.9-10 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

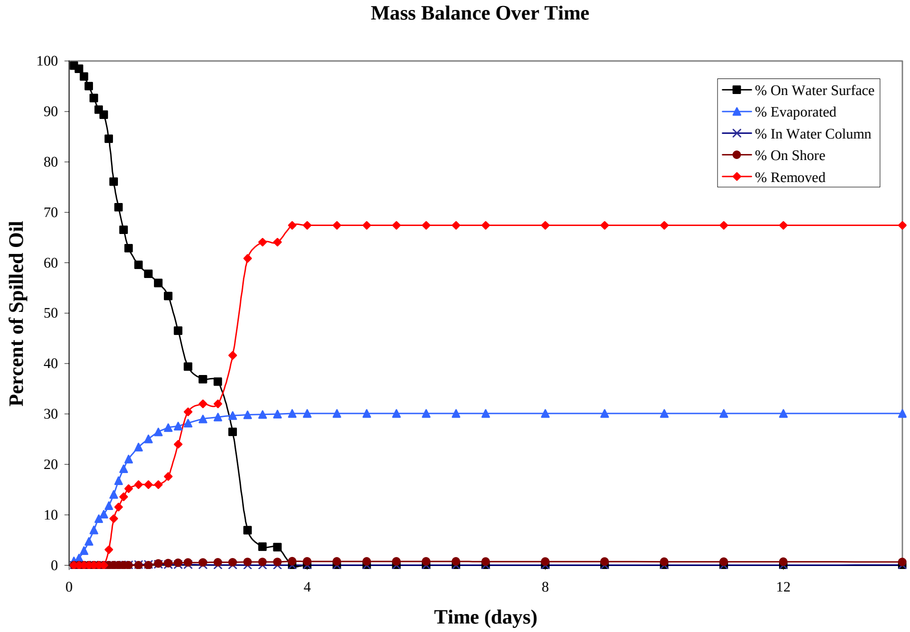


Figure XIV.B.9-11 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

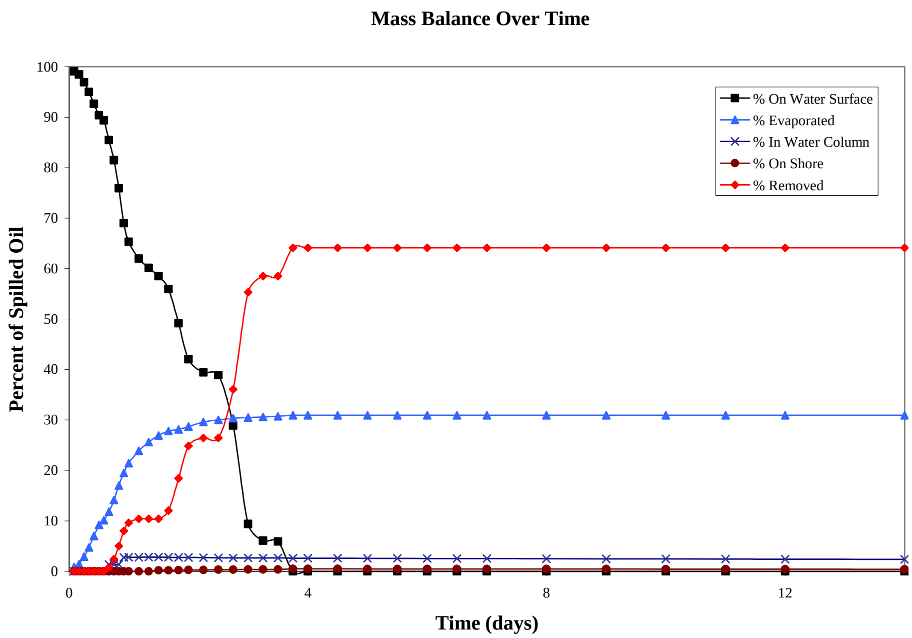


Figure XIV.B.9-12 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

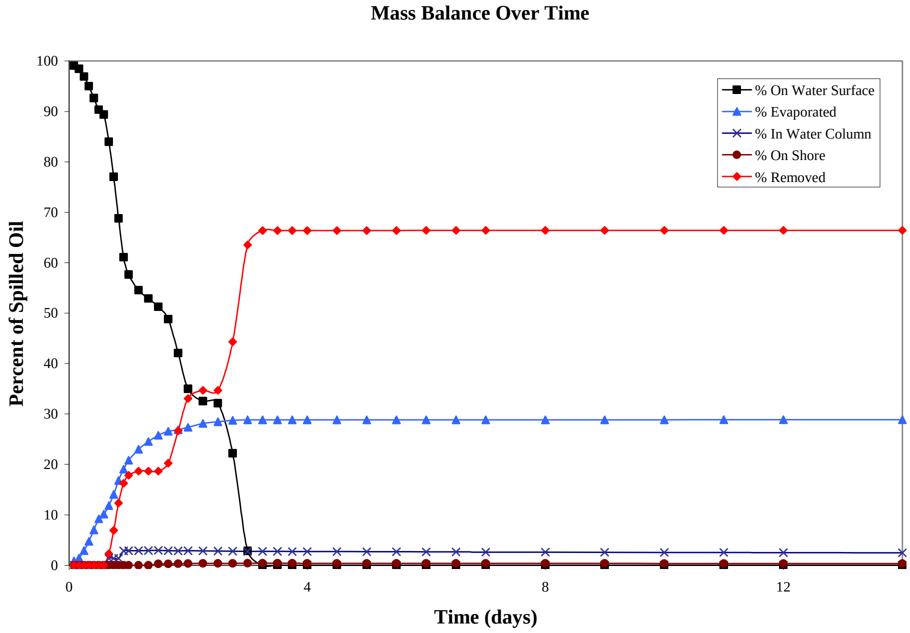


Figure XIV.B.9-13 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

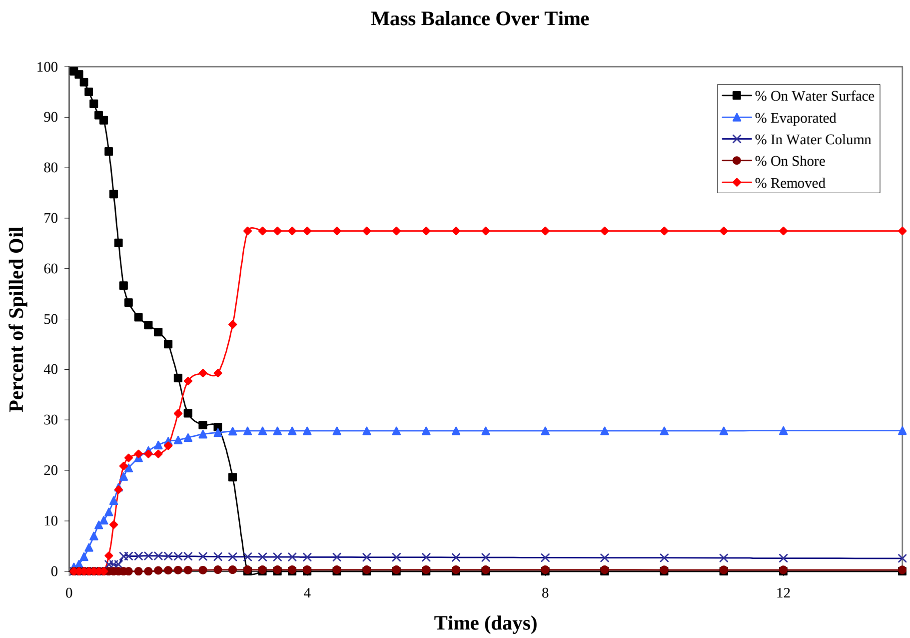


Figure XIV.B.9-14 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

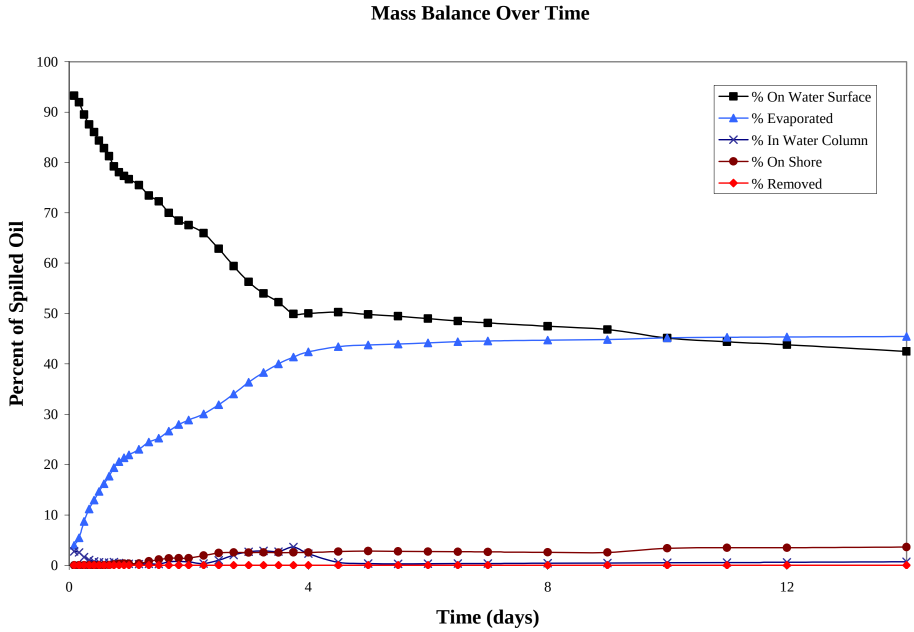


Figure XIV.B.9-15 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

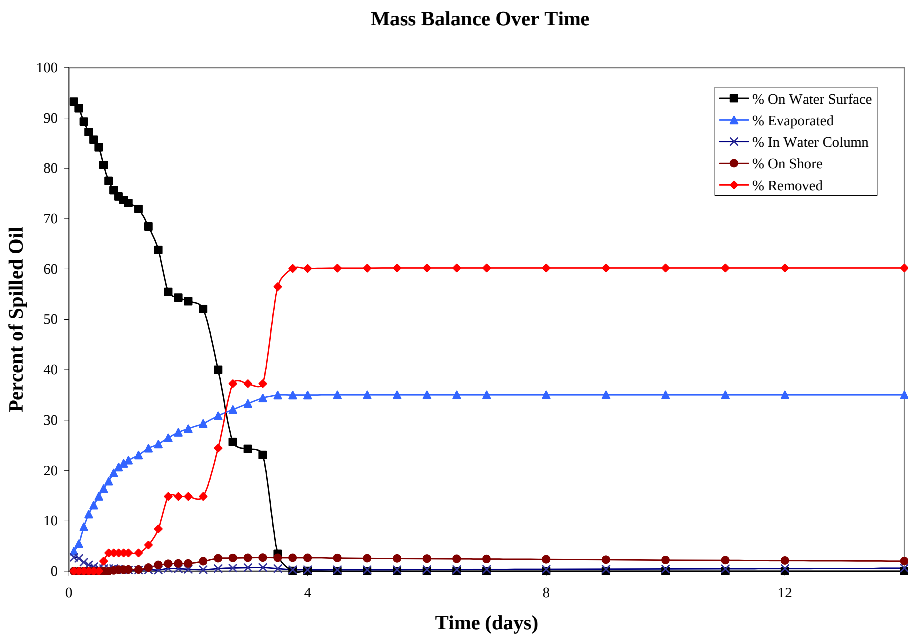


Figure XIV.B.9-16 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

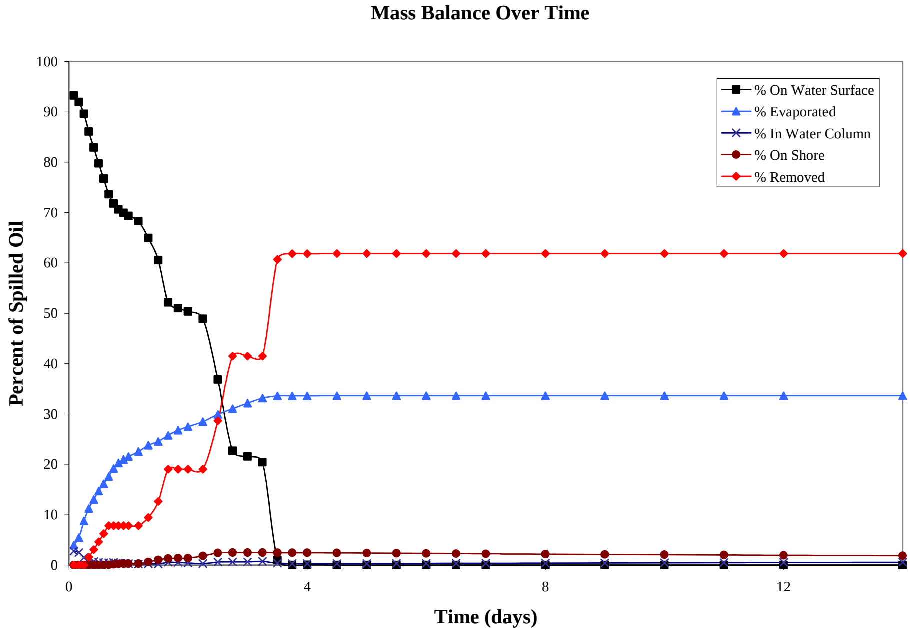


Figure XIV.B.9-17 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

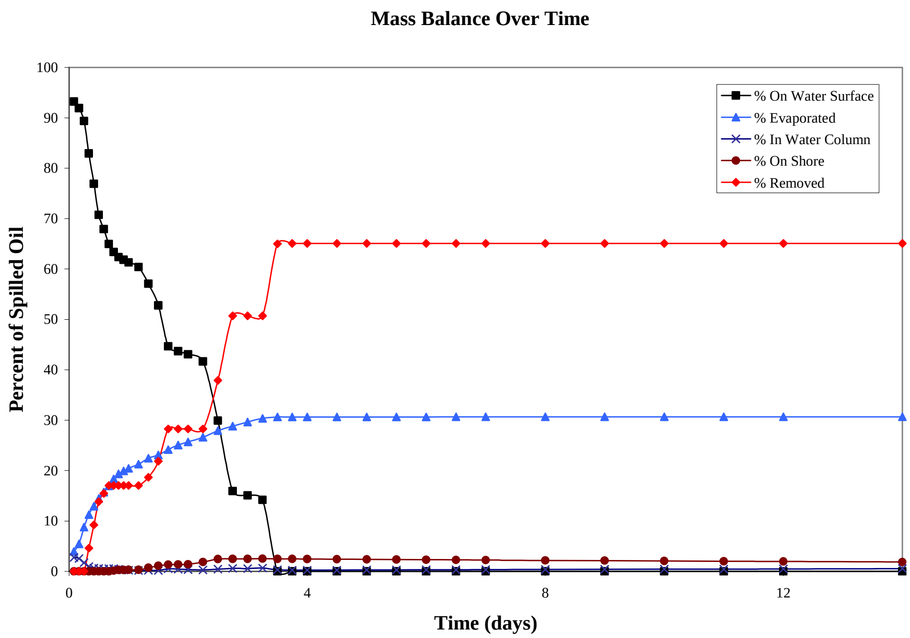


Figure XIV.B.9-18 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

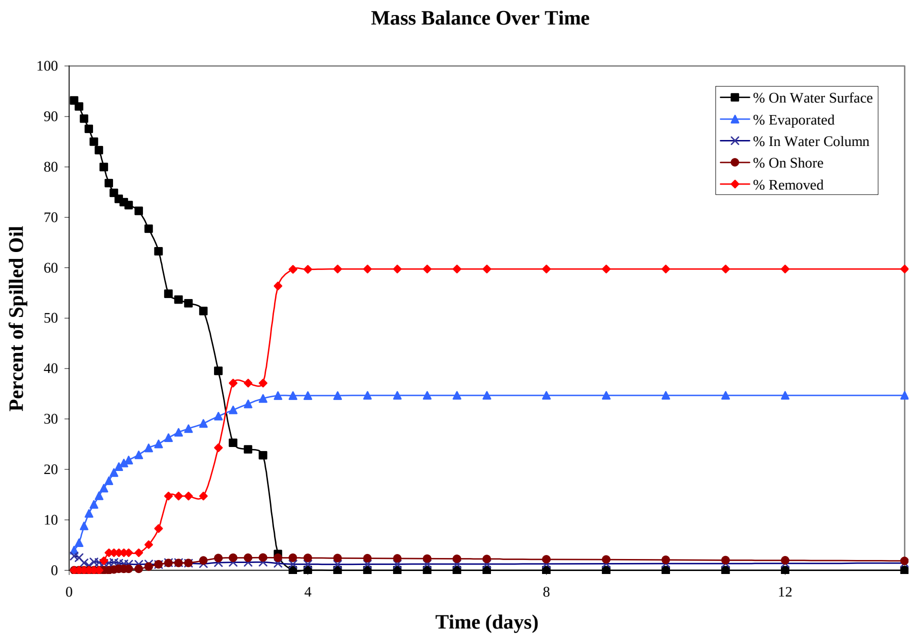


Figure XIV.B.9-19 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

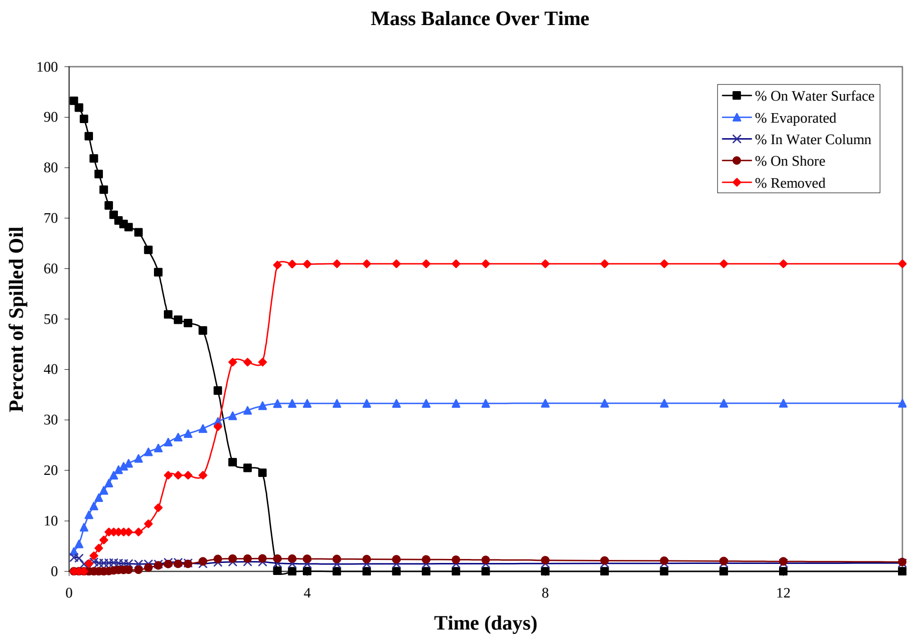


Figure XIV.B.9-20 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

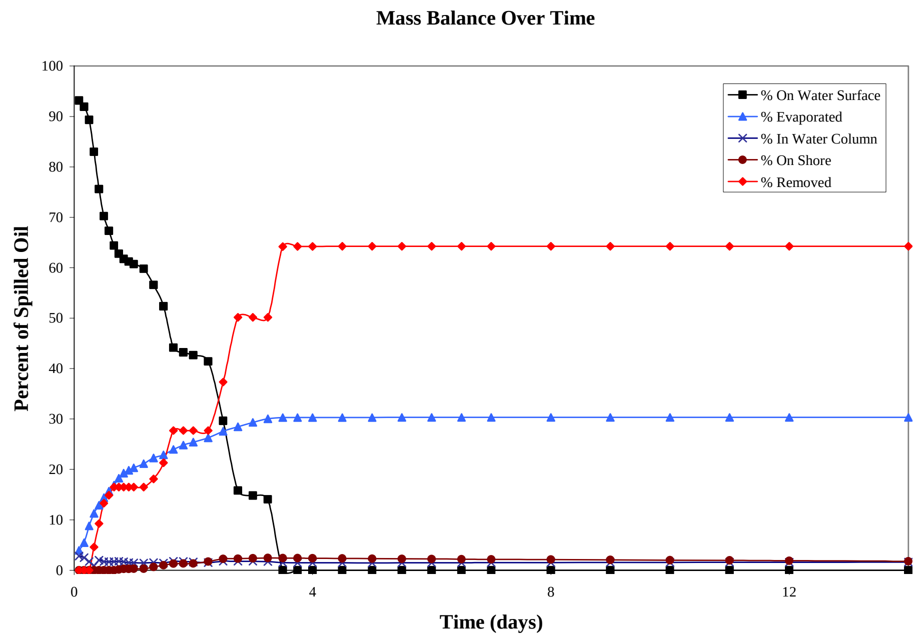
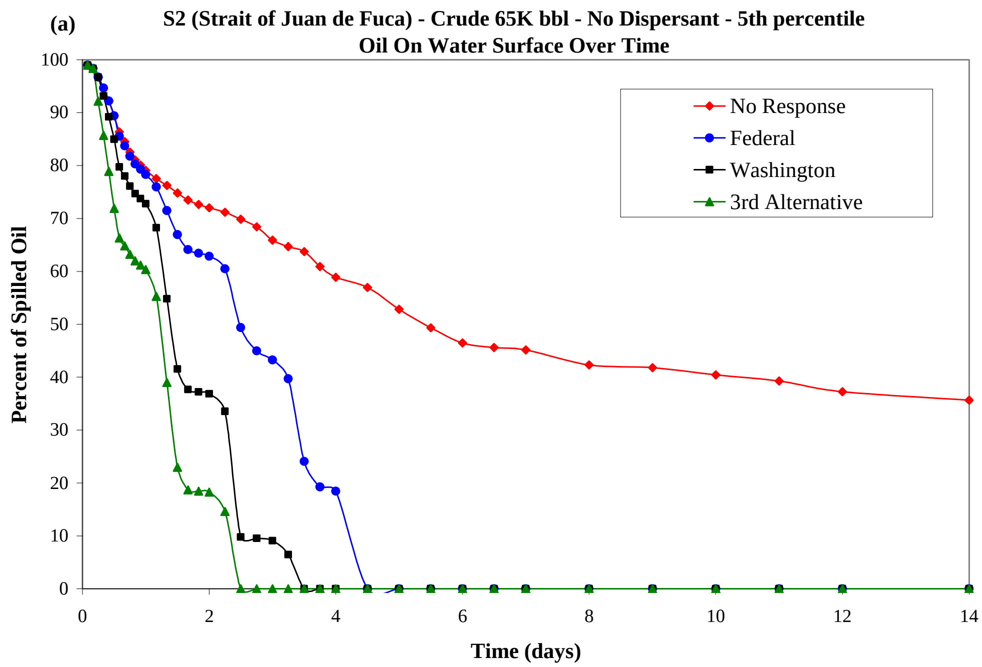


Figure XIV.B.9-21 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).



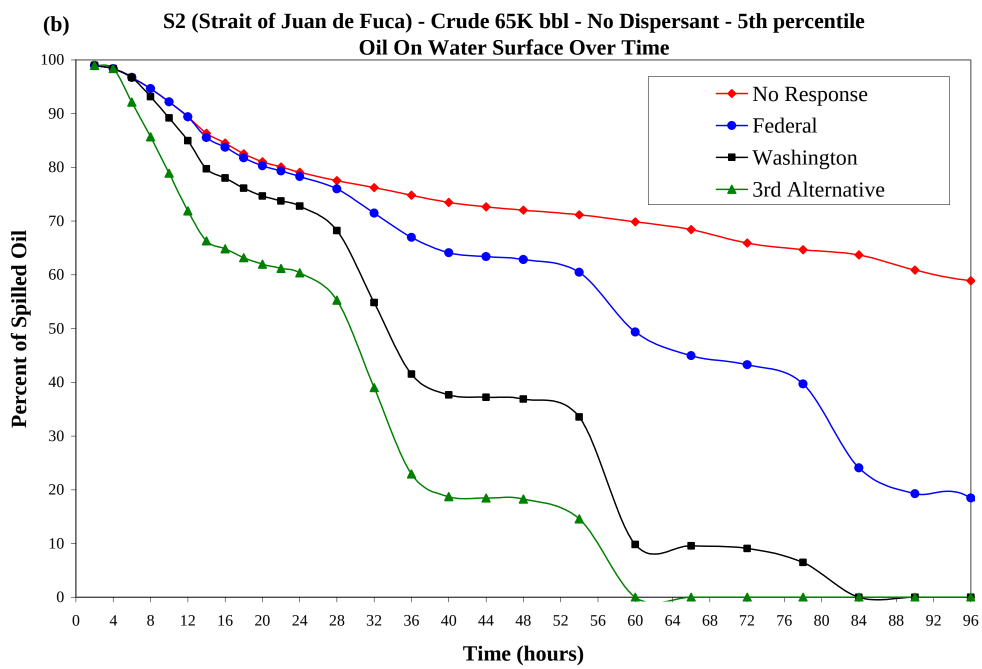
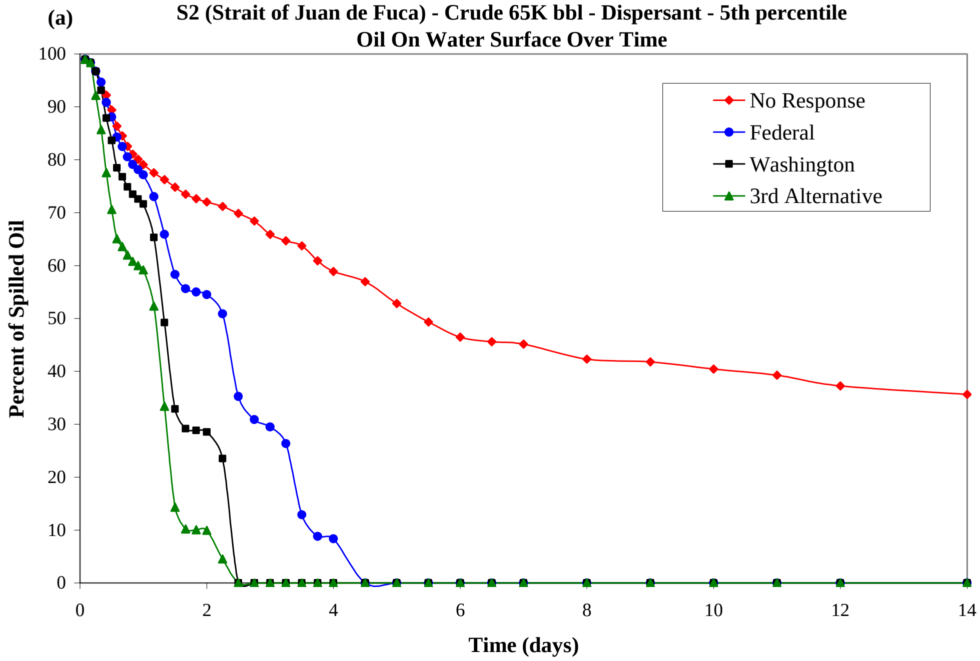


Figure XIV.B.9-22 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



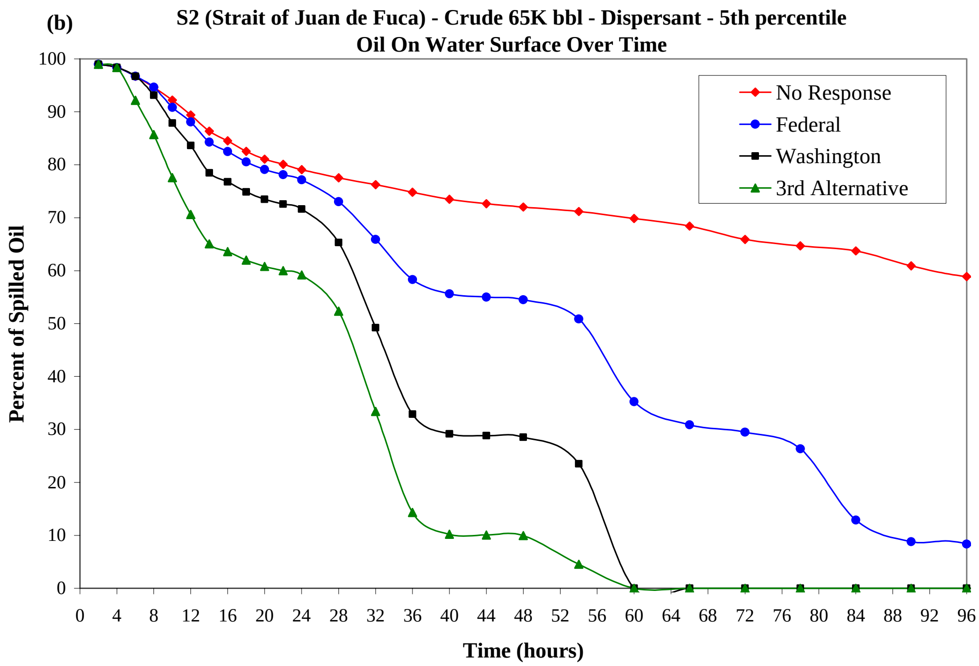
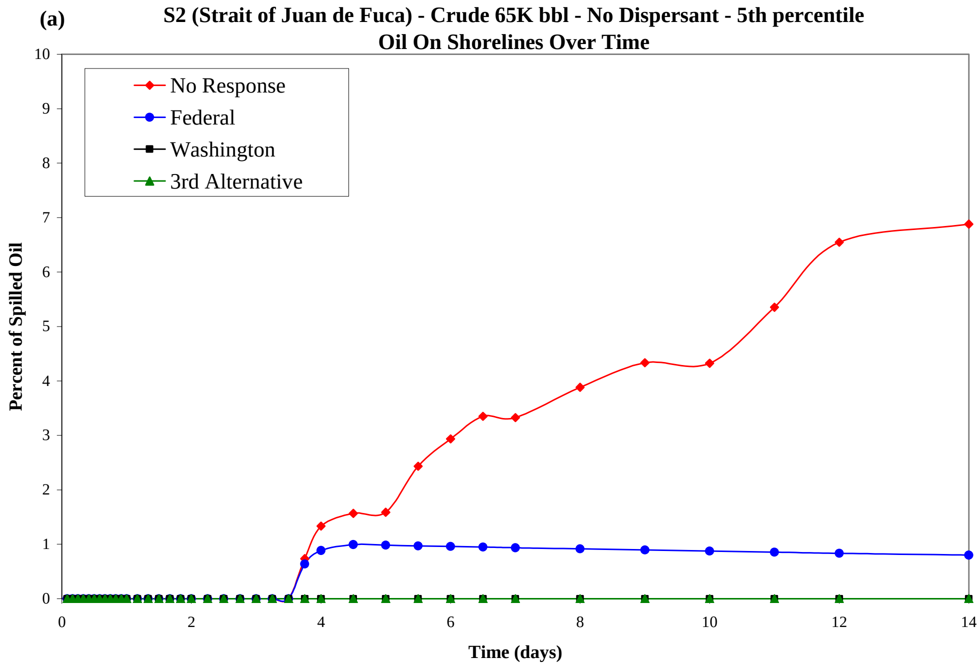


Figure XIV.B.9-23Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



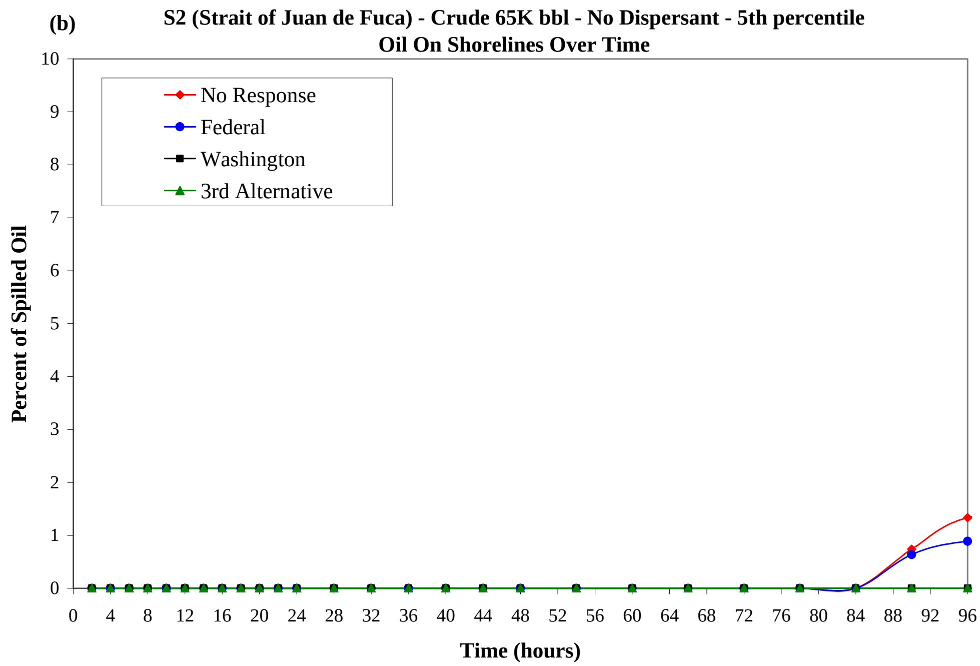
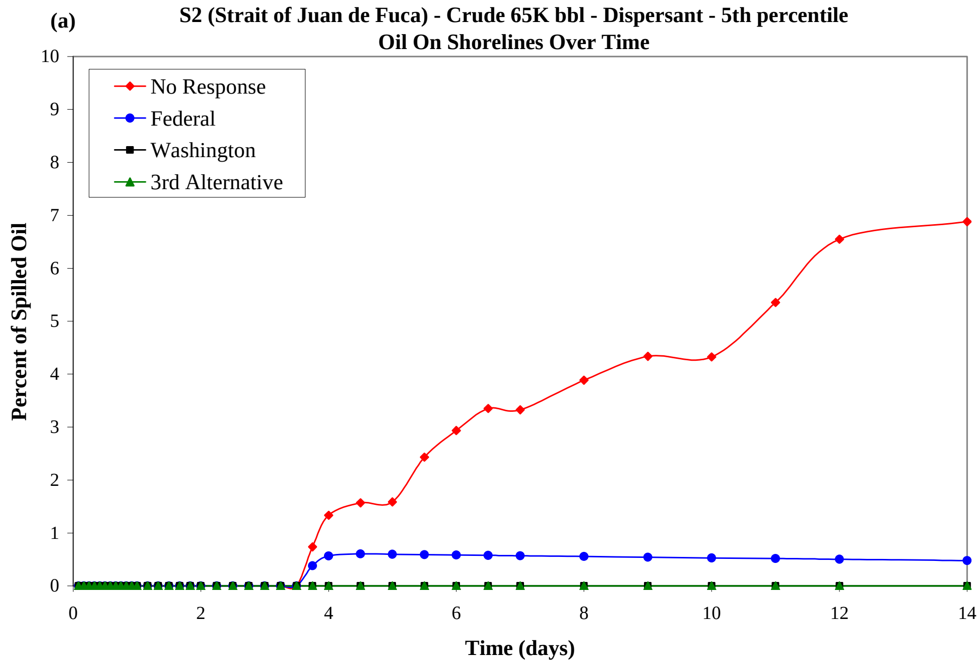


Figure XIV.B.9-24 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



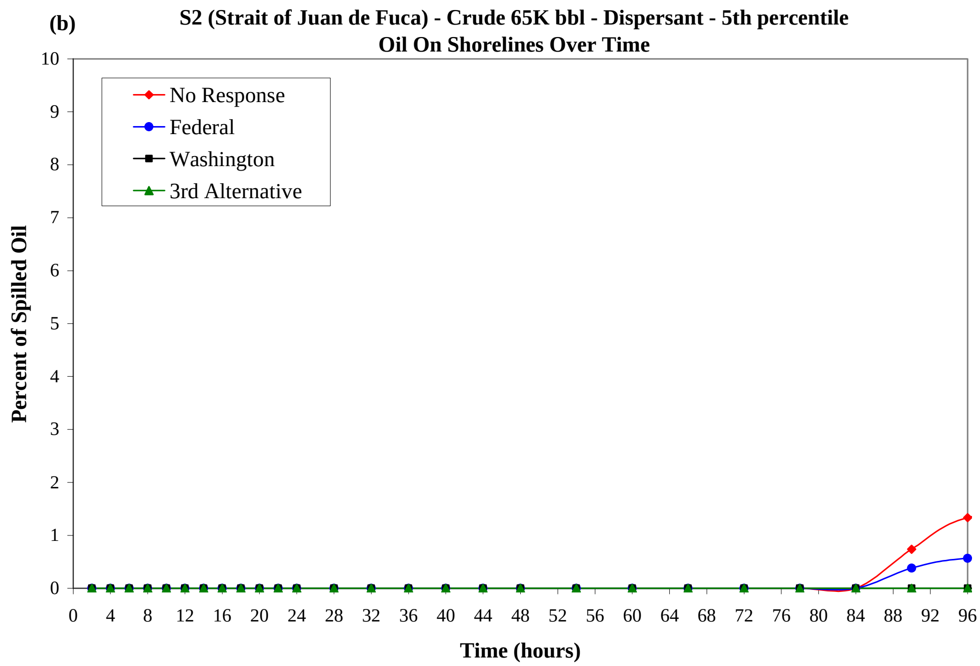
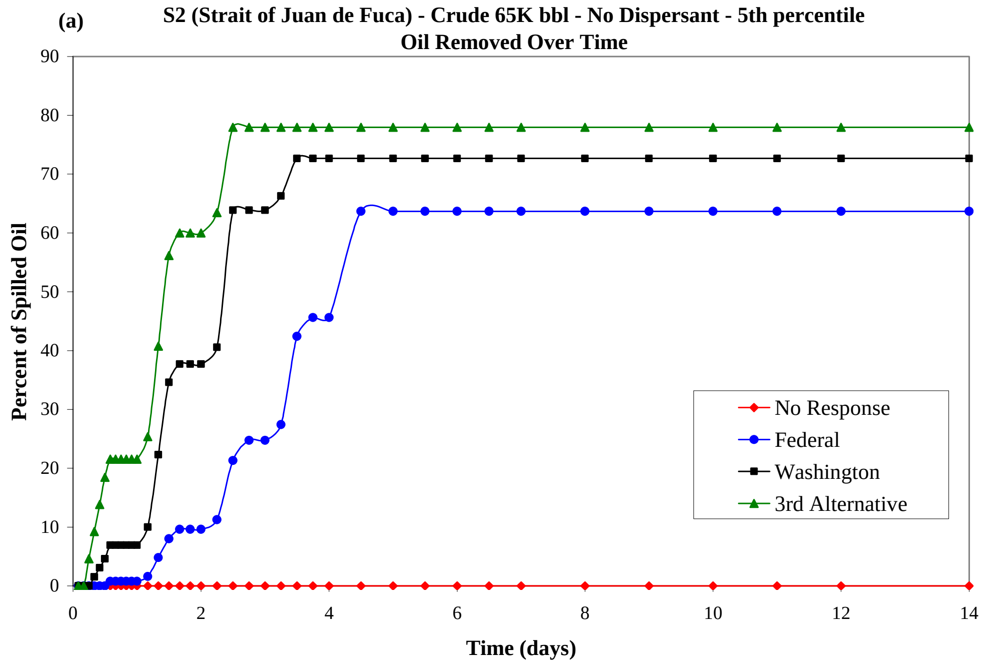


Figure XIV.B.9-25 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



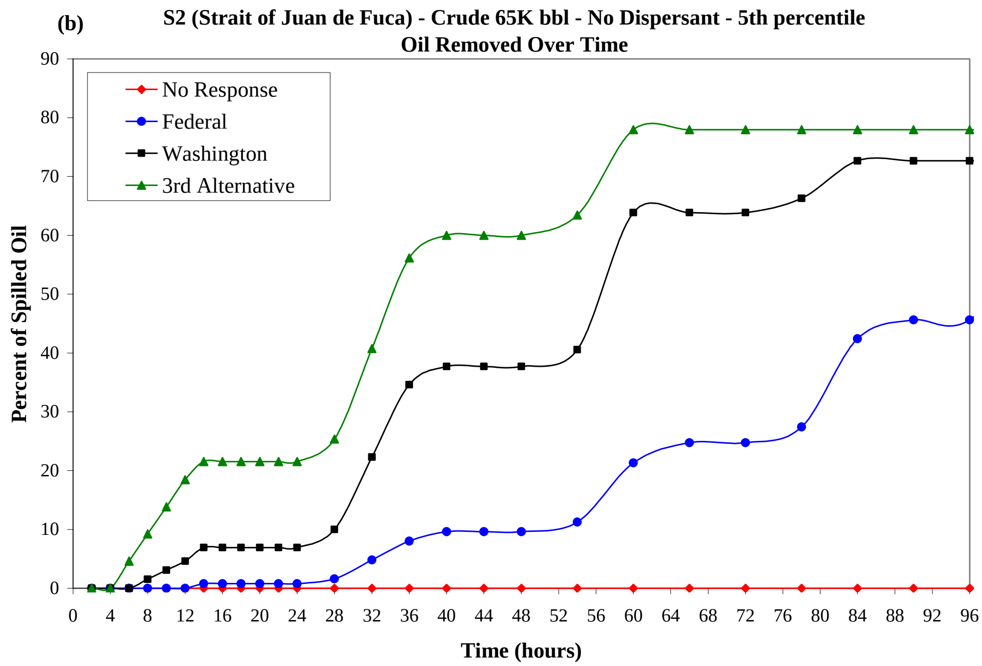
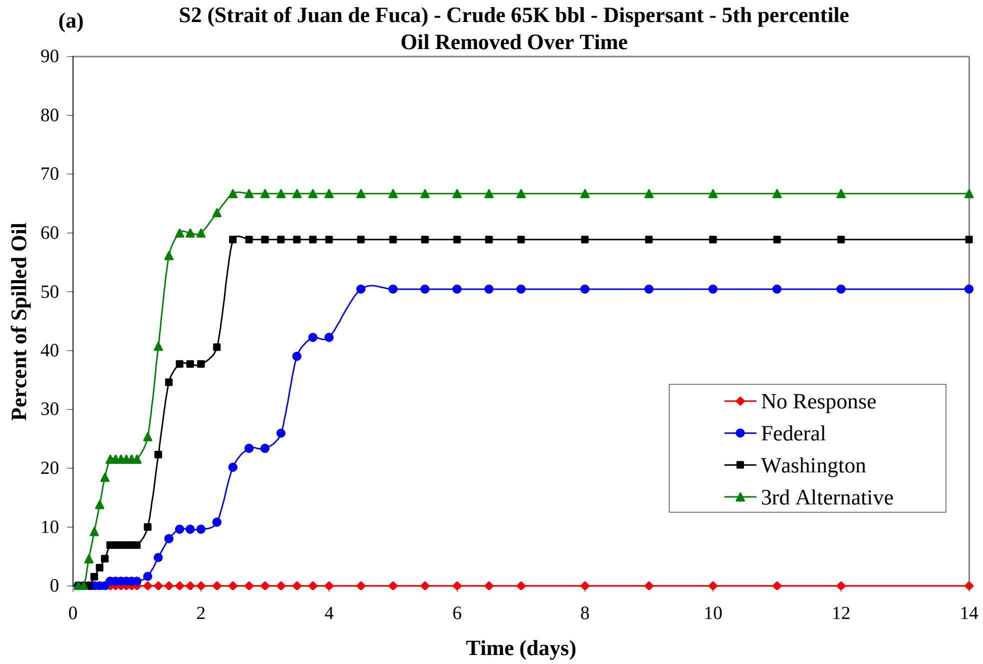


Figure XIV.B.9-26 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



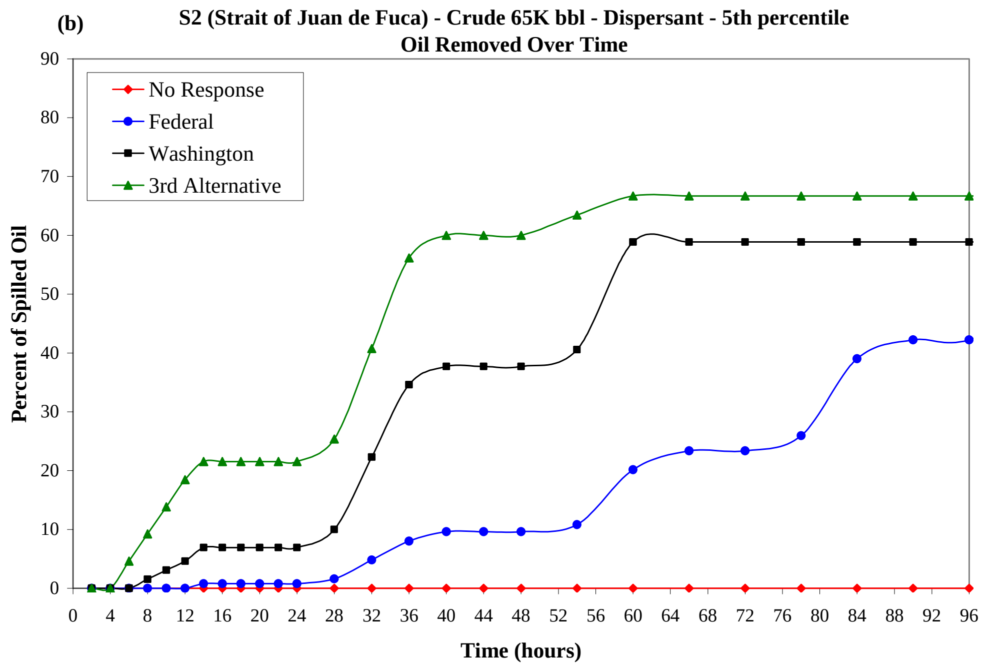
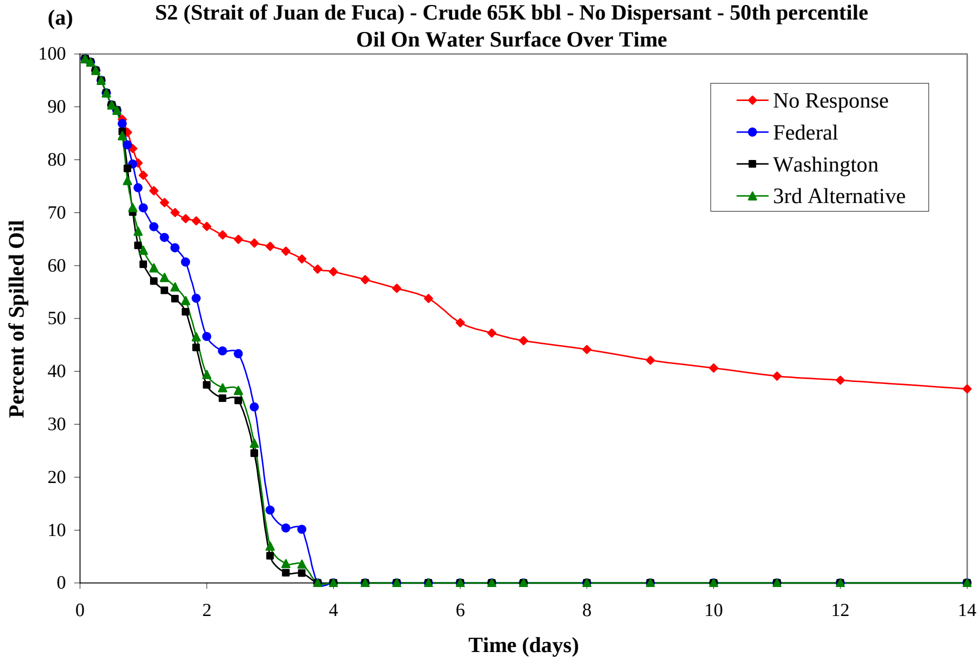


Figure XIV.B.9-27 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



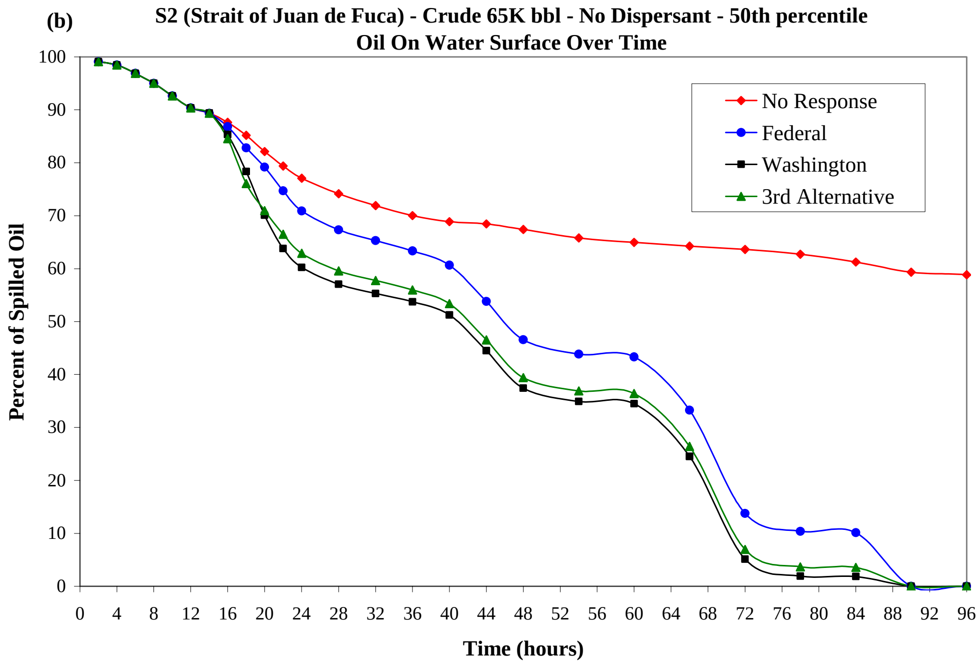


Figure XIV.B.9-28 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.

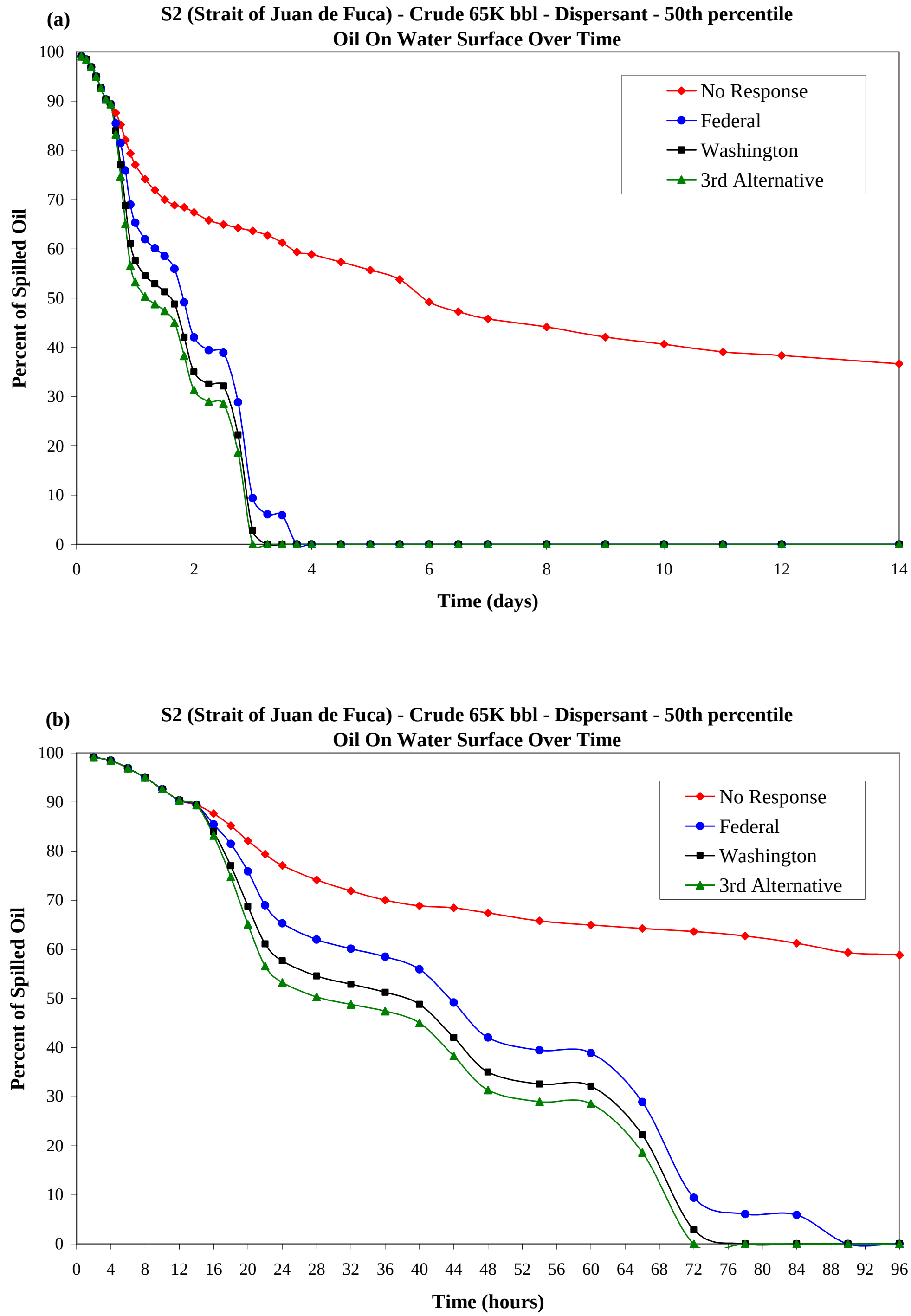
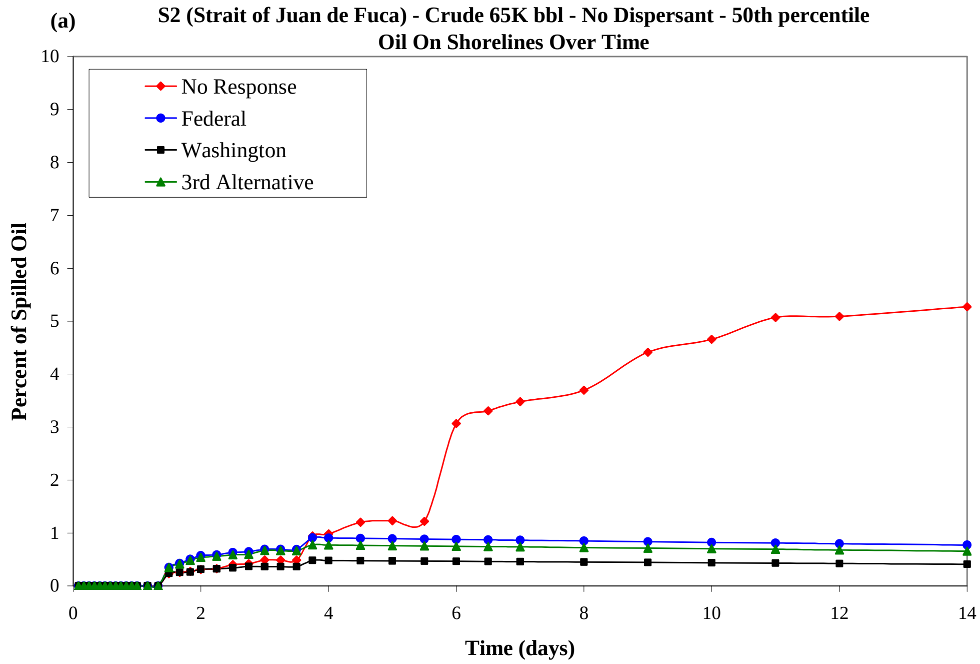


Figure XIV.B.9-29 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



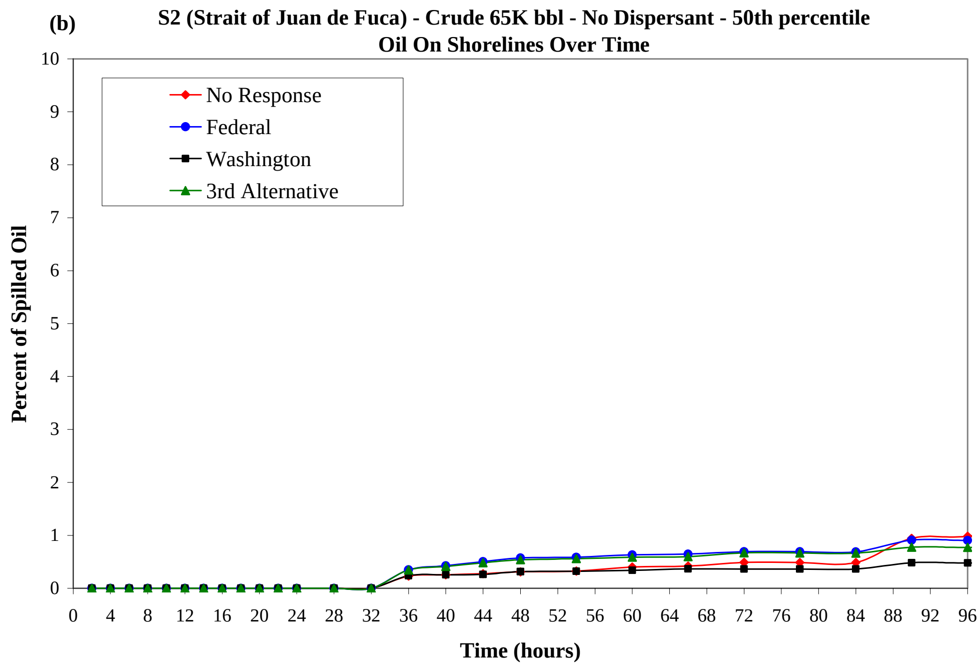
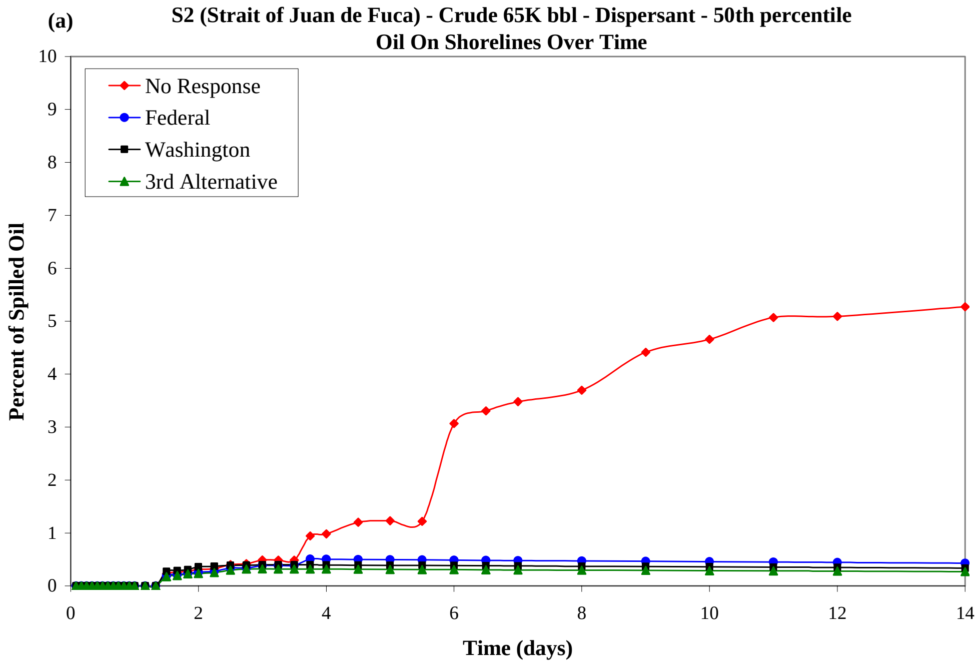


Figure XIV.B.9-30 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



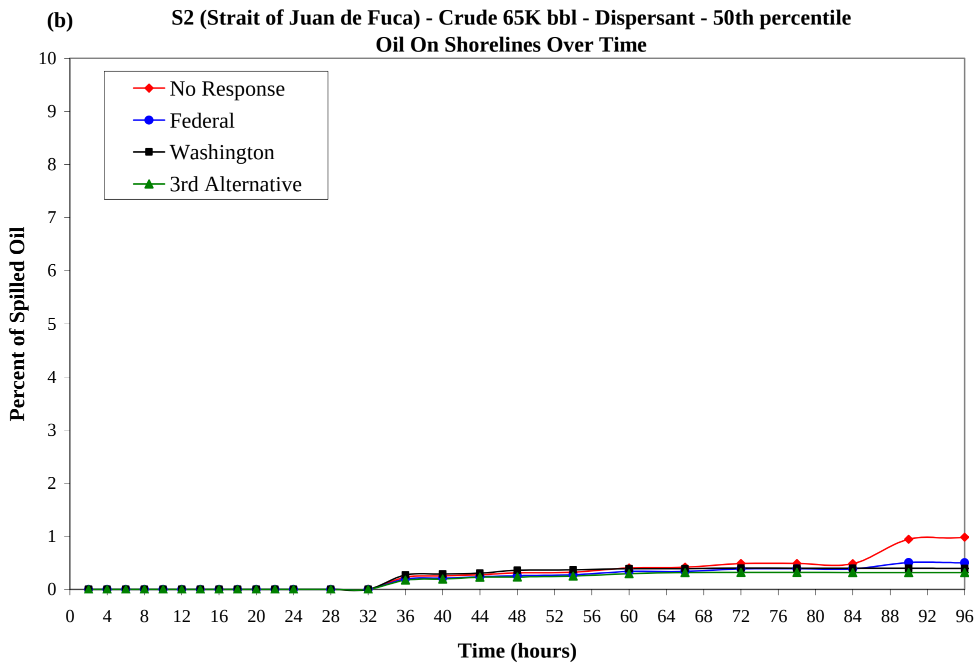
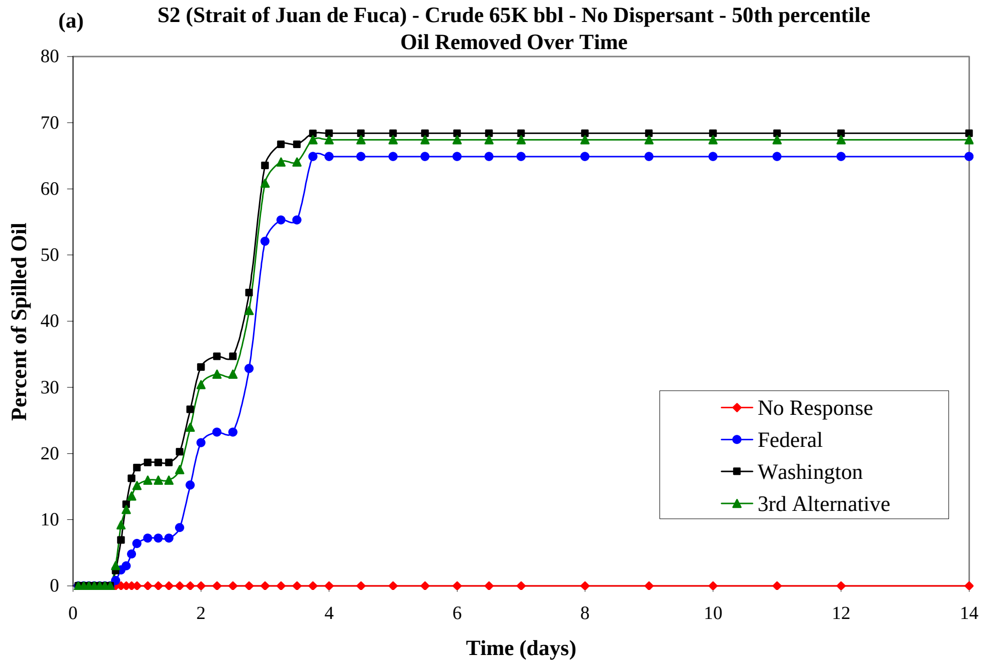


Figure XIV.B.9-31 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



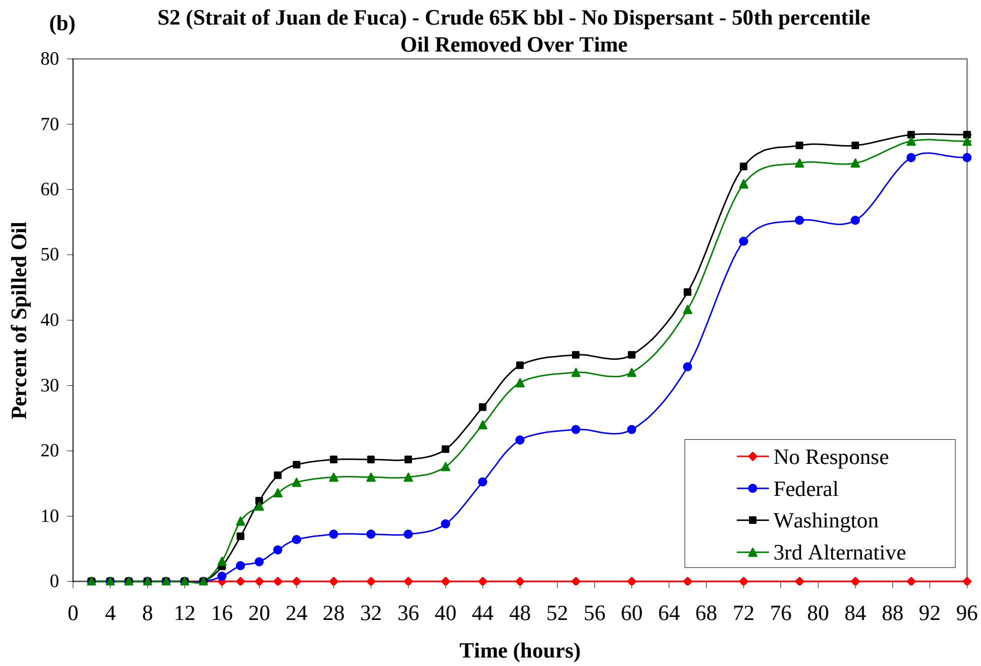
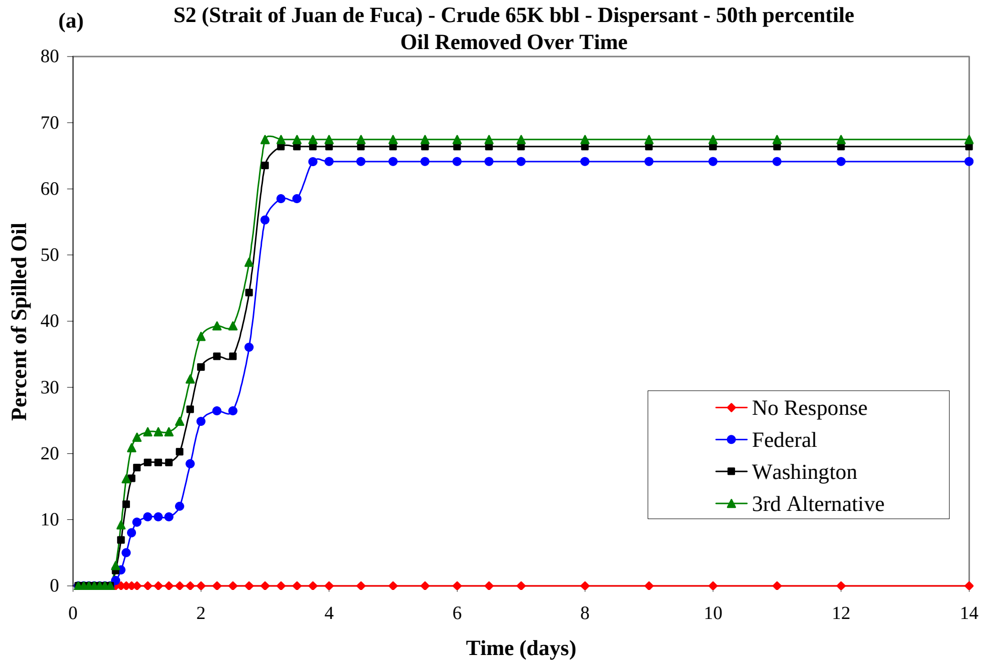


Figure XIV.B.9-32 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



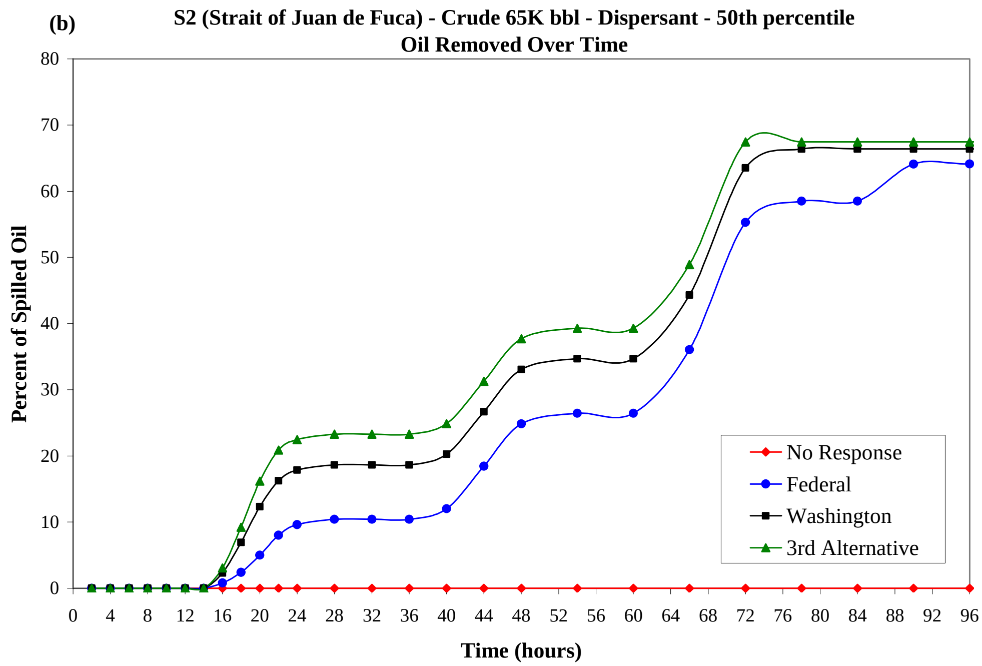


Figure XIV.B.9-33 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.

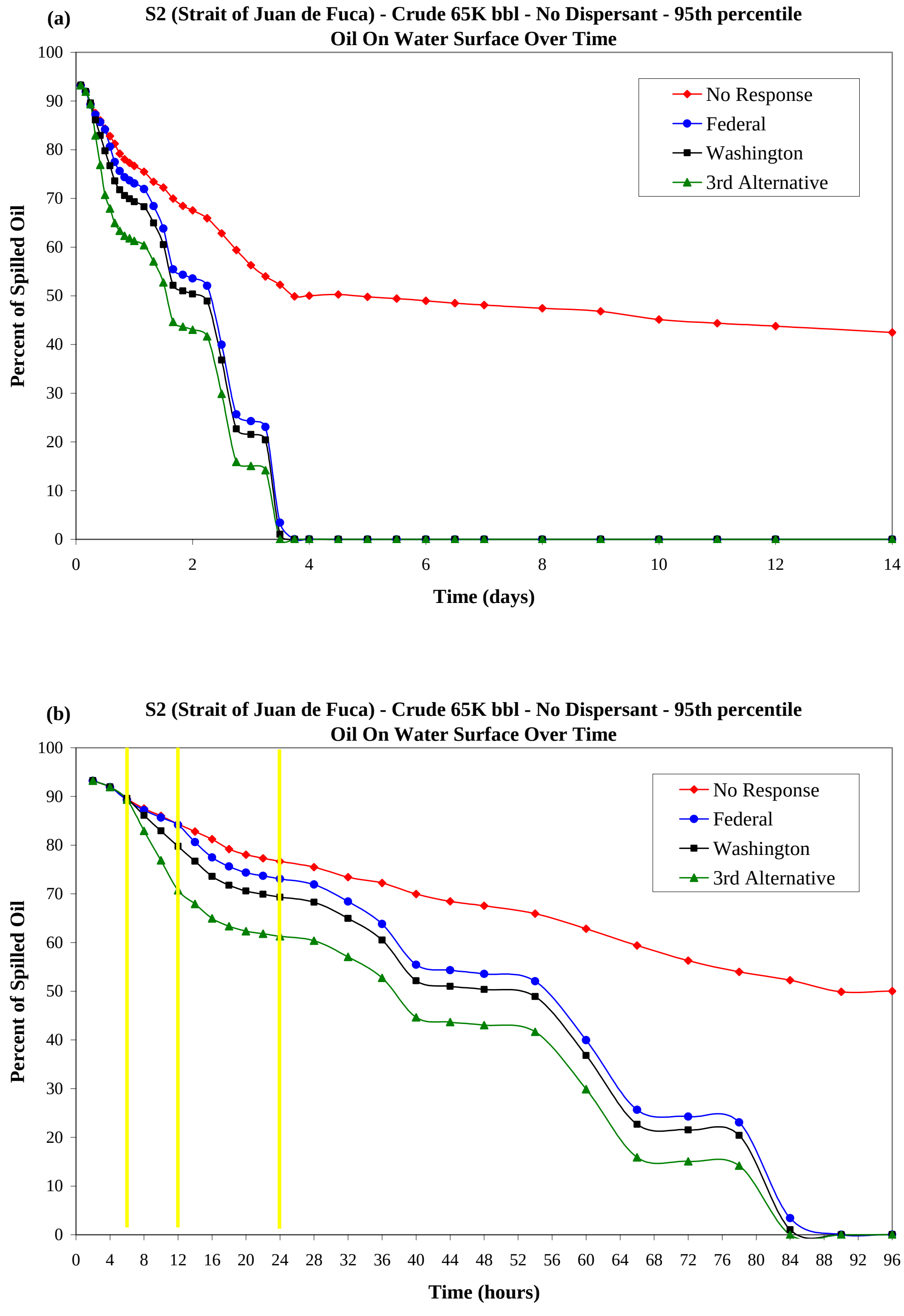
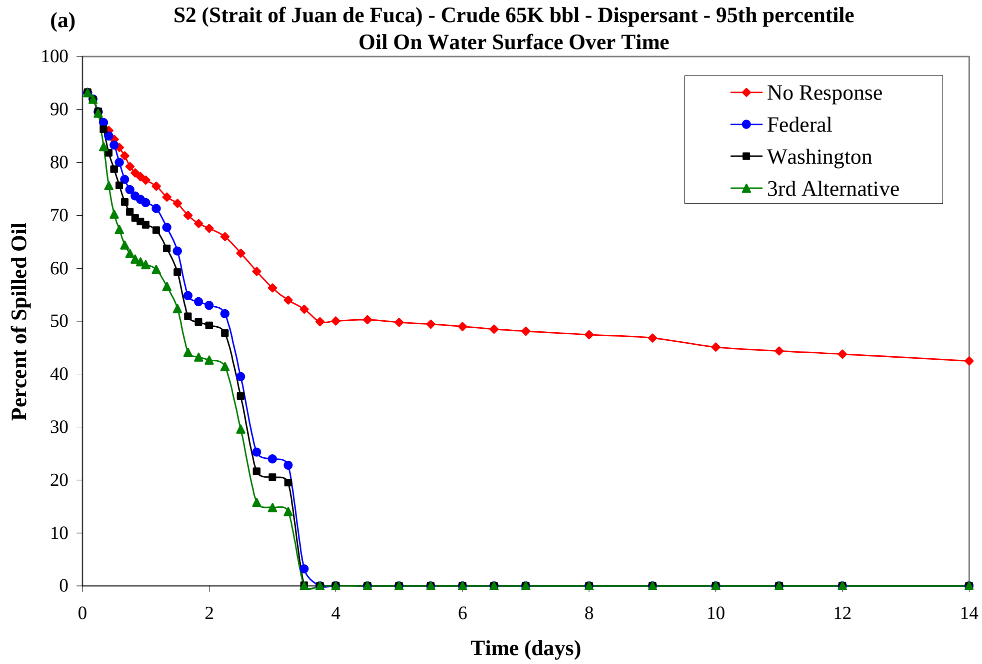


Figure XIV.B.9-34 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



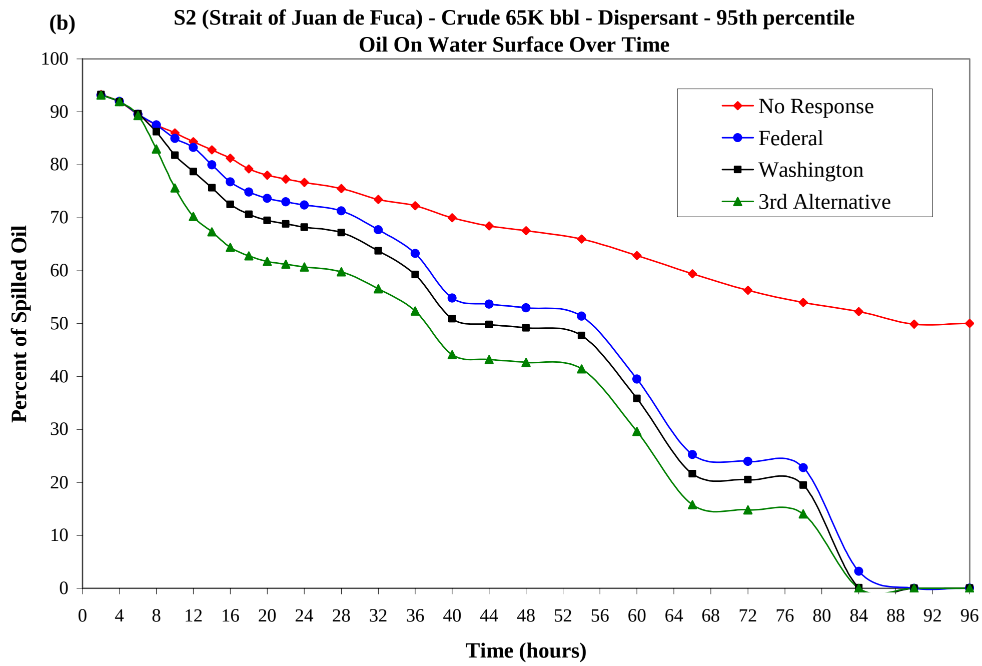


Figure XIV.B.9-35 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.

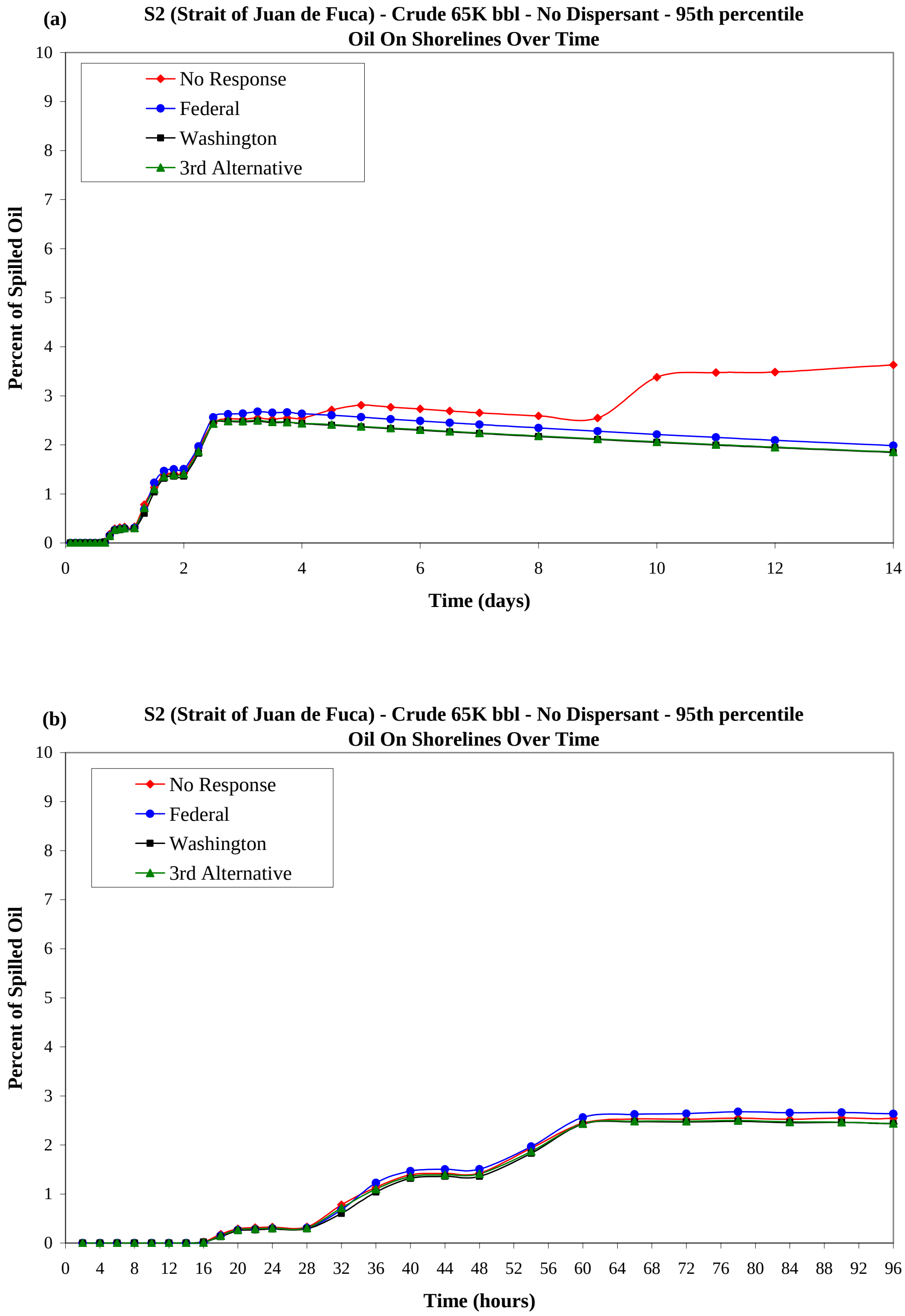
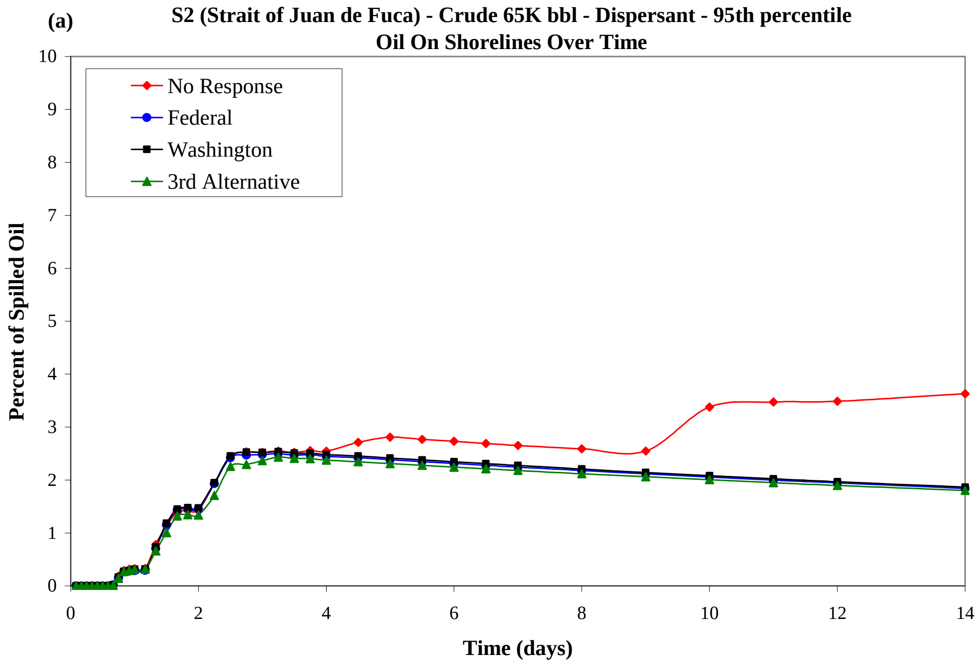


Figure XIV.B.9-36 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



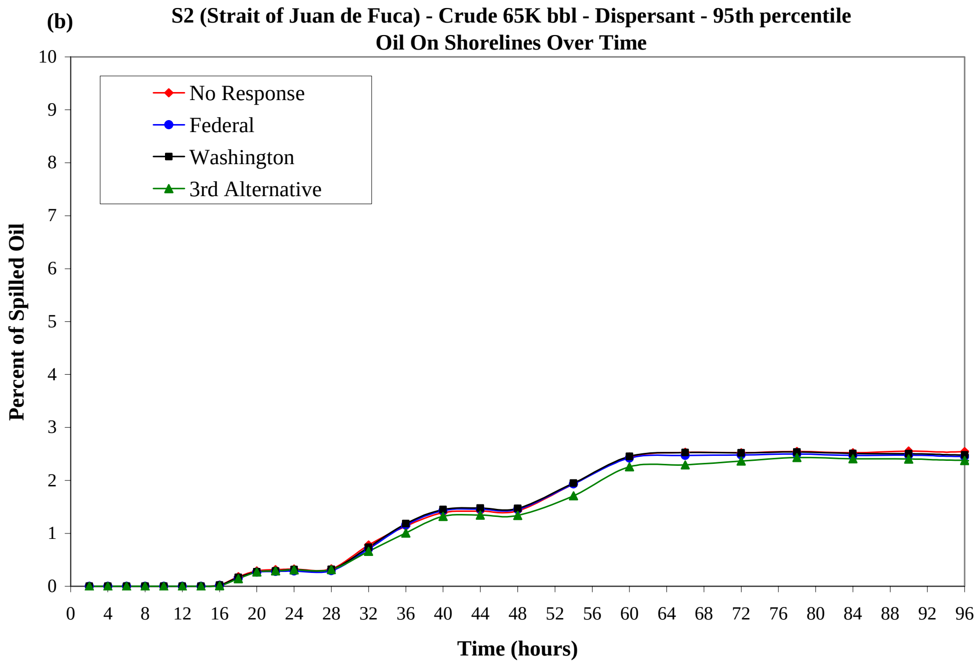
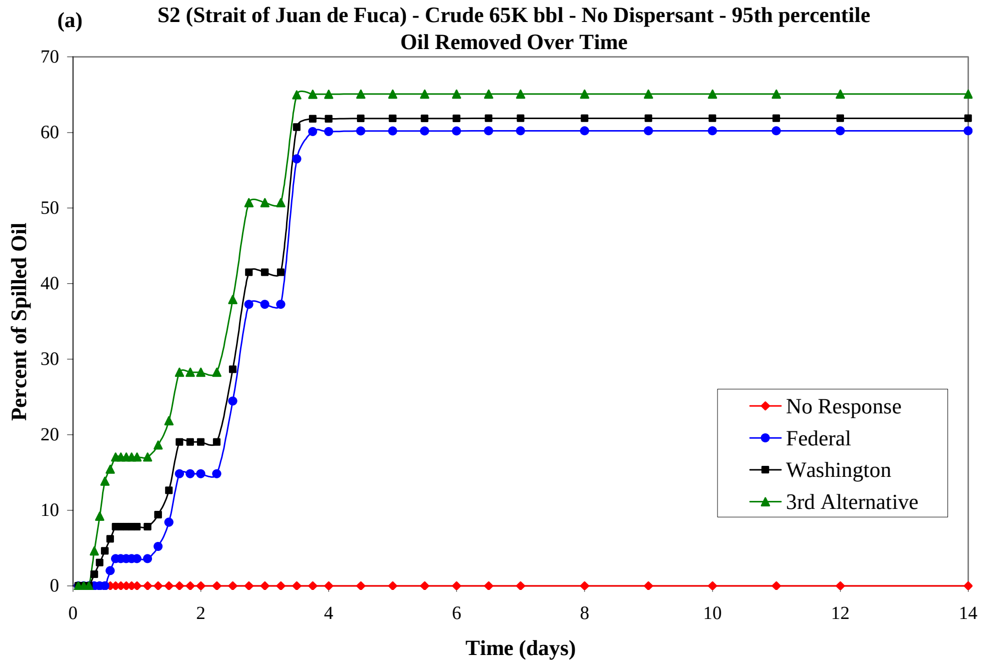


Figure XIV.B.9-37 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



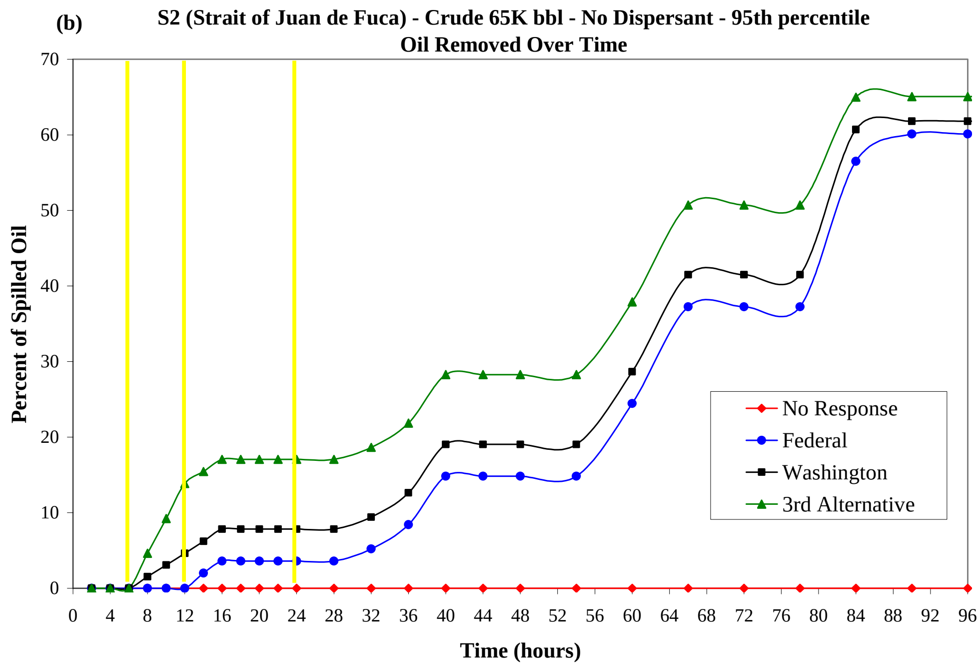


Figure XIV.B.9-38 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run. Part b is a subset of Part a.

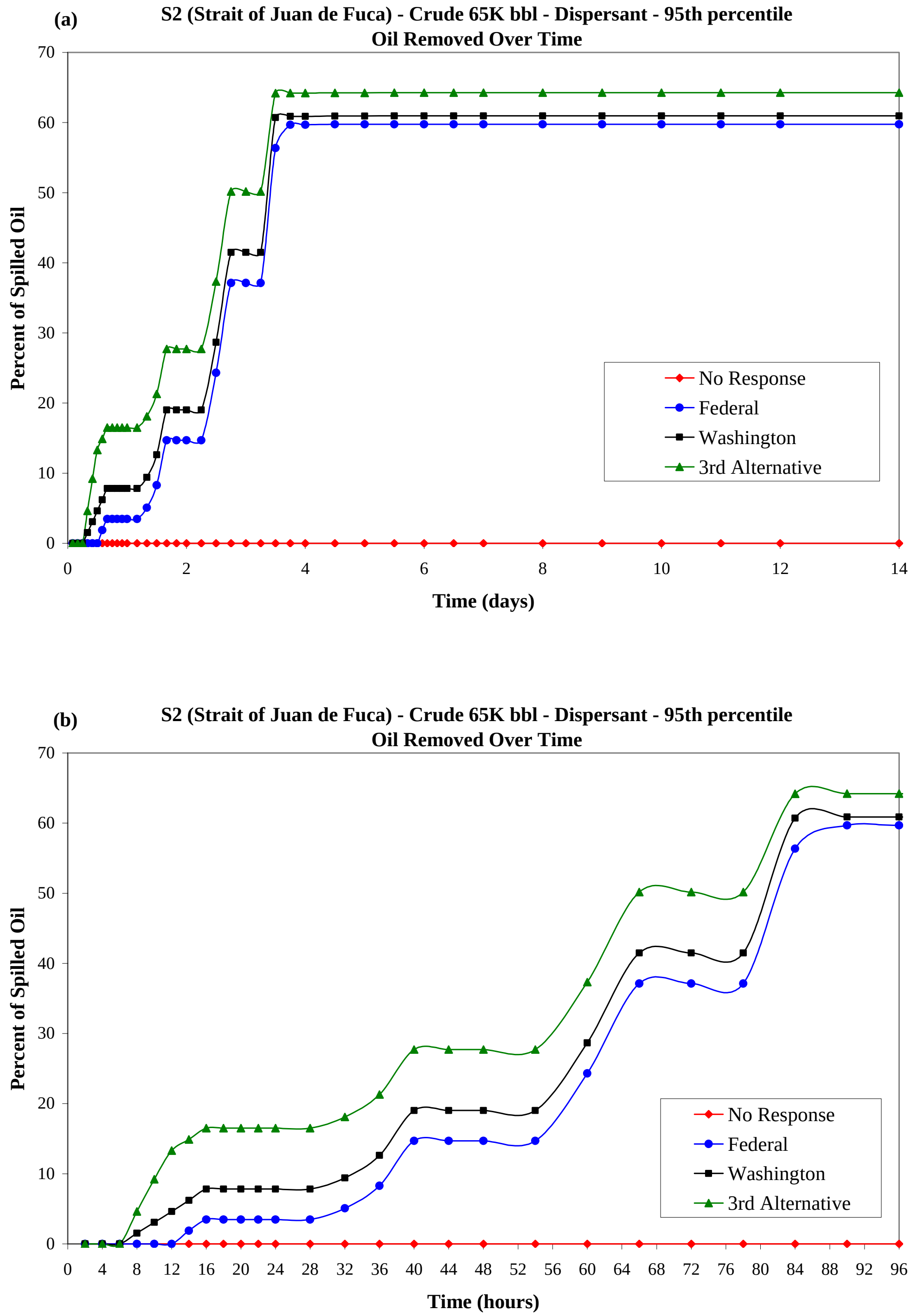


Figure XIV.B.9-39 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run. Part b is a subset of Part a.

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 5^{th}, 50^{th} and 95^{th} 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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

XV.A. Introduction 1
XV.B. Geographical Data 2
XV.B.1. Maps of the Vicinity of the Modeled Spill Locations 2
XV.B.2. Gridded Habitat Mapping 3
XV.B-3. Gridded Depth Data 4
XV.B-4. Areas Where Response Actions Assumed 5
XV.C. Current Data 8
XV.C.1. Basis of Current Data 8
XV.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations........ 9
XV.D: Oil Properties 14
XV.E: Inputs to the SIMAP Physical Fates Model.. 17

List of Figures

Figure XV.B.1-1 Map of the vicinity of the potential spill locations. 2
Figure XV.B.2-1 Habitat grid used for modeling the potential spills................................ 3
Figure XV.B.2-2 Habitat grid used for modeling the potential spills (closer view)........... 3
Figure XV.B.3-1 Depth grid used for modeling the potential spills................................. 4
Figure XV.B.3-2 Depth grid used for modeling the potential spills (closer view)............ 4
Figure XV.B.4-1 Jurisdictions in the area of the potential spills. 5
Figure XV.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 5
Figure XV.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 6
Figure XV.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 6
Figure XV.B.4-5 Areas where dispersant application was assumed to occur in modeling the potential spills. 7
Figure XV.C.1-1 Grid used for the hydrodynamic model-generated current data. 8
Figure XV.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island).. 9
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. 10
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. 10
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. 11
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. 11
Figure XV.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction. 12
Figure XV.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction. 12
Figure XV.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.......................... 13
Figure XV.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction. 13
Figure XV.E-1 Varied range of spill site, Rosario Strait/Georgia Strait from the south end of Lopez Island to off Cherry Point. 20
Figure XV.E-2 Wind Station Locations.. 24

List of Tables

Table XV.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling. 14
Table XV.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil.... 15
Table XV.E-1. Inputs to the Fates Model for Stochastic Scenarios 17
Table XV.E-2. Time, date and location inputs for each of the 100 stochastic runs. 21
Table XV.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 23
Table XV.E-4. Water temperature by month of the year (from French et al., 1996b). ... 23
Table XV.E-5. Wind data sources and records used. 24

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

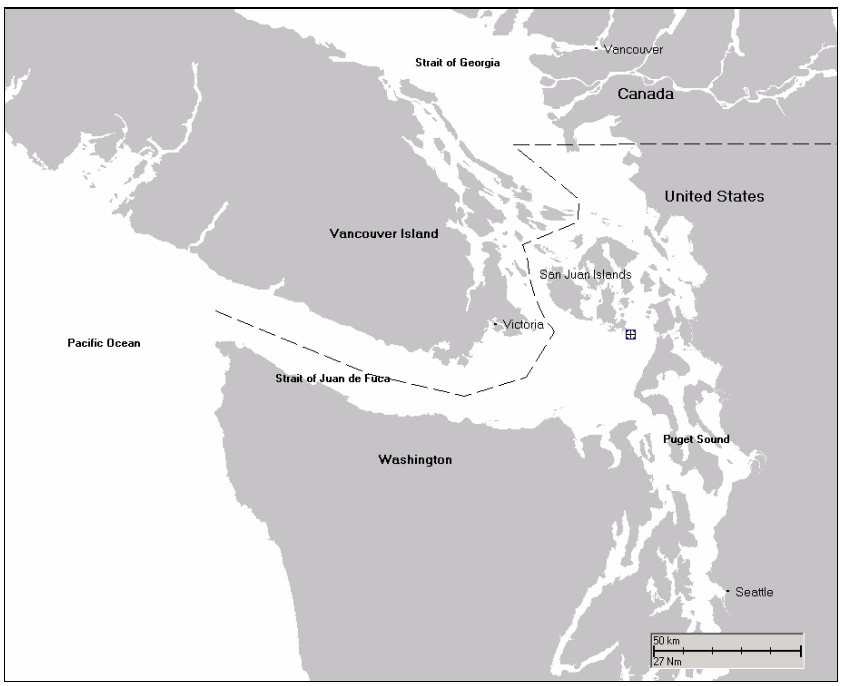


Figure XV.B.1-1 Map of the vicinity of the potential spill locations.

XV.B.2. Gridded Habitat Mapping

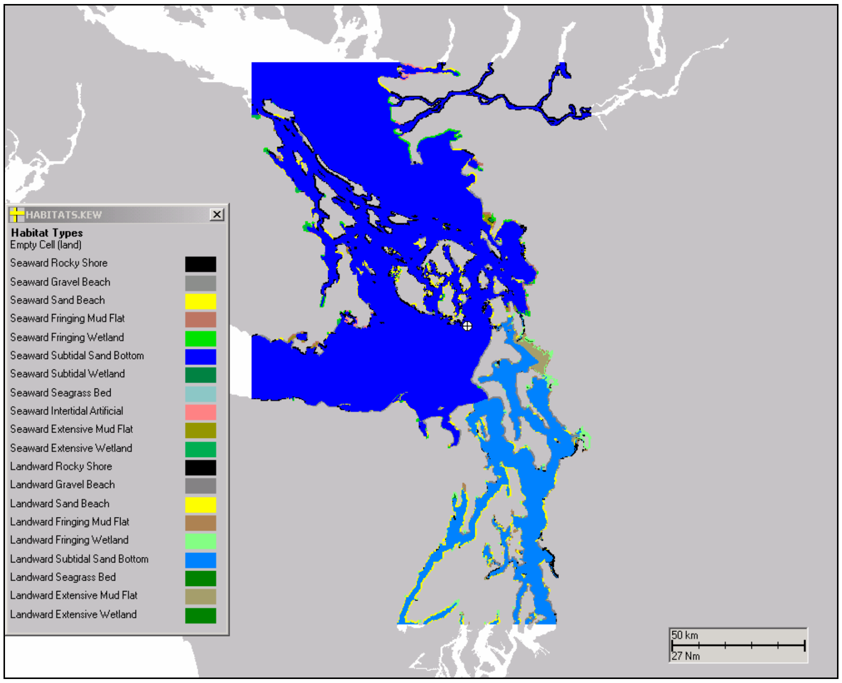


Figure XV.B.2-1 Habitat grid used for modeling the potential spills.

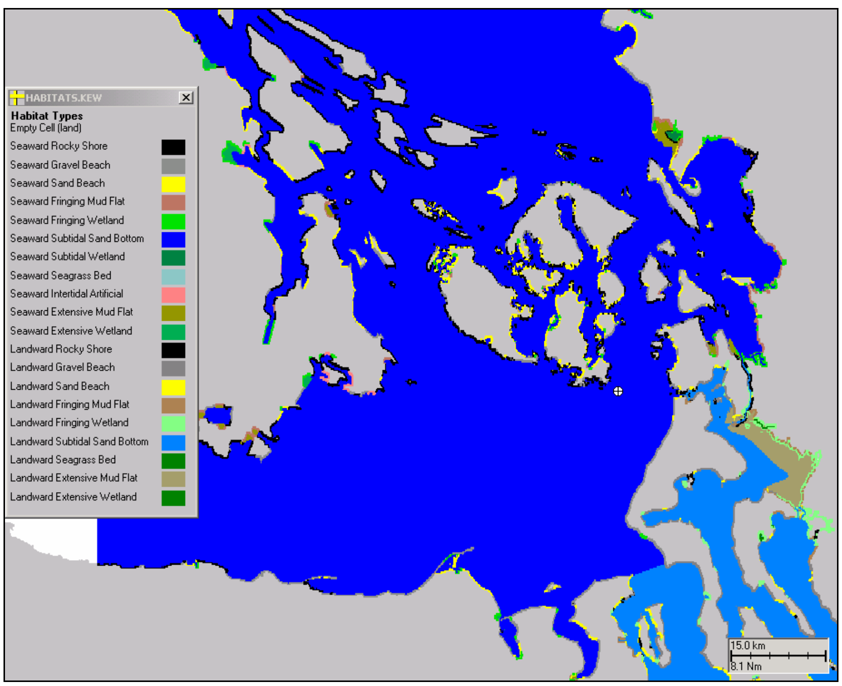


Figure XV.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XV.B-3. Gridded Depth Data

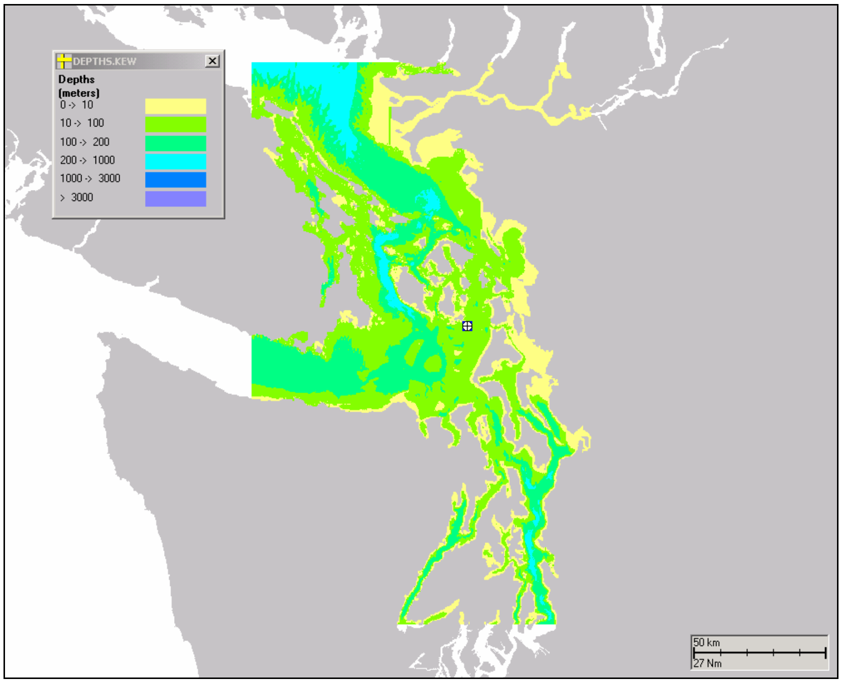


Figure XV.B.3-1 Depth grid used for modeling the potential spills.

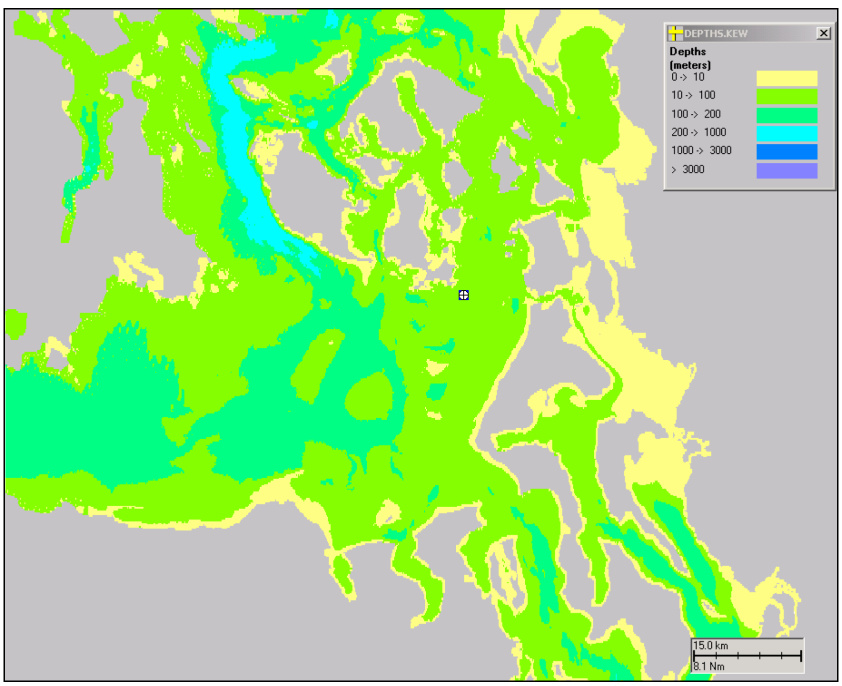


Figure XV.B.3-2 Depth grid used for modeling the potential spills (closer view).

XV.B-4. Areas Where Response Actions Assumed

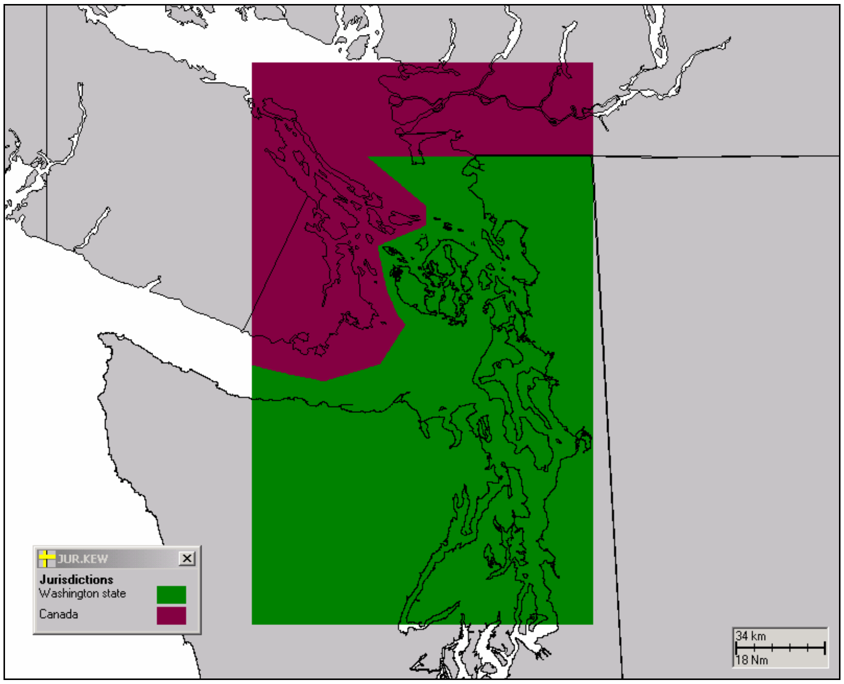


Figure XV.B.4-1 Jurisdictions in the area of the potential spills.

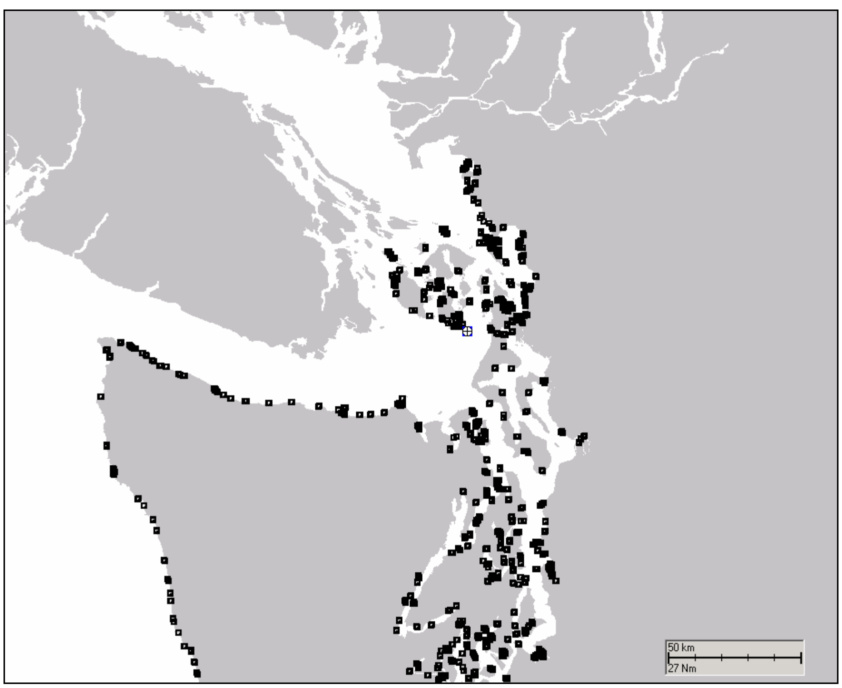


Figure XV.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

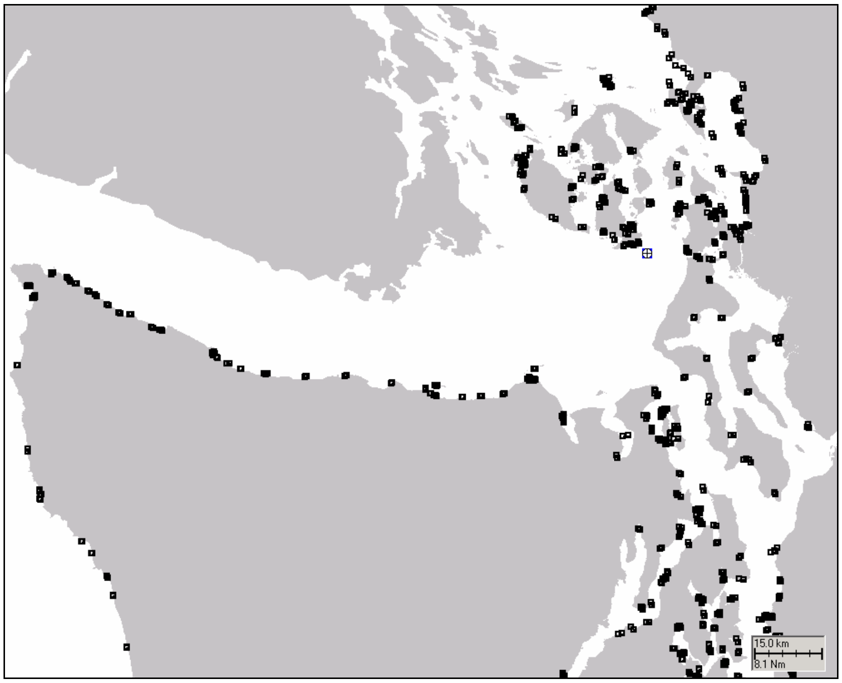


Figure XV.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

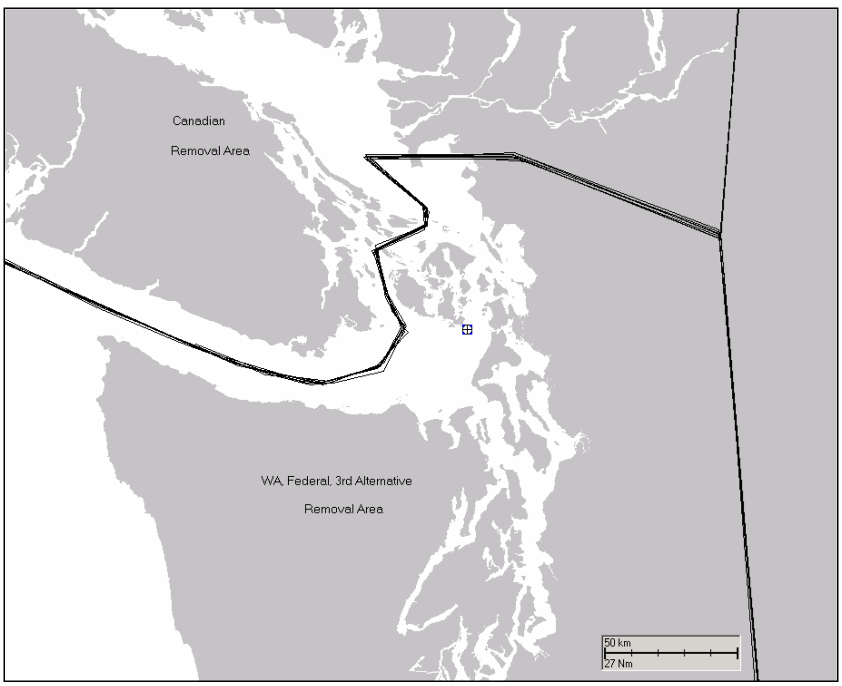


Figure XV.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

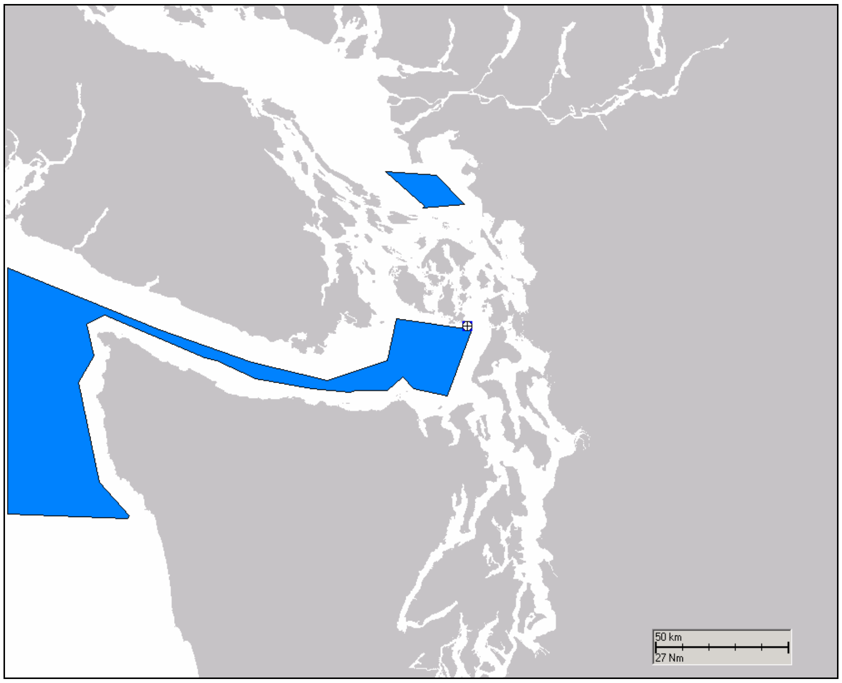


Figure XV.B.4-5 Areas where dispersant application was assumed to occur in modeling the potential spills.

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).

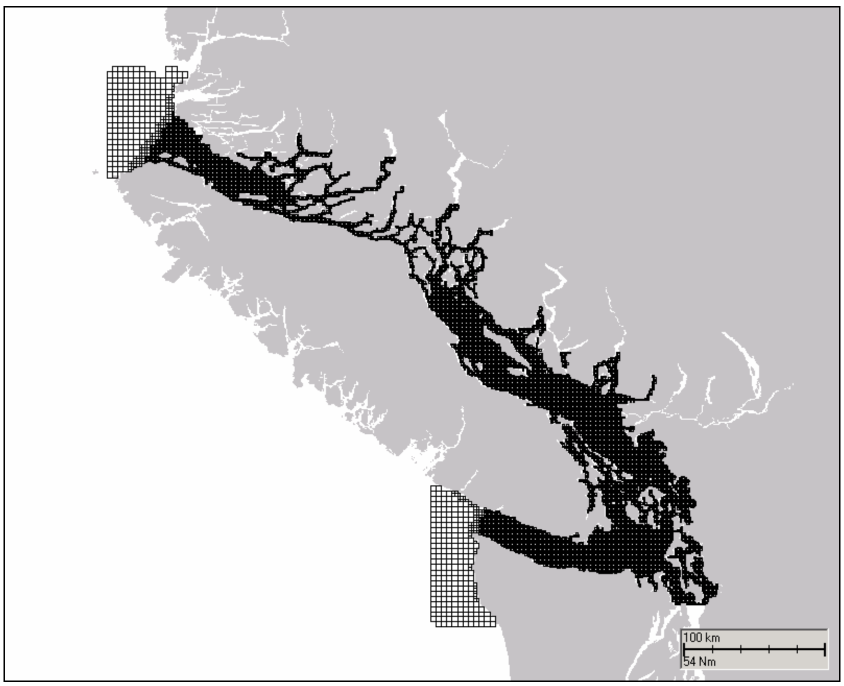


Figure XV.C.1-1 Grid used for the hydrodynamic model-generated current data.

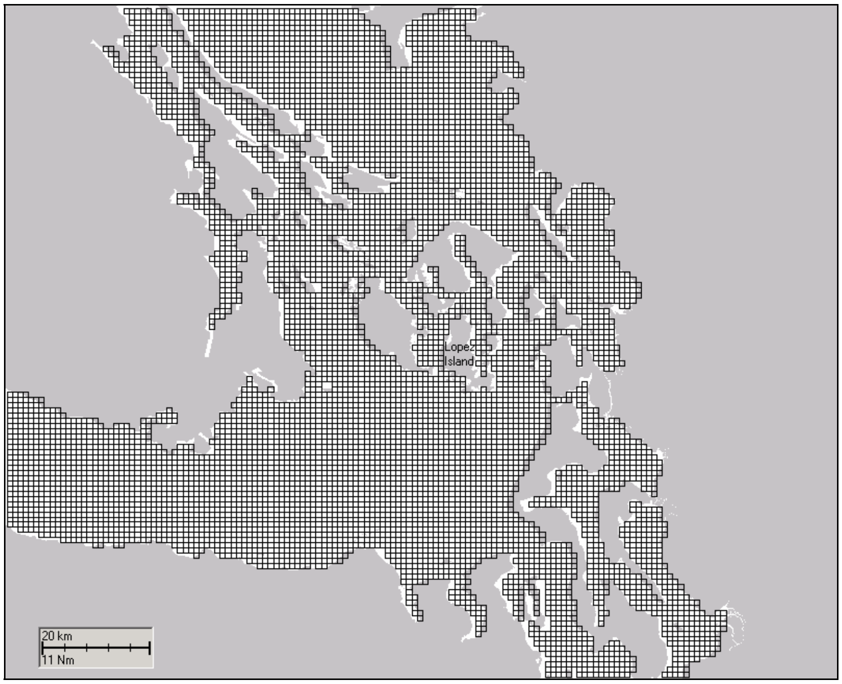


Figure XV.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island).

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.

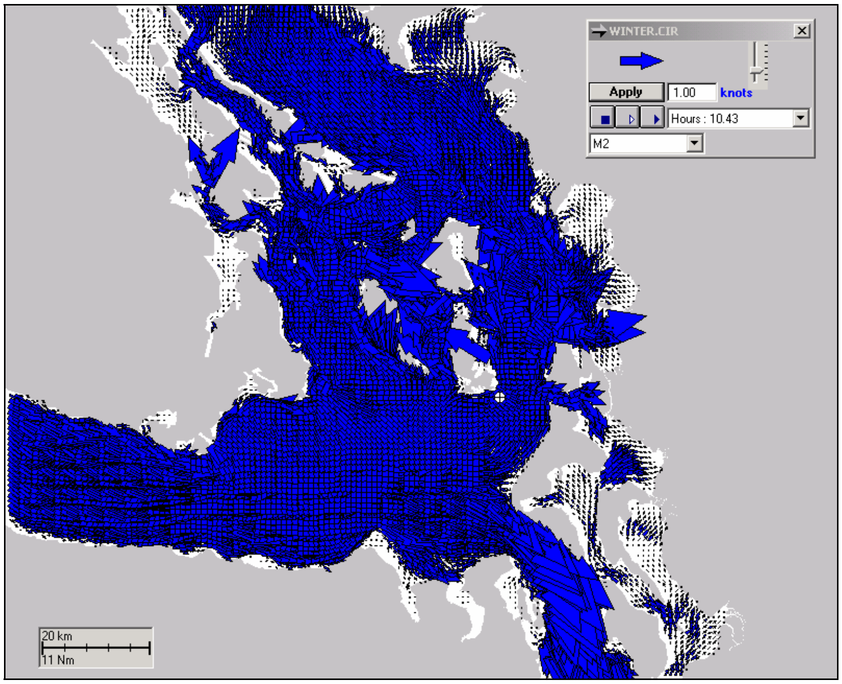


Figure XV.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Lopez Island.

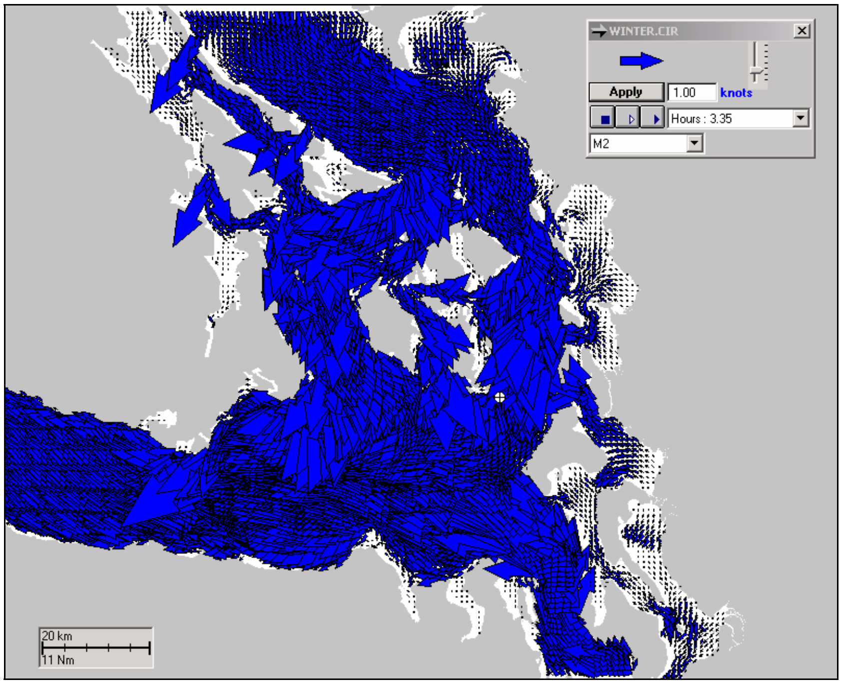


Figure XV.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Lopez Island.

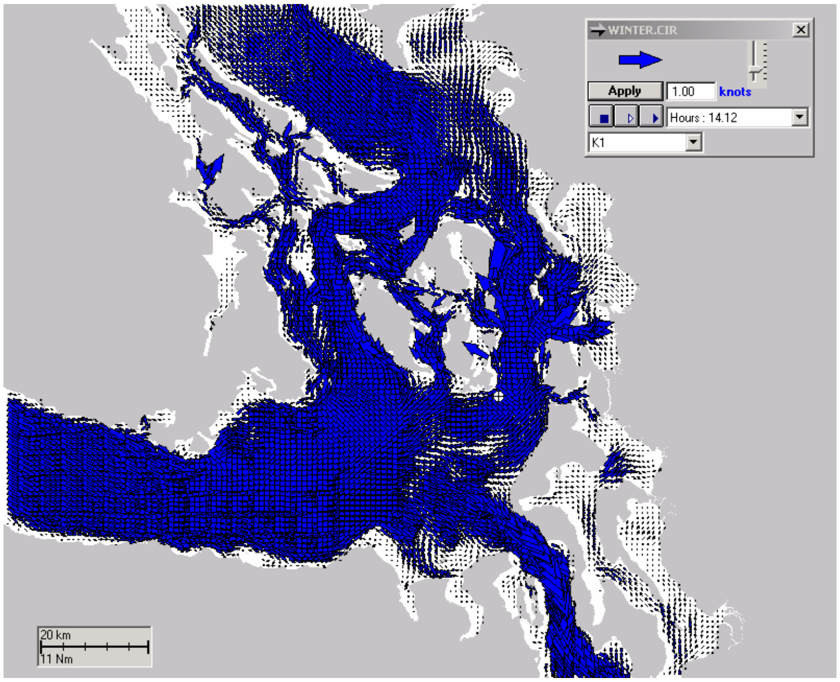


Figure XV.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Lopez Island.

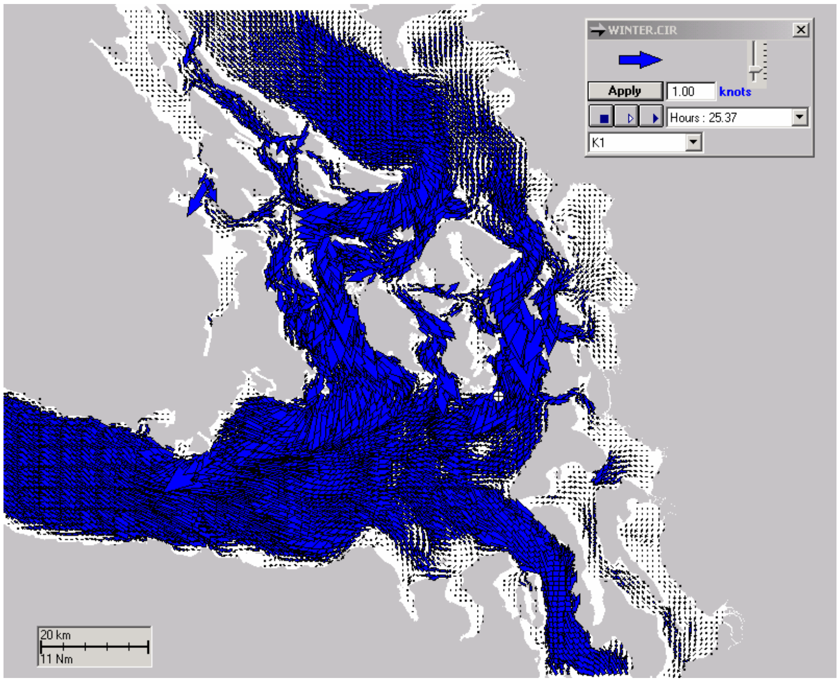


Figure XV.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Lopez Island.

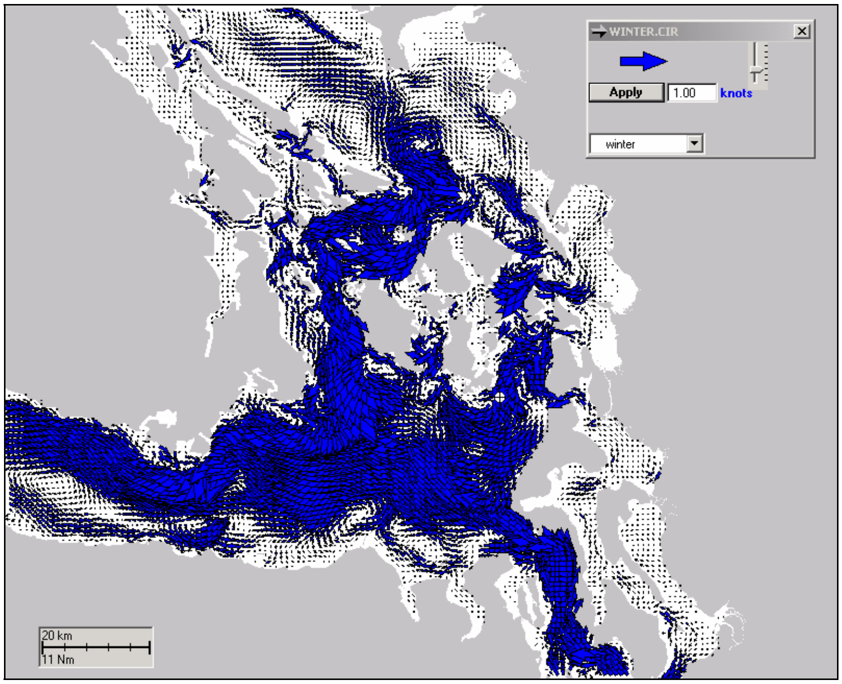


Figure XV.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction.

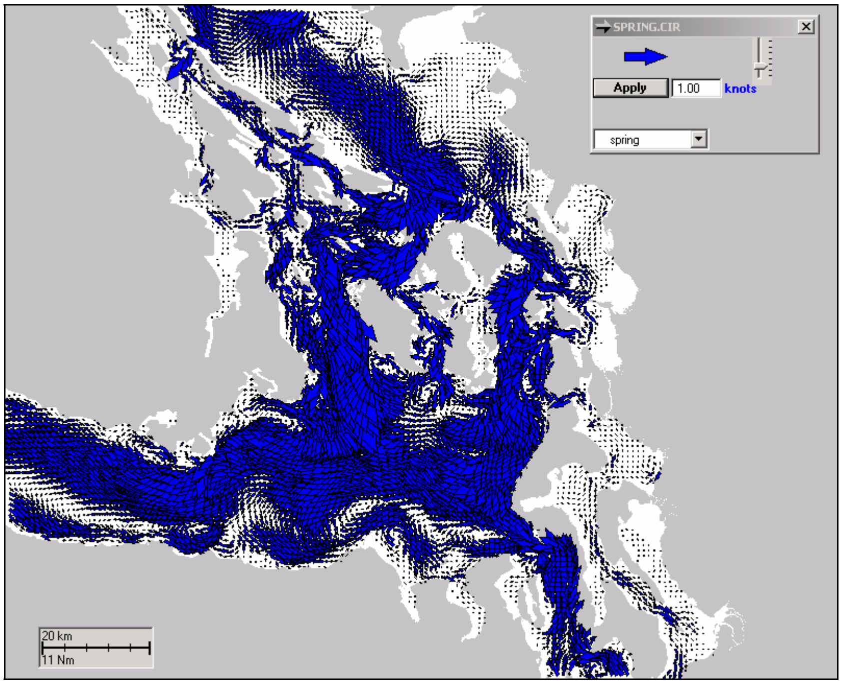


Figure XV.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction.

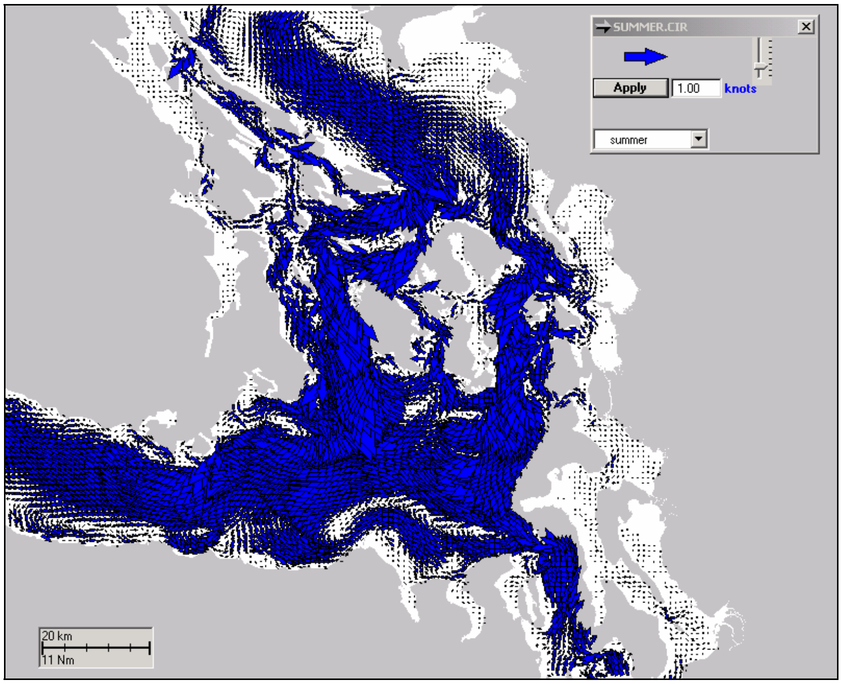


Figure XV.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.

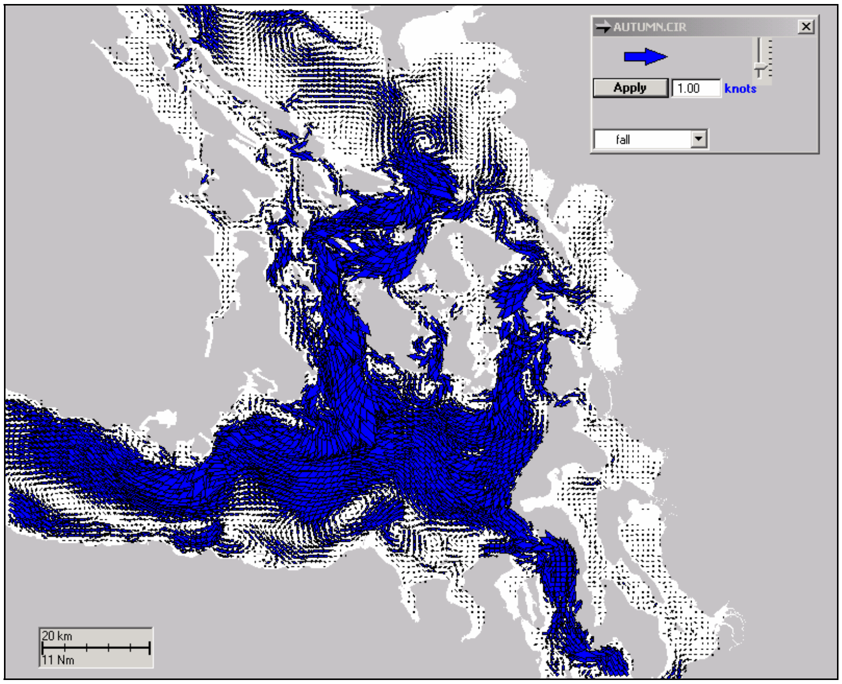


Figure XV.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction.

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

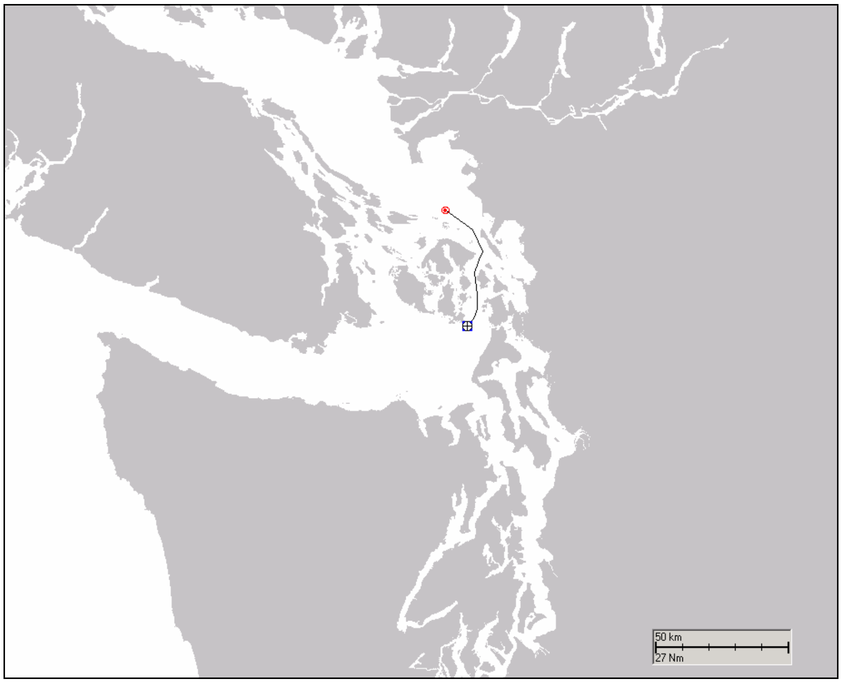


Figure XV.E-1 Varied range of spill site, Rosario Strait/Georgia Strait from the south end of Lopez Island to off Cherry Point.

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^o 57.76'W
Grid S edge	47^o 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.

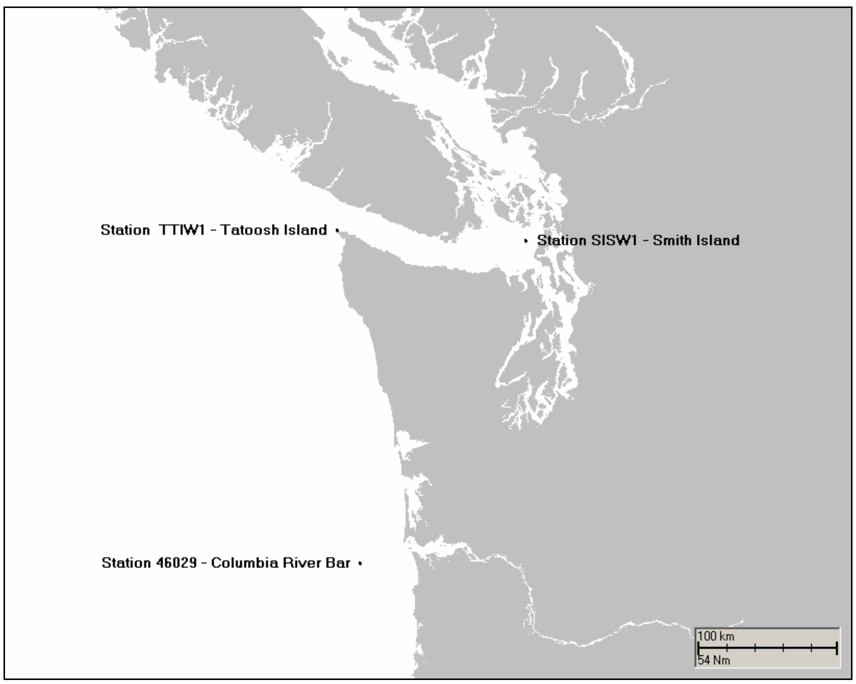


Figure XV.E-2 Wind Station Locations.

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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suàrez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

XVI.A. Introduction XVI-1
XVI.B. Maps of Exposure Probability, Time First Exposed, and Maximum Possible Contamination XVI-1
XVI.C. Rank Order Distributions for All Model Runs XVI-9
XVI.D. Shoreline Areas Exposed by Shore Type XVI-22
XVI.E. Exposure for Representative Individual Model Runs. XVI-26
XVI.F. Estimated Biological Impacts: Wildlife XVI-34
XVI.G. Estimated Biological Impacts: Fish and Invertebrates XVI-37
XVI.H. Estimated NRDA Costs: Habitat Restoration Costs XVI-40
XVI.I. Estimated NRDA Costs: Washington Compensation schedule XVI-45

List of Figures

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). XVI-2
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. .... XVI-3
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). XVI-3
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. XVI-4
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). XVI-4
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). XVI-5
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). XVI-5
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. .... XVI-6
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). XVI-6
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. XVI-7
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). XVI-7
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-8
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 $0.01 g/m^2$ times duration of exposure. XVI-9
Figure XVI.C-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of $>0.01 g/m^2$ (about 0.00001mm thick). XVI-10
Figure XVI.C-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of $>1 g/m^2$ (about 0.001mm thick). XVI-10
Figure XVI.C-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of $>10 g/m^2$ (about 0.01mm thick). XVI-11
Figure XVI.C-5. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of $>100 g/m^2$ (about 0.1mm thick). XVI-11
Figure XVI.C-6. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of $>1000 g/m^2$ (about 1mm thick). XVI-12
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. XVI-12
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. XVI-13
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. XVI-13
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). XVI-14
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 (%). XVI-14
Figure XVI.C-12. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass mechanically removed. XVI-15
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 $0.01 g/m^2$ times duration of exposure... XVI-15
Figure XVI.C-14. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of $>0.01 g/m^2$ (about 0.00001mm thick). XVI-16

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). XVI-16
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). XVI-17
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). XVI-17
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). XVI-18
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. XVI-18
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. XVI-19
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 XVI-19
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). XVI-20
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 (%). XVI-20
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-21
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. XVI-26
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. XVI-27
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. XVI-27
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. XVI-28
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. XVI-28
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. XVI-29
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. XVI-29
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. XVI-30
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. XVI-30
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. XVI-31
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. XVI-31
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. XVI-32
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. XVI-32
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-33

List of Tables

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). XVI-22
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). XVI-23
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). XVI-23
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). XVI-23
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). XVI-24
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). XVI-24
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). XVI-24
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). XVI-25
Table XVI.F-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost). XVI-35
Table XVI.F-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost). XVI-36
Table XVI.G-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). XVI-38
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). XVI-39
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. XVI-41
Table XVI.H-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. XVI-42
Table XVI.H-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. XVI-43
Table XVI.H-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration. XVI-44

Table XVI.I-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. XVI-45
Table XVI.I-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. XVI-45

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)

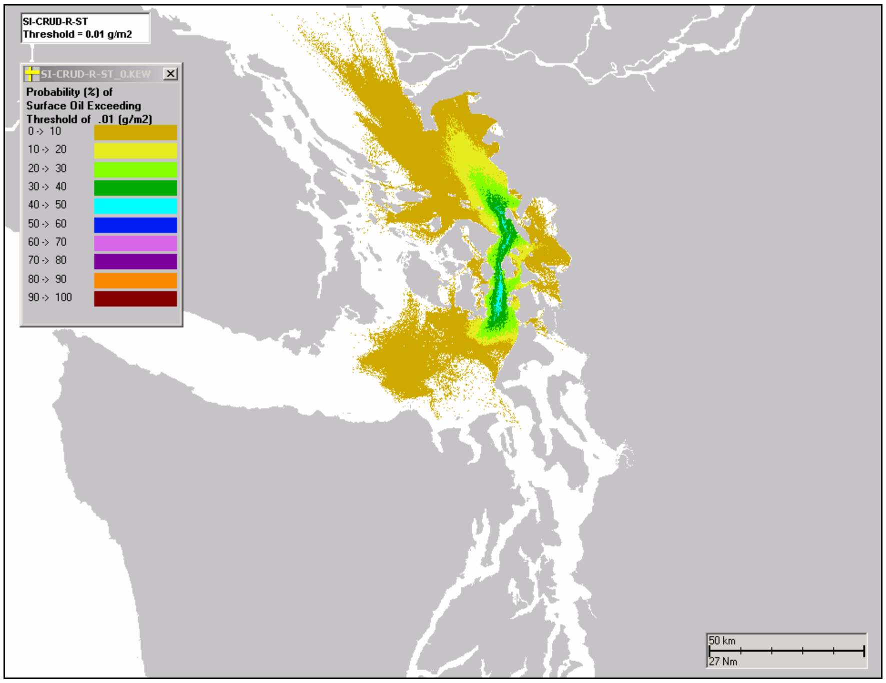


Figure XVI.B-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

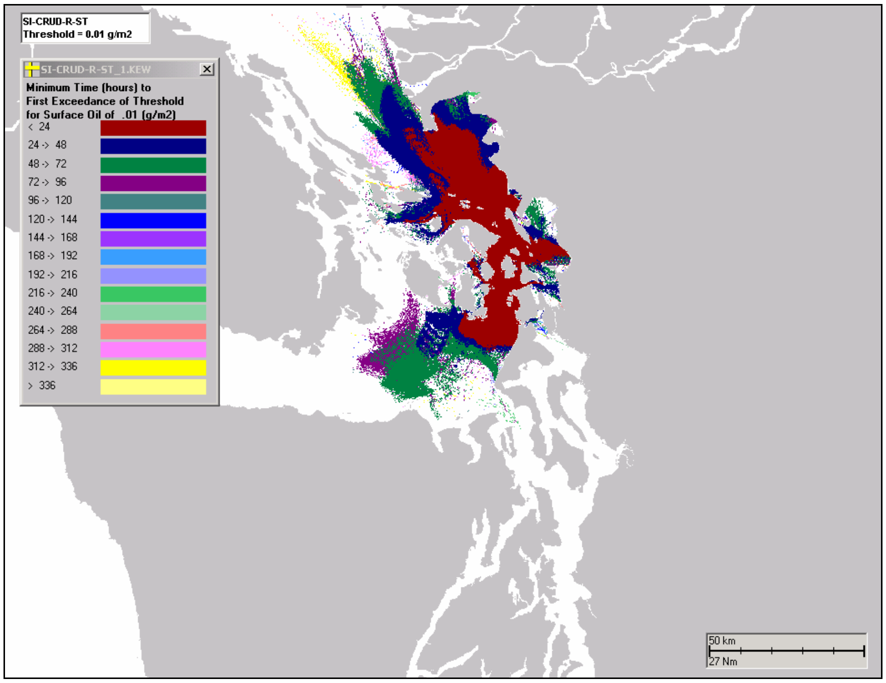


Figure XVI.B-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

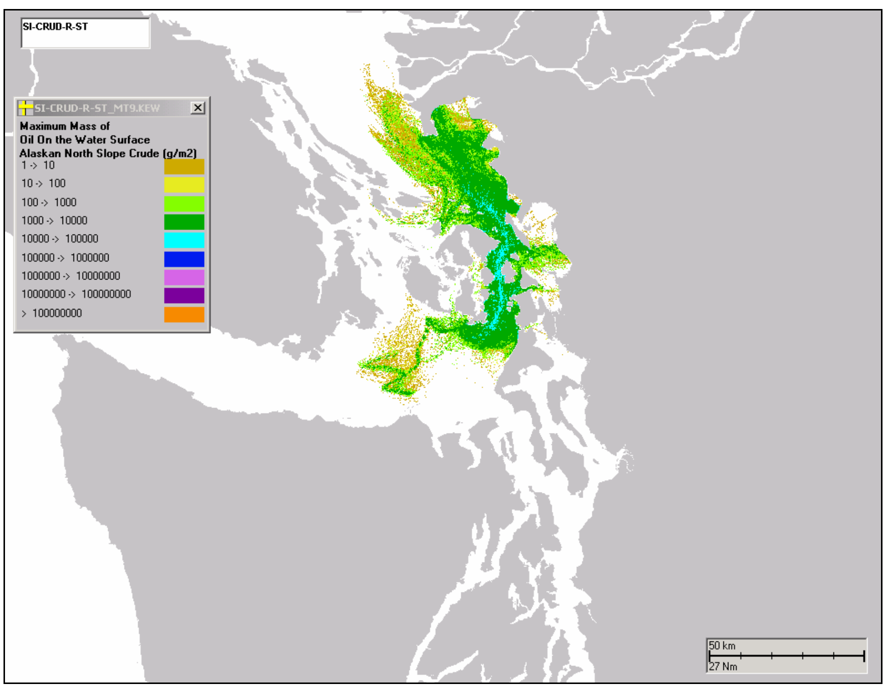


Figure XVI.B-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

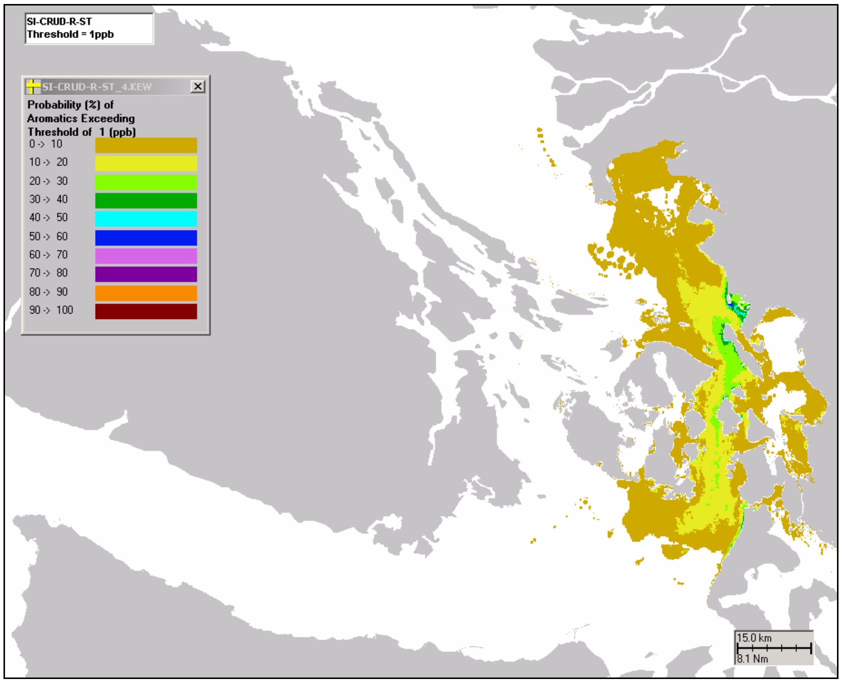


Figure XVI.B-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

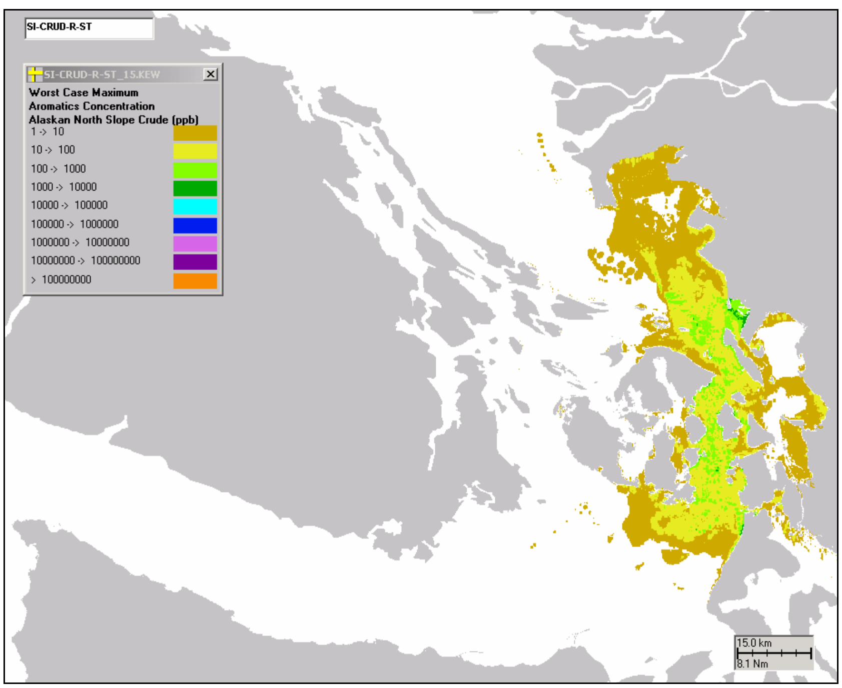


Figure XVI.B-5. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

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).

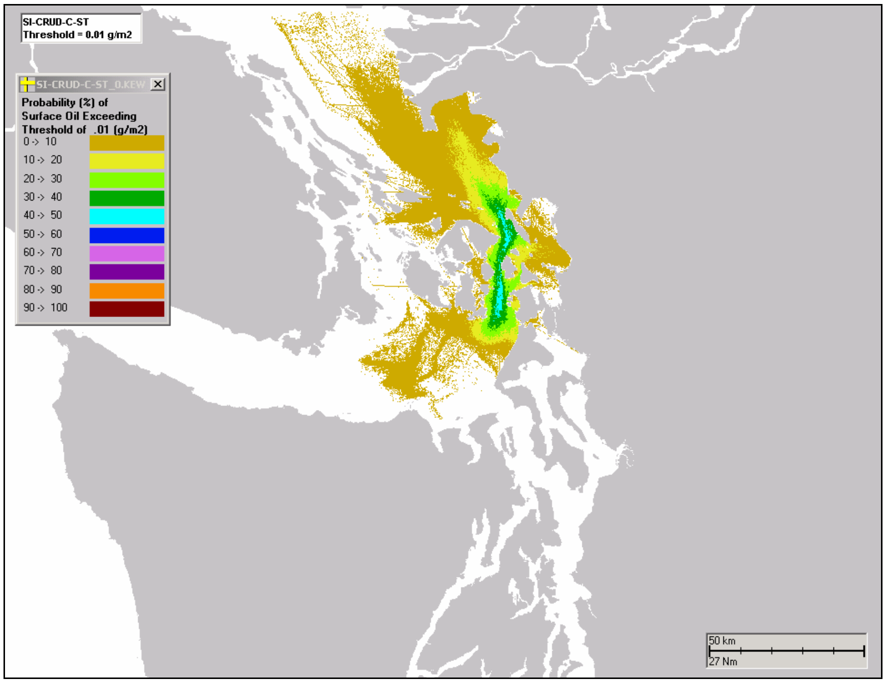


Figure XVI.B-7. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

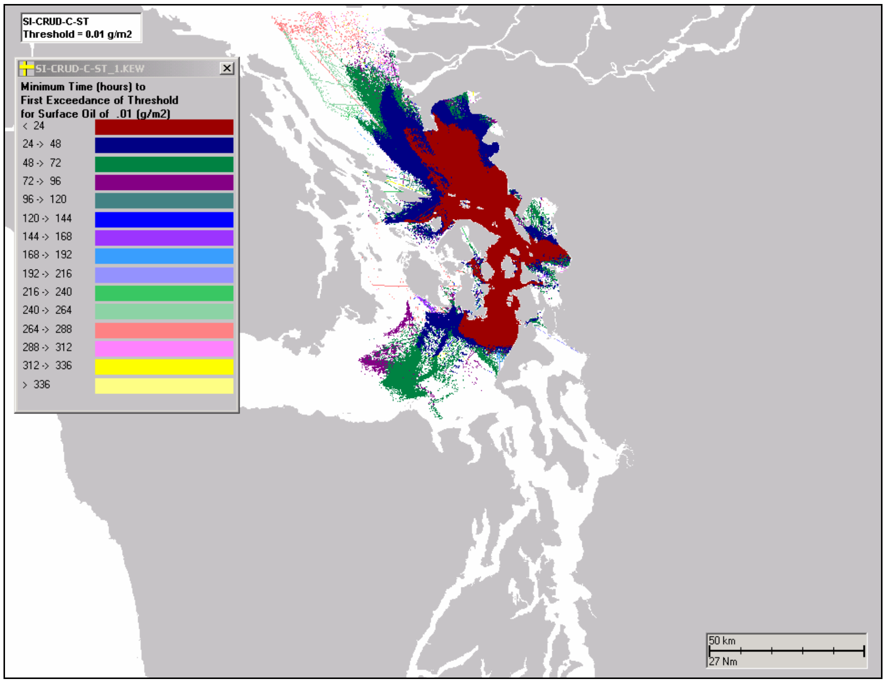


Figure XVI.B-8. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

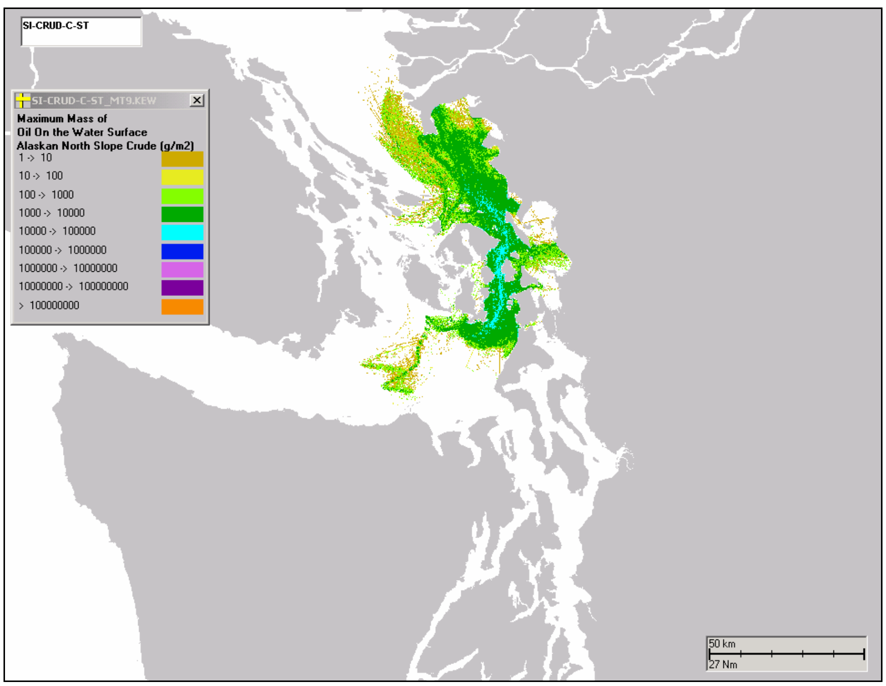


Figure XVI.B-9. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

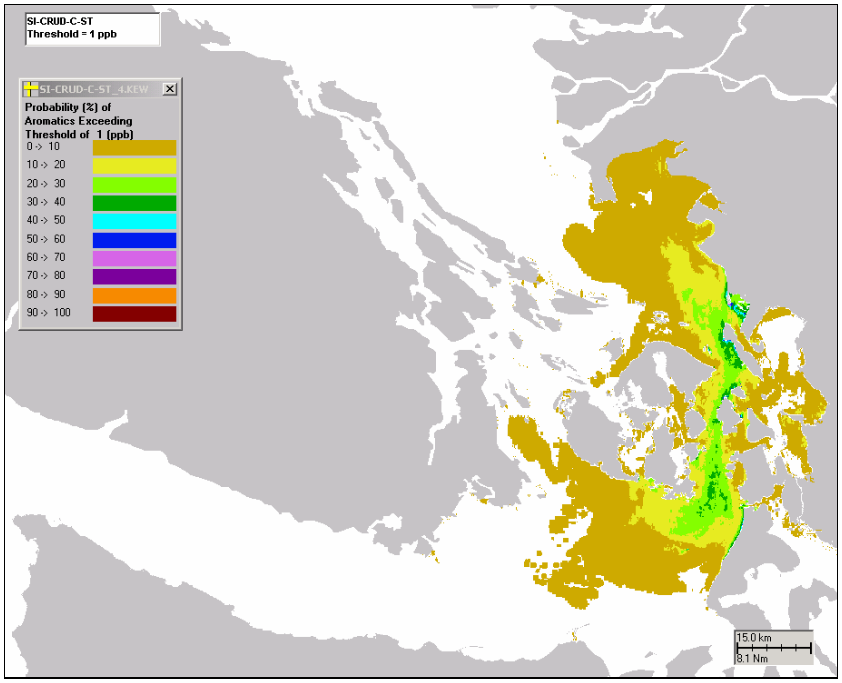


Figure XVI.B-10. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

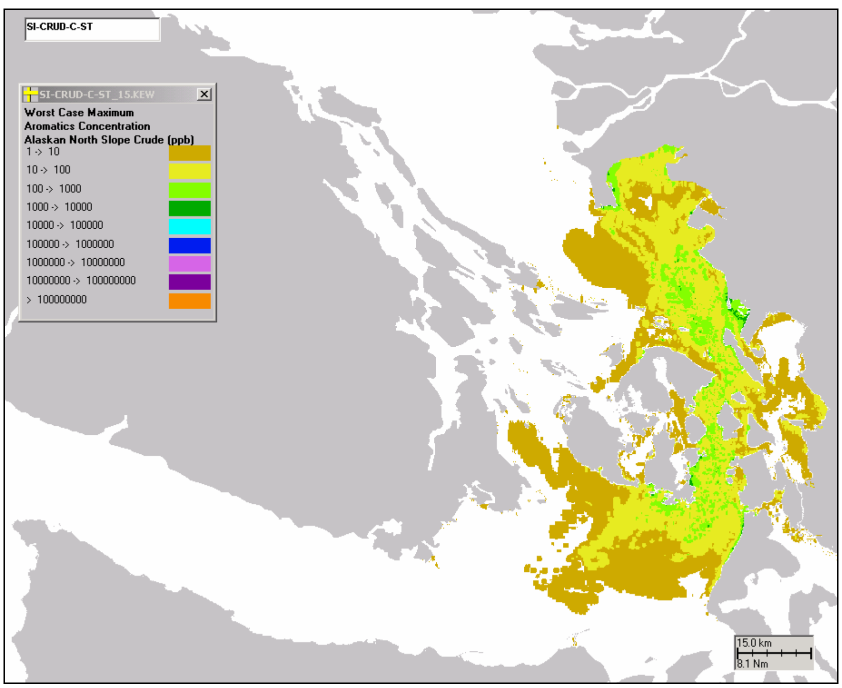


Figure XVI.B-11. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible 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).

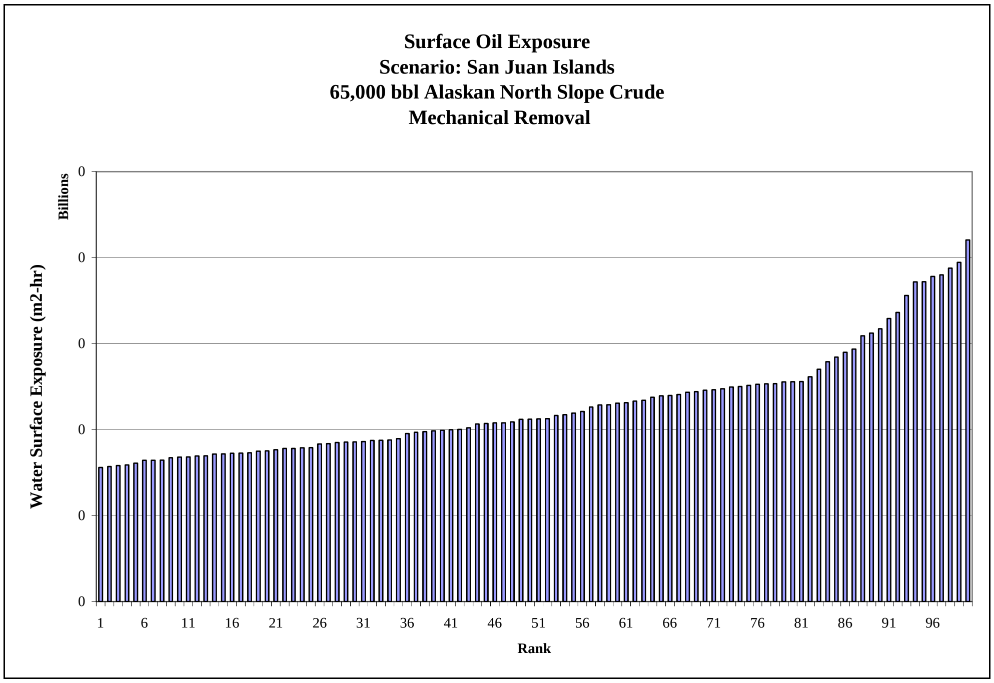


Figure XVI.C-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

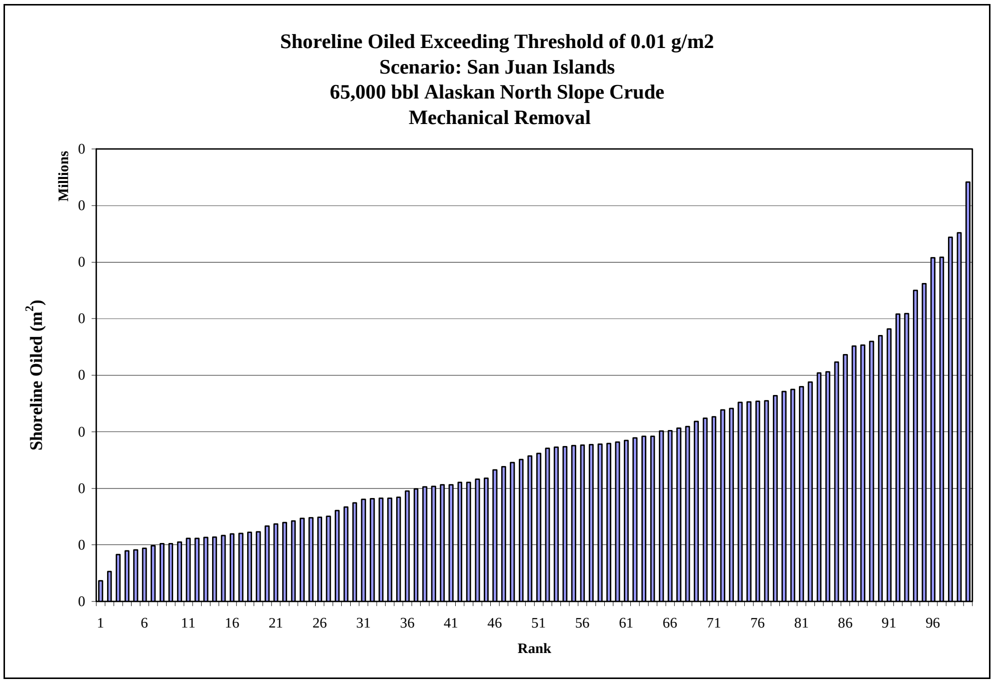


Figure XVI.C-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

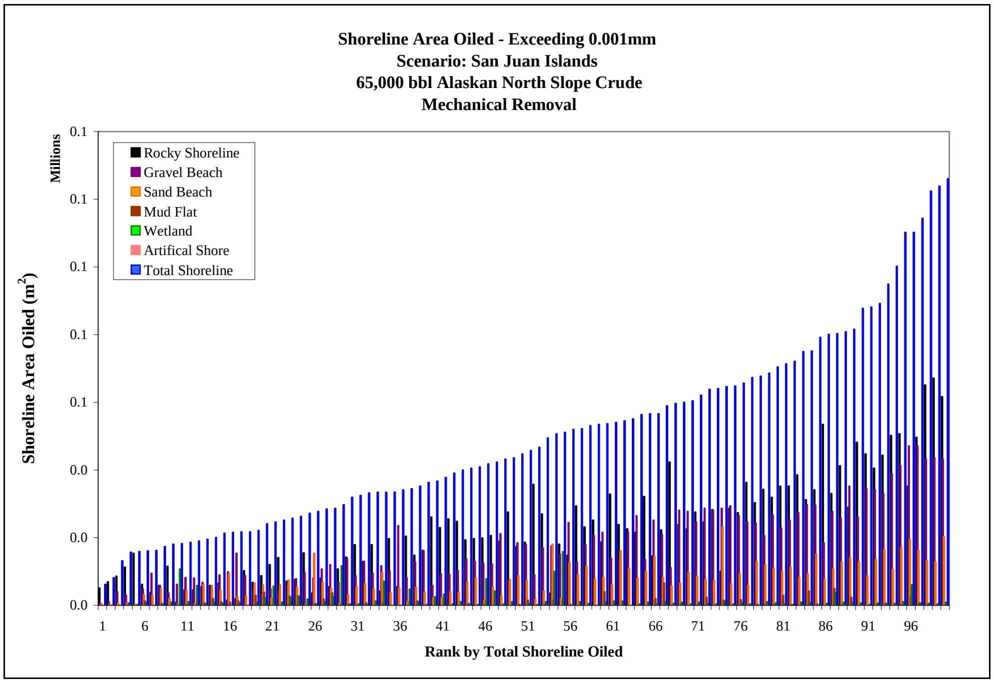


Figure XVI.C-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

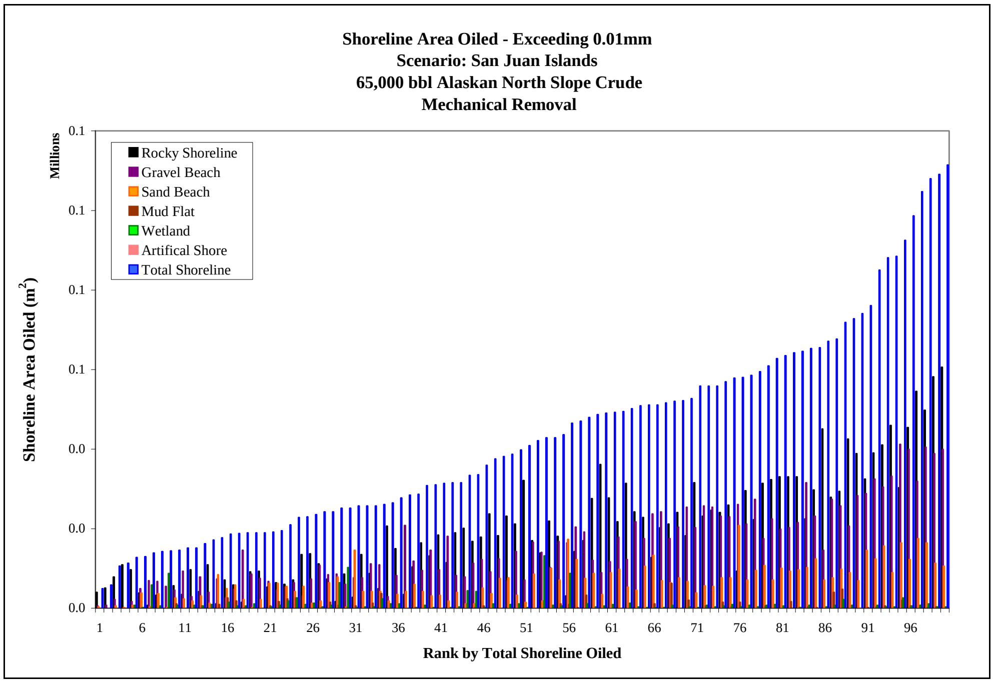


Figure XVI.C-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

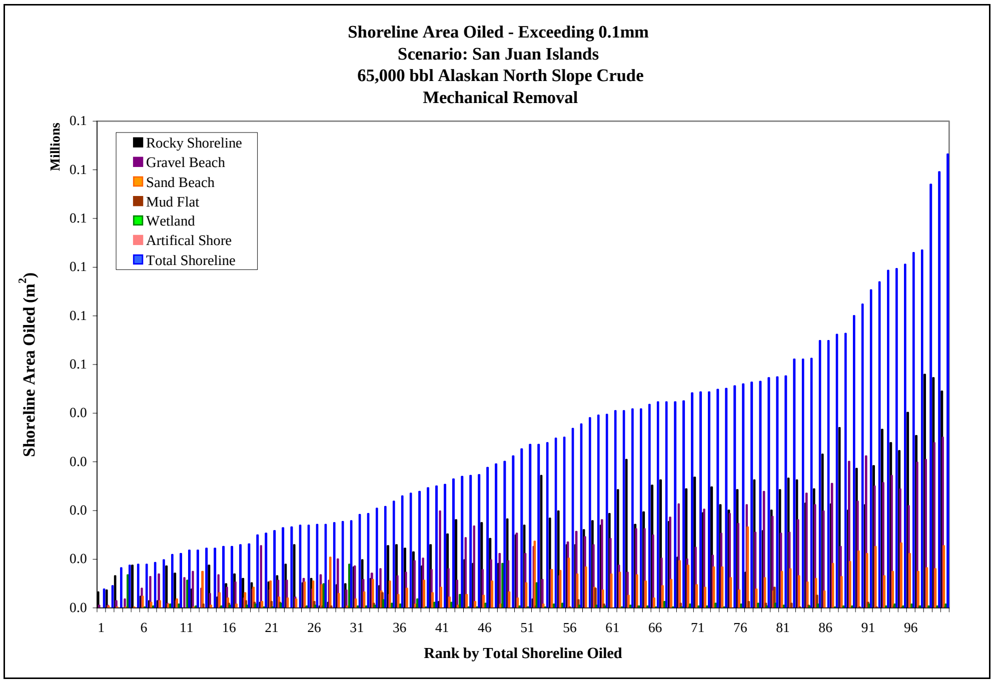


Figure XVI.C-5. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

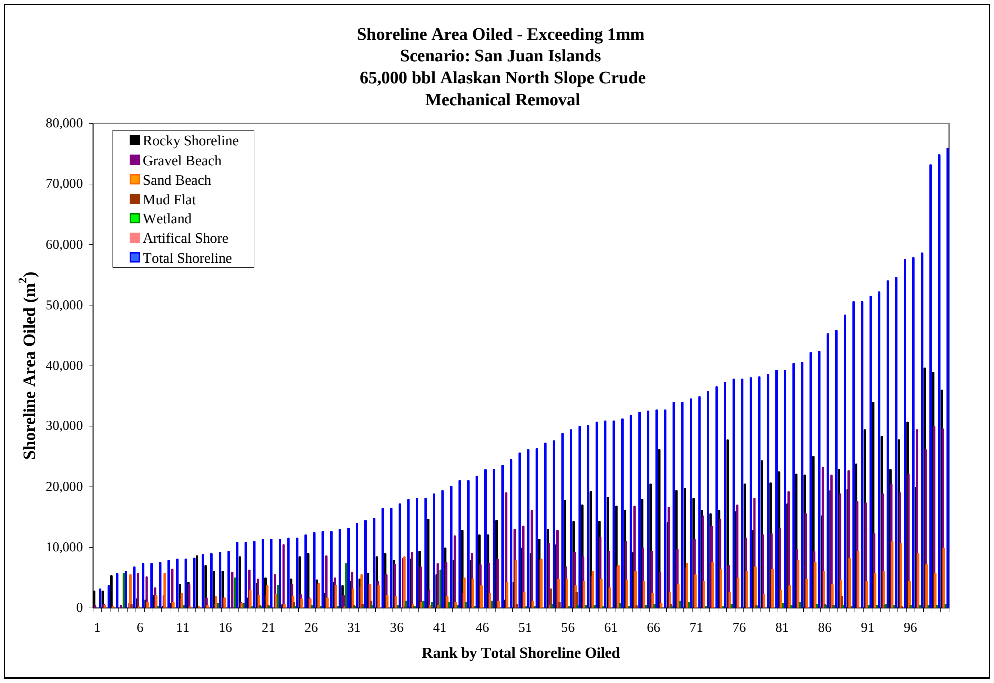


Figure XVI.C-6. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

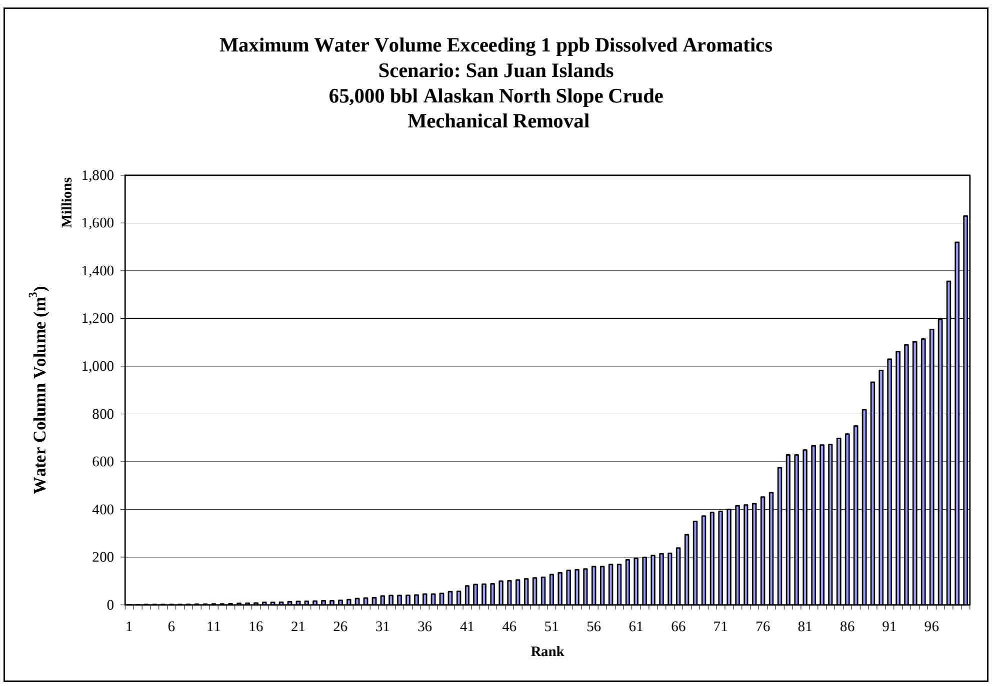


Figure XVI.C-7. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

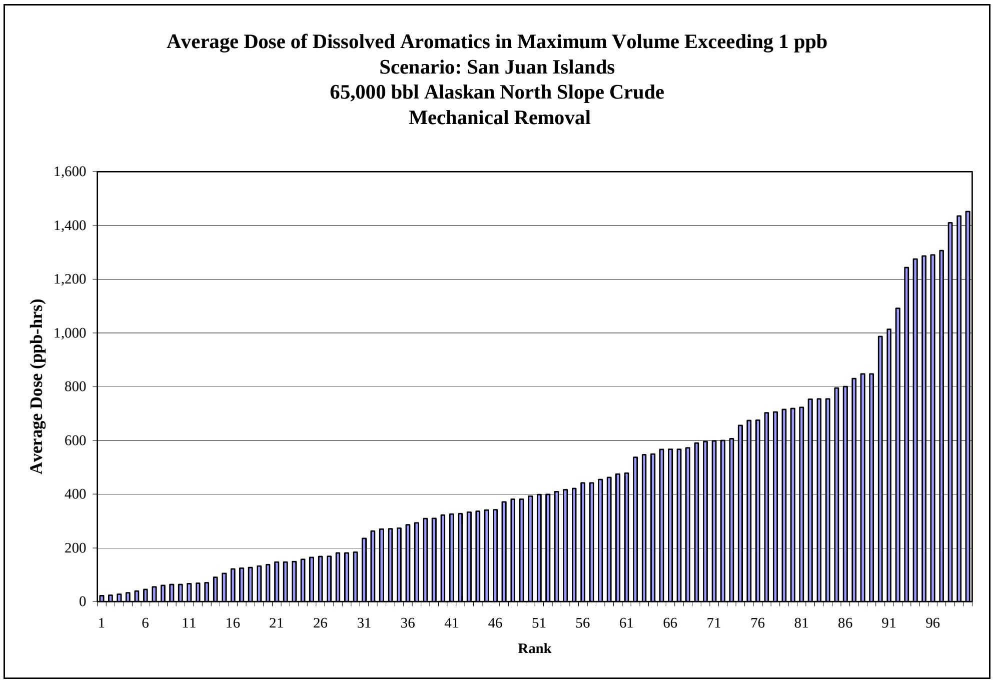


Figure XVI.C-8. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

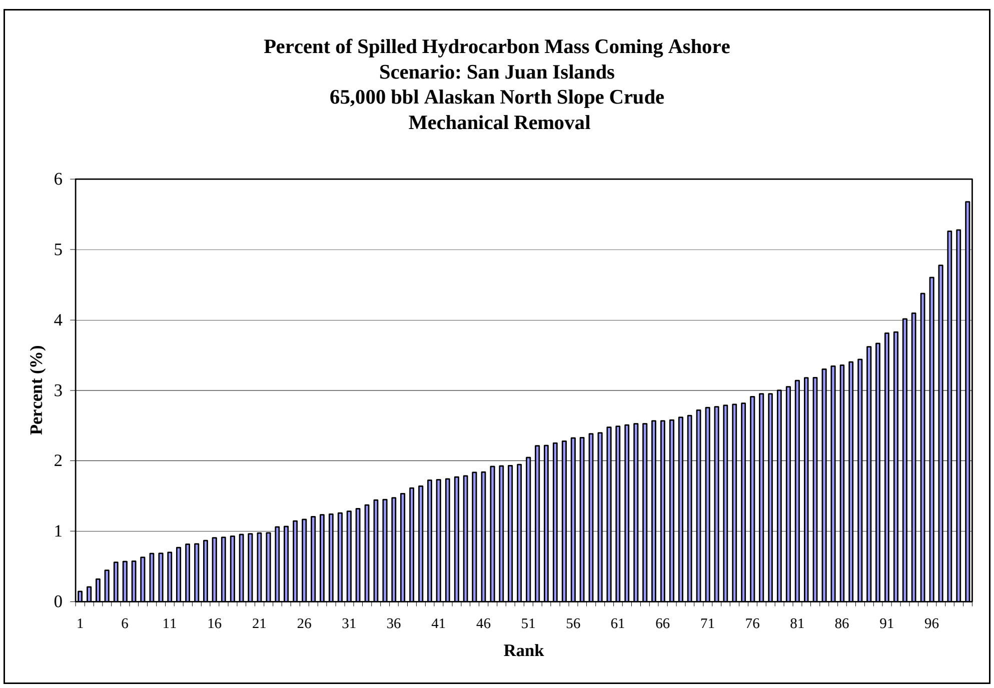


Figure XVI.C-9. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

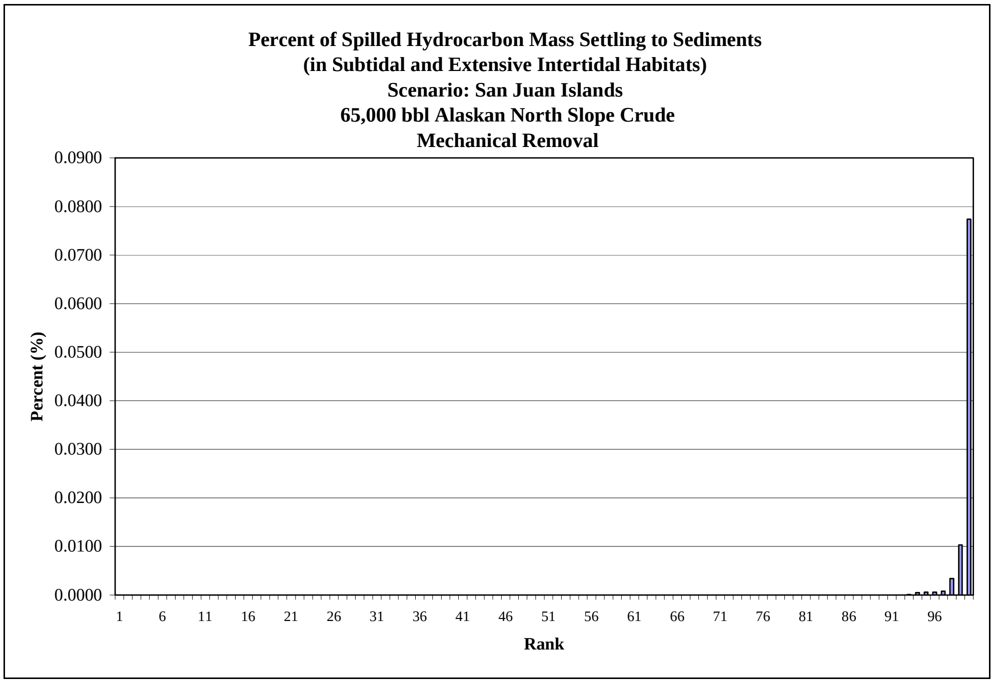


Figure XVI.C-10. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

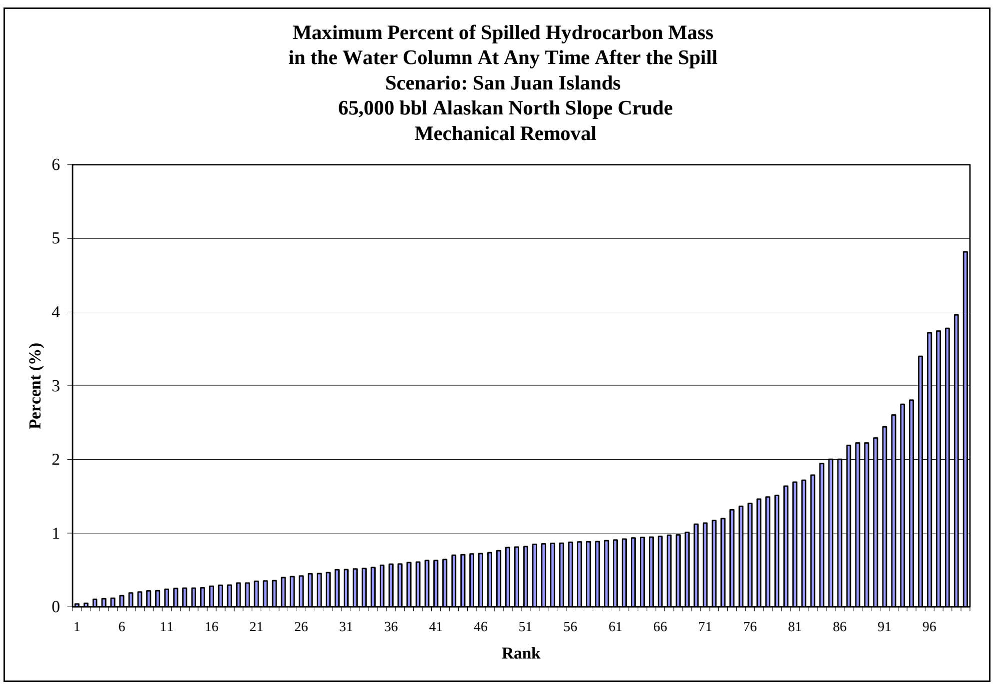


Figure XVI.C-11. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

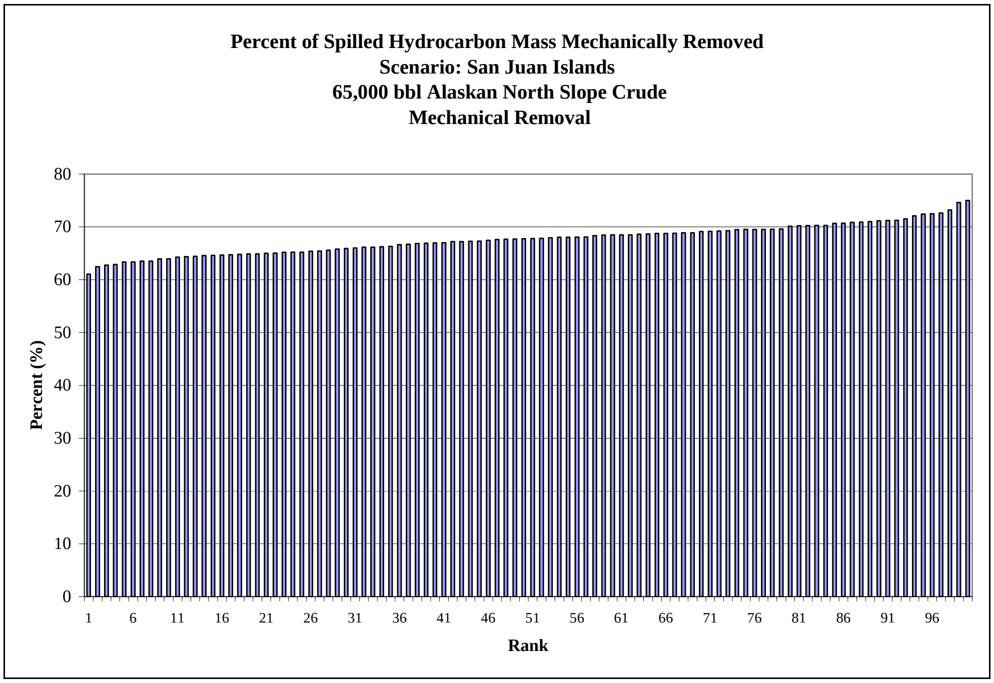


Figure XVI.C-12. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass mechanically removed.

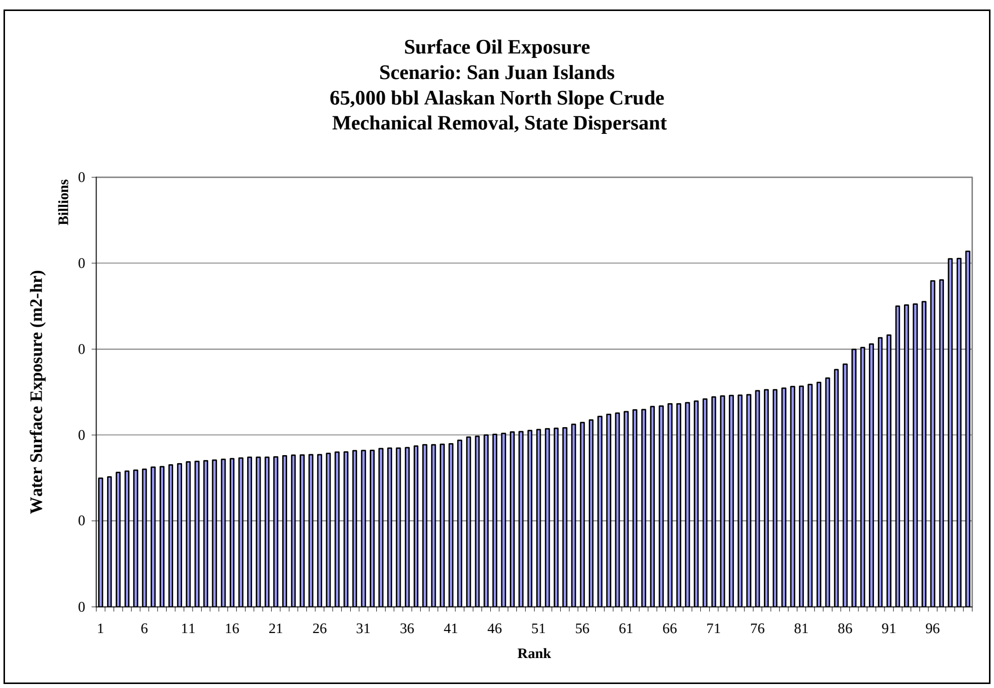


Figure XVI.C-13. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

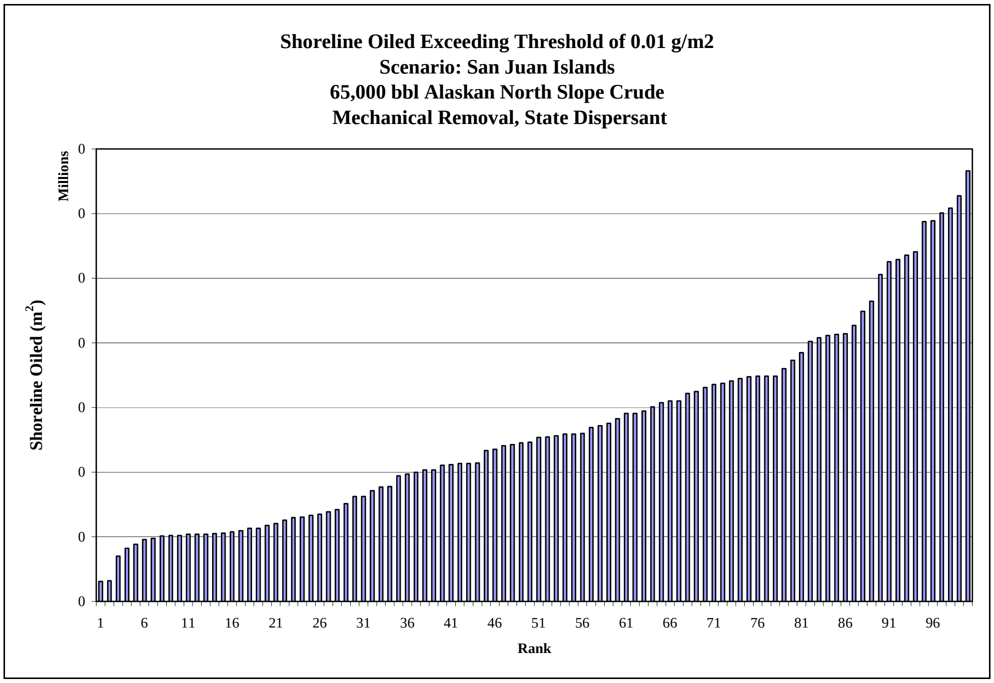


Figure XVI.C-14. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

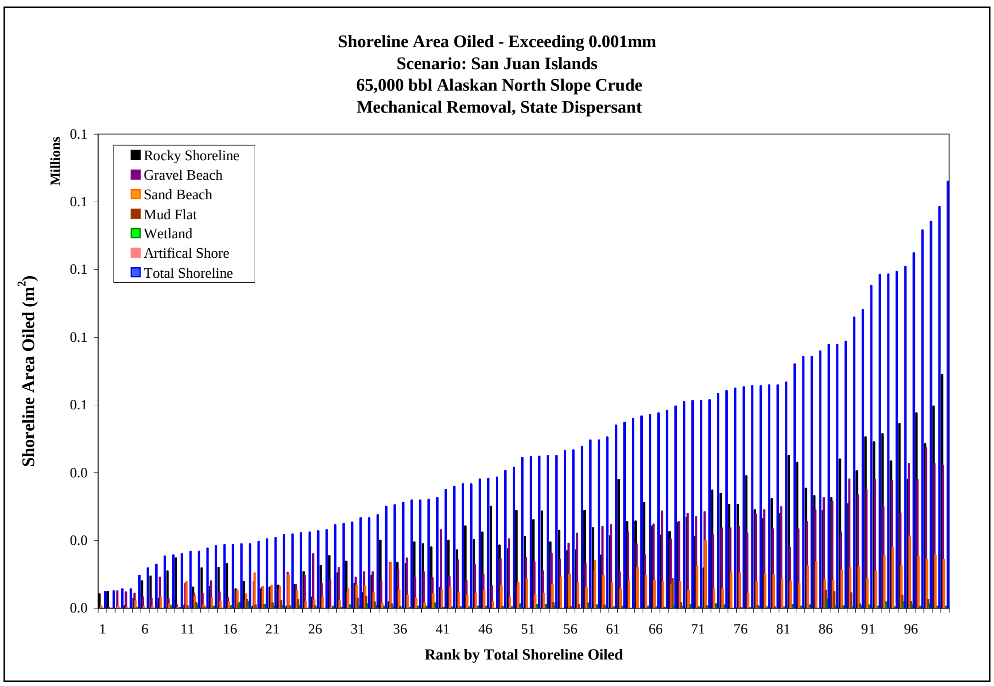


Figure XVI.C-15. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

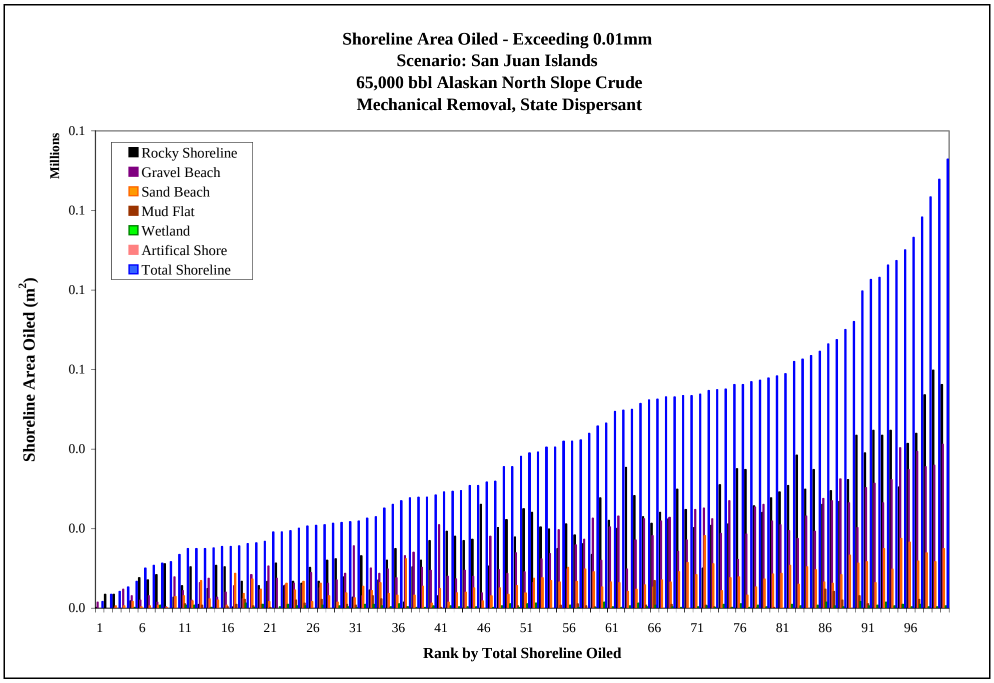


Figure XVI.C-16. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

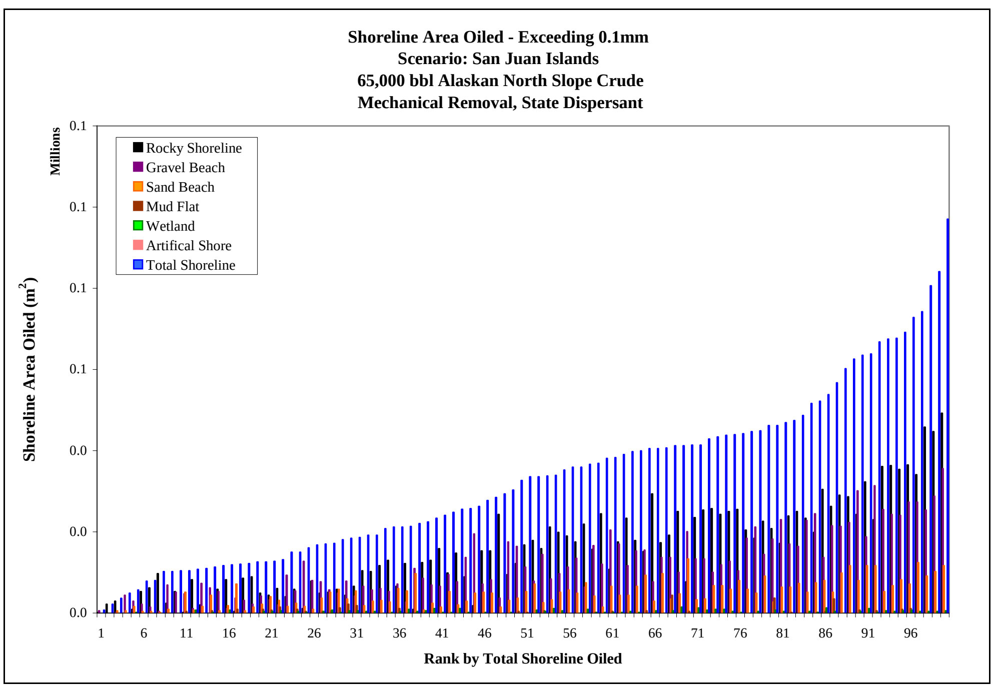


Figure XVI.C-17. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

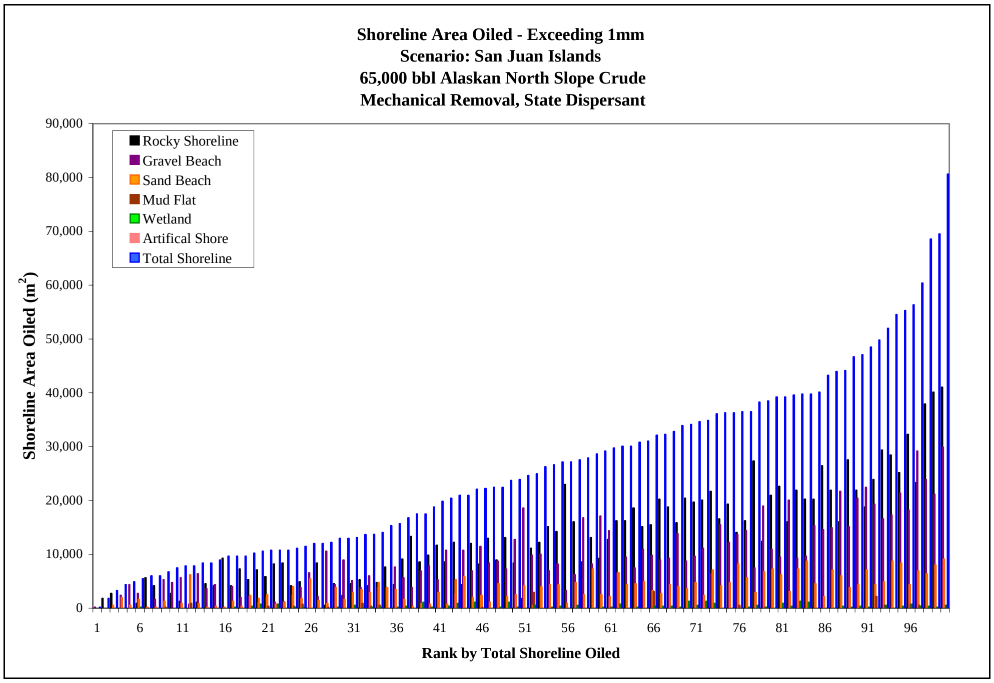


Figure XVI.C-18. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

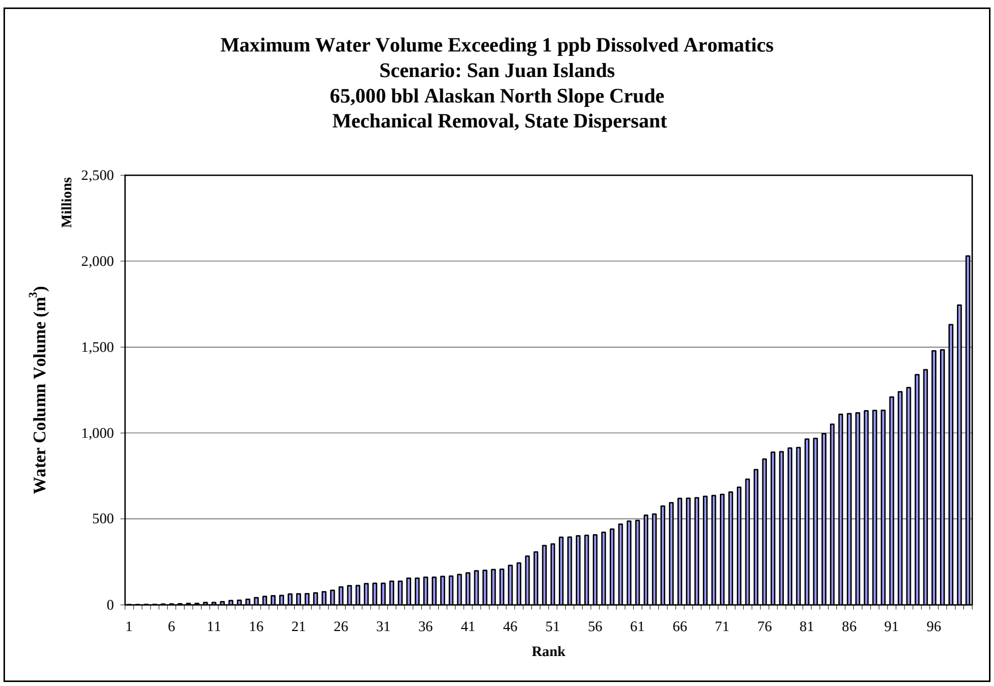


Figure XVI.C-19. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

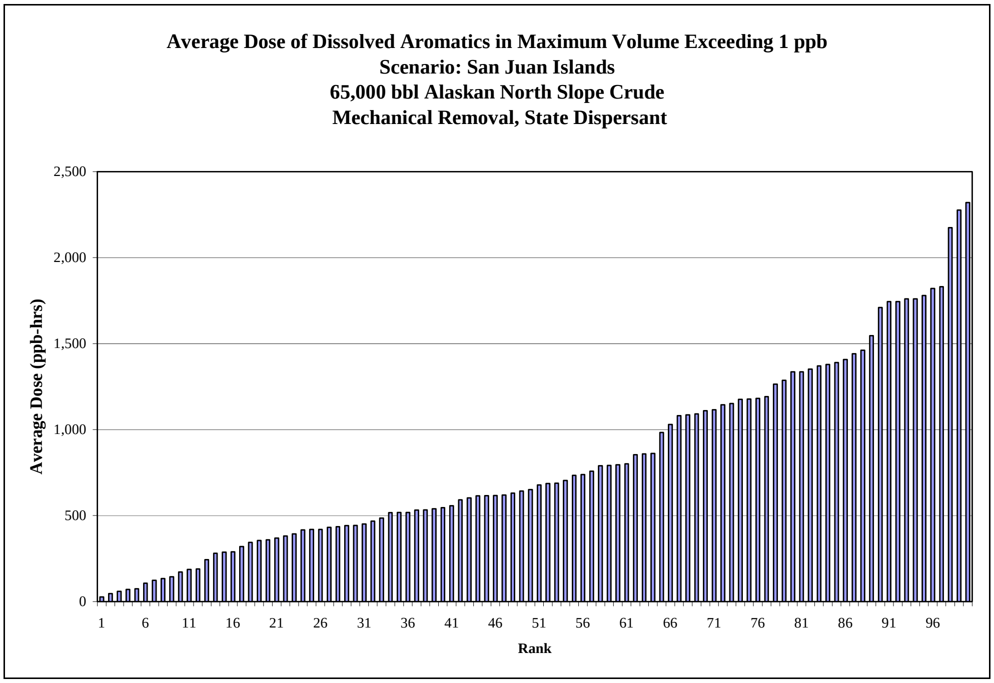


Figure XVI.C-20. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

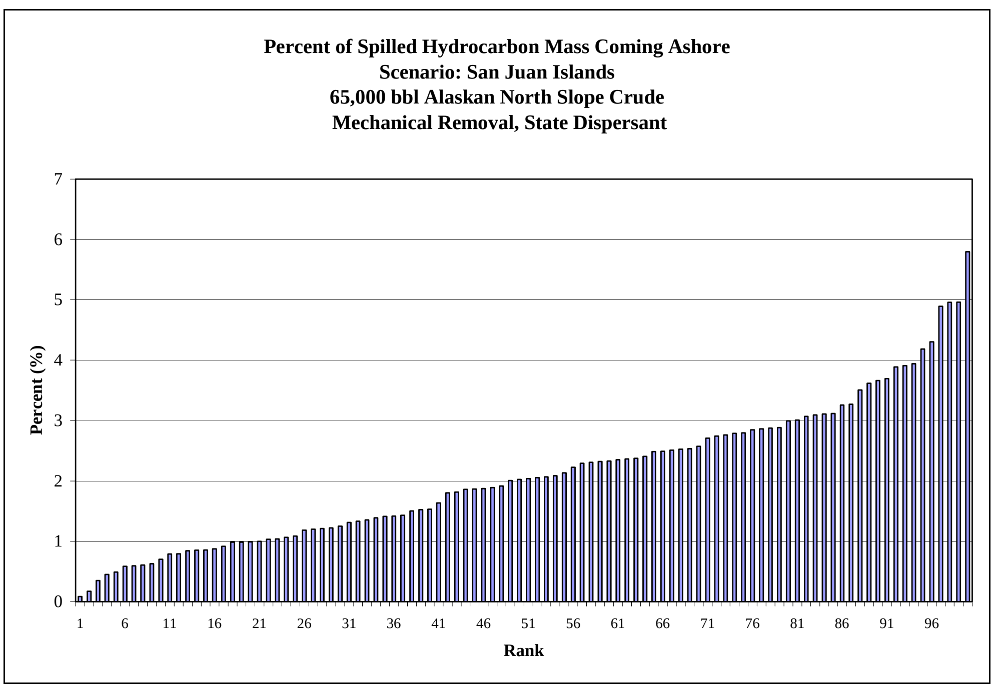


Figure XVI.C-21. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

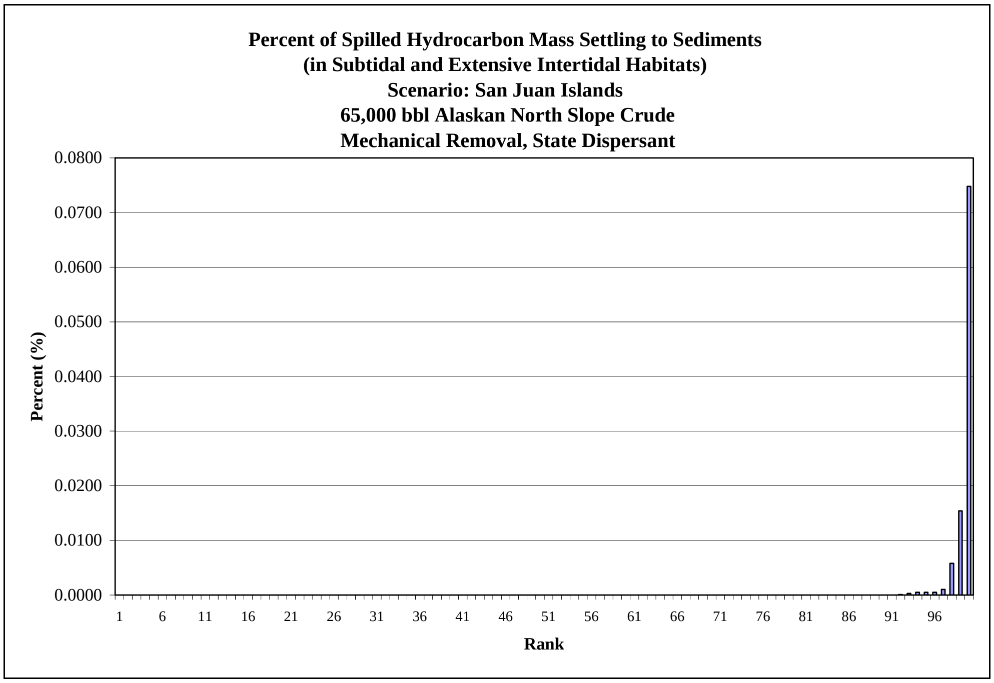


Figure XVI.C-22. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

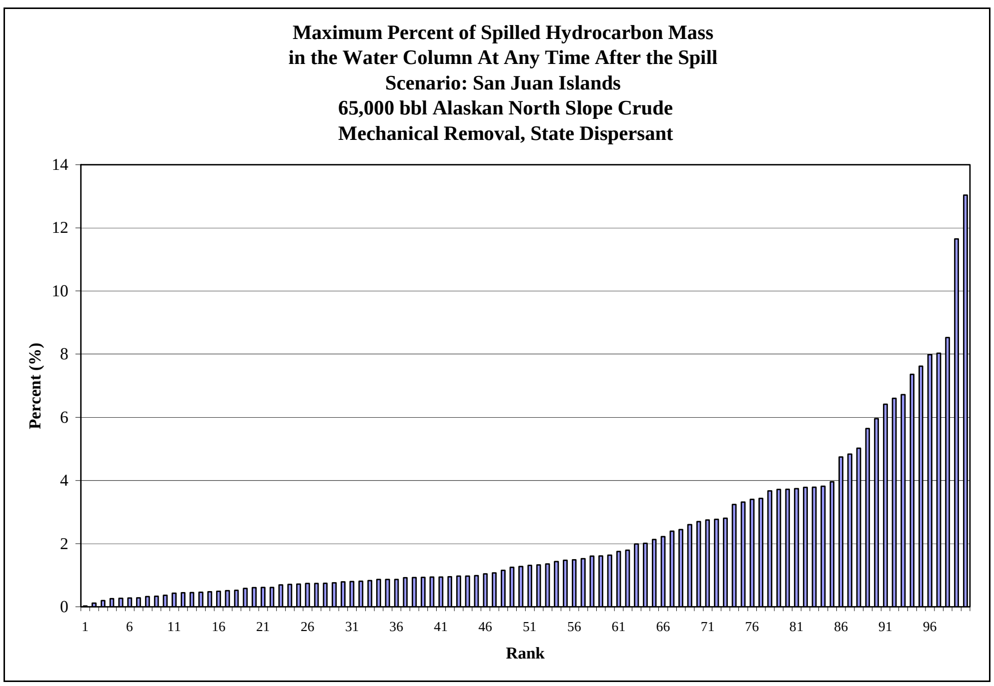


Figure XVI.C-23. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

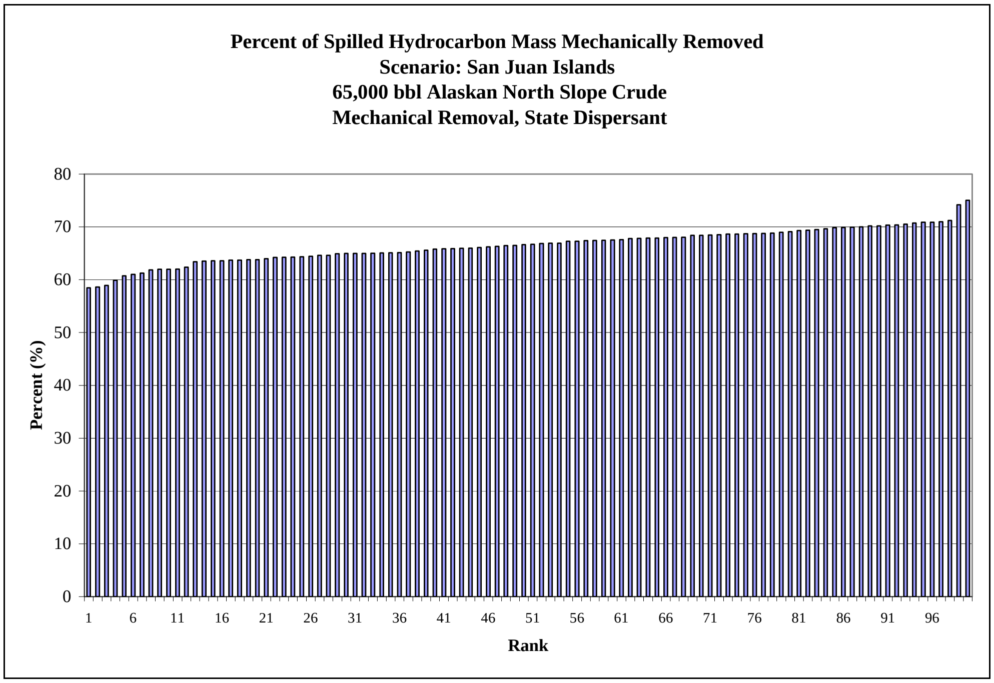


Figure XVI.C-24. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass mechanically removed.

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

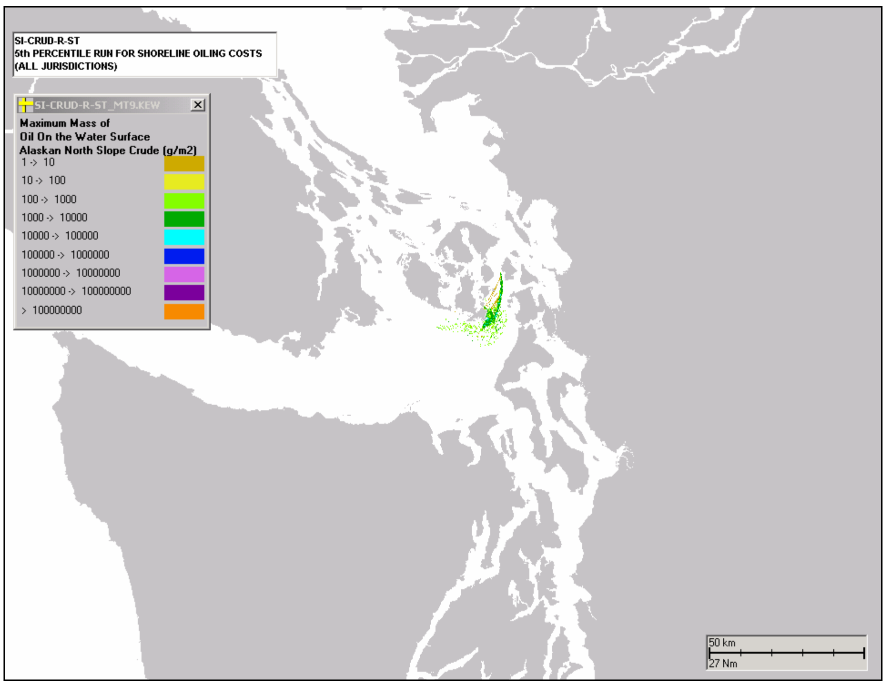


Figure XVI.E-1. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

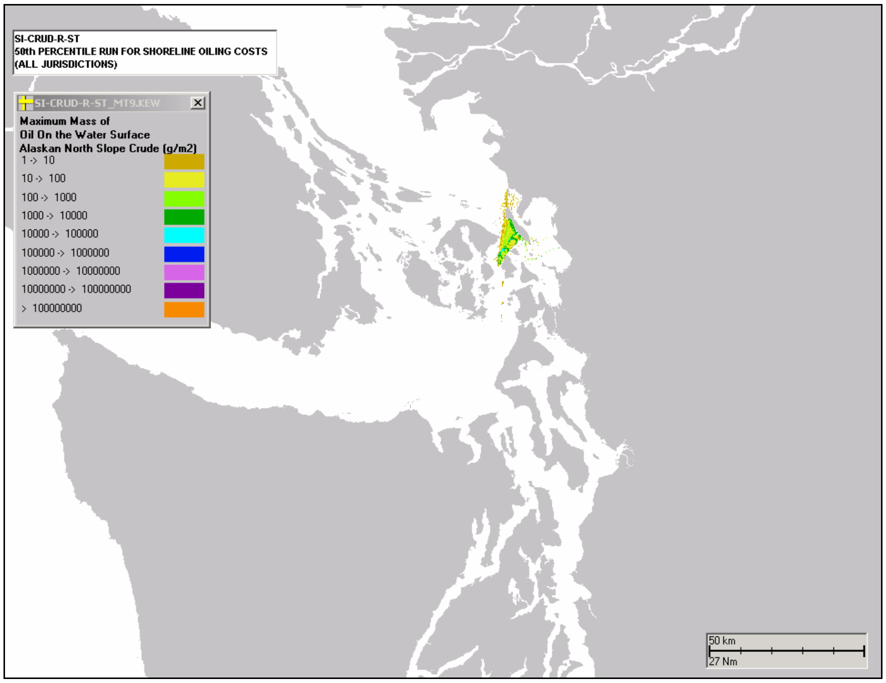


Figure XVI.E-2. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

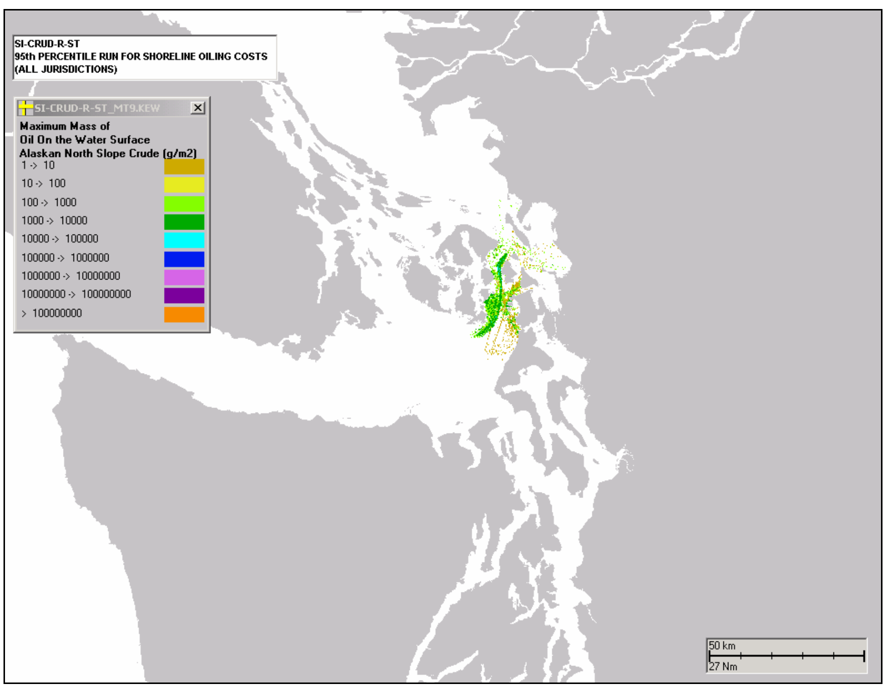


Figure XVI.E-3. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

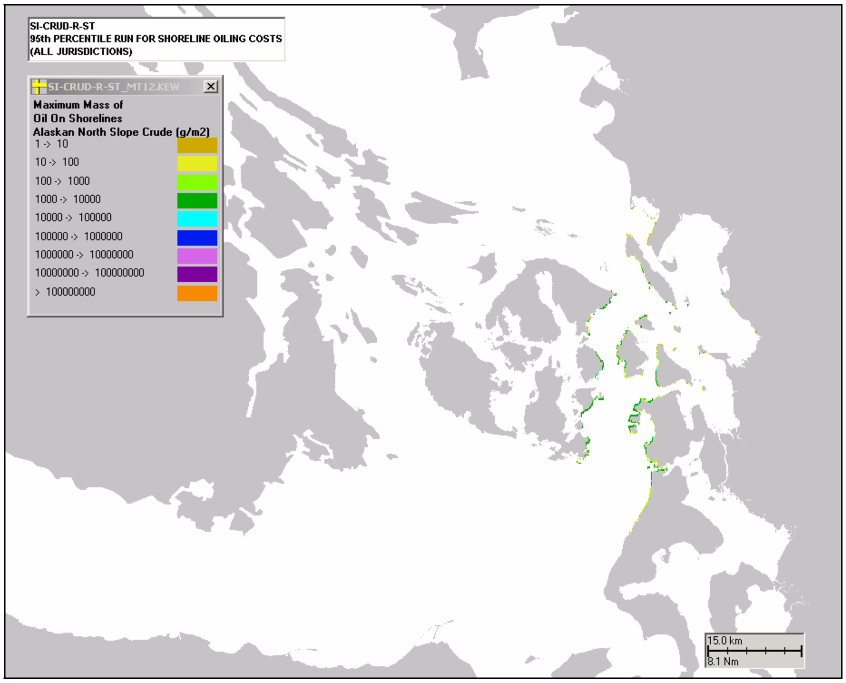


Figure XVI.E-4. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

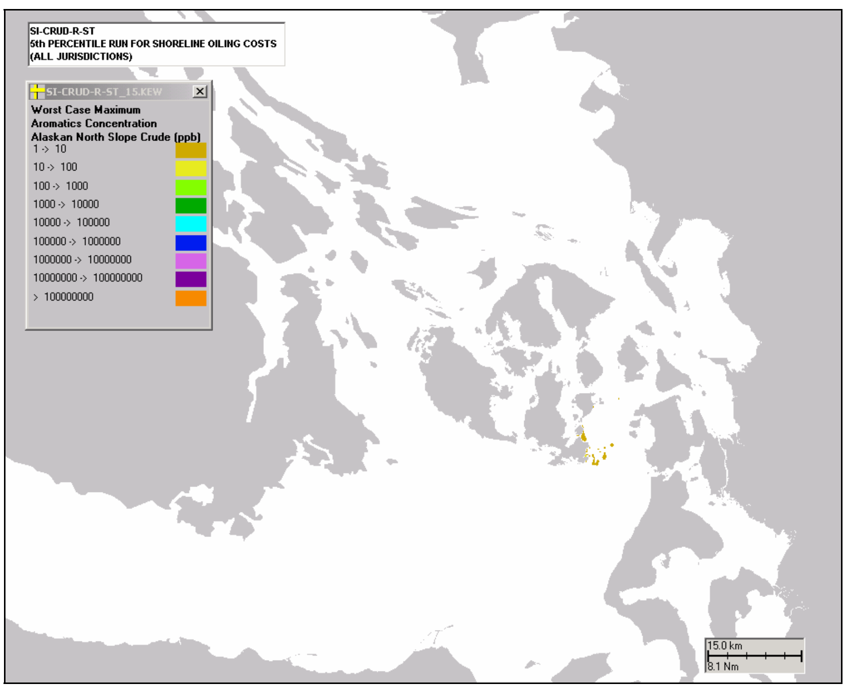


Figure XVI.E-5. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

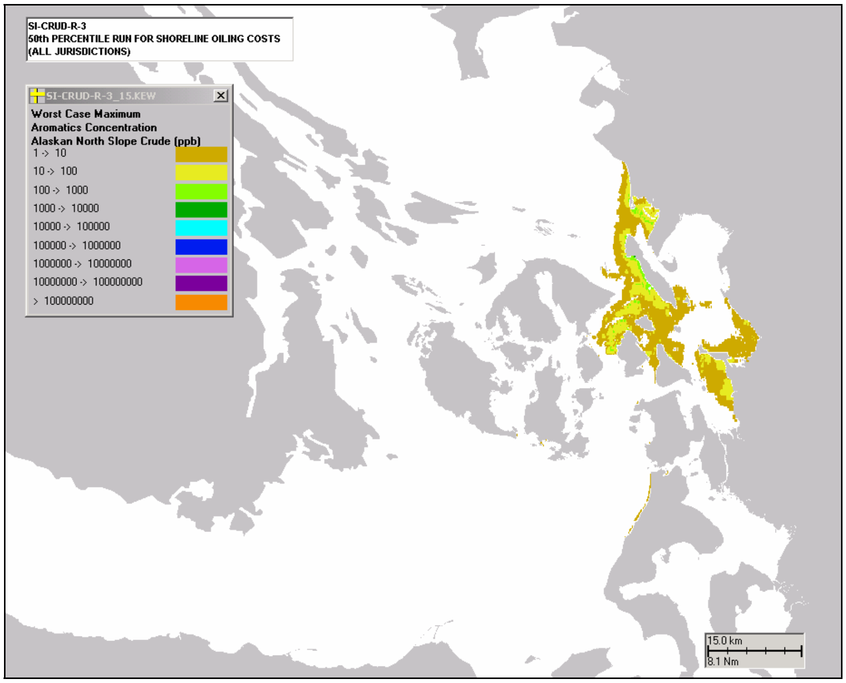


Figure XVI.E-6. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

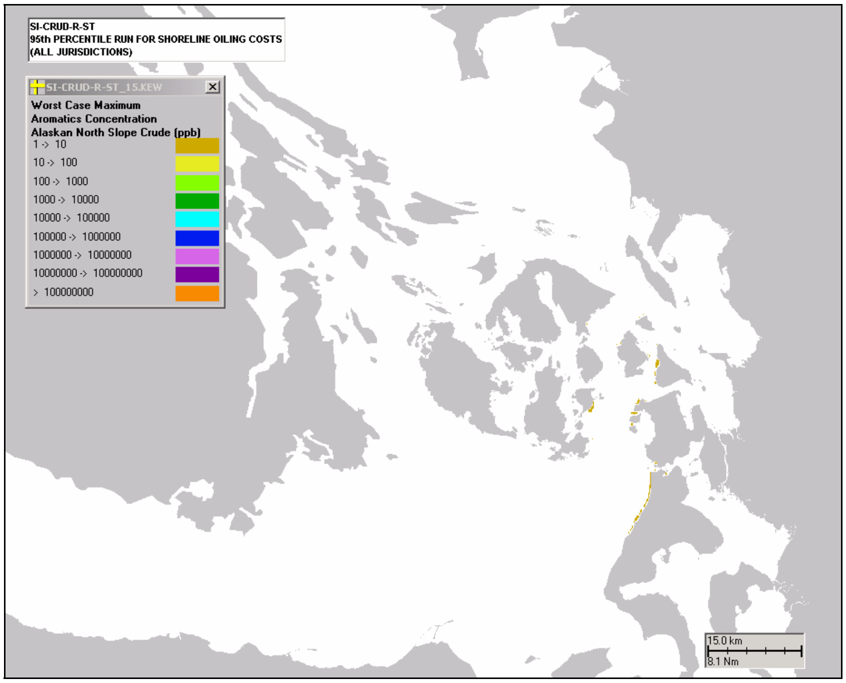


Figure XVI.E-7. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

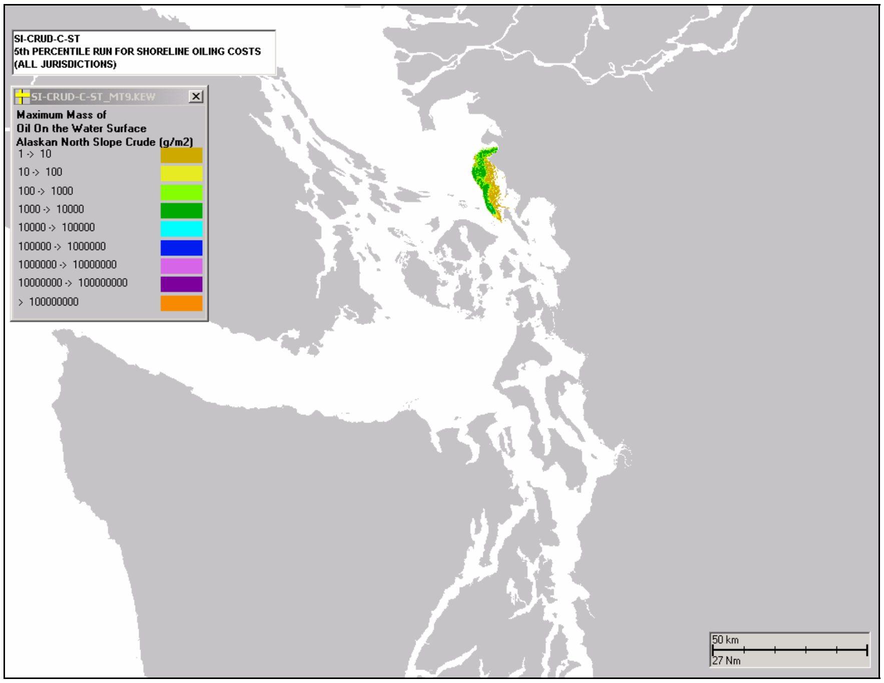


Figure XVI.E-8. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

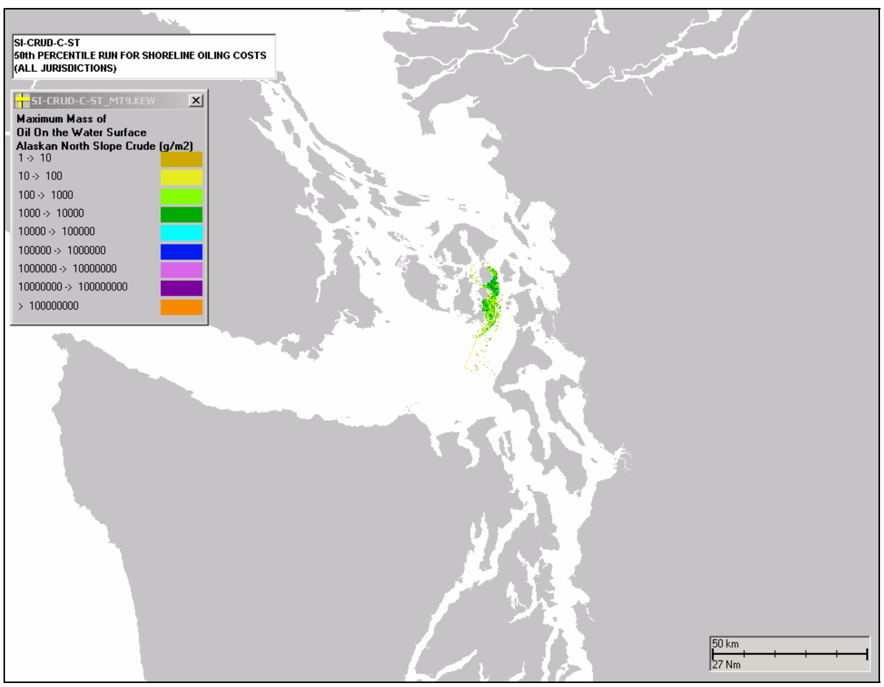


Figure XVI.E-9. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

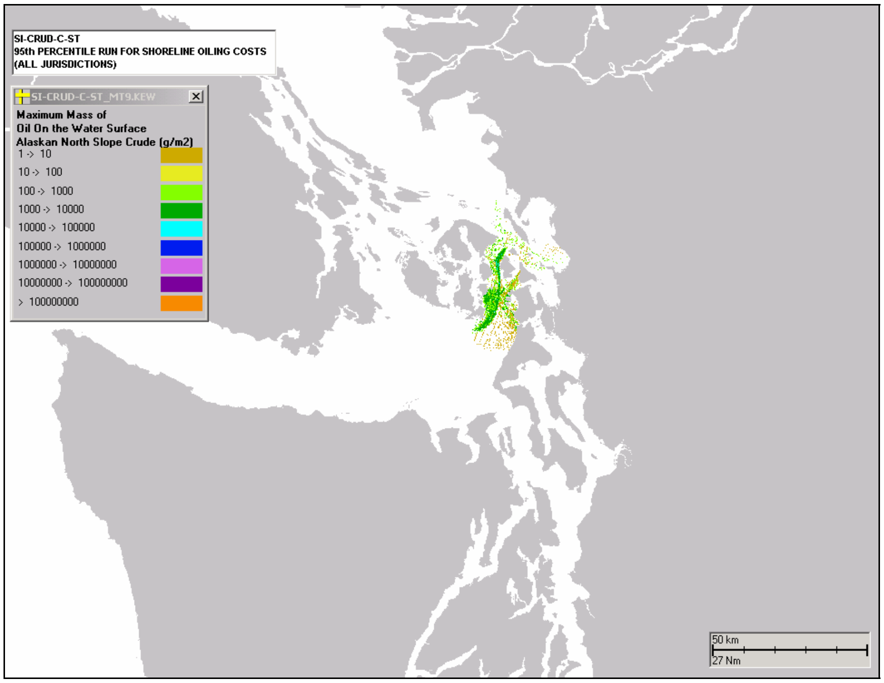


Figure XVI.E-10. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

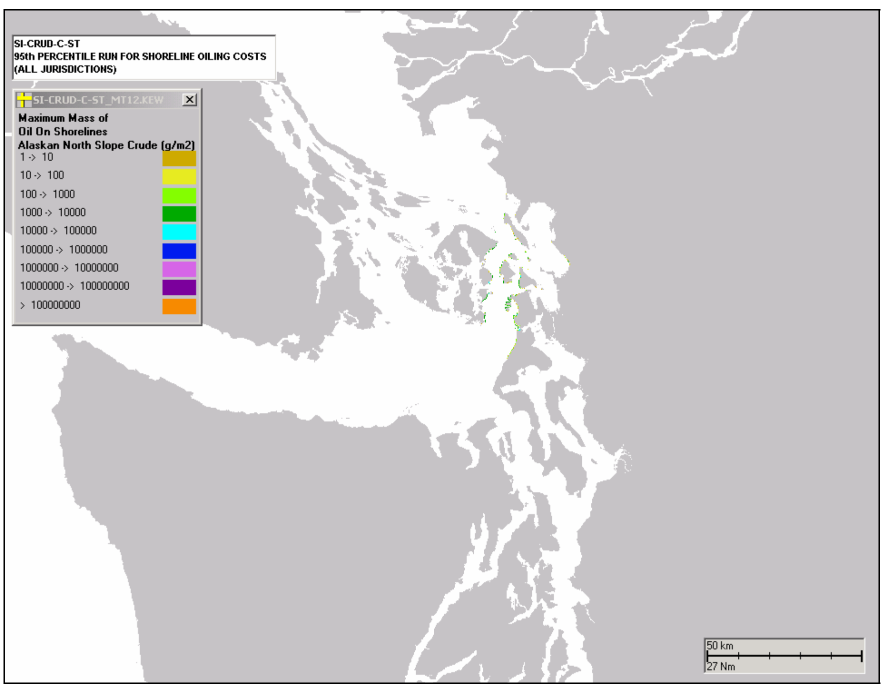


Figure XVI.E-11. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

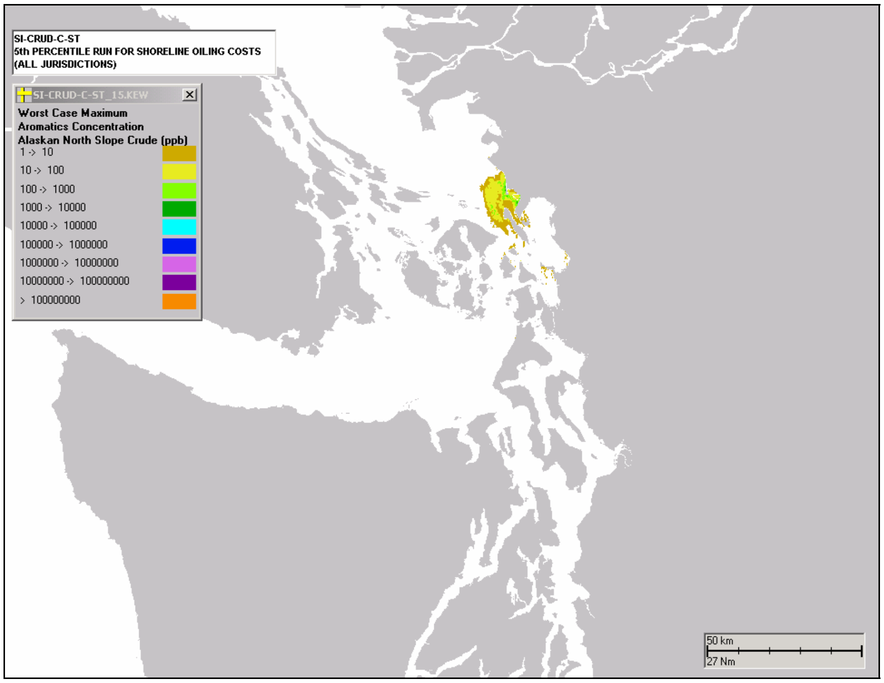


Figure XVI.E-12. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

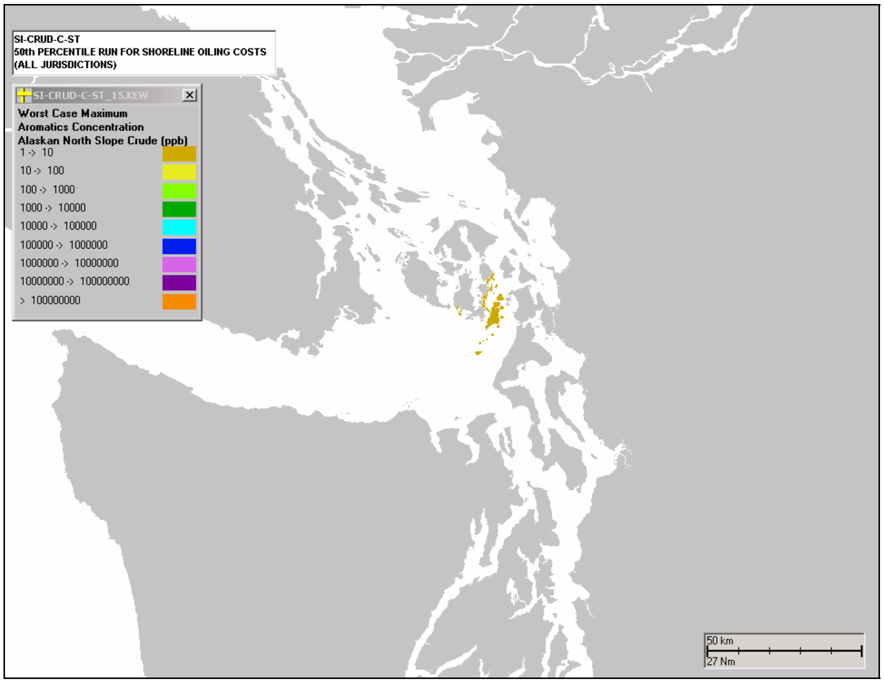


Figure XVI.E-13. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

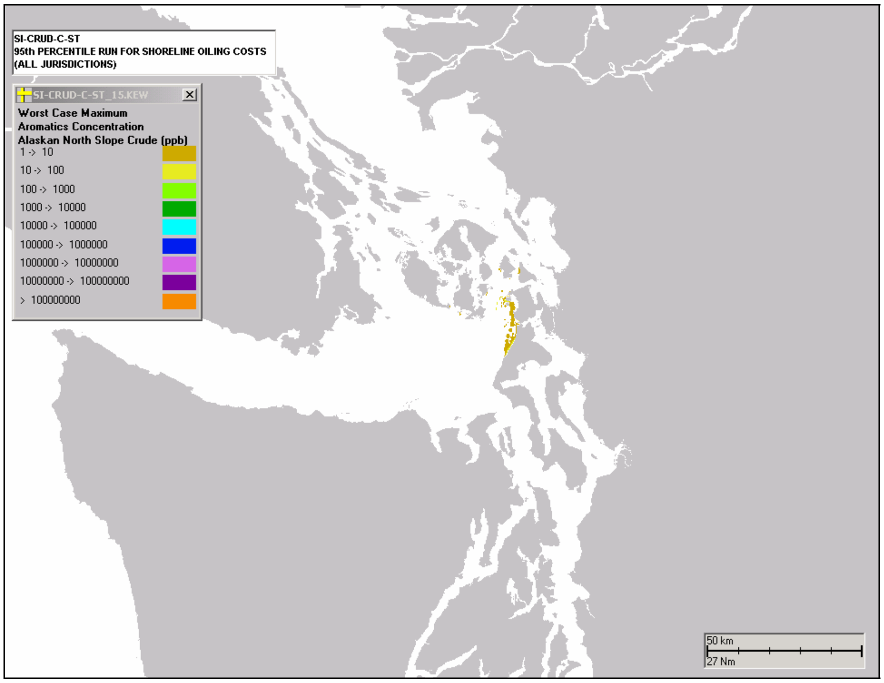


Figure XVI.E-14. San Juan Islands – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XVI.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated for the 5^{th}, 50^{th} and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} or 95^{th} 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 5^{th}, 50^{th} or 95^{th} percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5^{th}, 50^{th} or 95^{th} *runs based on shore costs*. The results for 5^{th}, 50^{th} or 95^{th} *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 5^{th}, 50^{th} or 95^{th} *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 5^{th}, 50^{th} and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} or 95^{th} 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 5^{th}, 50^{th} or 95^{th} percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5^{th}, 50^{th} or 95^{th} *runs based on shore costs*. The results for 5^{th}, 50^{th} or 95^{th} *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 5^{th}, 50^{th} or 95^{th} *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

Table XVI.I-2. San Juan Islands – 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.)	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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

XVII.A. Introduction 1
XVII.B. Exposure for Individual Model Runs.. 3
XVII.B.1. No Removal, Scenario SI-Crud-N.. 3
XVII.B.2. State Mechanical Removal, Scenario SI-Crud-R-ST 7
XVII.B.3. Federal Mechanical Removal, Scenario SI-Crud-R-Fed 11
XVII.B.4. 3rd Alternative Mechanical Removal, Scenario SI-Crud-R-3 15
XVII.B.5. State Mechanical Removal and dispersant, Scenario SI-Crud-C-ST 19
XVII.B.6. Federal Mechanical Removal and dispersant, Scenario SI-Crud-C-Fed 23
XVII.B.7. 3rd Alternative Mechanical Removal and dispersant, Scenario SI-Crud-C-3 27
XVII.B.8. Oil Fate Over Time 31
XVII.C. Estimated Biological Impacts: Wildlife.. 61
XVII.D. Estimated Biological Impacts: Fish and Invertebrates 68
XVII.E. Estimated NRDA Costs: Habitat Restoration Costs 75
XVII.F. Estimated NRDA Costs: Washington Compensation schedule 83

List of Figures

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...... 3
Figure XVII.B.1-2. San Juan Islands, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50^{th} percentile run based on shoreline costs..... 4
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.... 4
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.. 5
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 50^{th} percentile run based on shoreline costs... 5
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.. 6
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.. 7
Figure XVII. B.2-2. San Juan Islands, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50^{th} percentile run based on shoreline costs.. 8
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.. 8
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. 9
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 50^{th} percentile run based on shoreline costs. 9
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. 10
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.. 11
Figure XVII. B.3-2. San Juan Islands, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50^{th} percentile run based on shoreline costs.. 12
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.. 12

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. 13
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 50^{th} percentile run based on shoreline costs. 13
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. 14
Figure XVII.B.4-1. San Juan Islands, crude oil, 3^{rd} alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.. 15
Figure XVII.B.4-2. San Juan Islands, crude oil, 3^{rd} alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50^{th} percentile run based on shoreline costs.. 16
Figure XVII.B.4-3. San Juan Islands, crude oil, 3^{rd} alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.. 16
Figure XVII.B.4-4. San Juan Islands, crude oil, 3^{rd} 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. 17
Figure XVII.B.4-5. San Juan Islands, crude oil, 3^{rd} alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50^{th} percentile run based on shoreline costs. 17
Figure XVII.B.4-6. San Juan Islands, crude oil, 3^{rd} 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. 18
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.. 19
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 50^{th} percentile run based on shoreline costs.. 20
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.. 20
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. 21
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 50^{th} percentile run based on shoreline costs. 21
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. 22

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. 23
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 50^{th} percentile run based on shoreline costs. 24
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. 24
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. 25
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 50^{th} percentile run based on shoreline costs. 25
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. 26
Figure XVII.B.7-1. San Juan Islands, crude oil, 3^{rd} alternative mechanical removal, dispersant: San Juan Islands, crude oil, 3^{rd} alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs. 27
Figure XVII.B.7-2. San Juan Islands, crude oil, 3^{rd} alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50^{th} percentile run based on shoreline costs. 28
Figure XVII.B.7-3. San Juan Islands, crude oil, 3^{rd} alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs. 28
Figure XVII.B.7-4. San Juan Islands, crude oil, 3^{rd} 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. 29
Figure XVII.B.7-5. San Juan Islands, crude oil, 3^{rd} alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50^{th} percentile run based on shoreline costs. 29
Figure XVII.B.7-6. San Juan Islands, crude oil, 3^{rd} 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. 30
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). 32
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). 32

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). 33
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). 33
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).. 34
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).. 34
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)..................................... 35
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). 35
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). 36
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). 36
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). 37
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).. 37
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).. 38
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)................................... 38
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). 39
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). 39
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). 40

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). 40
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)... 41
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)... 41
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).................................... 42
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 5^{th} percentile run (based on shore cost). Part b is a subset of Part a. 43
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 5^{th} percentile run (based on shore cost). Part b is a subset of Part a. 44
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 5^{th} percentile run (based on shore cost). Part b is a subset of Part a... 45
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 5^{th} percentile run (based on shore cost). Part b of this figure is a subset of Part a... 46
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 5^{th} percentile run (based on shore cost). Part b of this figure is a subset of Part a. 47
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 5^{th} percentile run (based on shore cost). Part b of this figure is a subset of Part a... 48
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 50^{th} percentile run (based on shore cost). Part b is a subset of Part a. 49
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 50^{th} percentile run (based on shore cost). Part b is a subset of Part a. 50
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 50^{th} percentile run (based on shore cost). Part b is a subset of Part a.. 51

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. 52
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. 53
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. 54
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. 55
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. 56
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. 57
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. 58
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. 59
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. 60

List of Tables

Table IXVII.C-1 San Juan Islands, no removal: Wildlife injury (as numbers lost). 61
Table IXVII.C-2 San Juan Islands, WA state mechanical removal: Wildlife injury (as numbers lost)... 62
Table IXVII.C-3 San Juan Islands, federal mechanical removal: Wildlife injury (as numbers lost)... 63
Table IXVII.C-4 San Juan Islands, 3rd alternative mechanical removal: Wildlife injury (as numbers lost)... 64
Table IXVII.C-5 San Juan Islands, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost). 65
Table IXVII.C-6 San Juan Islands, federal mechanical removal and dispersant application: Wildlife injury (as numbers lost). 66
Table IXVII.C-7 San Juan Islands, 3rd alternative mechanical removal and dispersant application: Wildlife injury (as numbers lost). 67
Table XVII.D-1. San Juan Islands, no removal: Fish and invertebrate injury (as biomass lost in kg). 68
Table XVII.D-2. San Juan Islands, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 69
Table XVII.D-3. San Juan Islands, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 70
Table XVII.D-4. San Juan Islands, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 71
Table XVII.D-5. San Juan Islands, WA state mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg). 72
Table XVII.D-6. San Juan Islands, federal mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg). 73
Table XVII.D-7. San Juan Islands, 3rd alternative mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg). 74
Table XVII.E-1. San Juan Islands, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 76
Table XVII.E-2. San Juan Islands, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 76
Table XVII.E-3. San Juan Islands, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 77
Table XVII.E-4. San Juan Islands, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.. 77
Table XVII.E-5. San Juan Islands, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 78
Table XVII.E-6. San Juan Islands, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.. 78
Table XVII.E-7. San Juan Islands, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 79
Table XVII.E-8. San Juan Islands, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.. 79

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.. 80
Table XVII.E-10. San Juan Islands, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.... 80
Table XVII.E-11. San Juan Islands, federal mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.. 81
Table XVII.E-12. San Juan Islands, federal mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.... 81
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.. 82
Table XVII.E-14. San Juan Islands, 3rd alternative mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.... 82
Table XVII.F-1. San Juan Islands, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule... 83
Table XVII.F-2. San Juan Islands, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule............. 83
Table XVII.F-3. San Juan Islands, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 83
Table XVII.F-4. San Juan Islands, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule............. 84
Table XVII.F-5. San Juan Islands, WA state mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 84
Table XVII.F-6. San Juan Islands, federal mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 84
Table XVII.F-7. San Juan Islands, 3rd alternative mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 84

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.

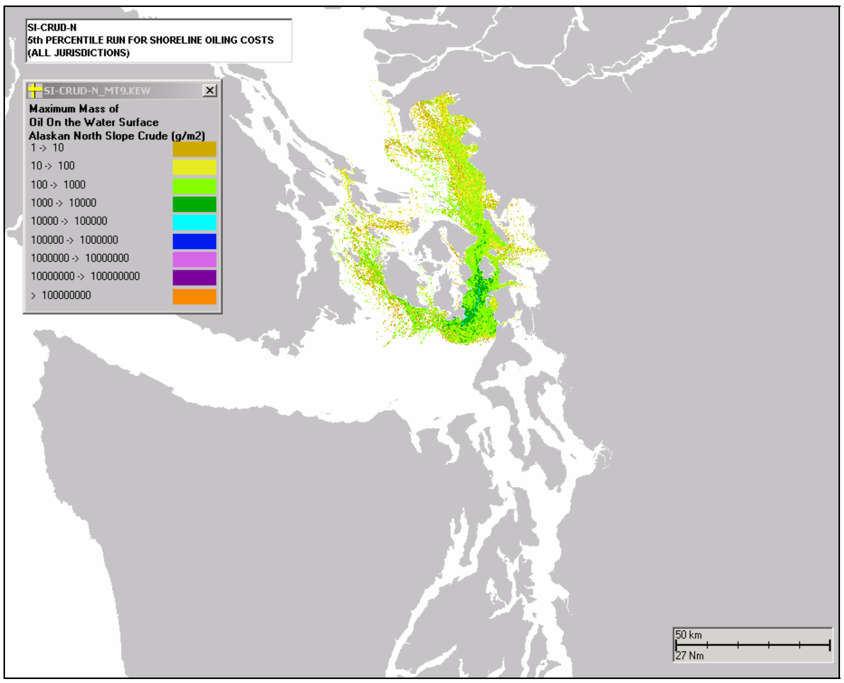


Figure XVII.B.1-1. San Juan Islands, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

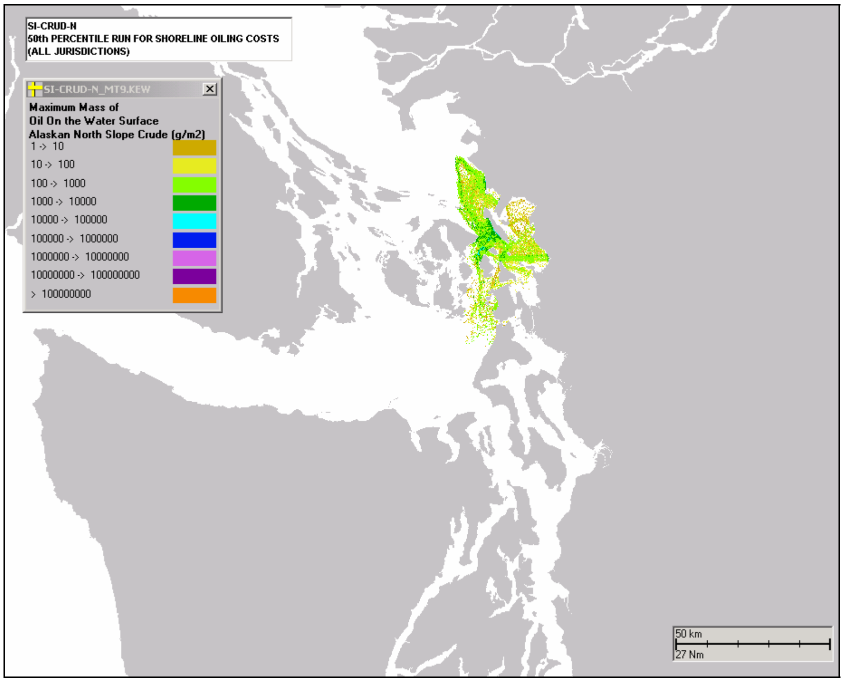


Figure XVII.B.1-2. San Juan Islands, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

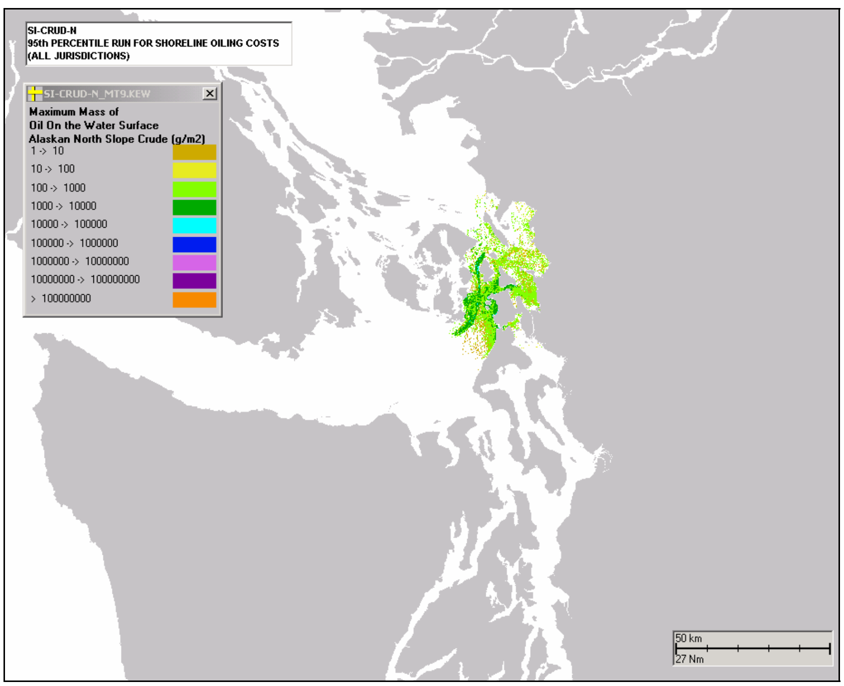


Figure XVII.B.1-3. San Juan Islands, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

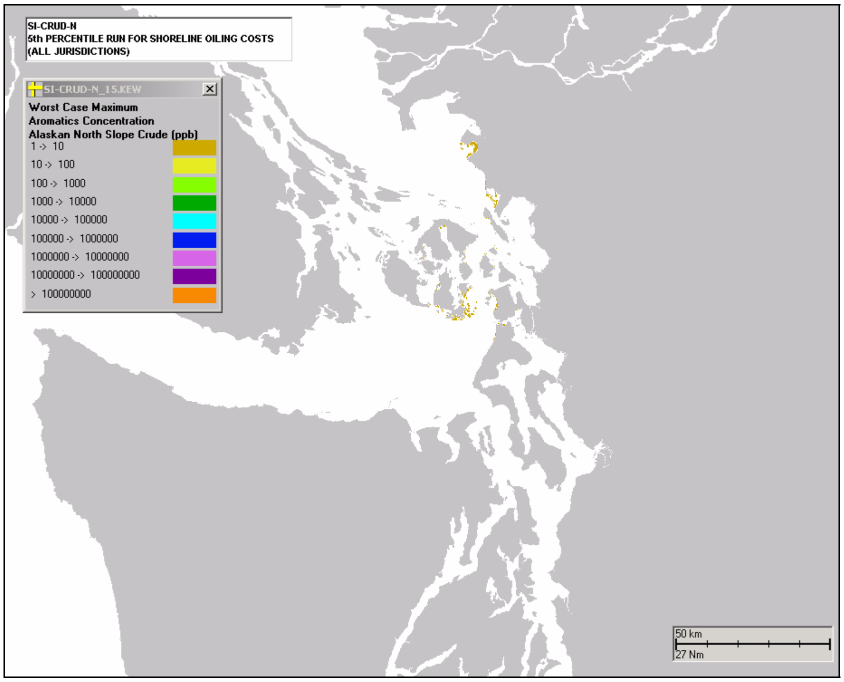


Figure XVII.B.1-4. San Juan Islands, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

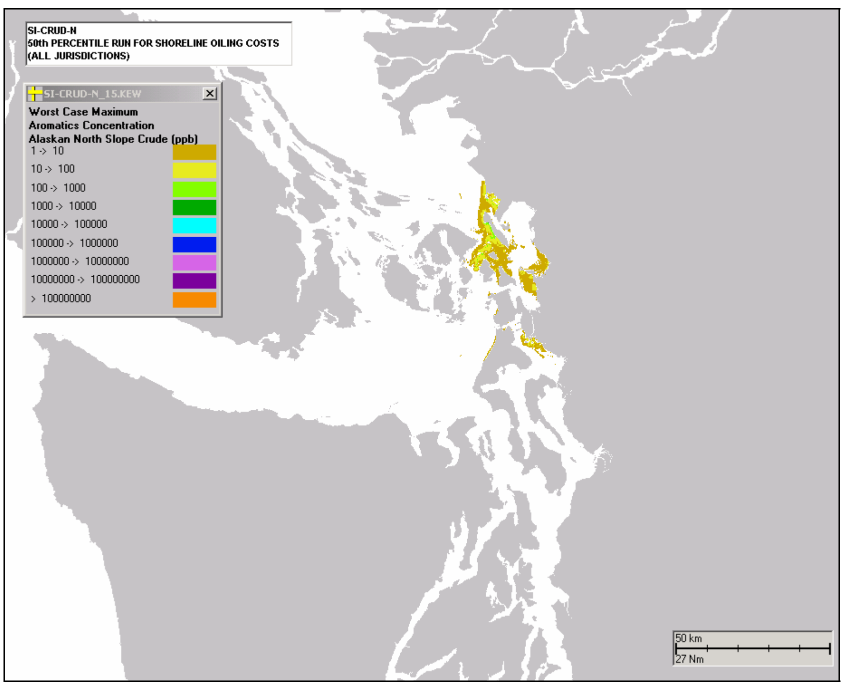


Figure XVII.B.1-5. San Juan Islands, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

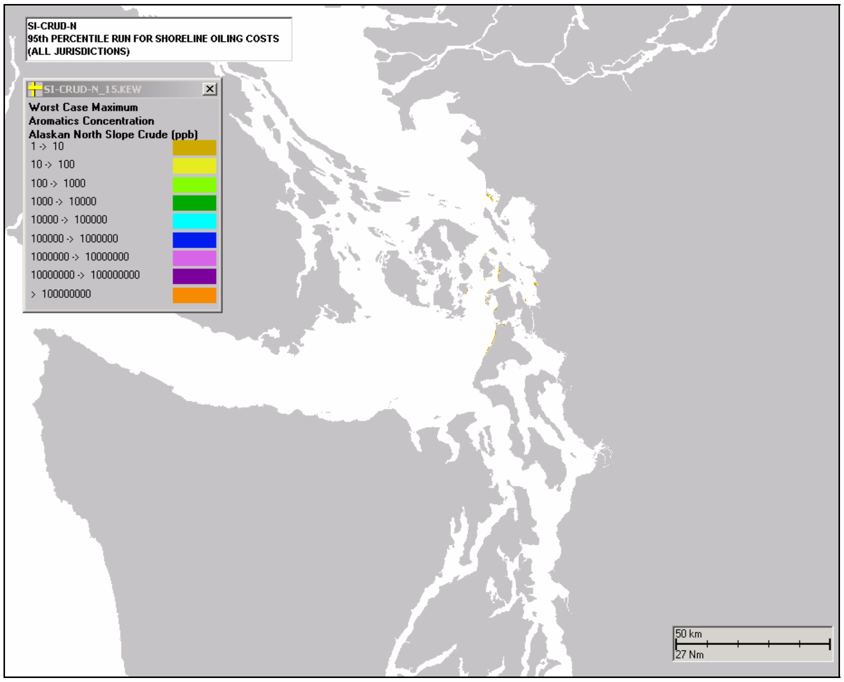


Figure XVII.B.1-6. San Juan Islands, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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".

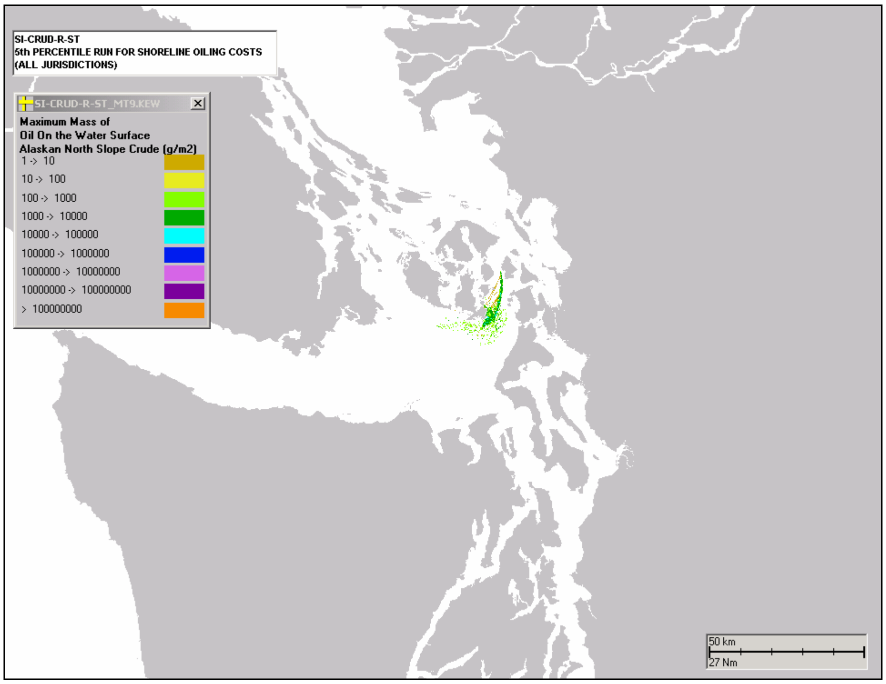


Figure XVII.B.2-1. San Juan Islands, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

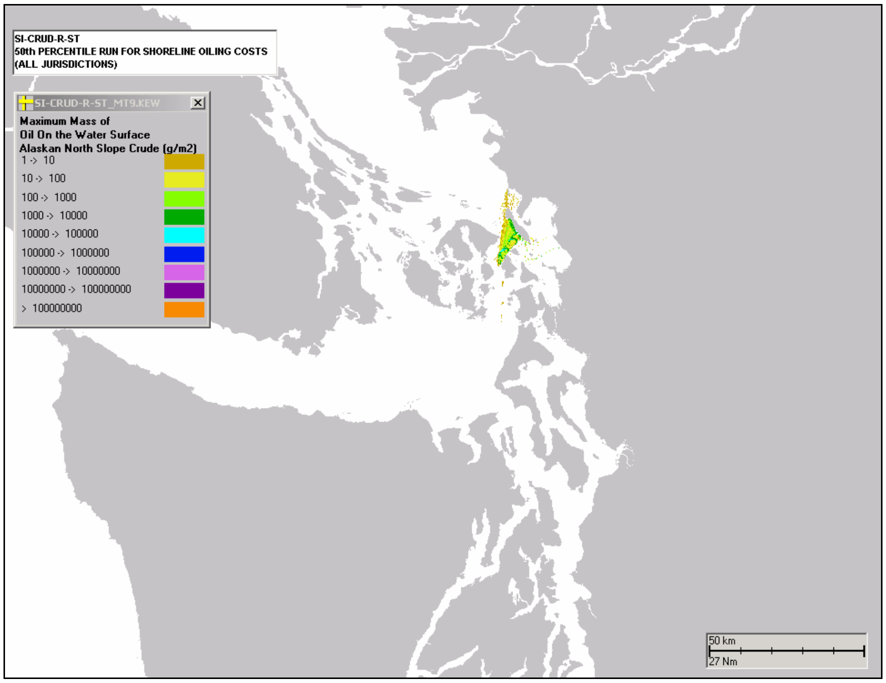


Figure XVII. B.2-2. San Juan Islands, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

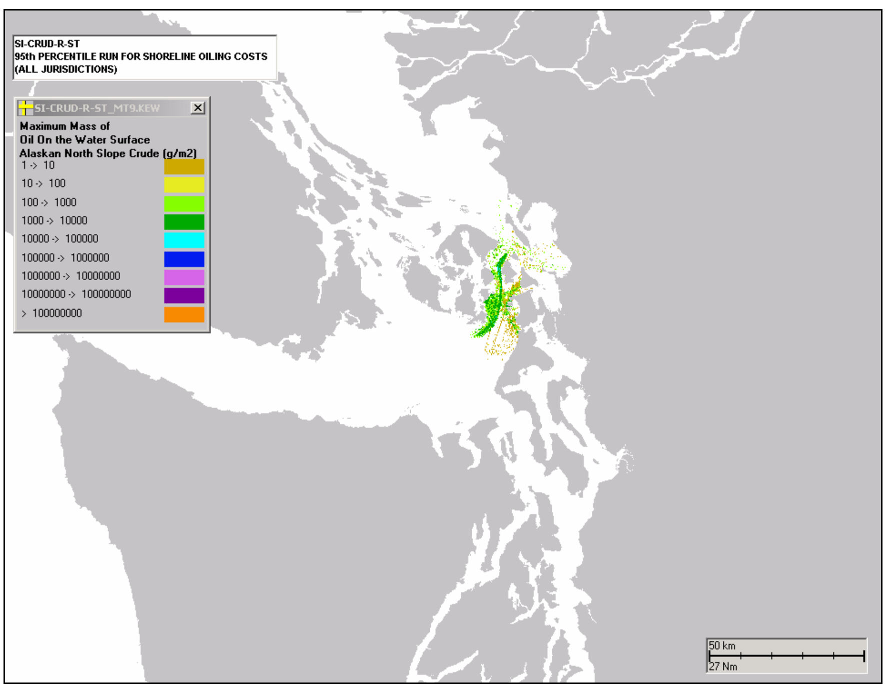


Figure XVII. B.2-3. San Juan Islands, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

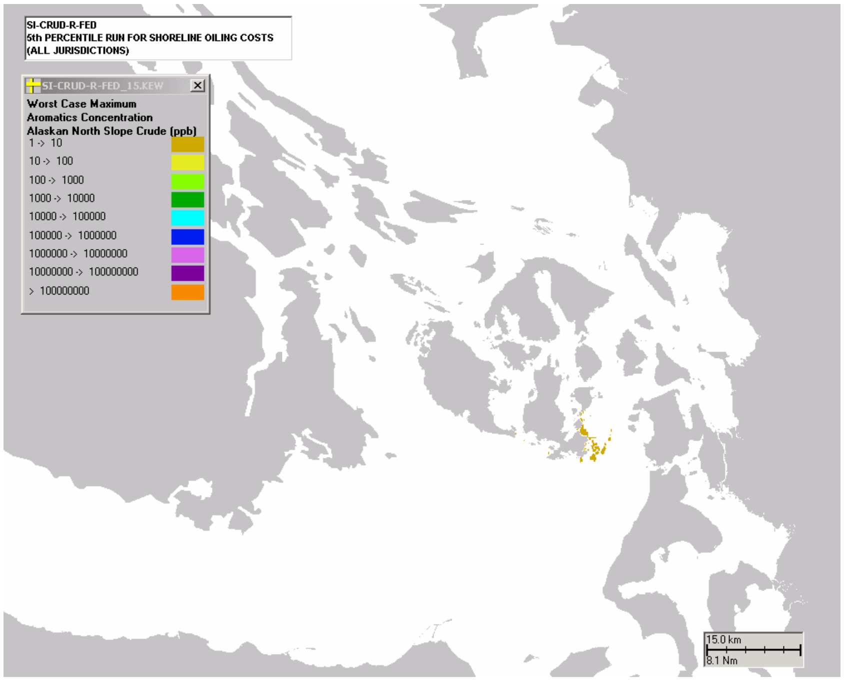


Figure XVII. B.2-4. San Juan Islands, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

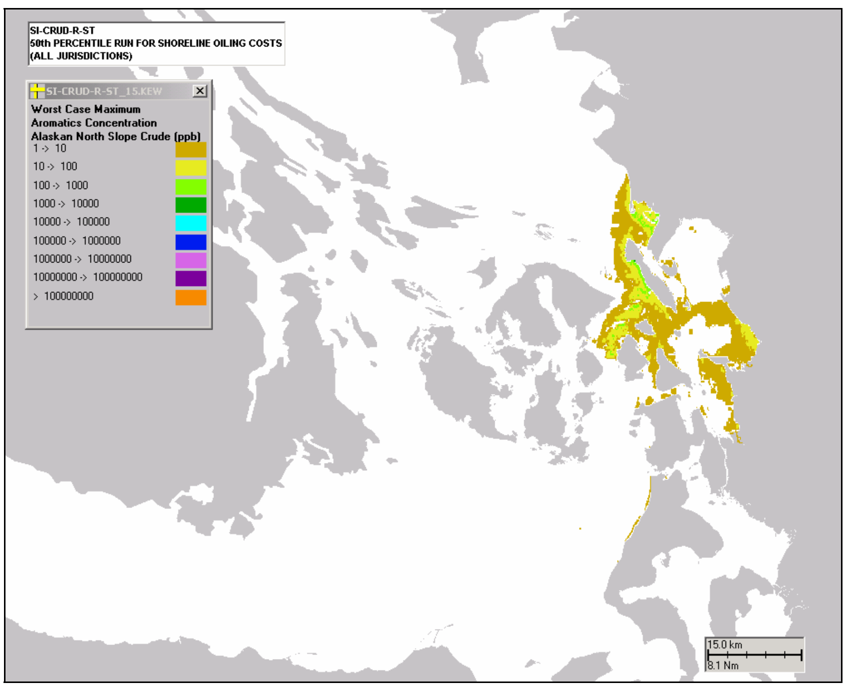


Figure XVII. B.2-5. San Juan Islands, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

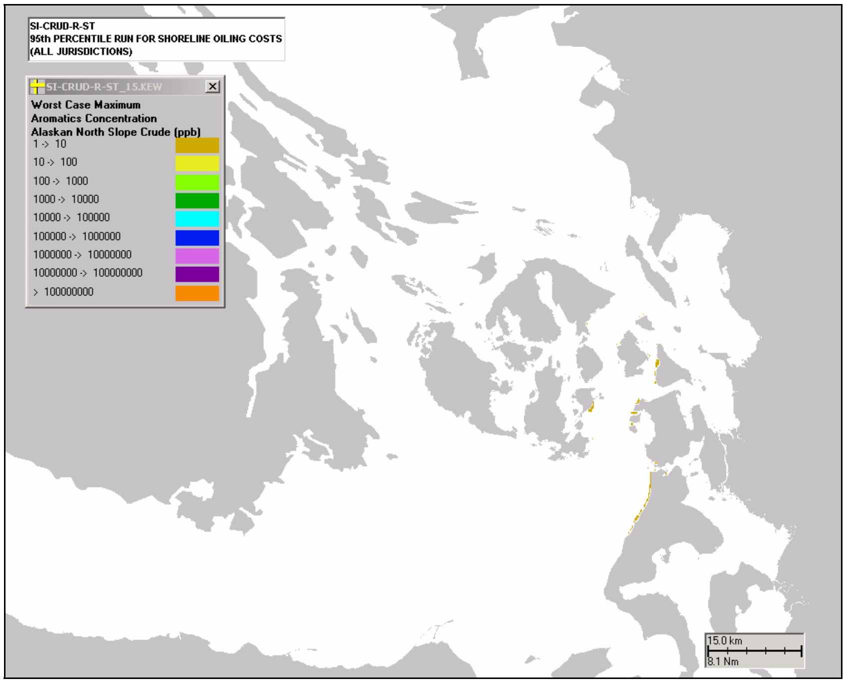


Figure XVII. B.2-6. San Juan Islands, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

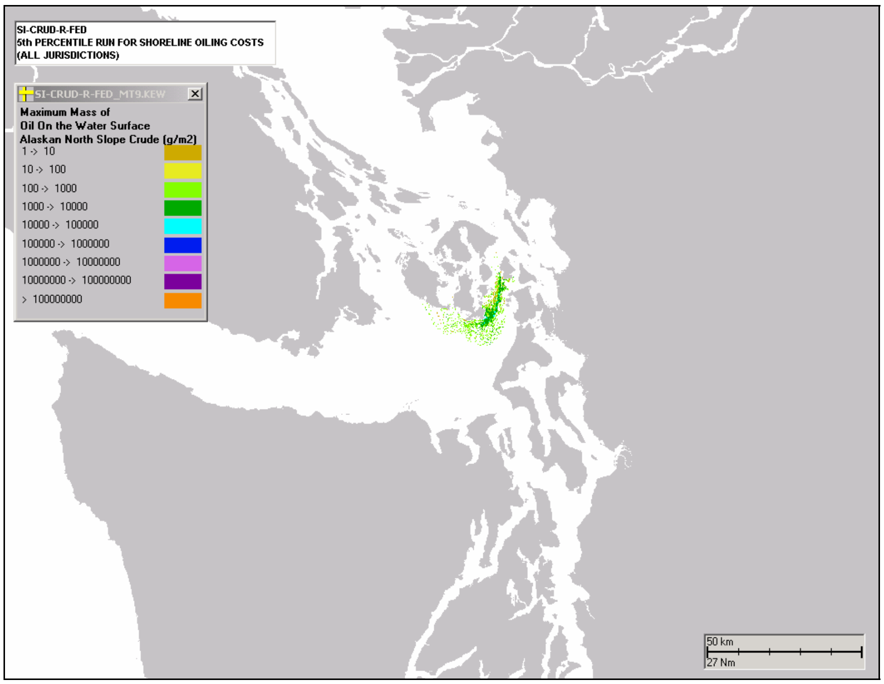


Figure XVII.B.3-1. San Juan Islands, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

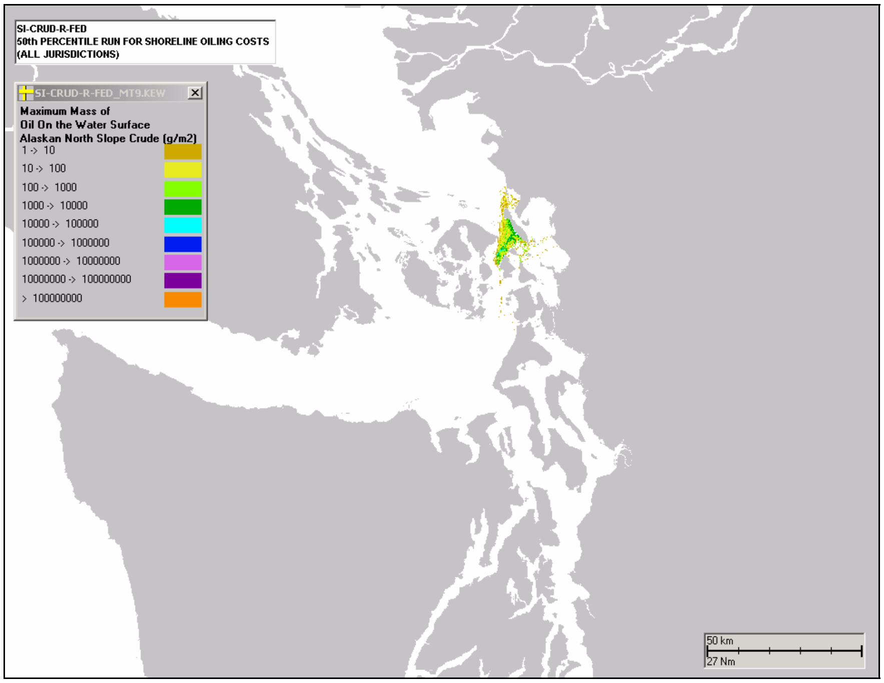


Figure XVII. B.3-2. San Juan Islands, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

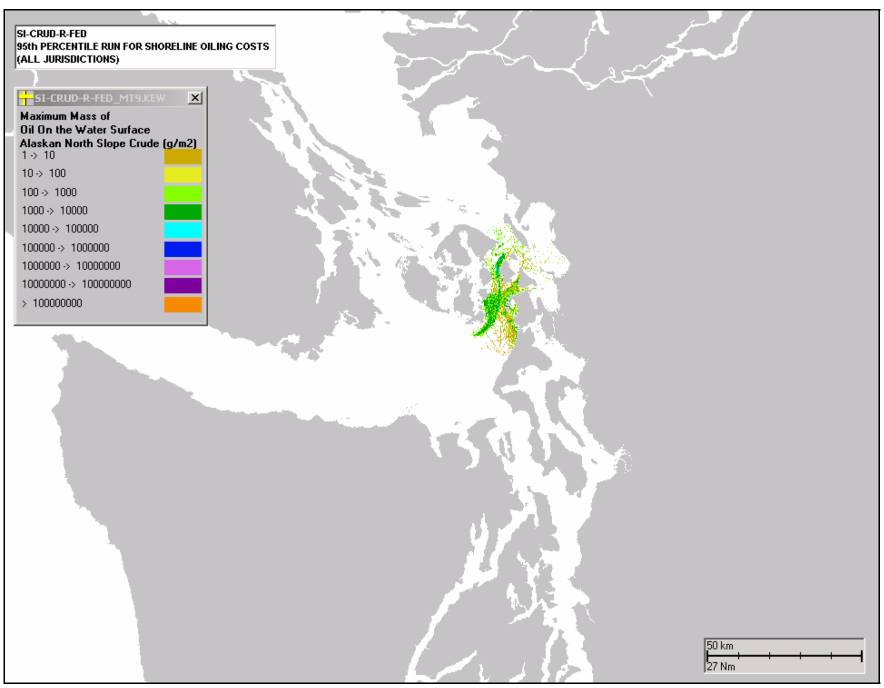


Figure XVII. B.3-3. San Juan Islands, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

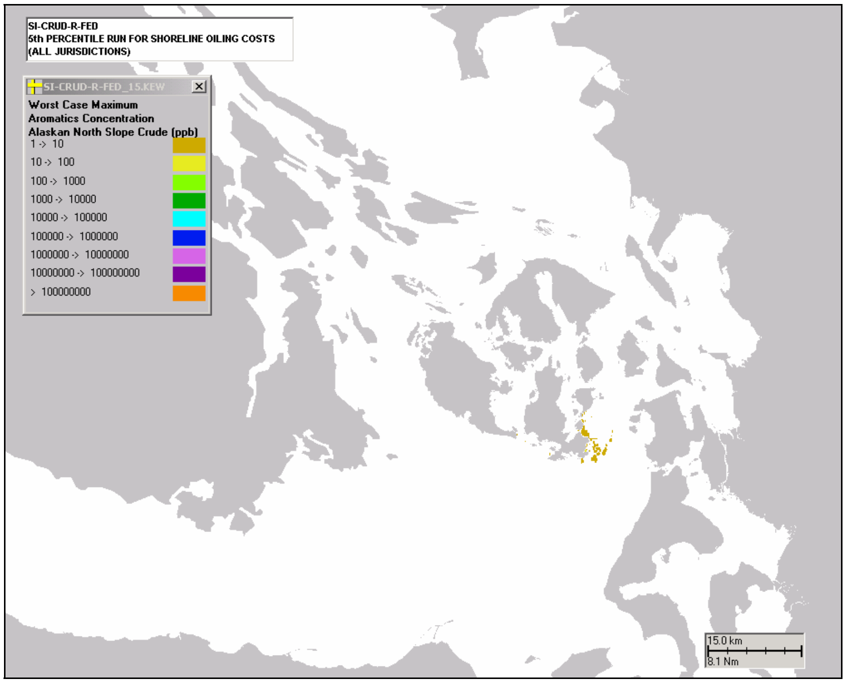


Figure XVII.B.3-4. San Juan Islands, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

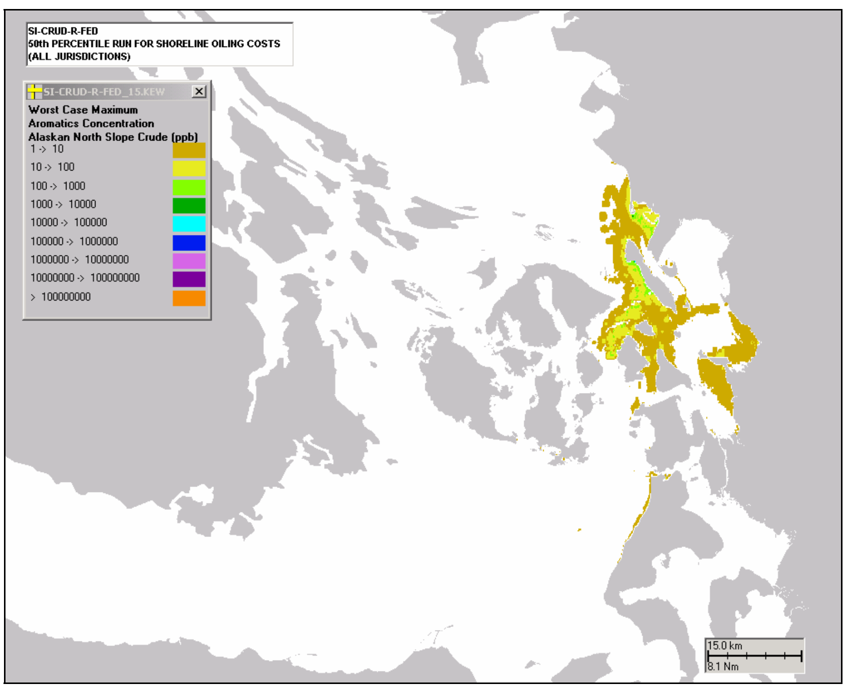


Figure XVII.B.3-5. San Juan Islands, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

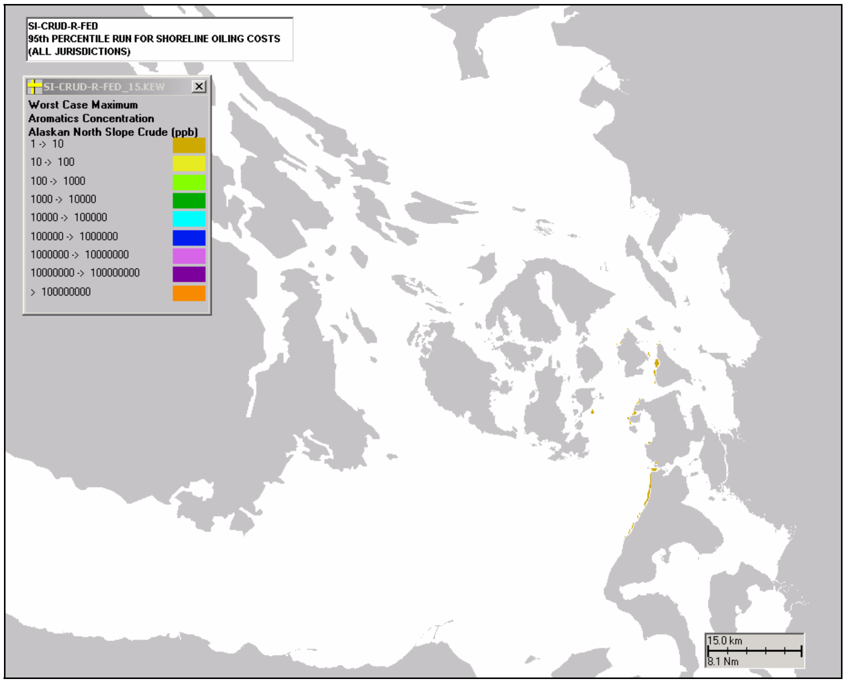


Figure XVII.B.3-6. San Juan Islands, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

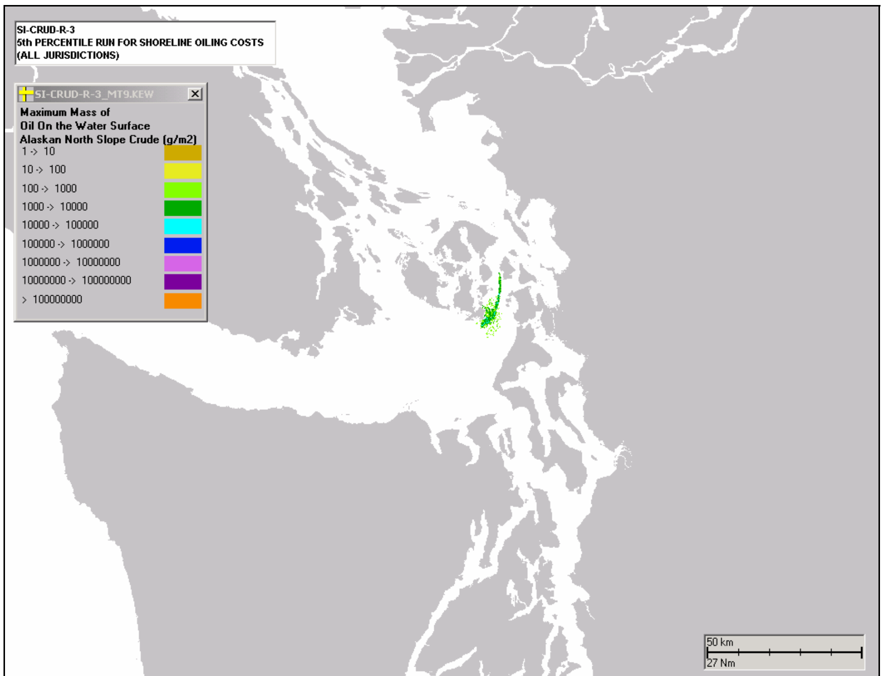


Figure XVII.B.4-1. San Juan Islands, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

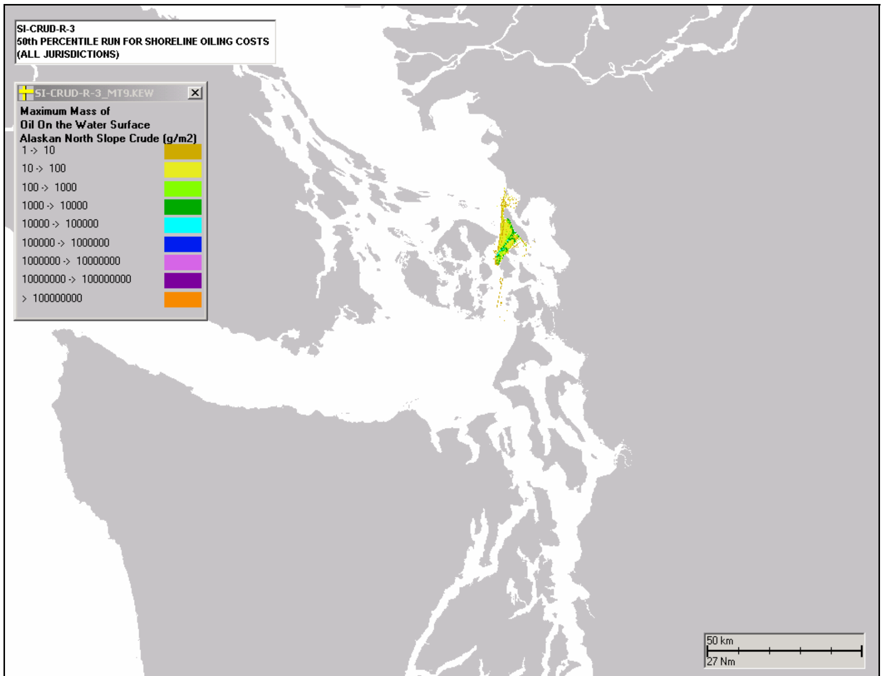


Figure XVII.B.4-2. San Juan Islands, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

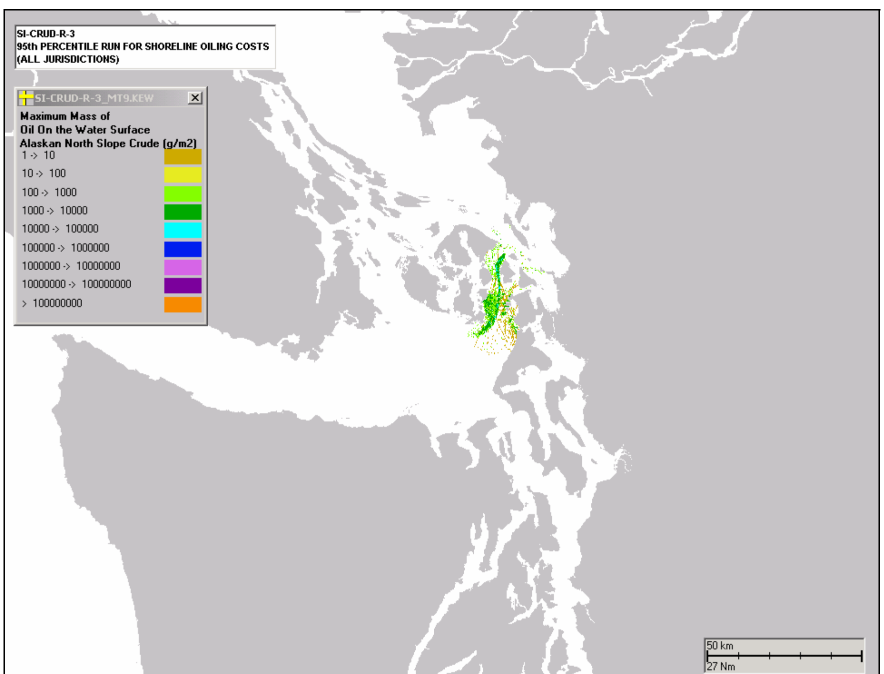


Figure XVII.B.4-3. San Juan Islands, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

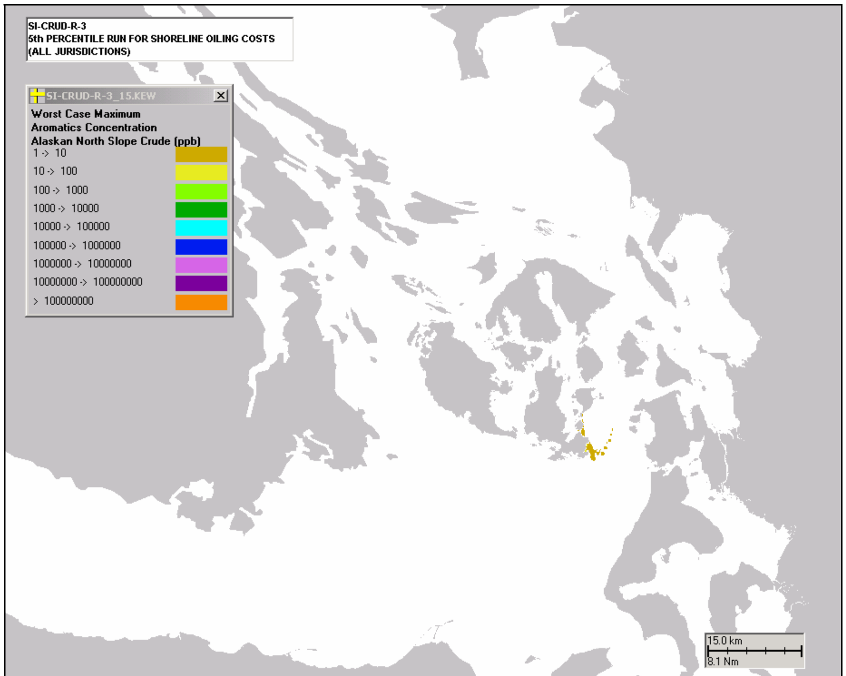


Figure XVII.B.4-4. San Juan Islands, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

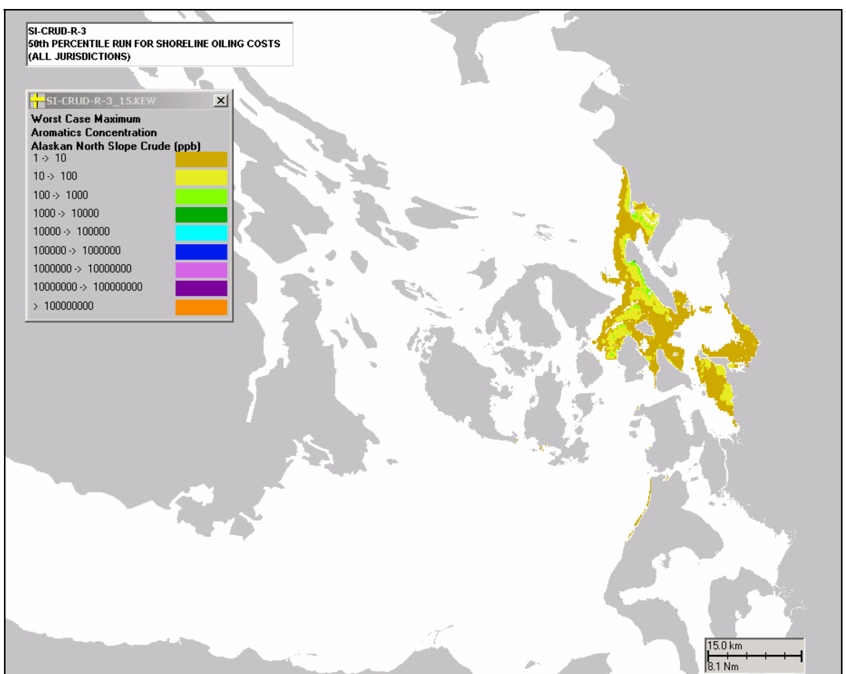


Figure XVII.B.4-5. San Juan Islands, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

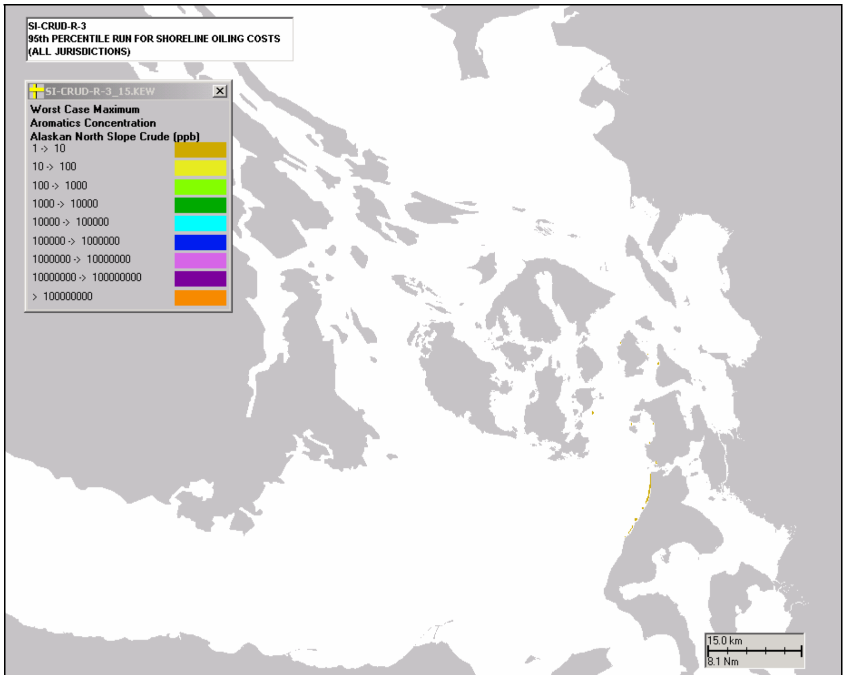


Figure XVII.B.4-6. San Juan Islands, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

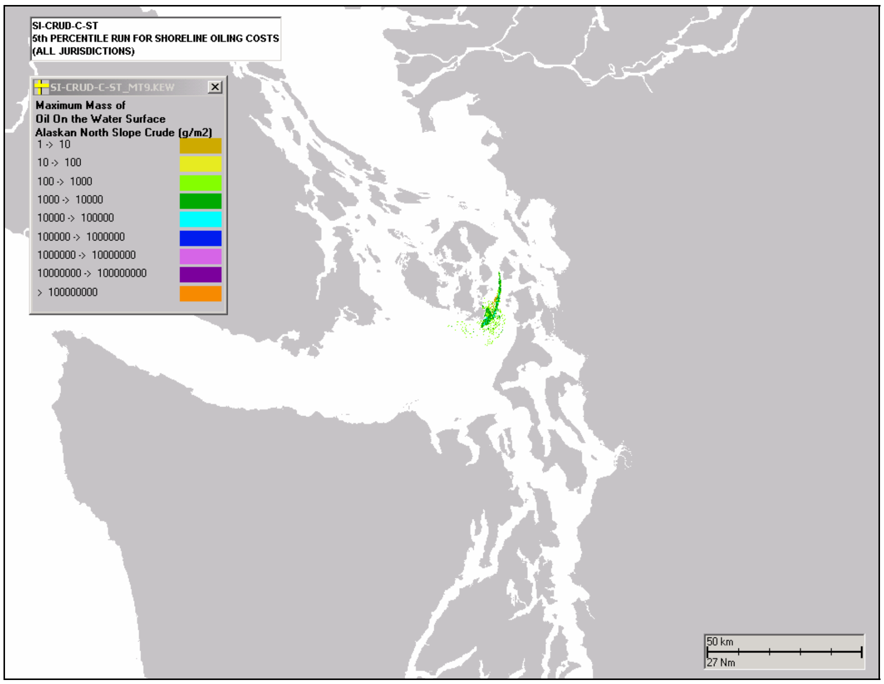


Figure XVII.B.5-1. San Juan Islands, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

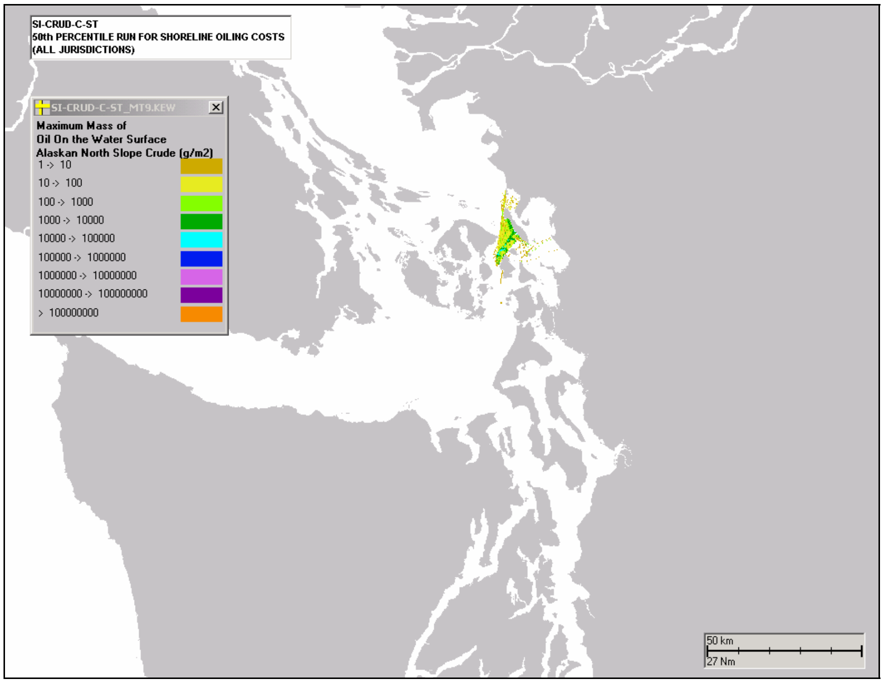


Figure XVII.B.5-2. San Juan Islands, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

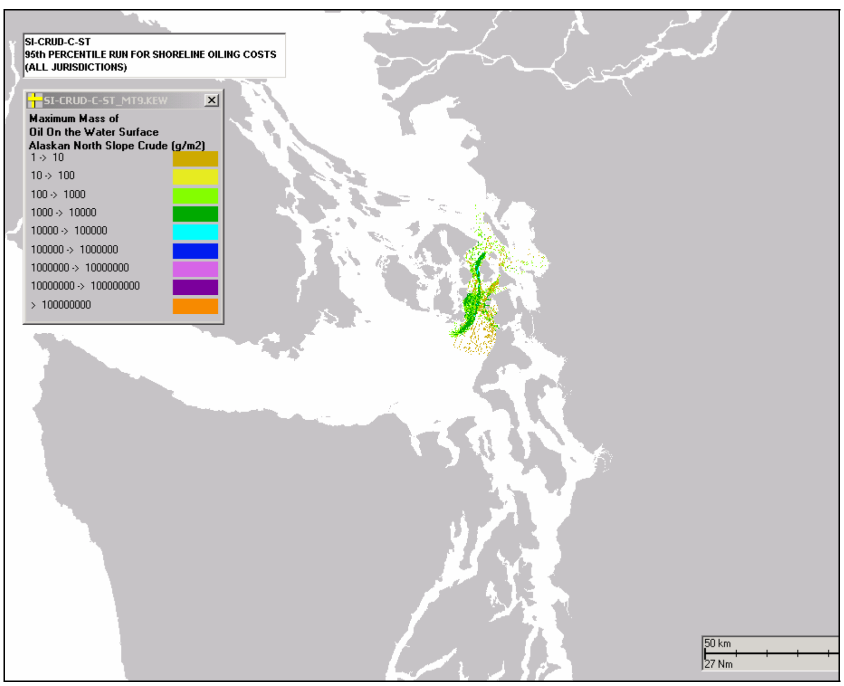


Figure XVII.B.5-3. San Juan Islands, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

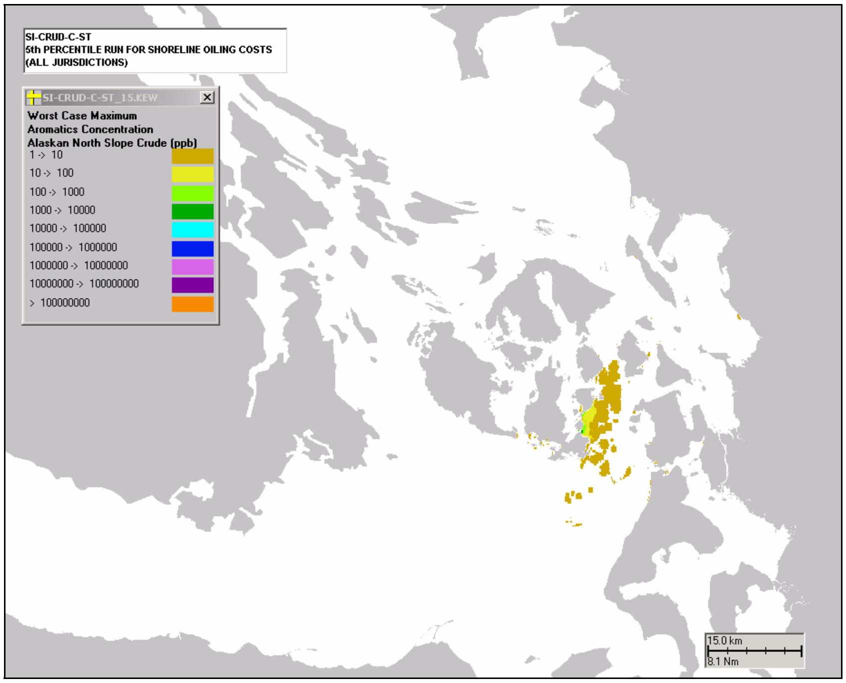


Figure XVII.B.5-4. San Juan Islands, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

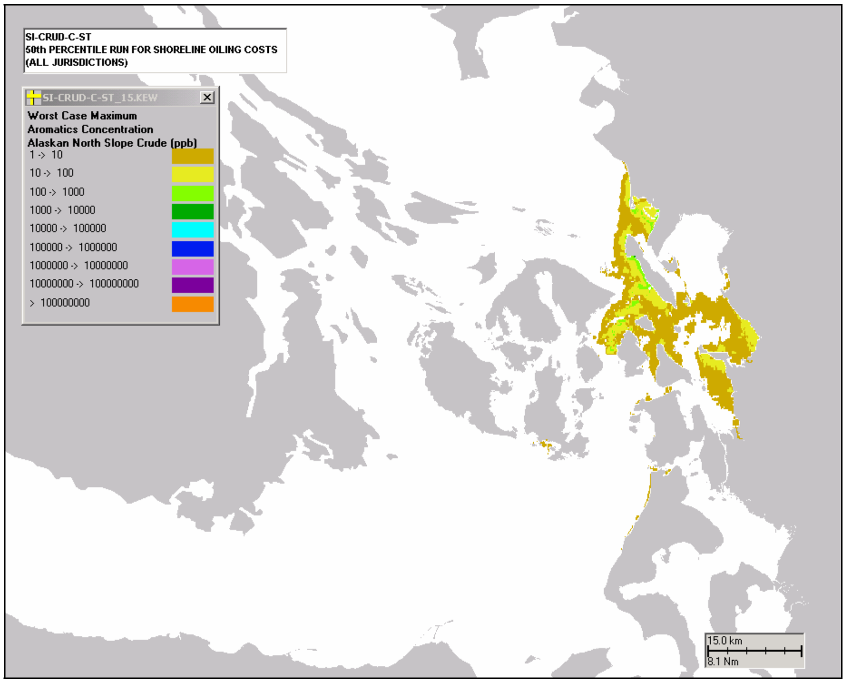


Figure XVII.B.5-5. San Juan Islands, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

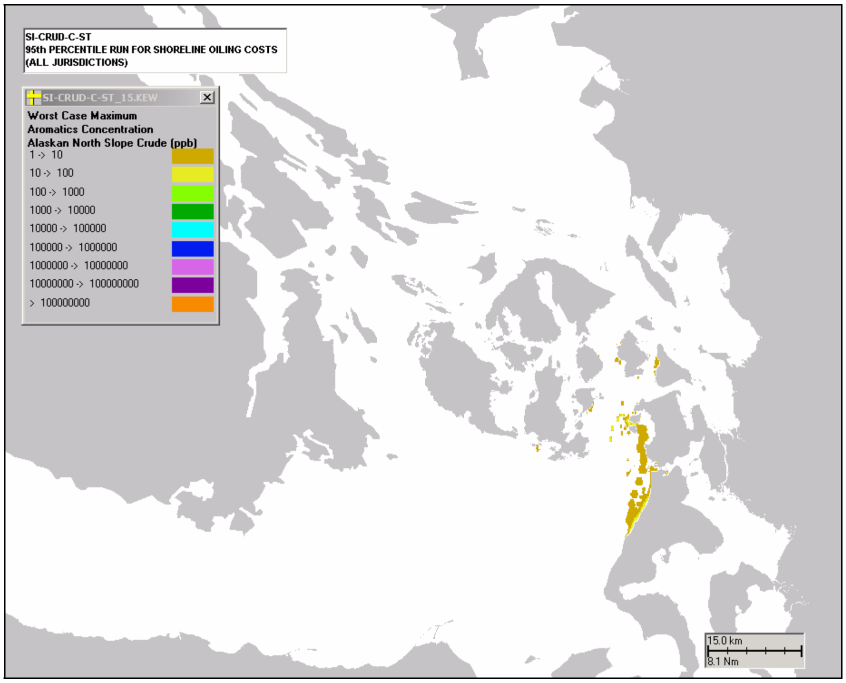


Figure XVII.B.5-6. San Juan Islands, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

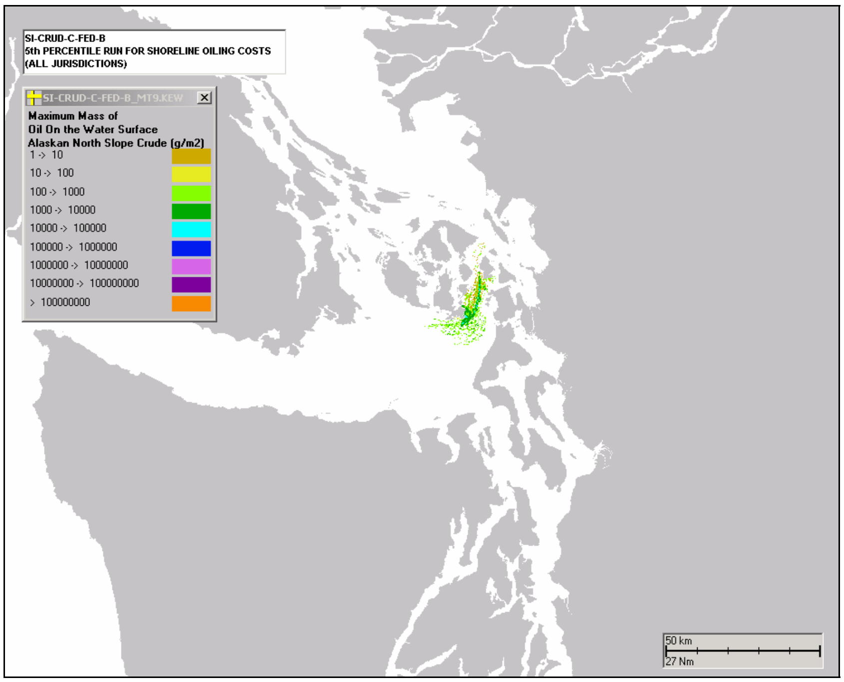


Figure XVII.B.6-1. San Juan Islands, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

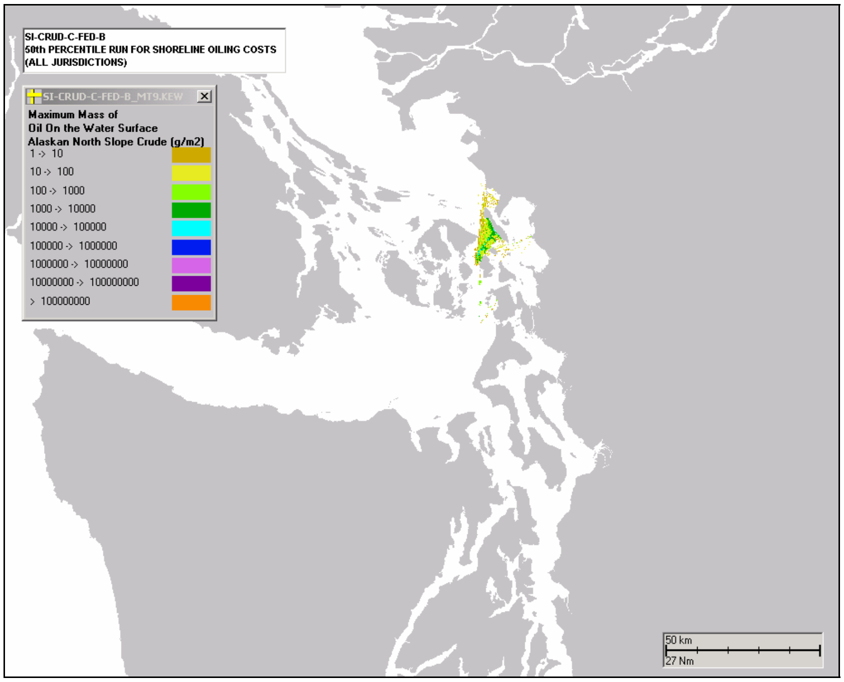


Figure XVII.B.6-2. San Juan Islands, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

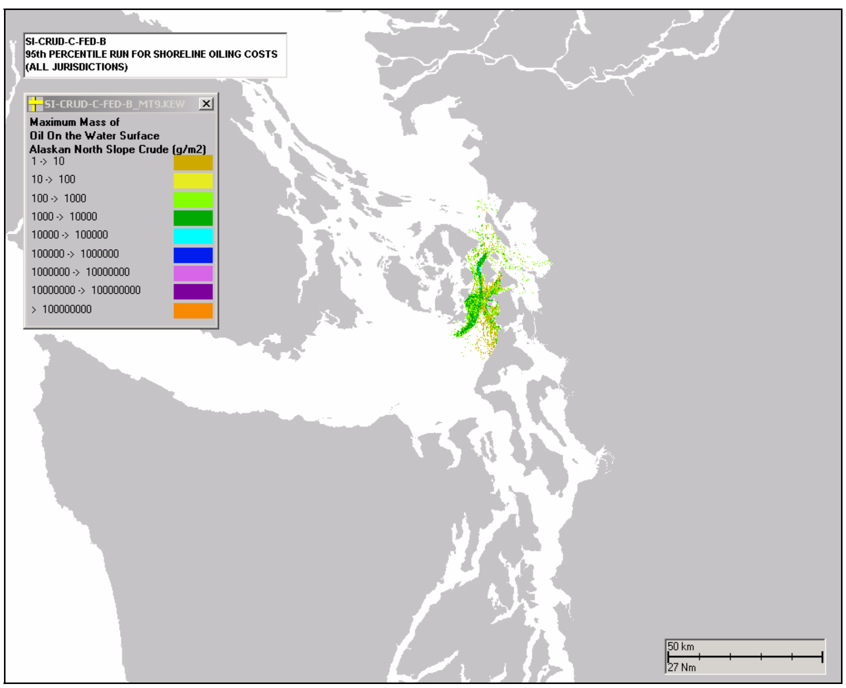


Figure XVII.B.6-3. San Juan Islands, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

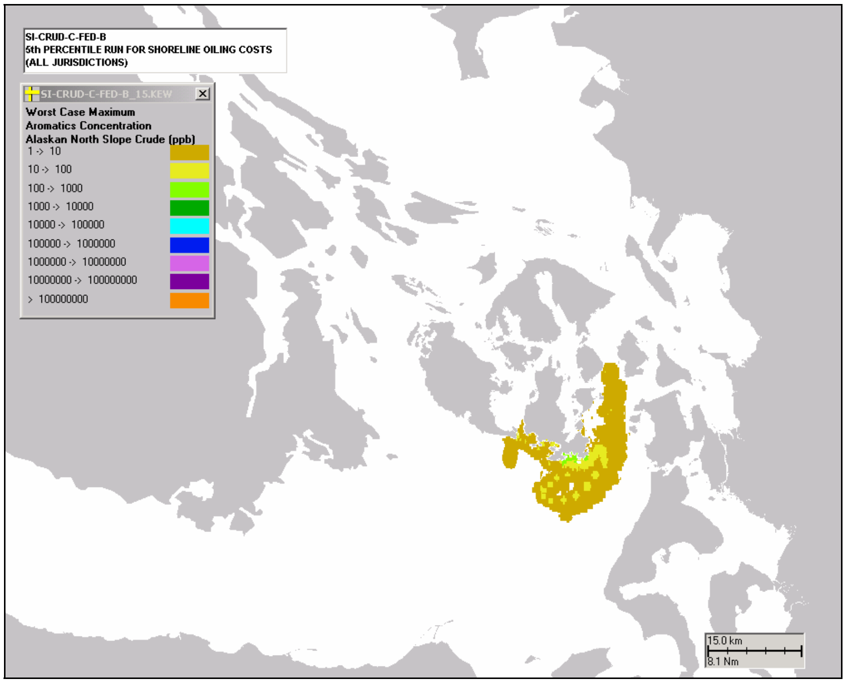


Figure XVII.B.6-4. San Juan Islands, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

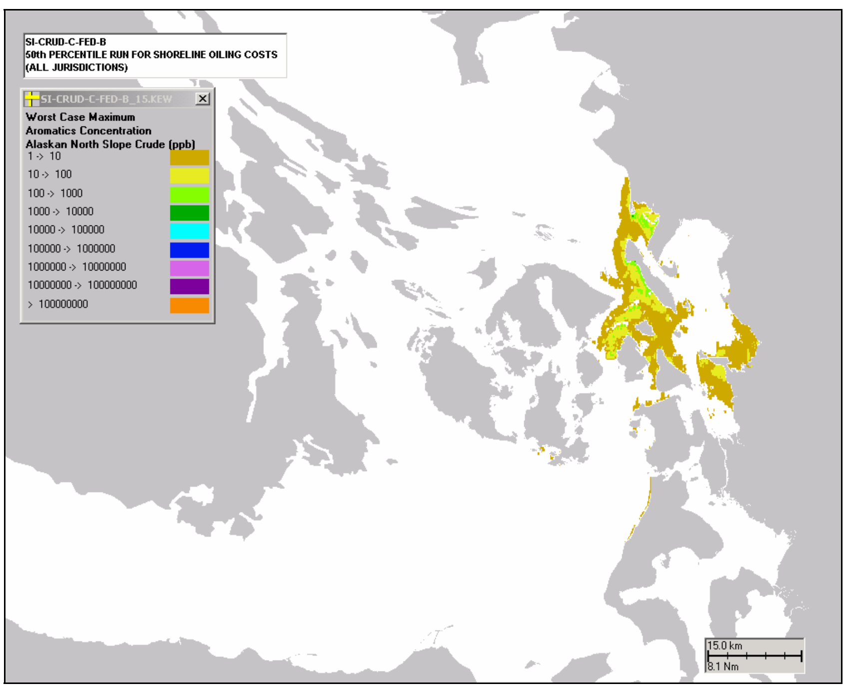


Figure XVII.B.6-5. San Juan Islands, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

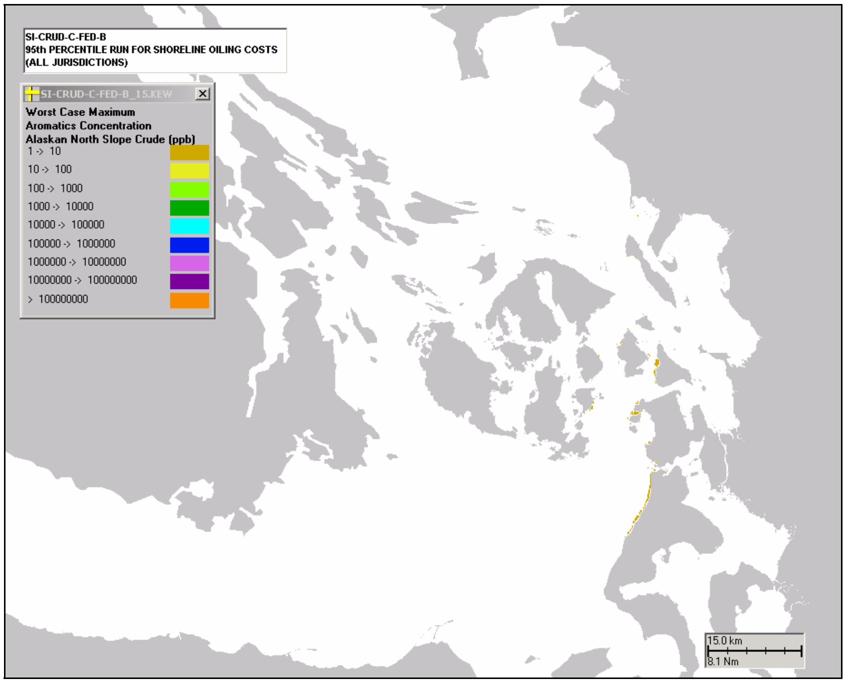


Figure XVII.B.6-6. San Juan Islands, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

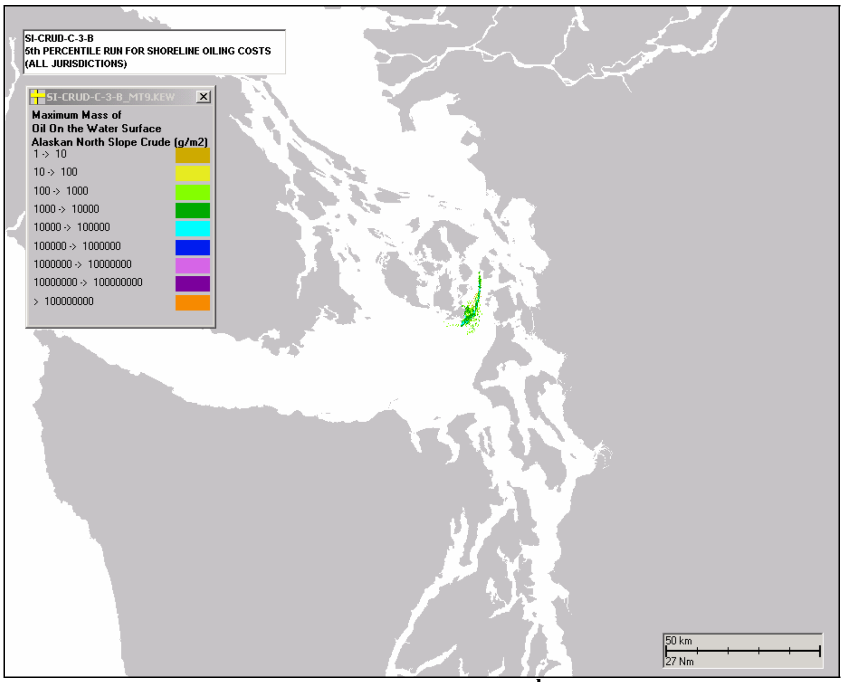


Figure XVII.B.7-1. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

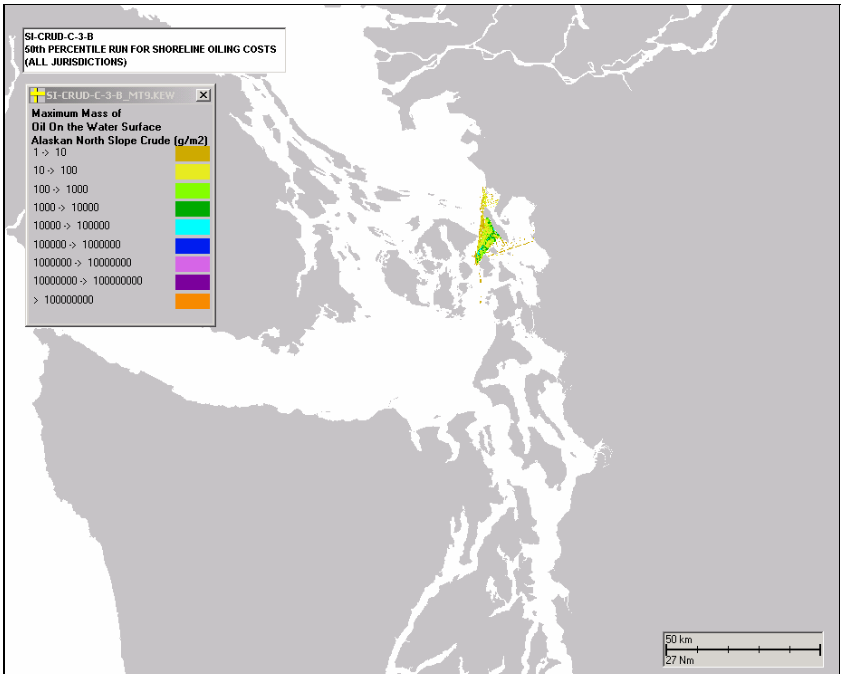


Figure XVII.B.7-2. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

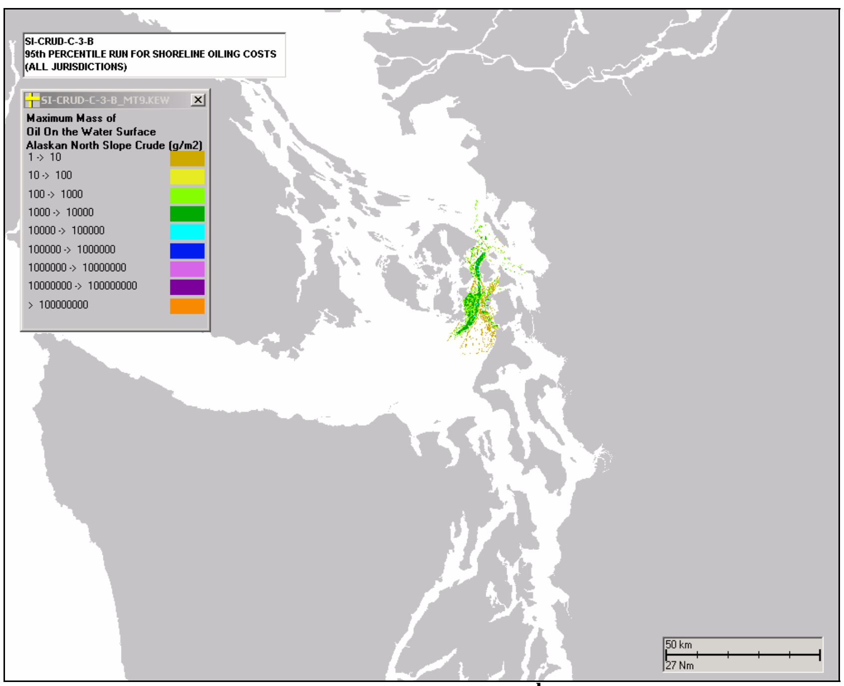


Figure XVII.B.7-3. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

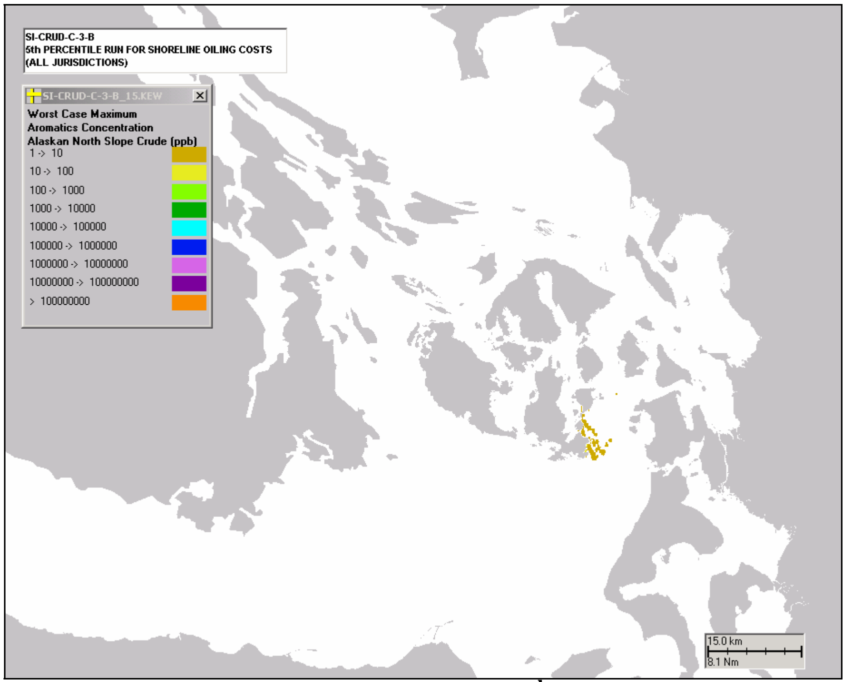


Figure XVII.B.7-4. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

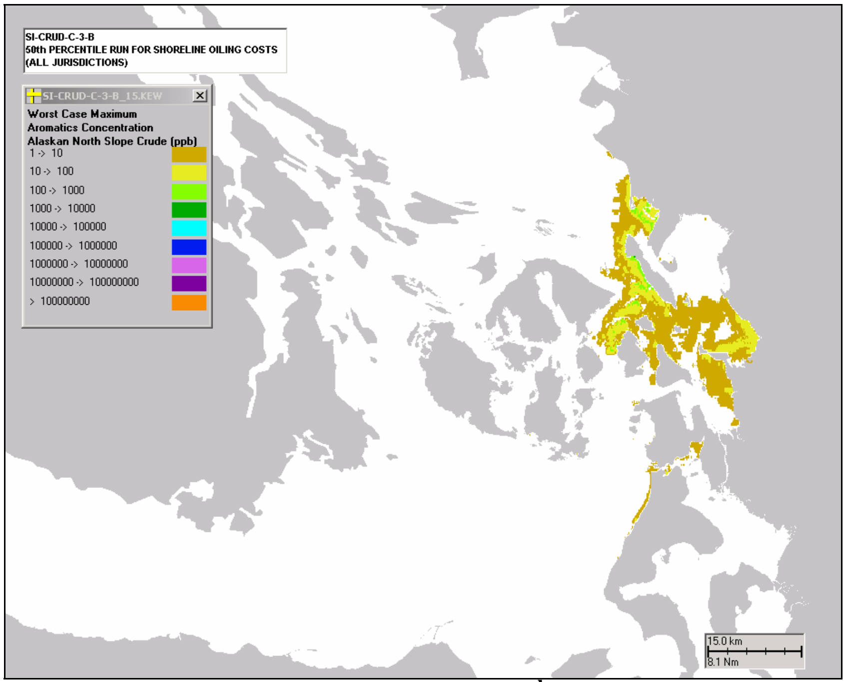


Figure XVII.B.7-5. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

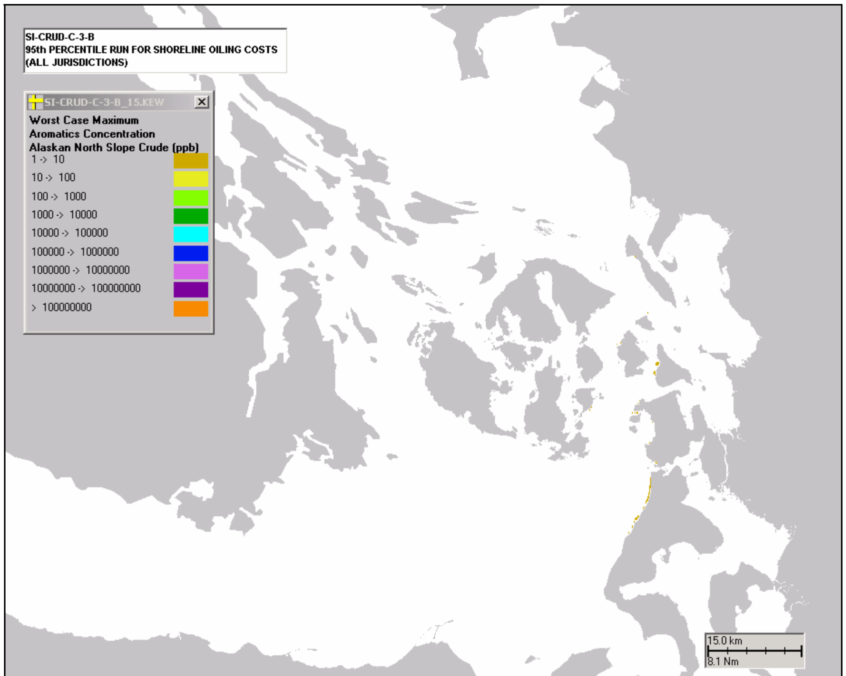


Figure XVII.B.7-6. San Juan Islands, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

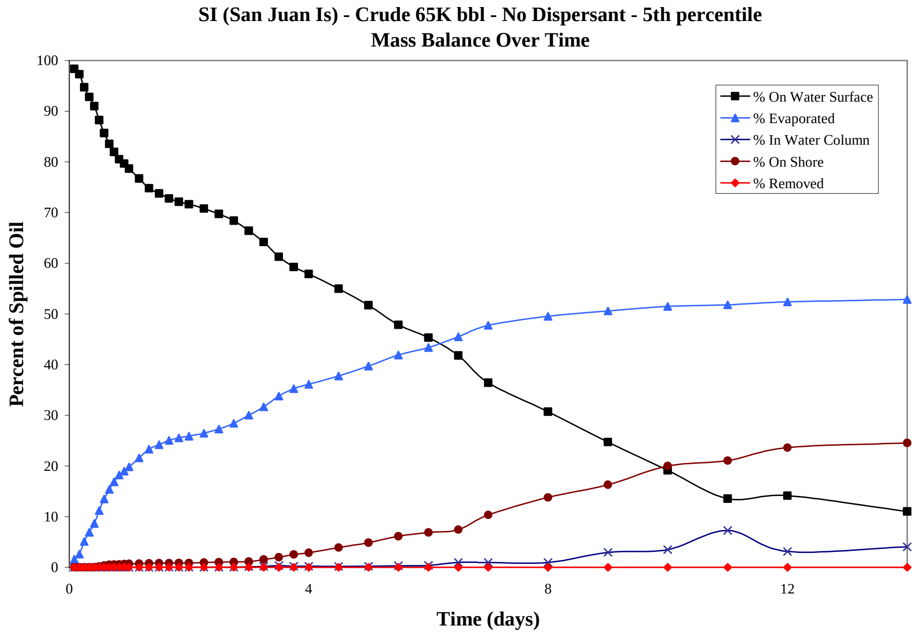


Figure XVII.B.8-1 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

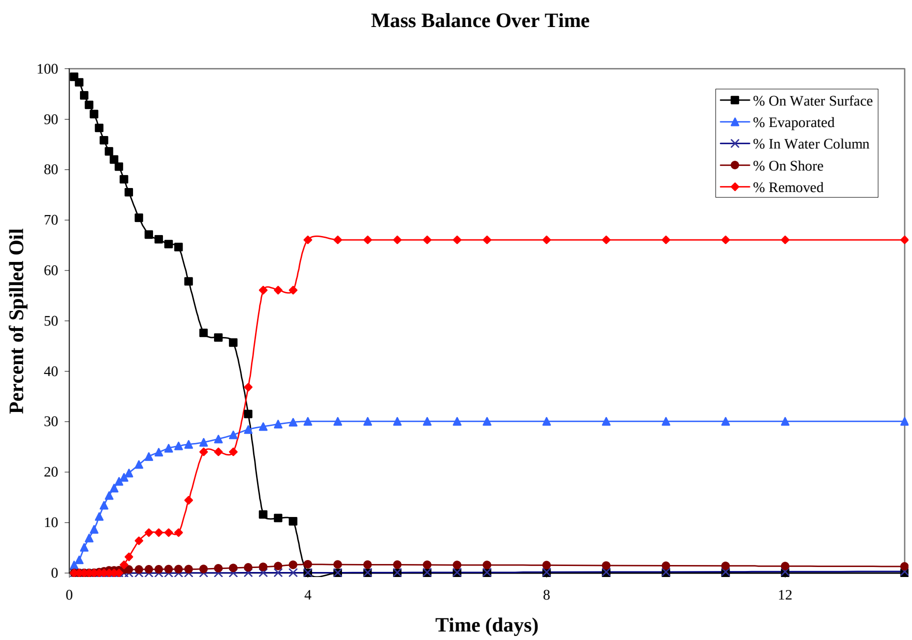


Figure XVII.B.8-2 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

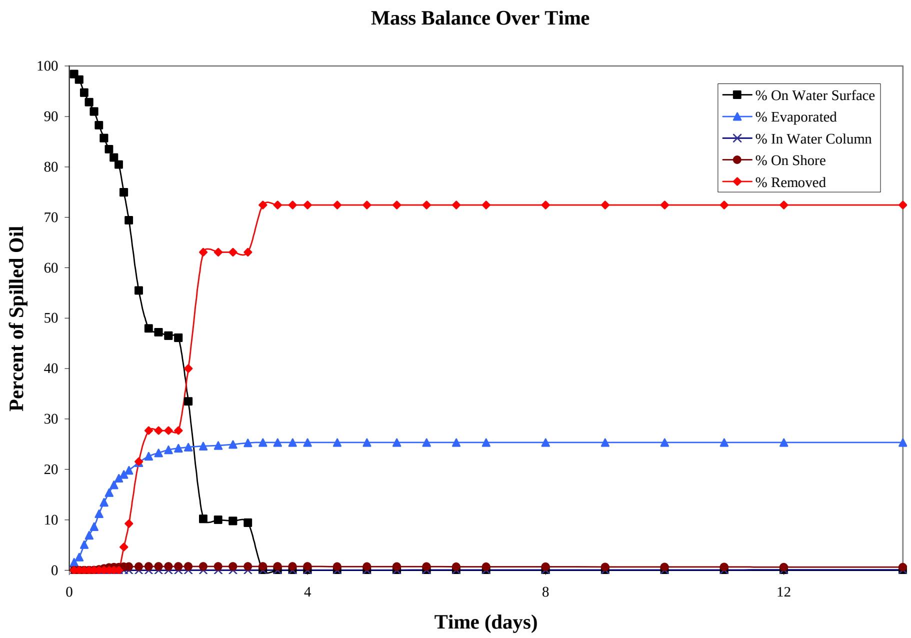


Figure XVII.B.8-3 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

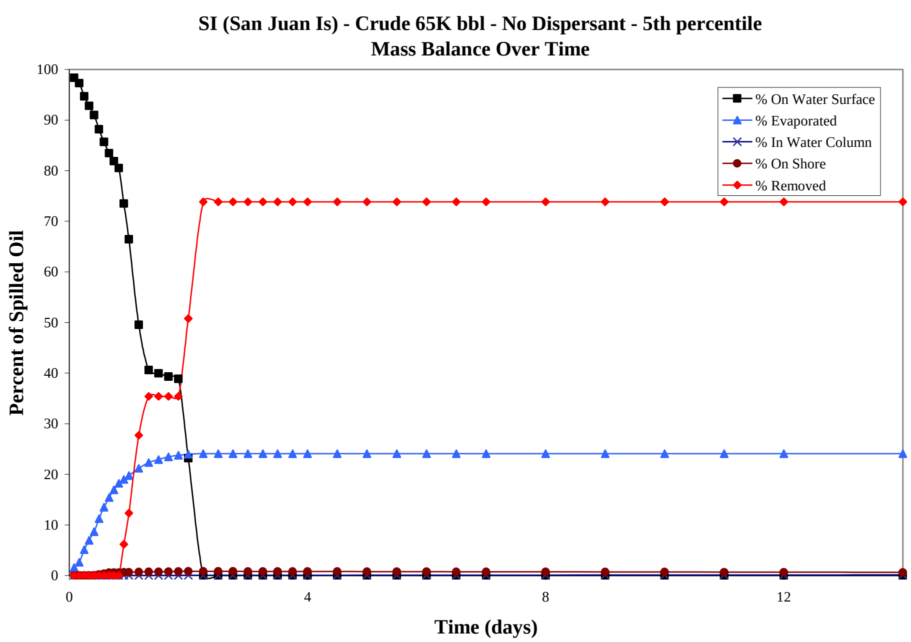


Figure XVII.B.8-4 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

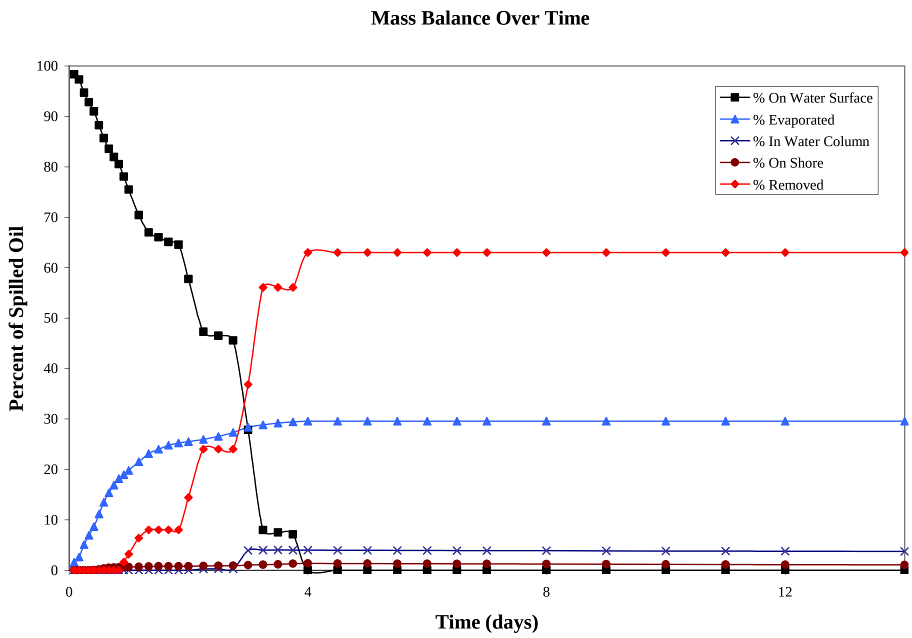


Figure XVII.B.8-5 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

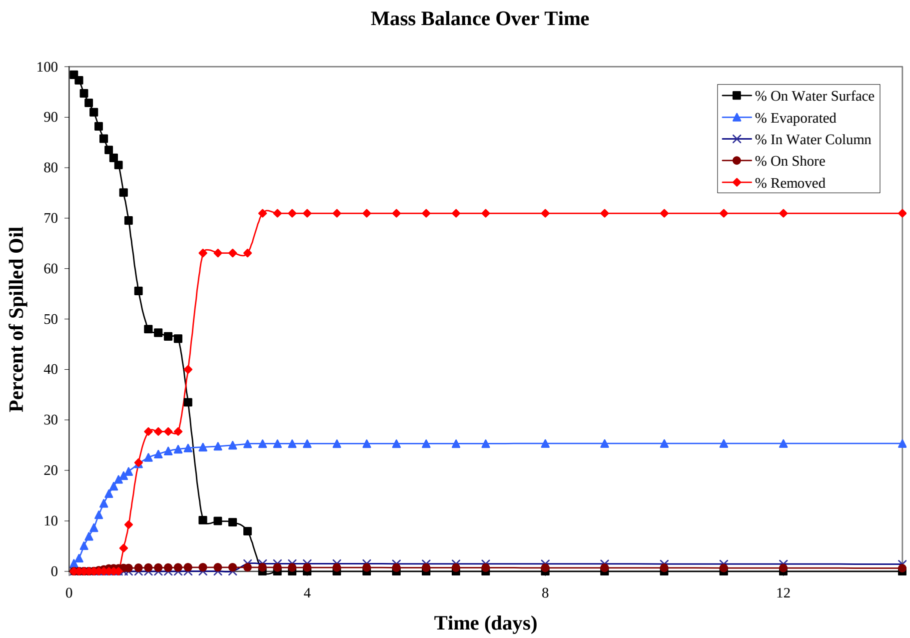


Figure XVII.B.8-6 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

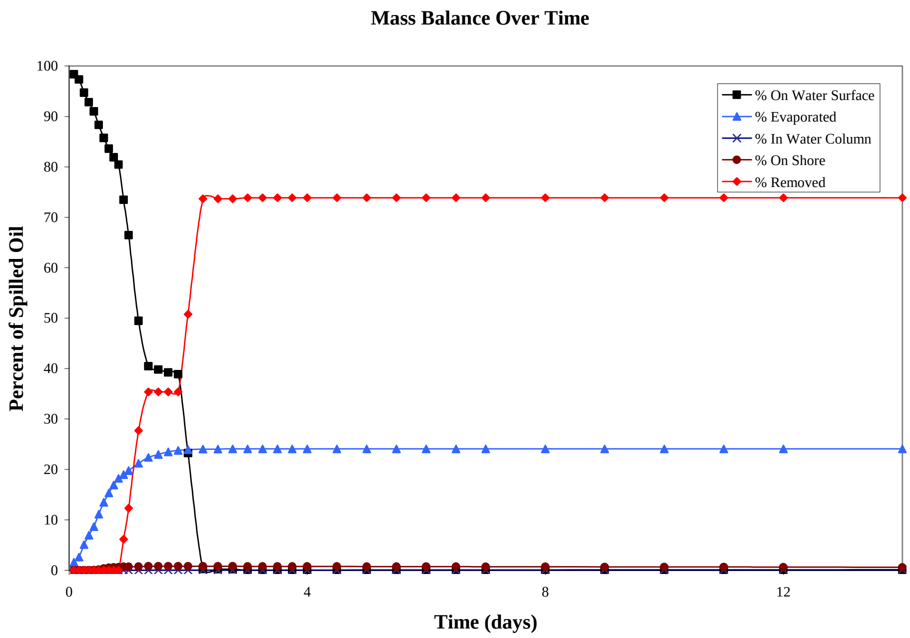


Figure XVII.B.8-7 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

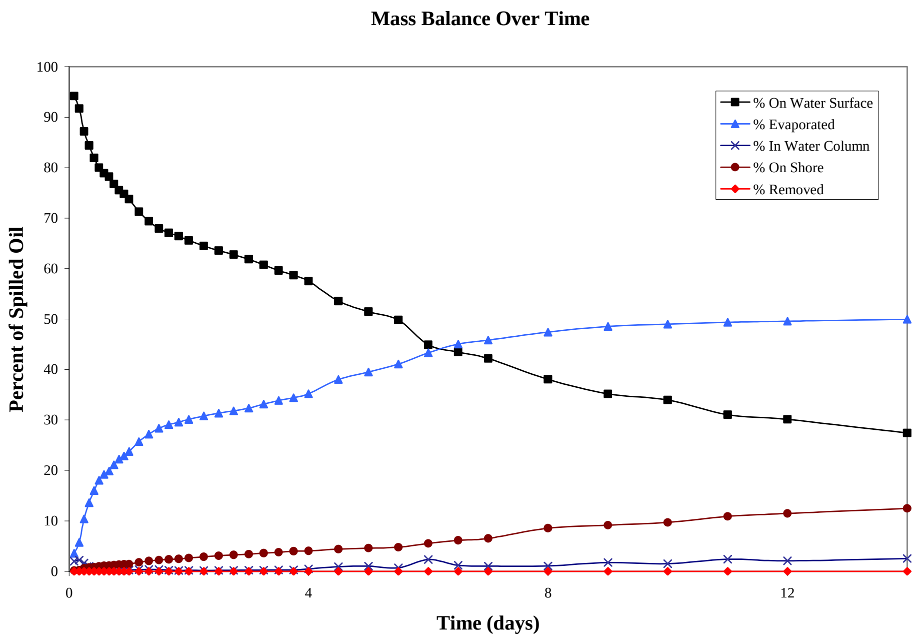


Figure XVII.B.8-8 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

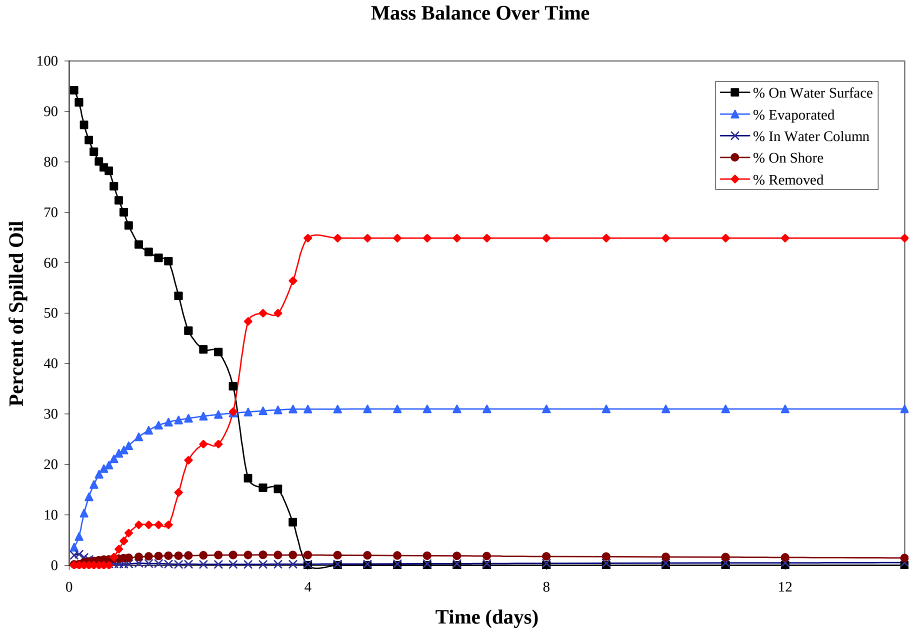


Figure XVII.B.8-9 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

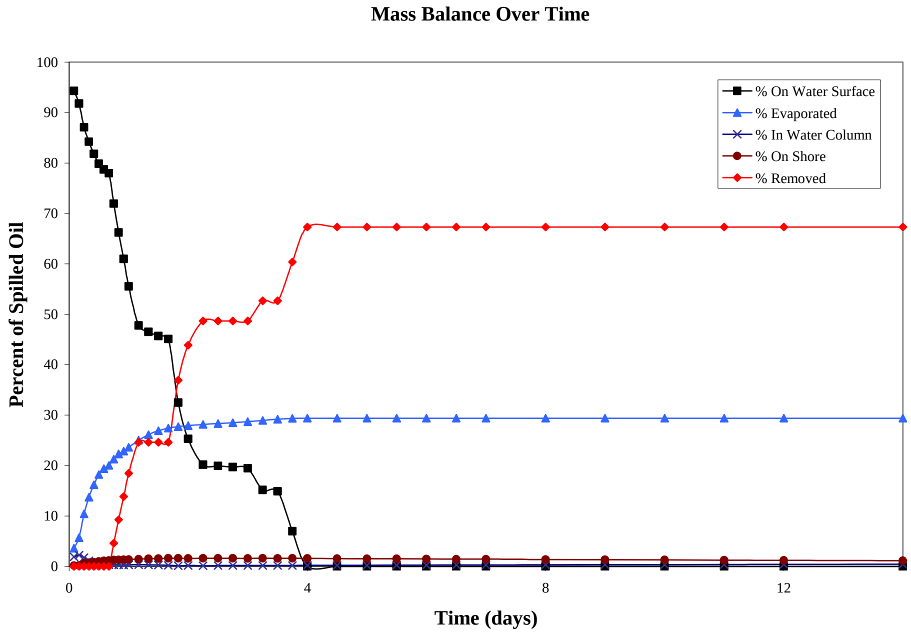


Figure XVII.B.8-10 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

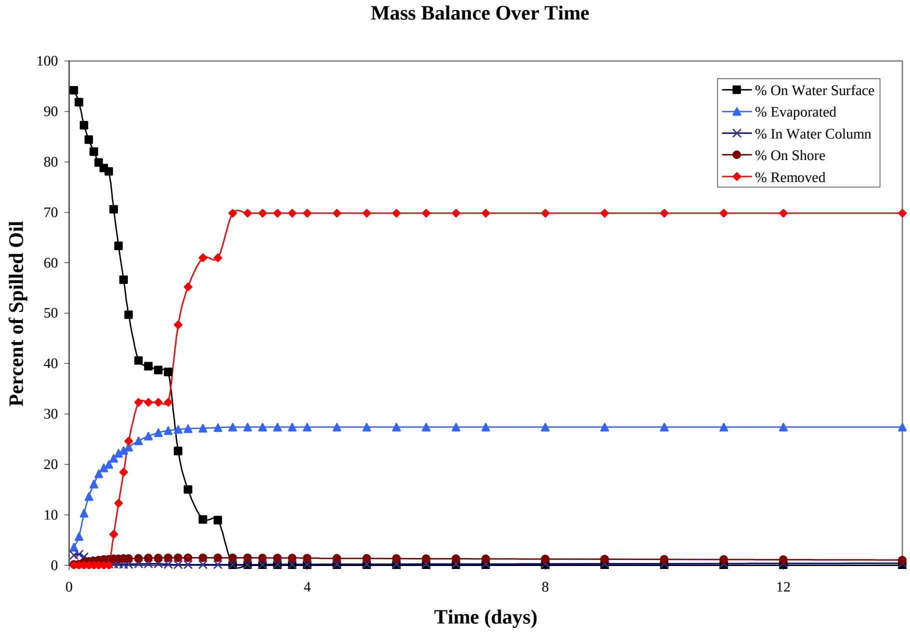


Figure XVII.B.8-11 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

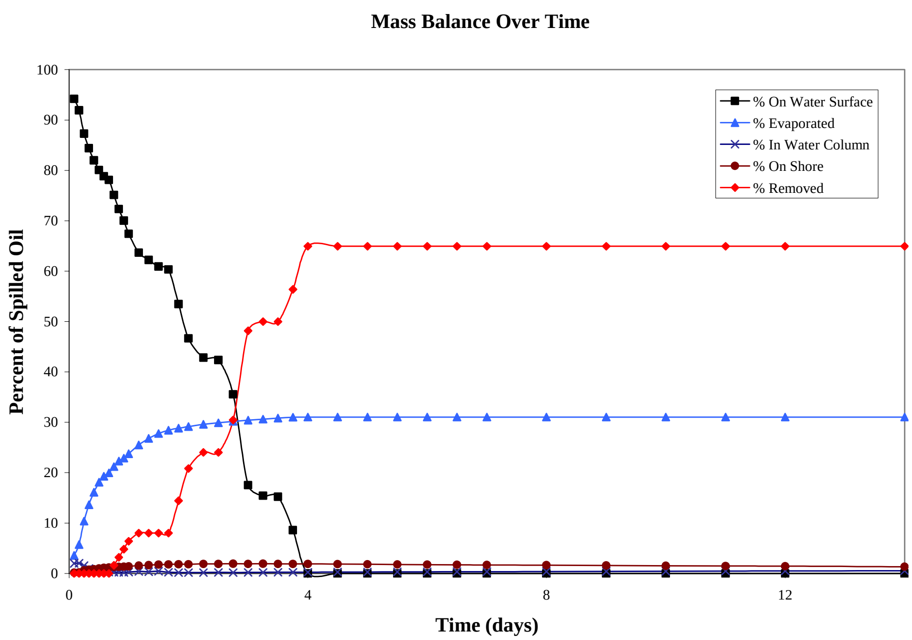


Figure XVII.B.8-12 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

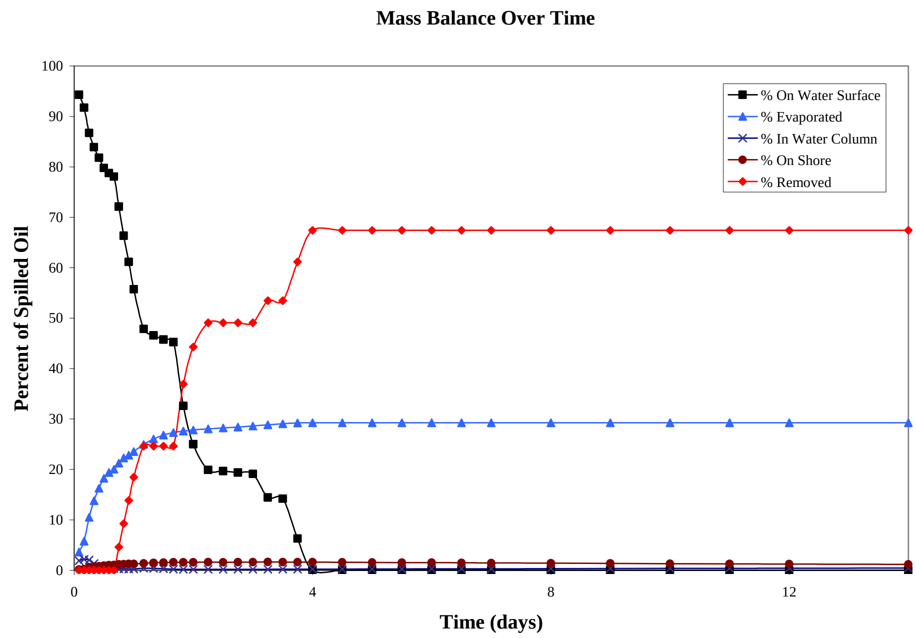


Figure XVII.B.8-13 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

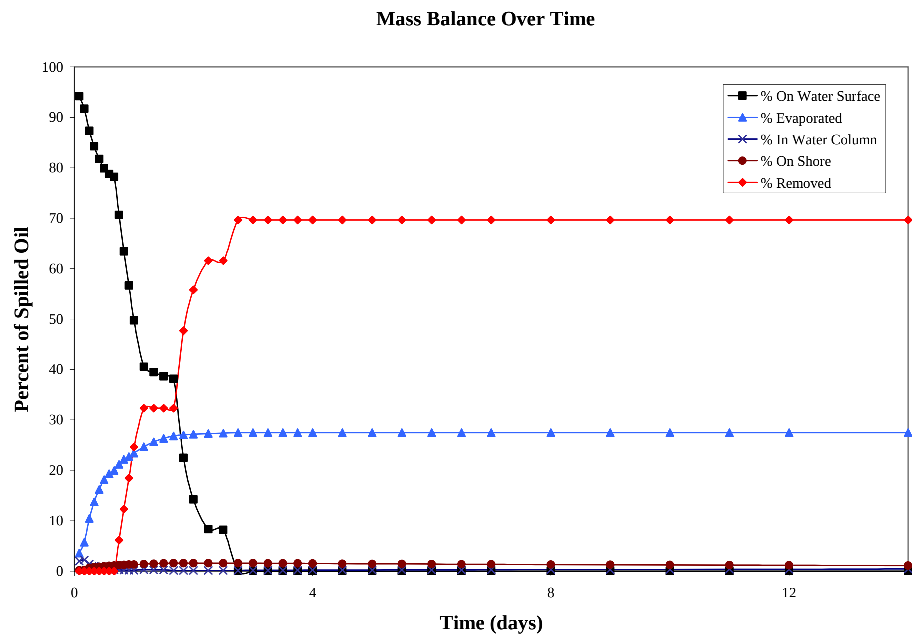


Figure XVII.B.8-14 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

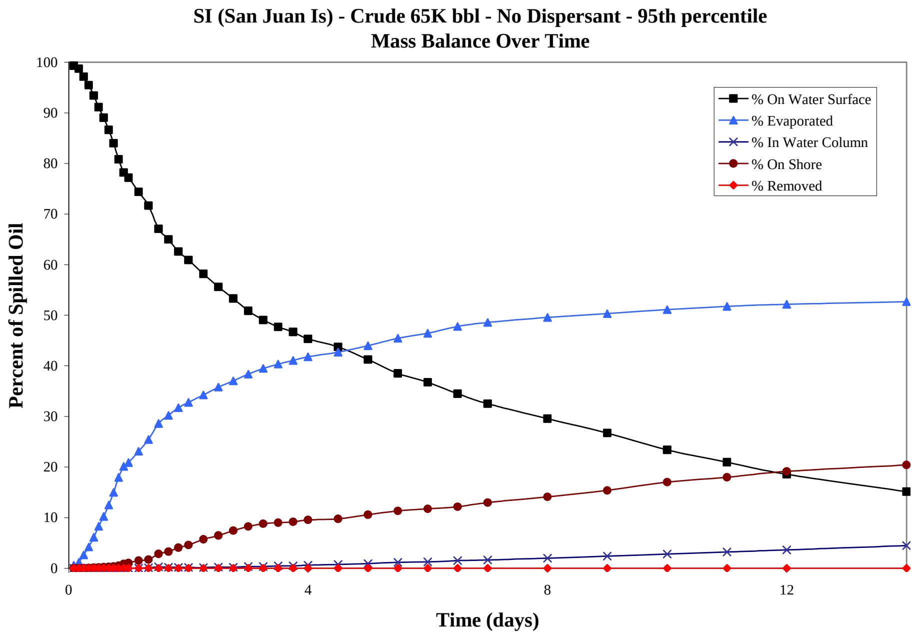


Figure XVII.B.8-15 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

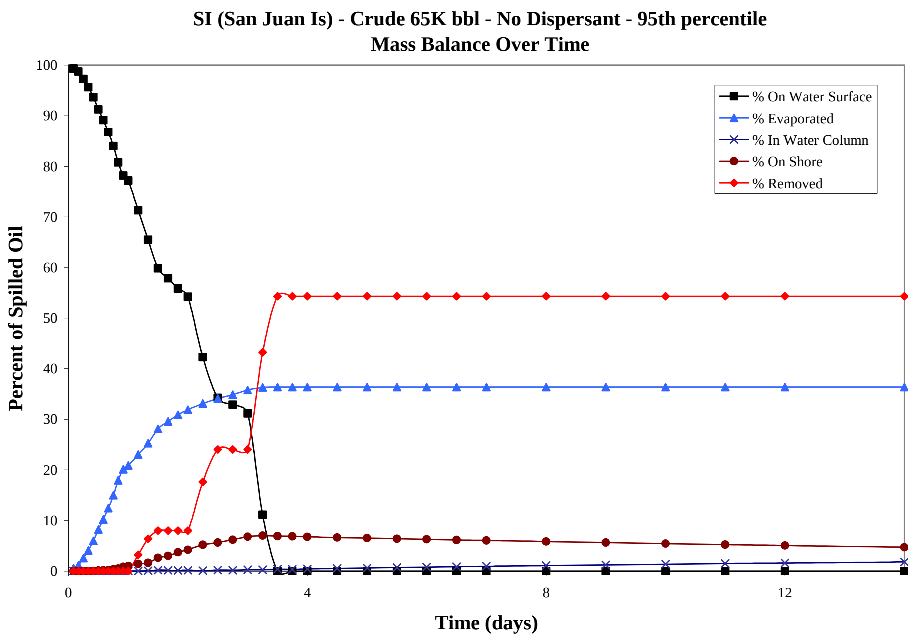


Figure XVII.B.8-16 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

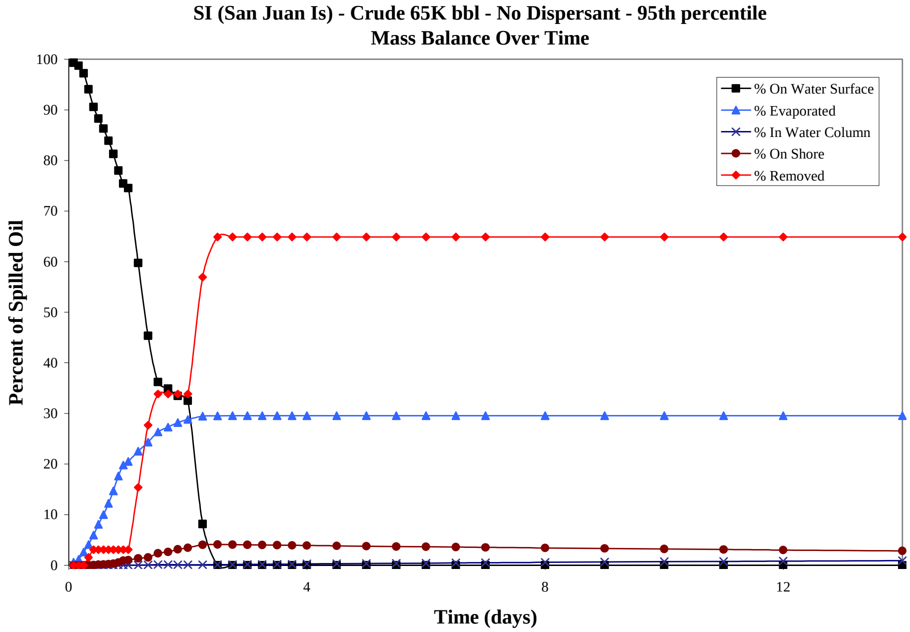


Figure XVII.B.8-17 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

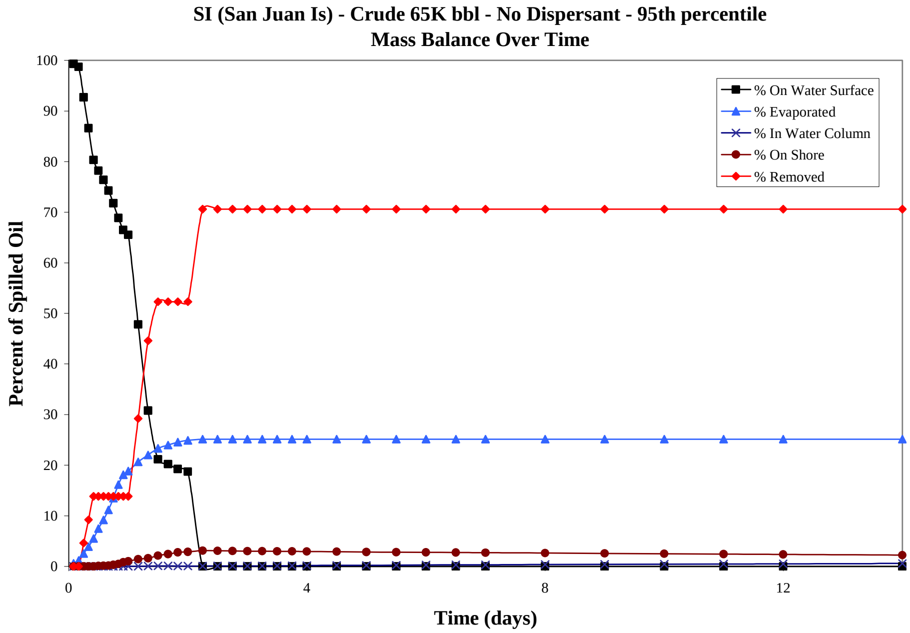


Figure XVII.B.8-18 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

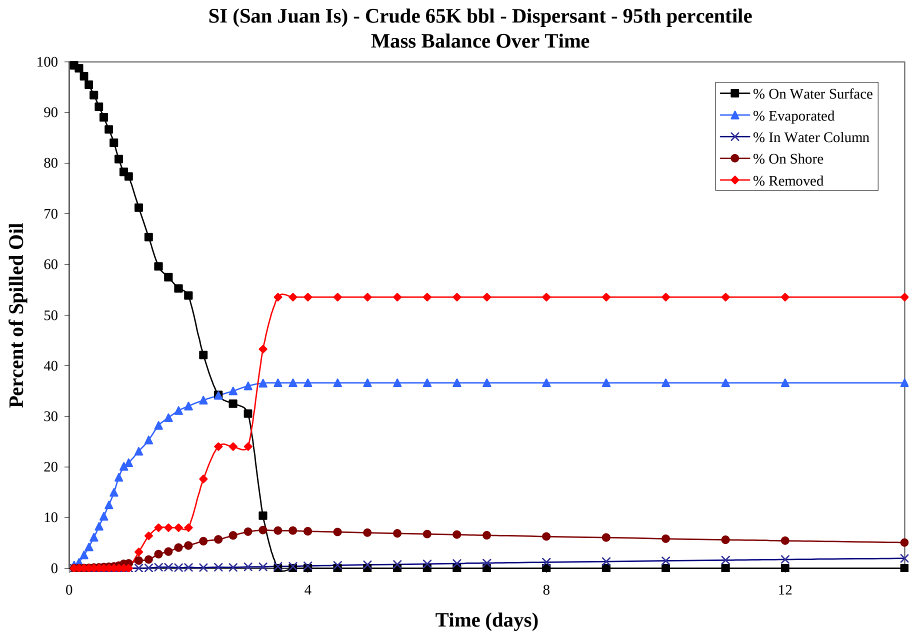


Figure XVII.B.8-19 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

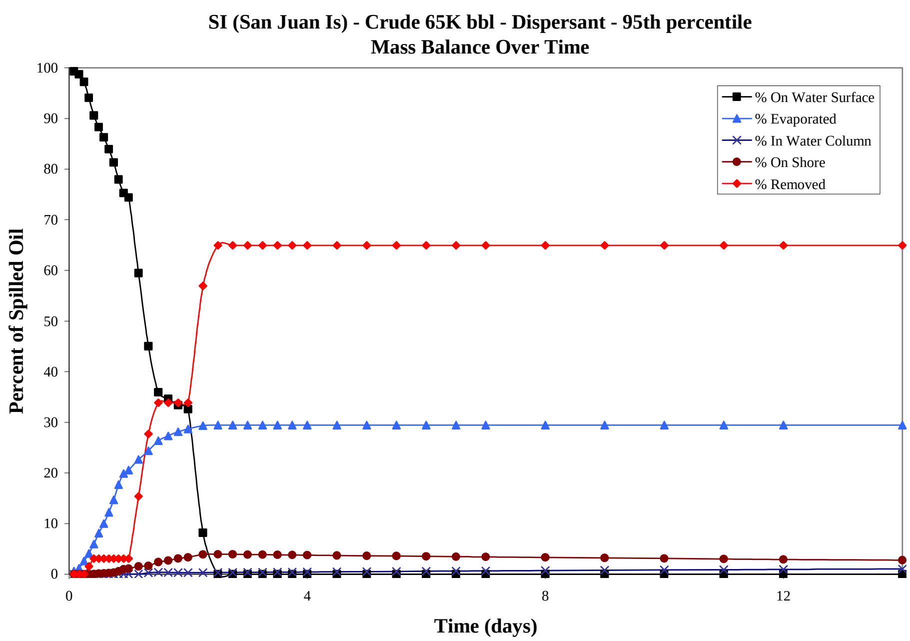


Figure XVII.B.8-20 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

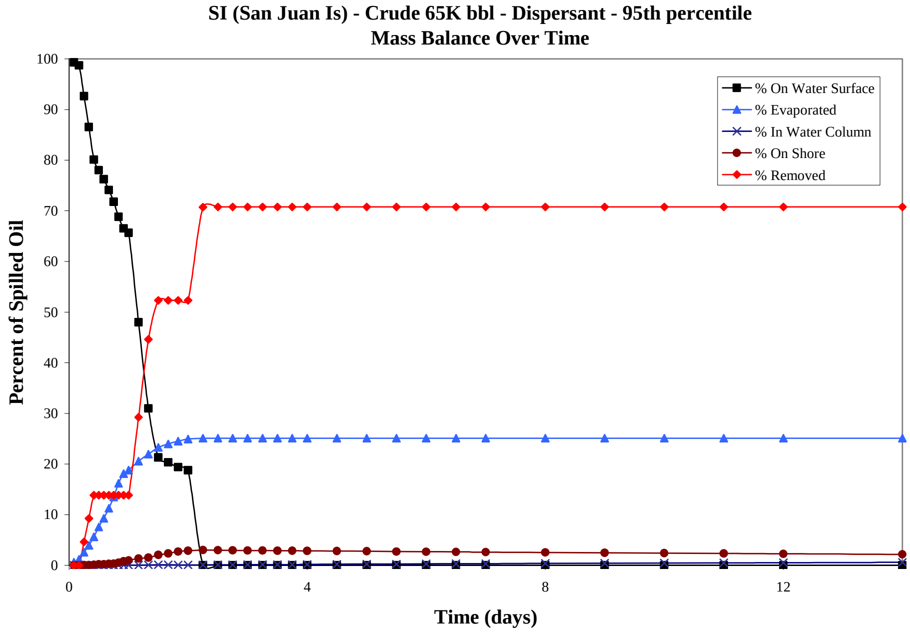


Figure XVII.B.8-21 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

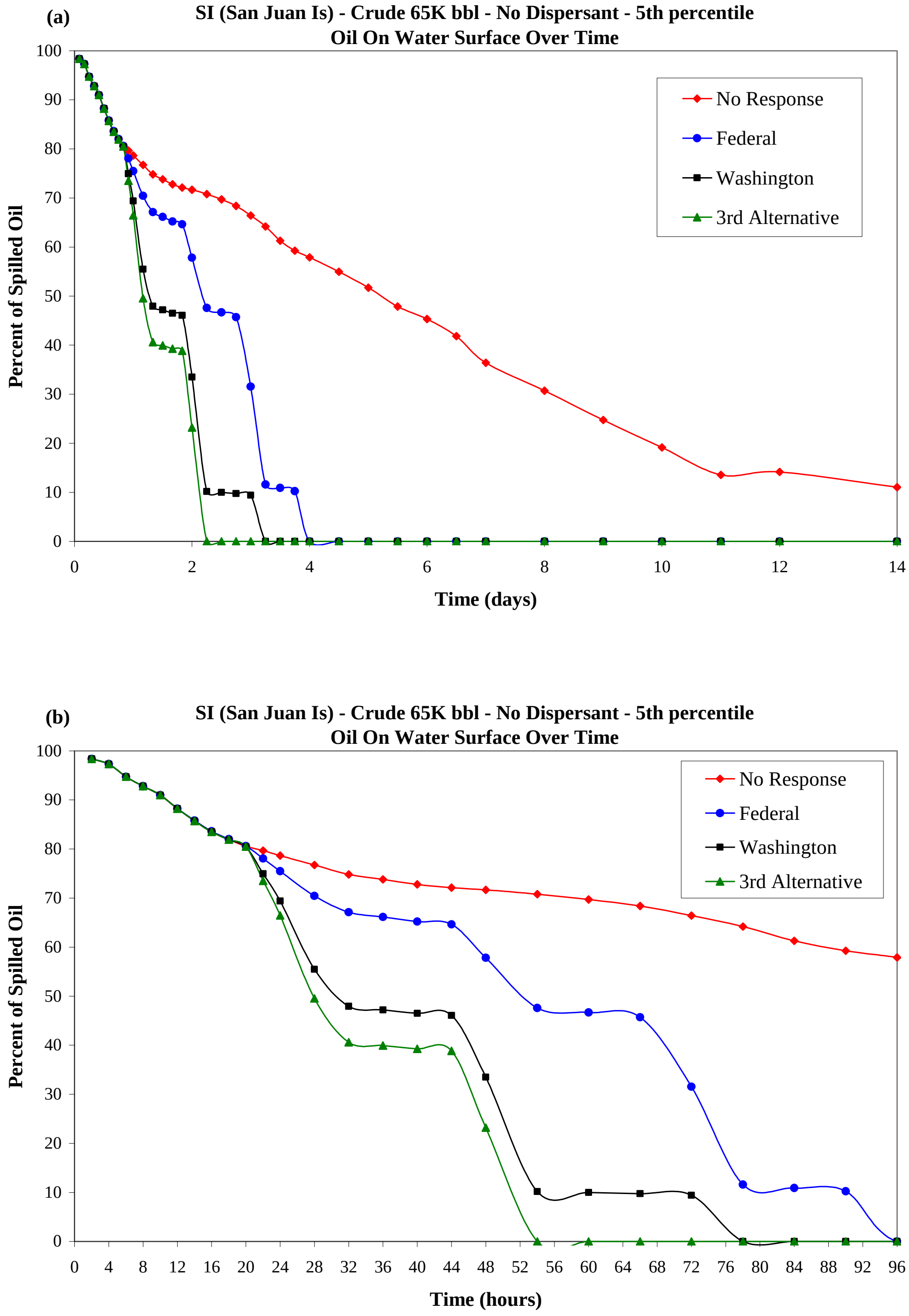
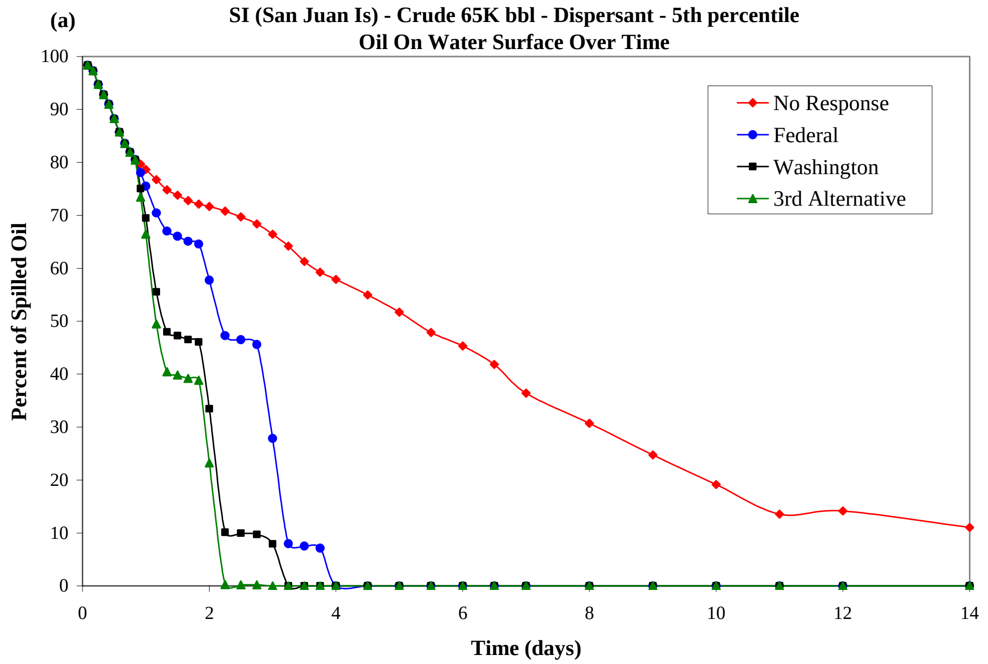


Figure XVII.B.8-22 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.



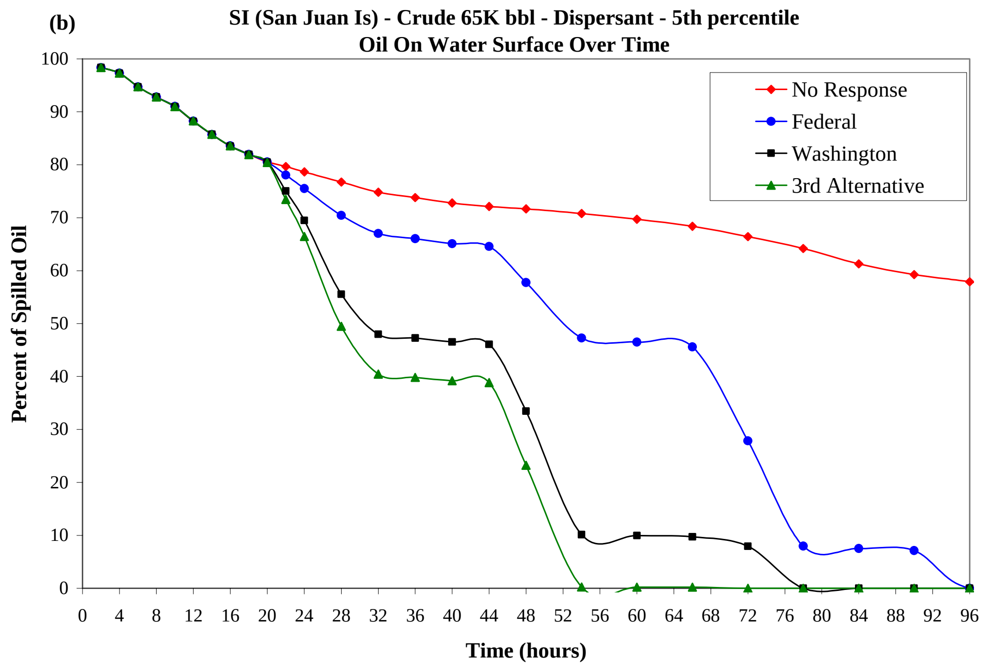


Figure XVII.B.8-23 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.

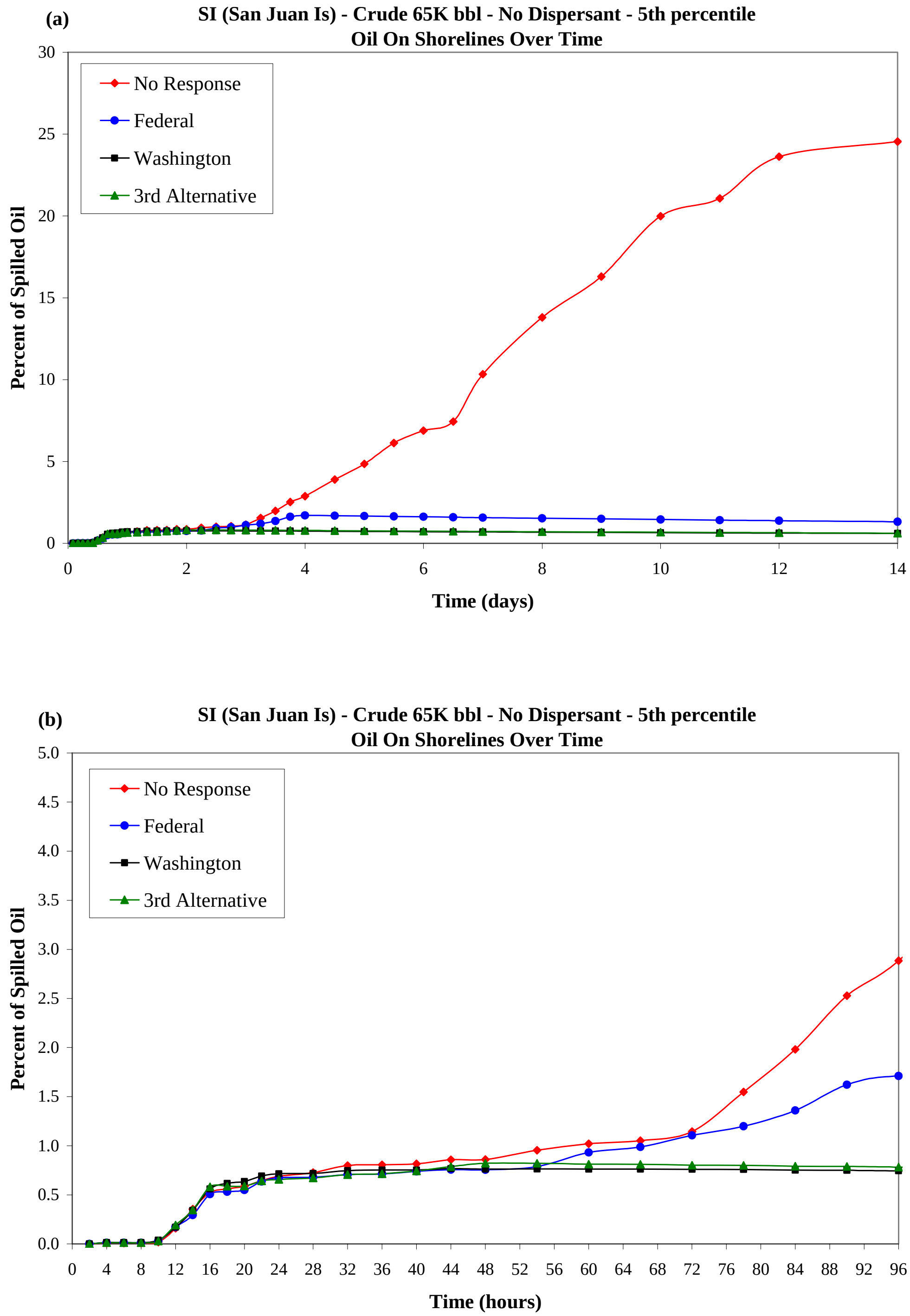


Figure XVII.B.8-24 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.

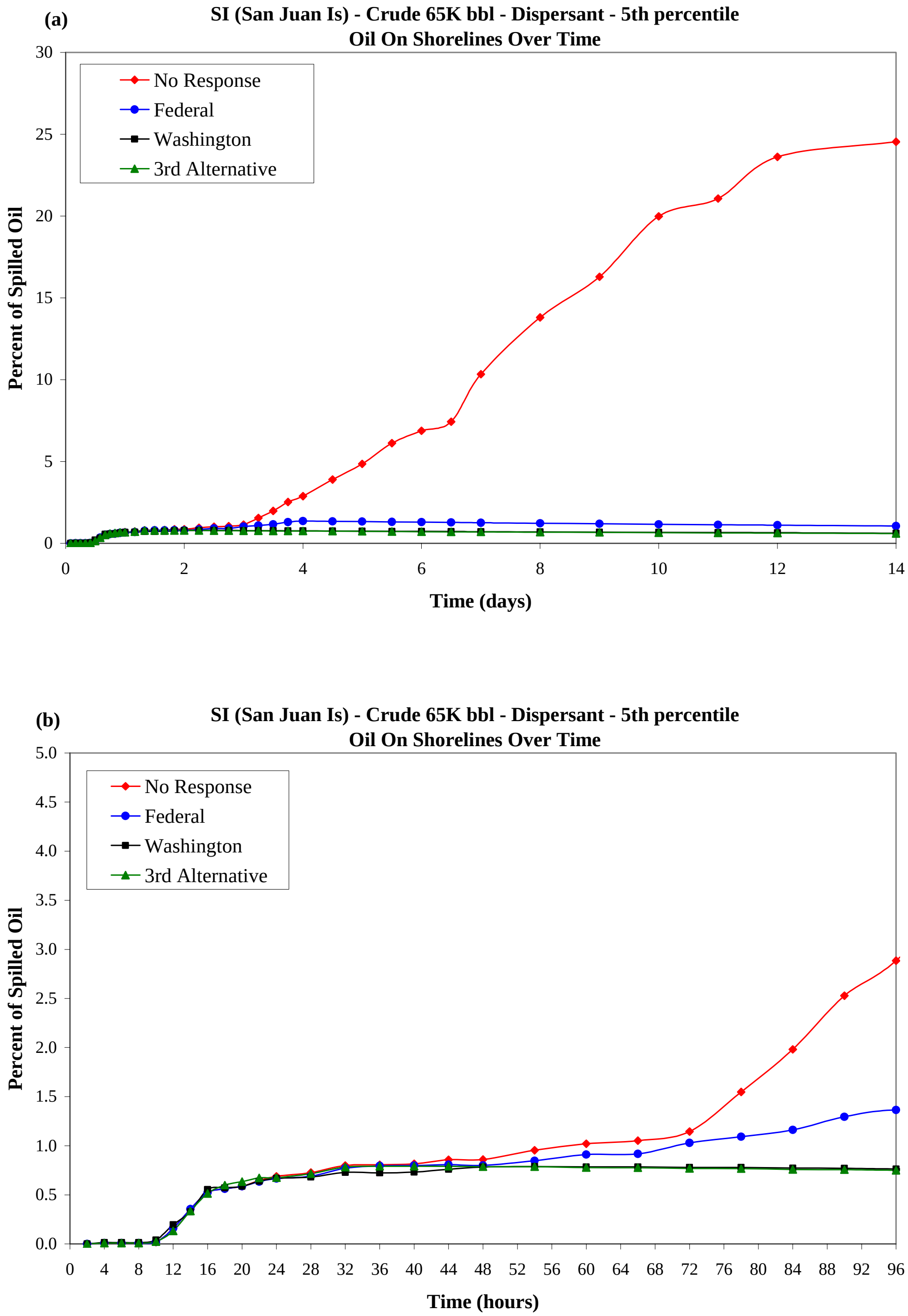
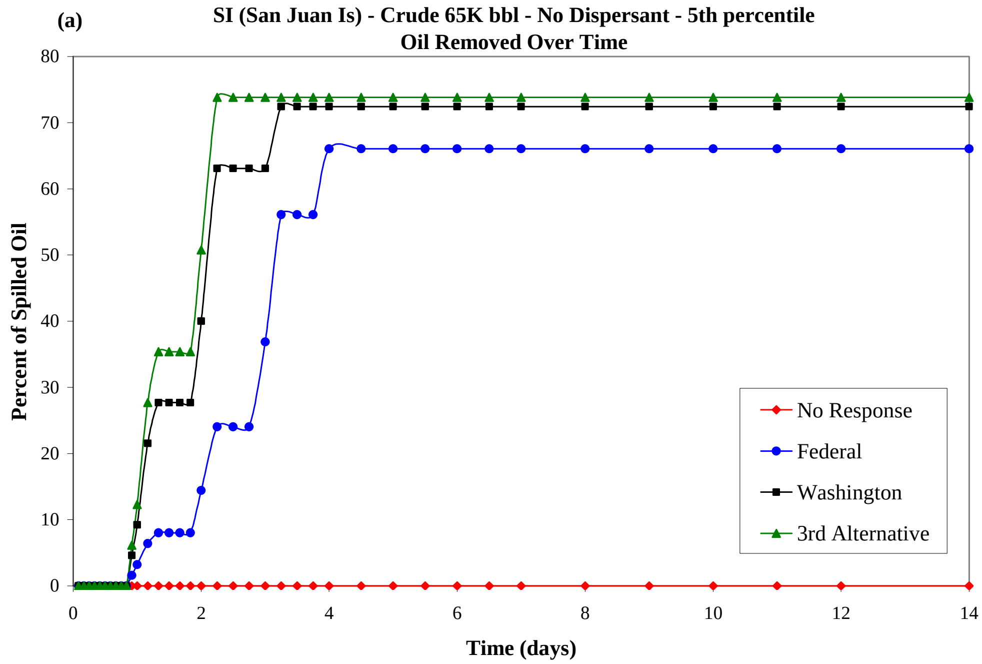


Figure XVII.B.8-25 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



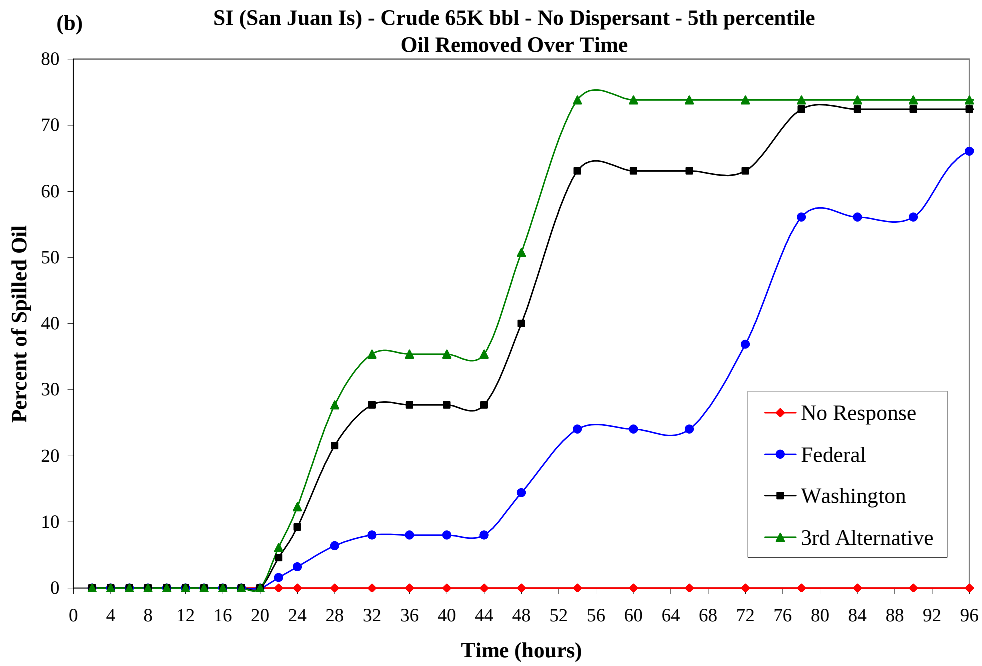


Figure XVII.B.8-26 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.

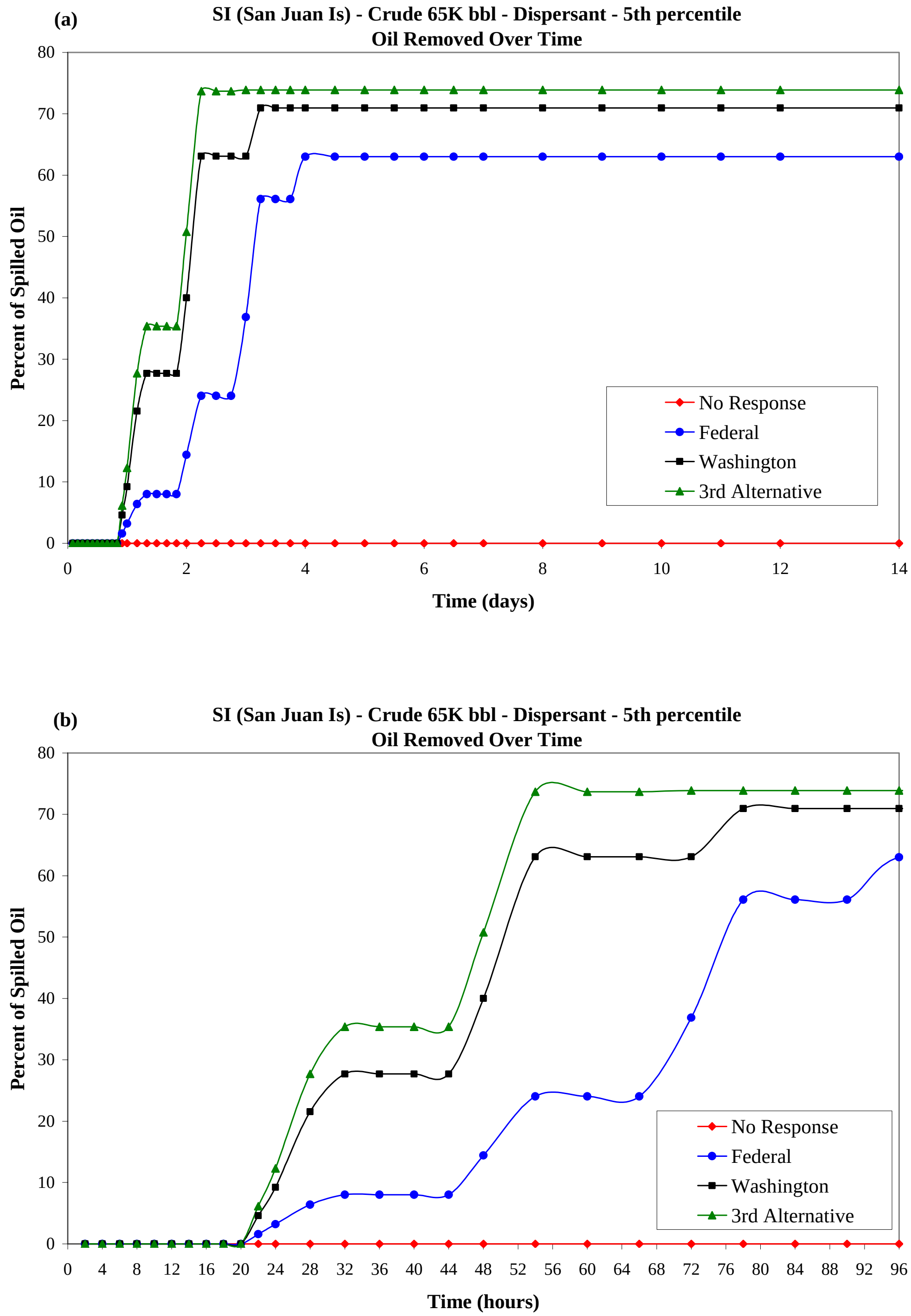


Figure XVII.B.8-27 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.

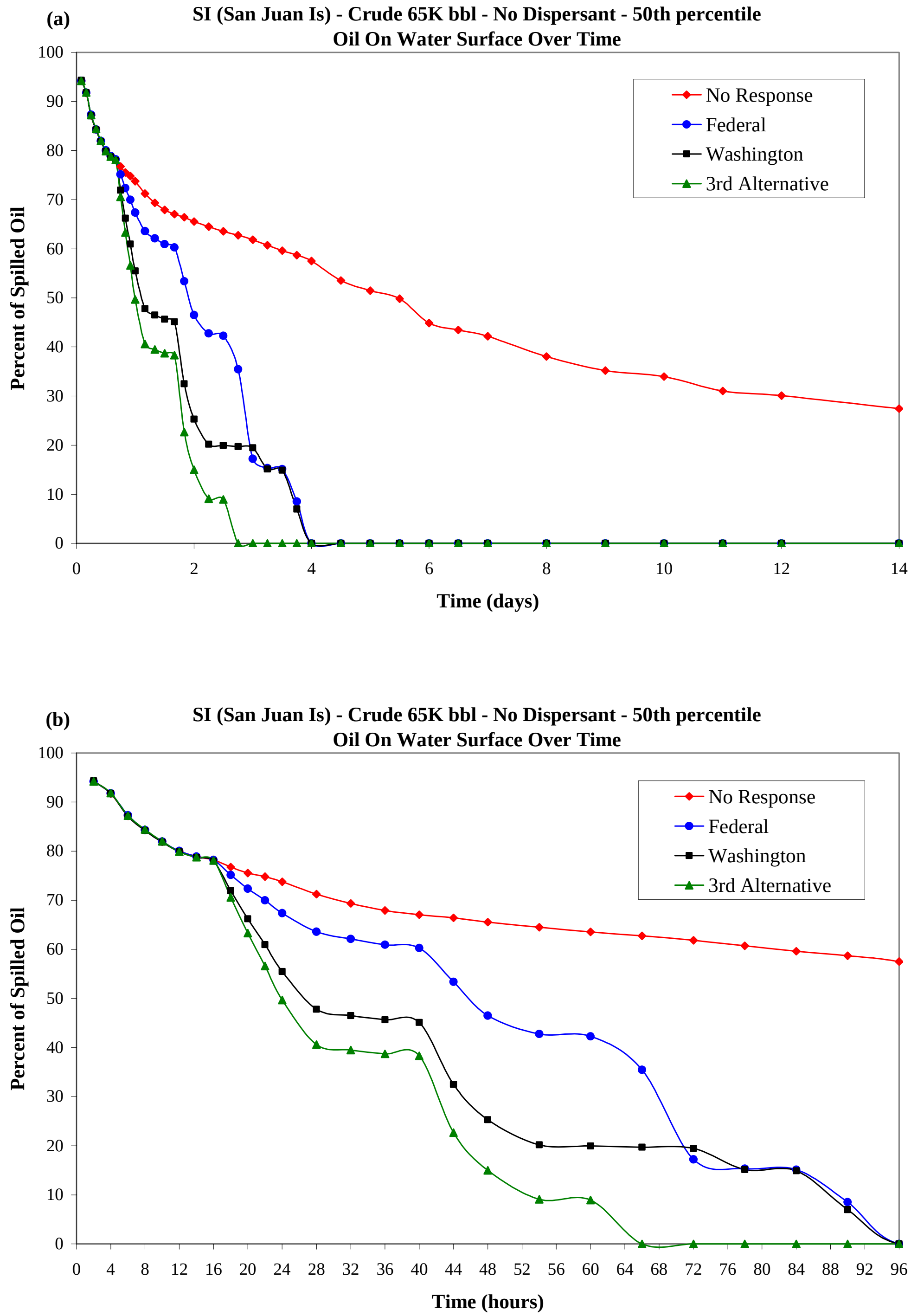
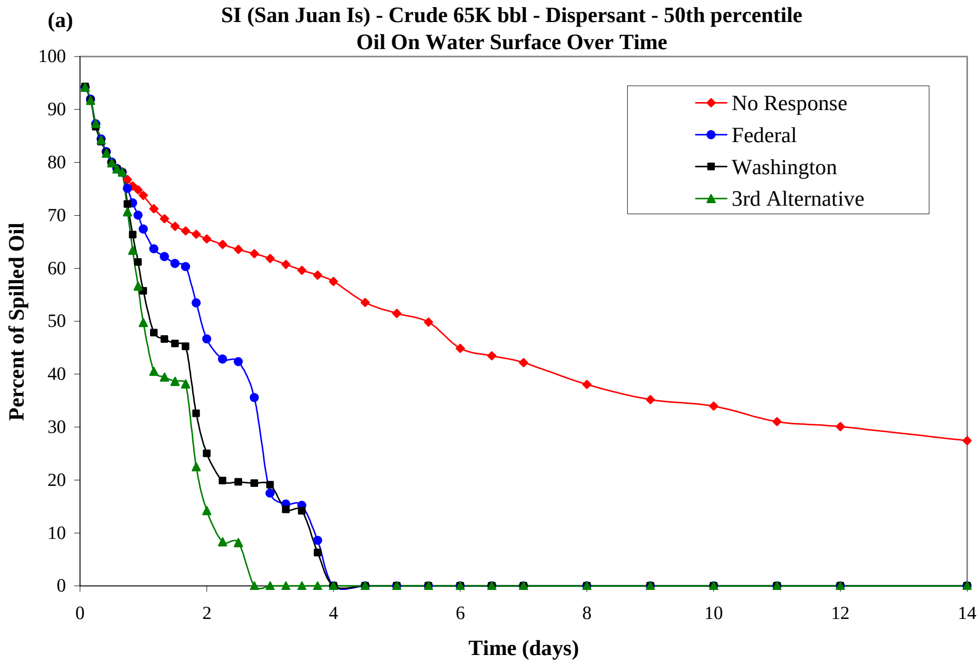


Figure XVII.B.8-28 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.

(a)



(b)

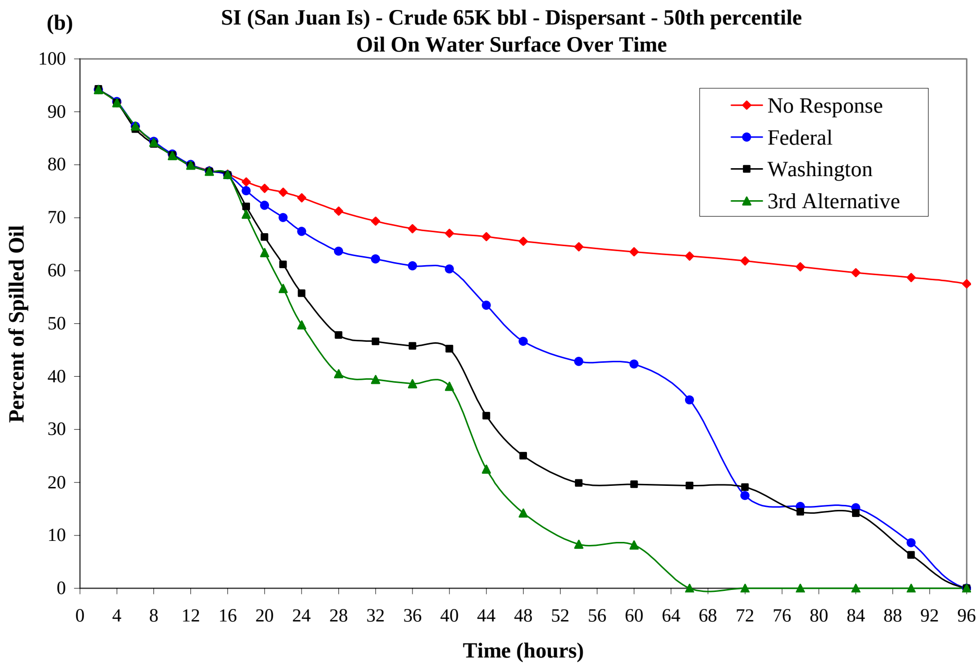
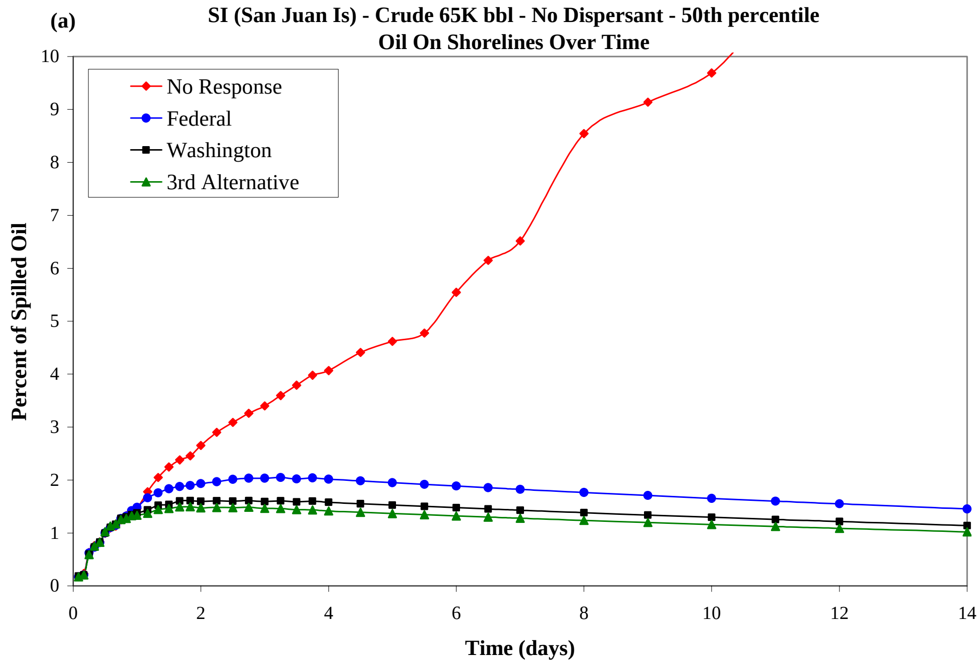


Figure XVII.B.8-29 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



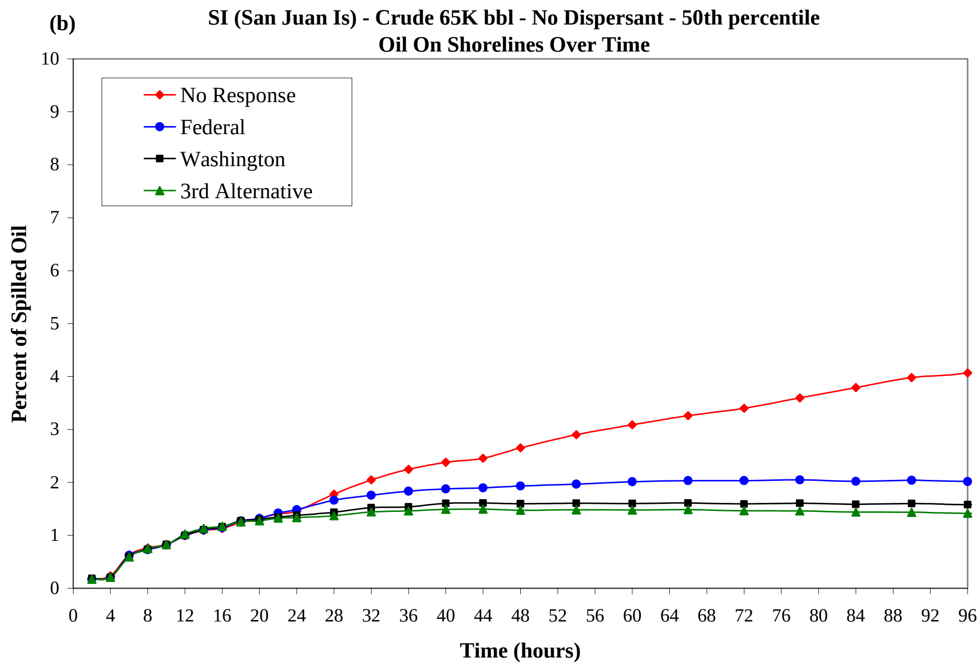
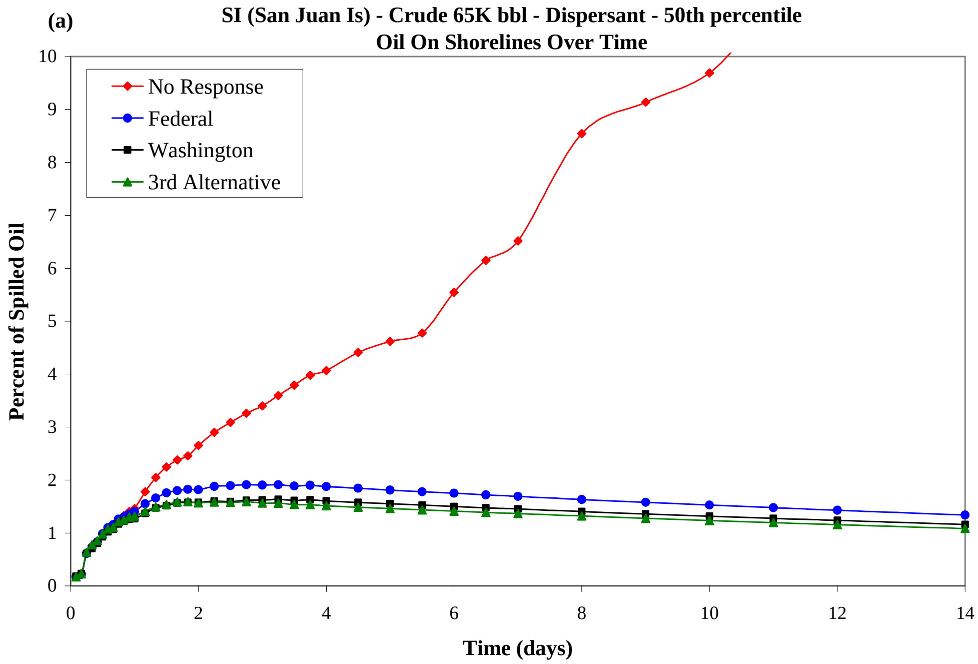


Figure XVII.B.8-30 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



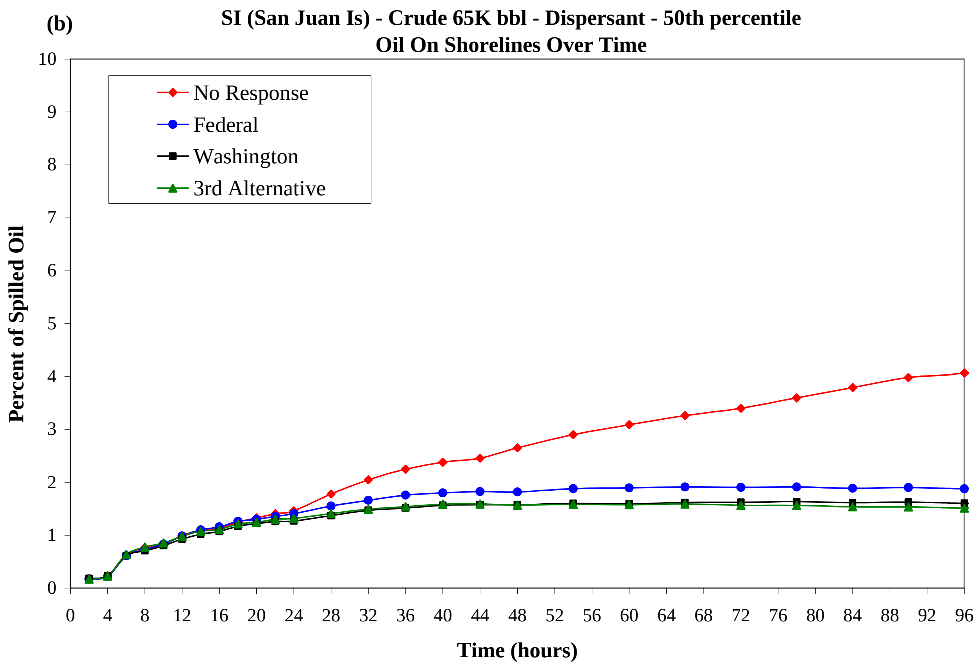
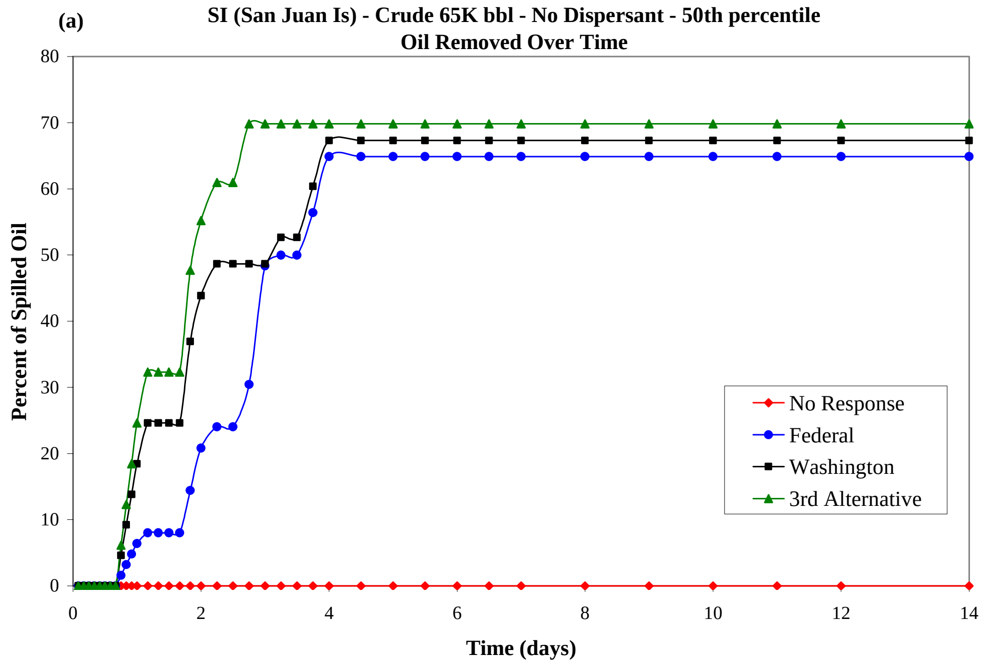


Figure XVII.B.8-31 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



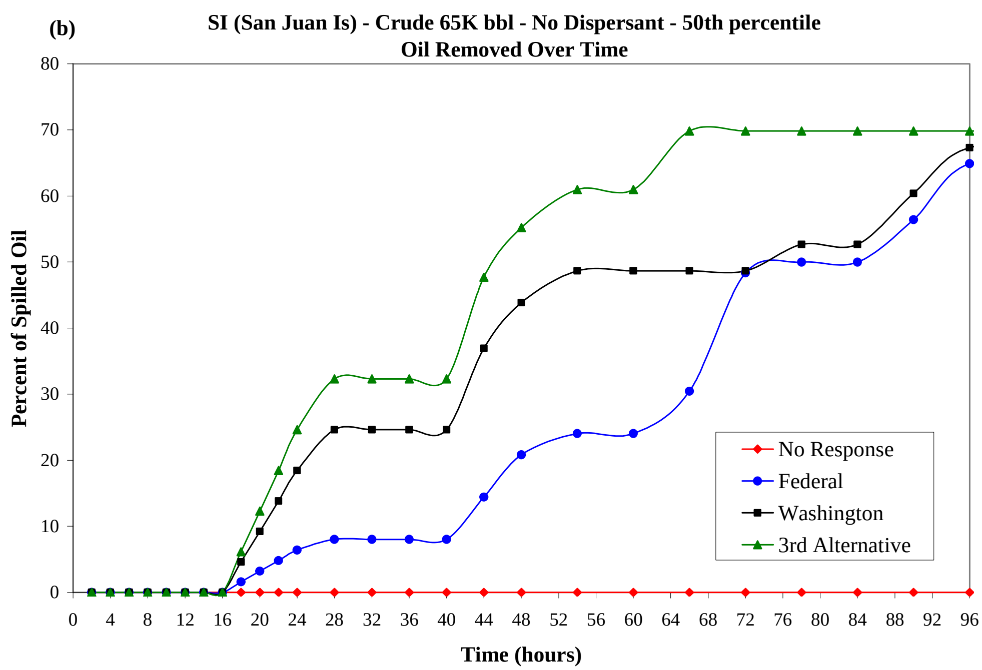
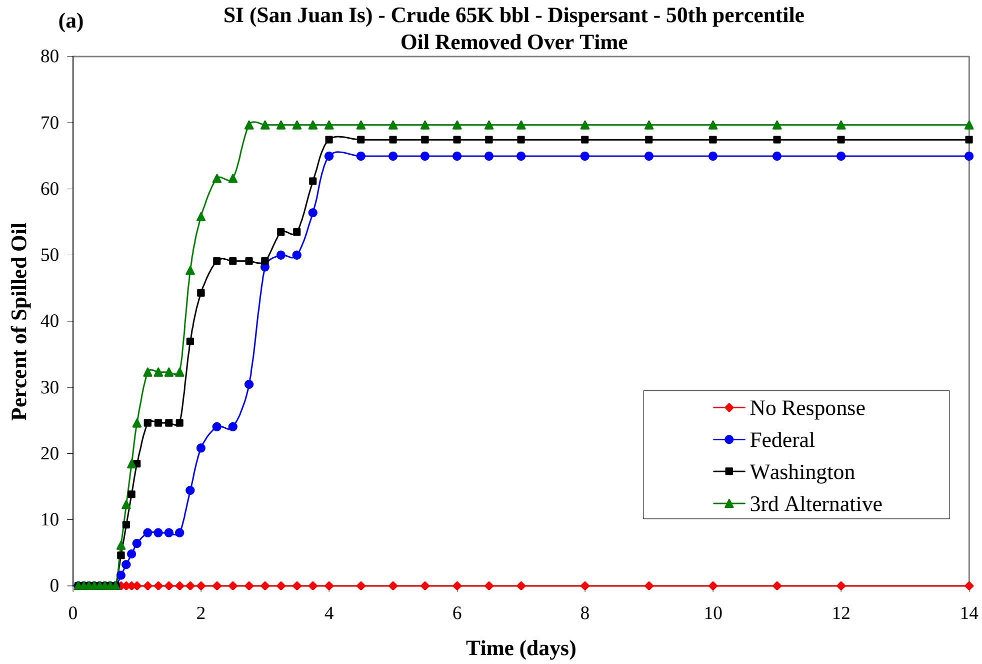


Figure XVII.B.8-32 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



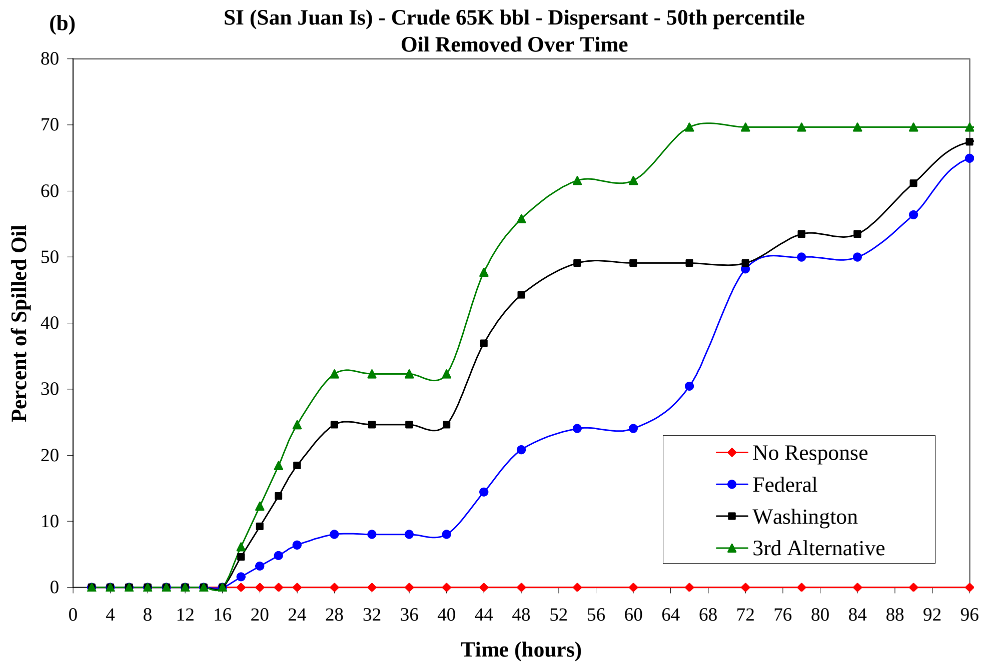
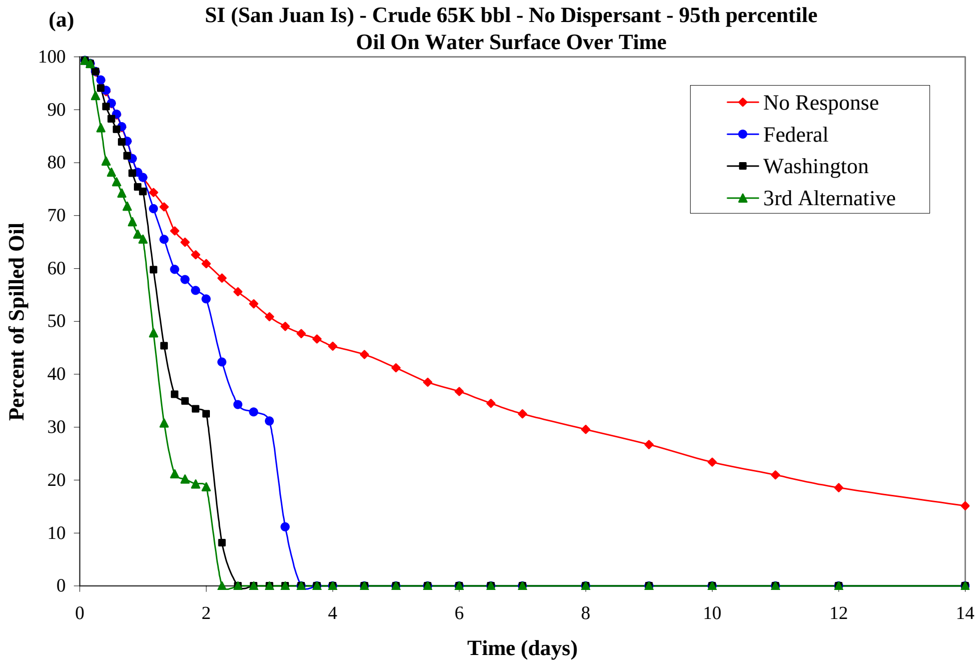


Figure XVII.B.8-33 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



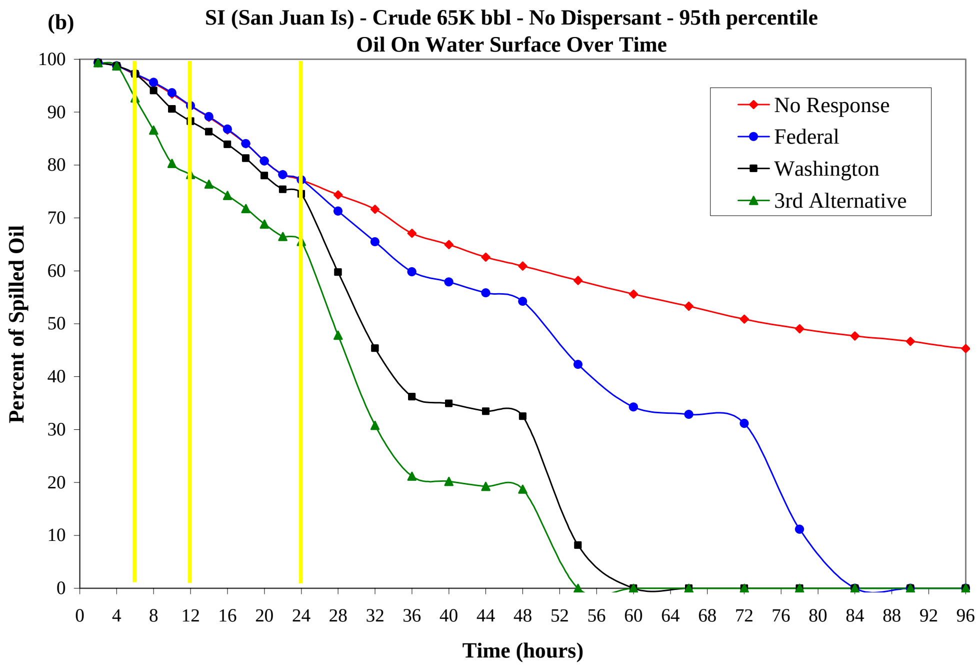
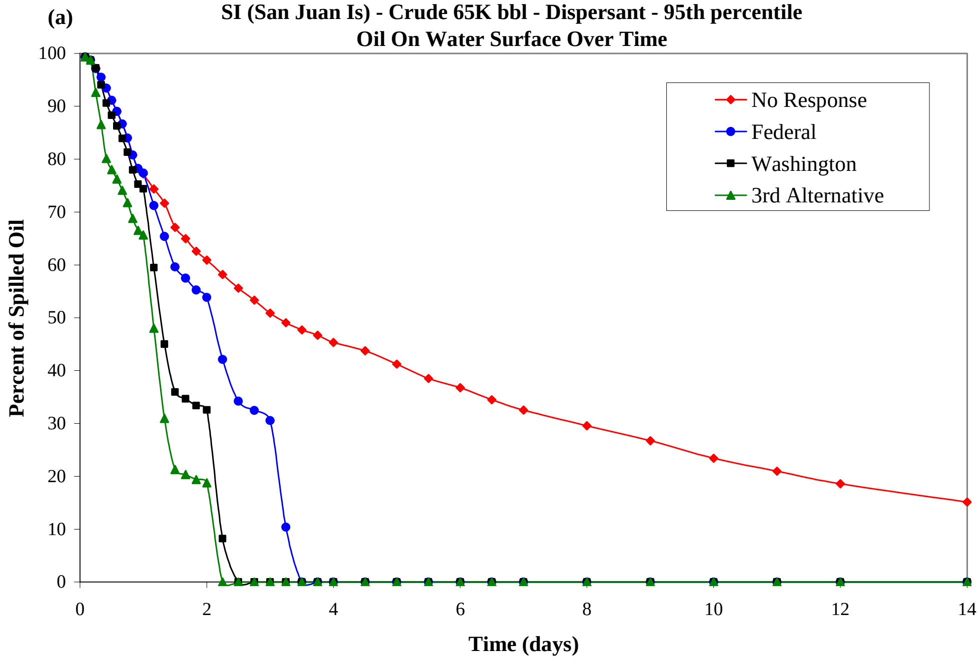


Figure XVII.B.8-34 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



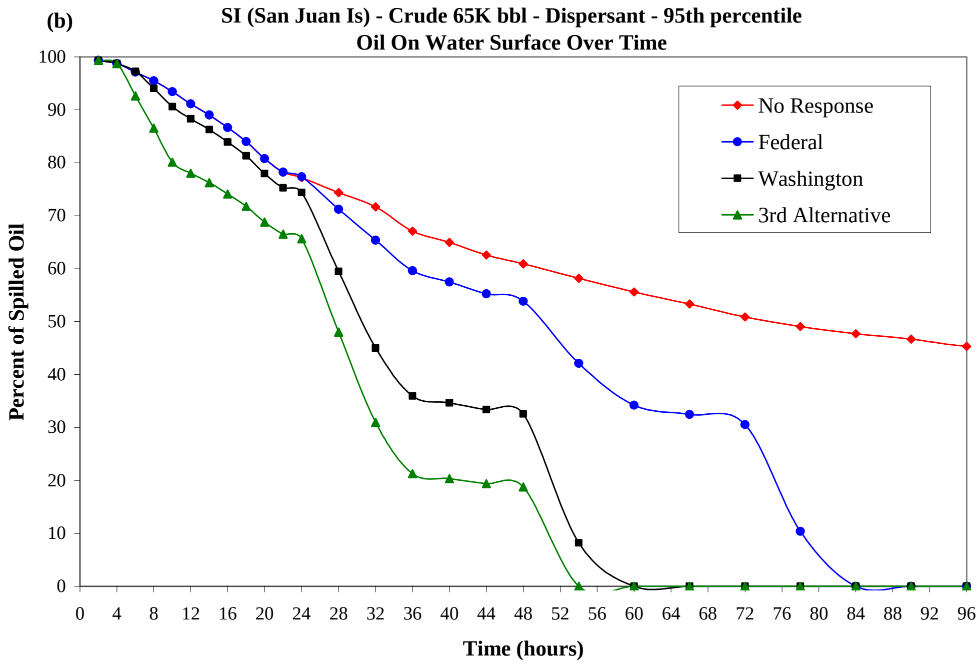
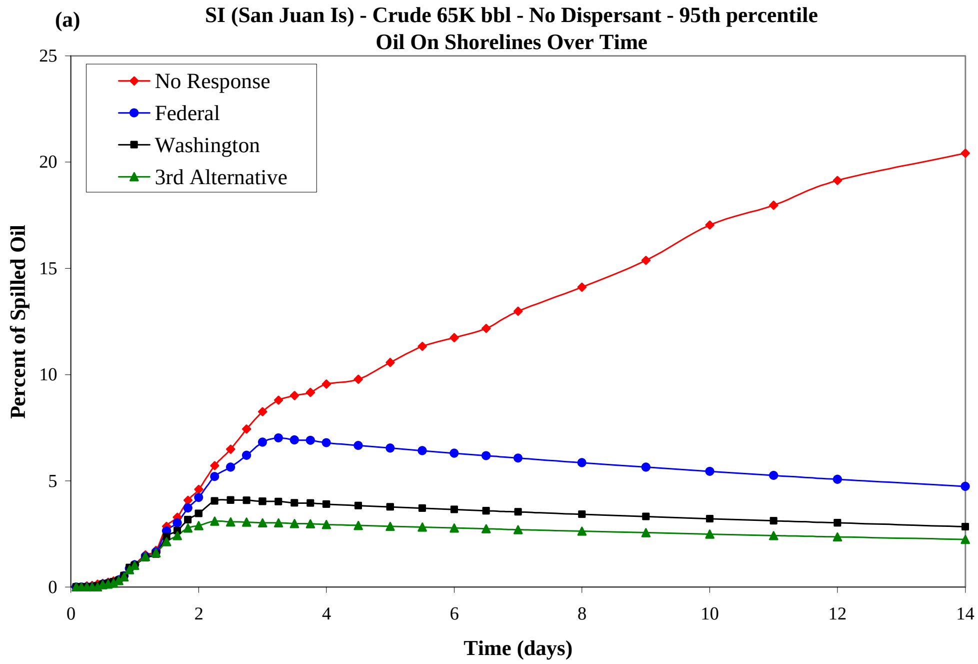


Figure XVII.B.8-35 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



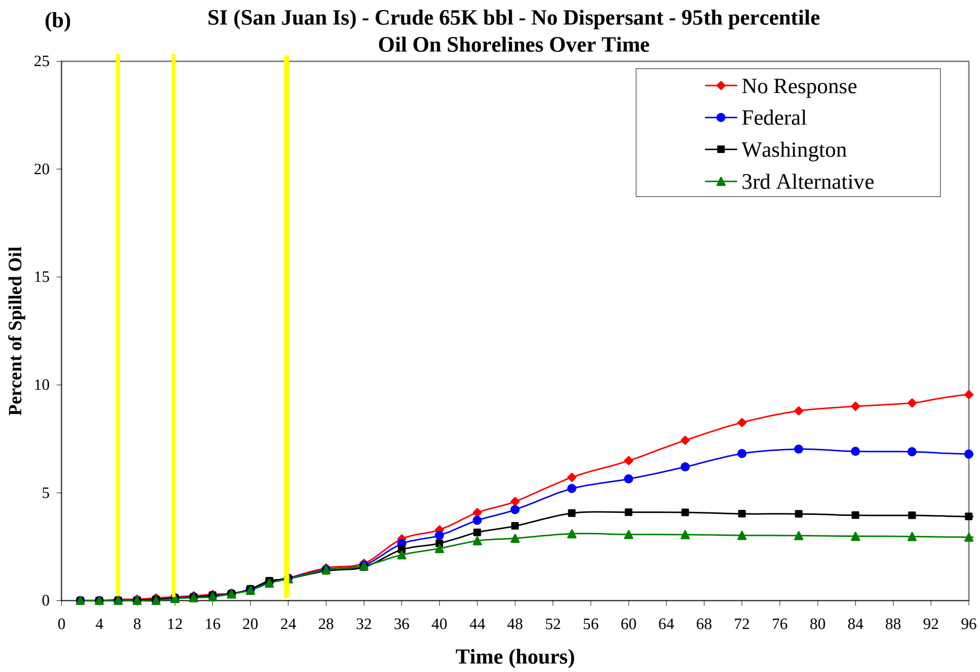
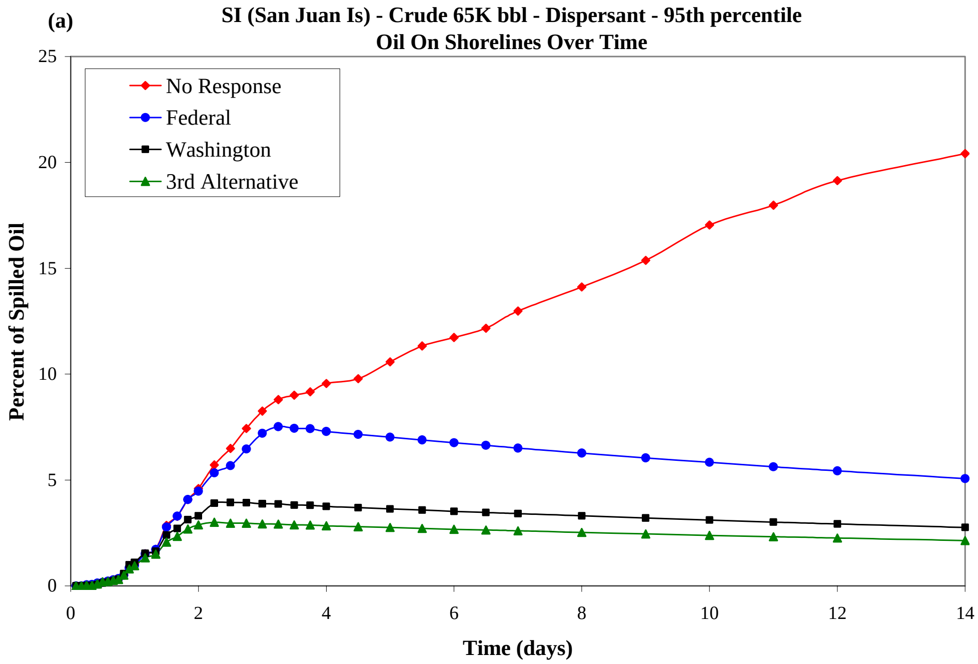


Figure XVII.B.8-36 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



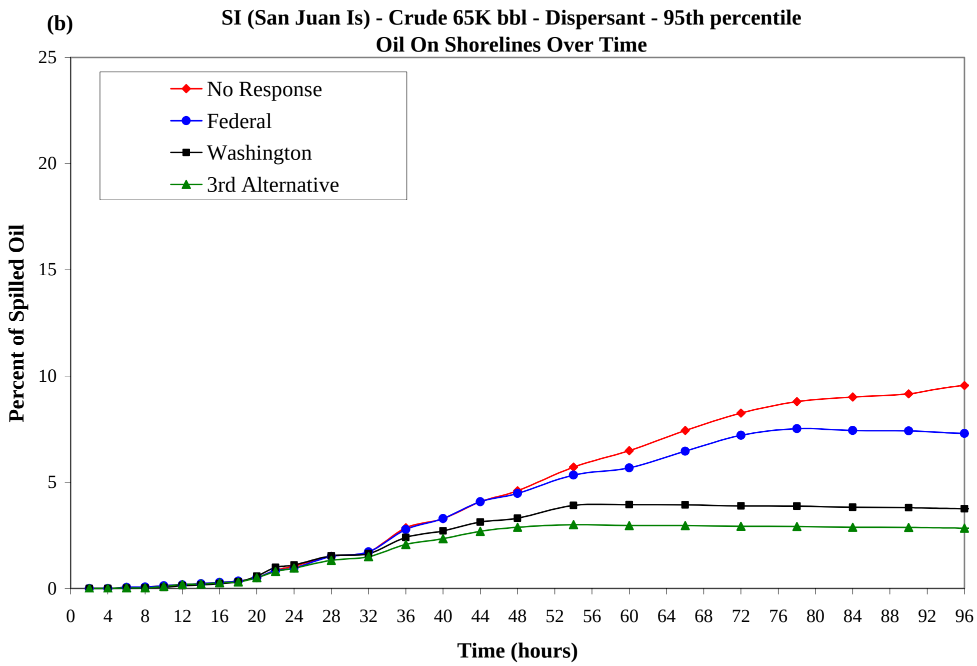
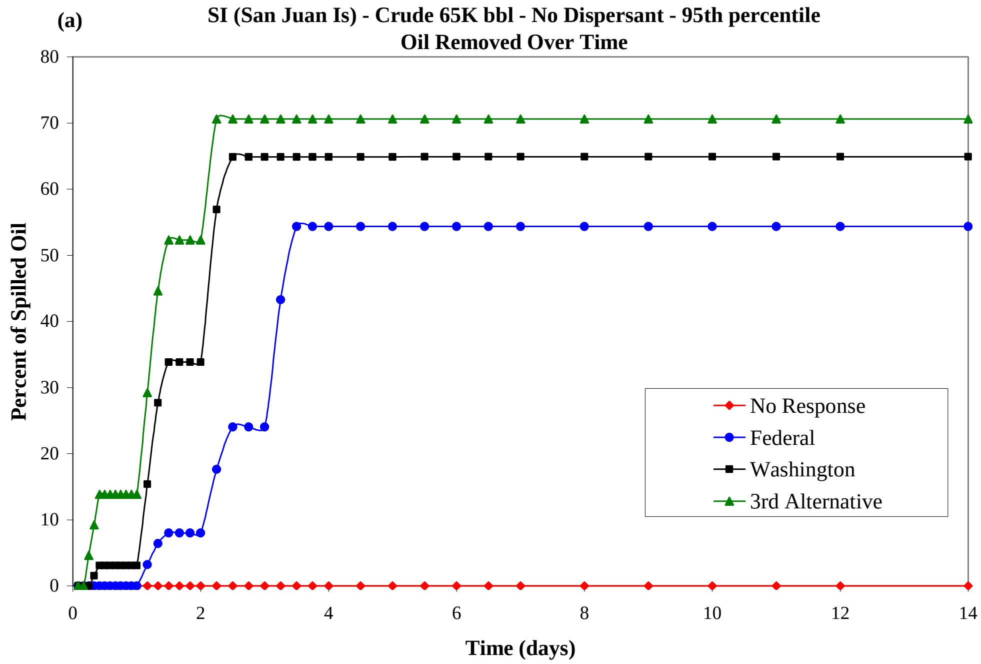


Figure XVII.B.8-37 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



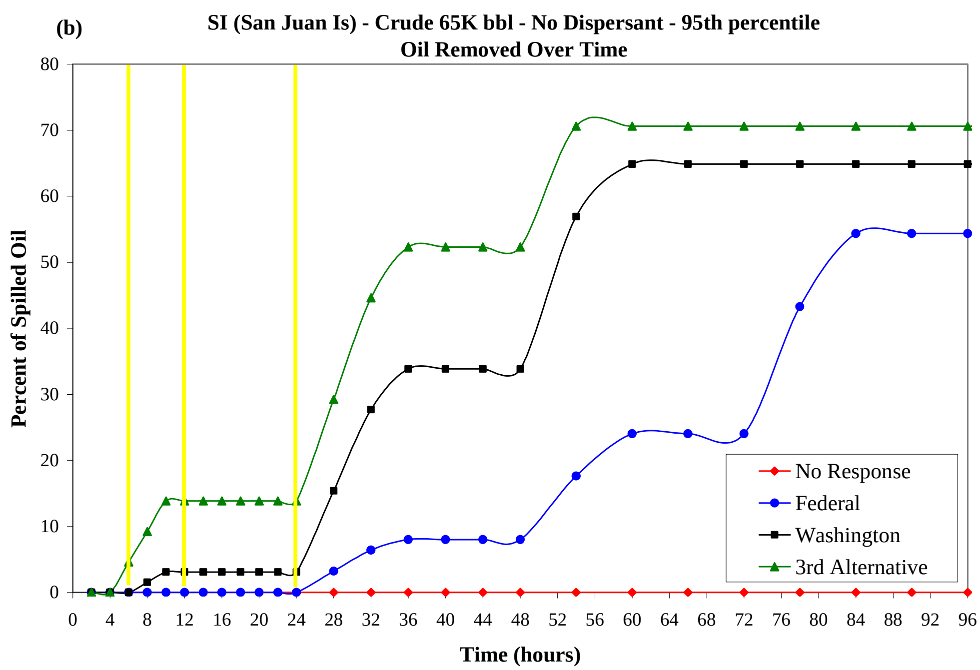
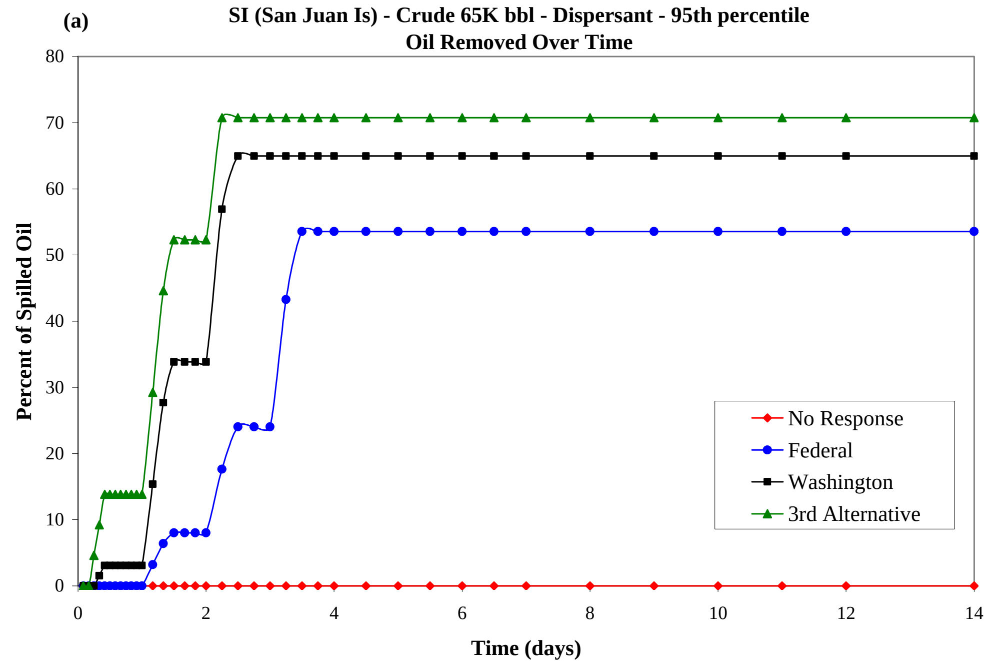


Figure XVII.B.8-38 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run. Part b is a subset of Part a.



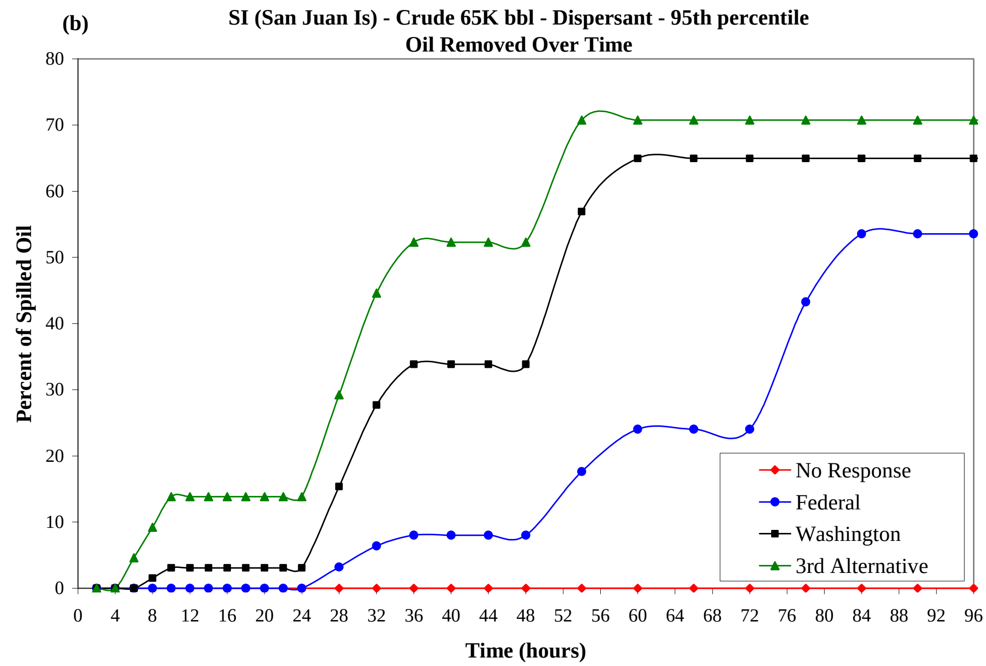


Figure XVII.B.8-39 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run. Part b is a subset of Part a.

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 5^{th}, 50^{th} and 95^{th} 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 5^{th} to 95^{th} 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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

XVIII.A. Introduction 1
XVIII.B. Geographical Data 2
XVIII.B.1. Maps of the Vicinity of the Modeled Spill Locations 2
XVIII.B.2. Gridded Habitat Mapping 3
XVIII.B-3. Gridded Depth Data 4
XVIII.B-4. Areas Where Response Actions Assumed 5
XVIII.C. Current Data 7
XVIII.C.1. Basis of Current Data 7
XVIII.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations.... 9
XVIII.D: Oil Properties 14
XVIII.E: Inputs to the SIMAP Physical Fates Model.. 17

List of Figures

Figure XVIII.B.1-1 Map of the vicinity of the potential spill locations. 2
Figure XVIII.B.2-1 Habitat grid used for modeling the potential spills............................ 3
Figure XVIII.B.2-2 Habitat grid used for modeling the potential spills (closer view)....... 3
Figure XVIII.B.3-1 Depth grid used for modeling the potential spills............................. 4
Figure XVIII.B.3-2 Depth grid used for modeling the potential spills (closer view)......... 4
Figure XVIII.B.4-1 Jurisdictions in the area of the potential spills.................................. 5
Figure XVIII.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 5
Figure XVIII.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 6
Figure XVIII.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 6
Figure XVIII.B.4-5 Areas where dispersant application was assumed to occur in modeling the potential spills. 7
Figure XVIII.C.1-1 Grid used for the hydrodynamic model-generated current data. 8
Figure XVIII.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island).. 8
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. 9
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. 10
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. 10
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. 11
Figure XVIII.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction. 11
Figure XVIII.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction. 12
Figure XVIII.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.......................... 12
Figure XVIII.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction. 13
Figure XVIII.E-1 Varied range of spill site, from Port Angeles to the south end of Lopez Island.. 20
Figure XVIII.E-2 Wind Station Locations... 24

List of Tables

Table XVIII.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling. 14
Table XVIII.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil.15
Table XVIII.E-1. Inputs to the Fates Model for Stochastic Scenarios 17
Table XVIII.E-2. Time, date and location inputs for each of the 100 stochastic runs. 21
Table XVIII.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 23
Table XVIII.E-4. Water temperature by month of the year (from French et al., 1996b). 23
Table XVIII.E-5. Wind data sources and records used. 24

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

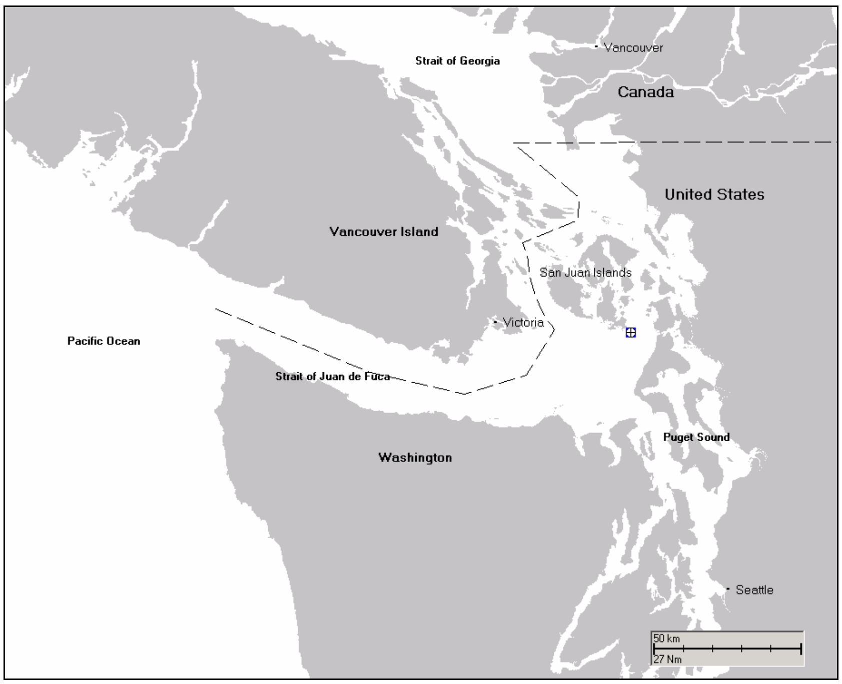


Figure XVIII.B.1-1 Map of the vicinity of the potential spill locations.

XVIII.B.2. Gridded Habitat Mapping

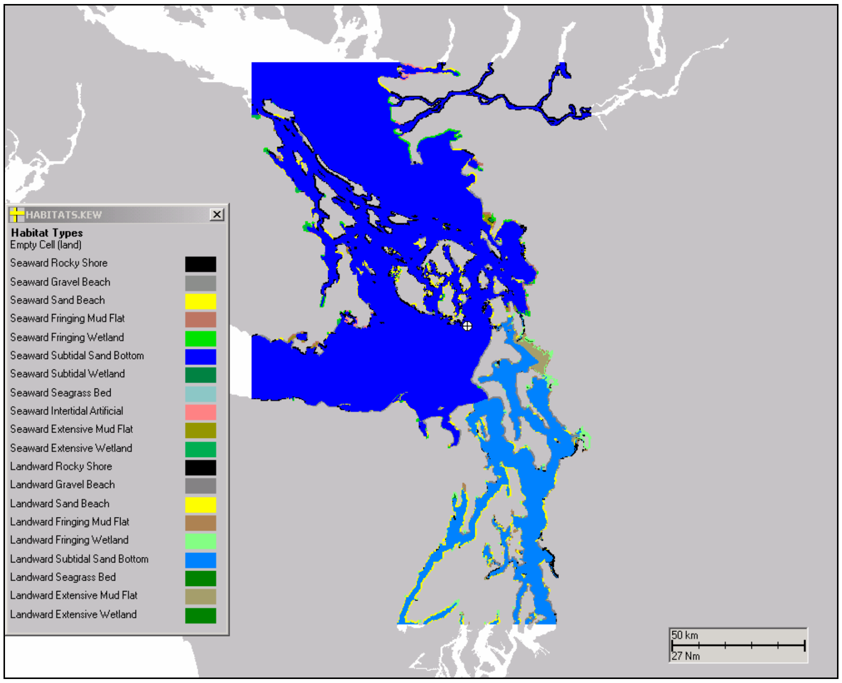


Figure XVIII.B.2-1 Habitat grid used for modeling the potential spills.

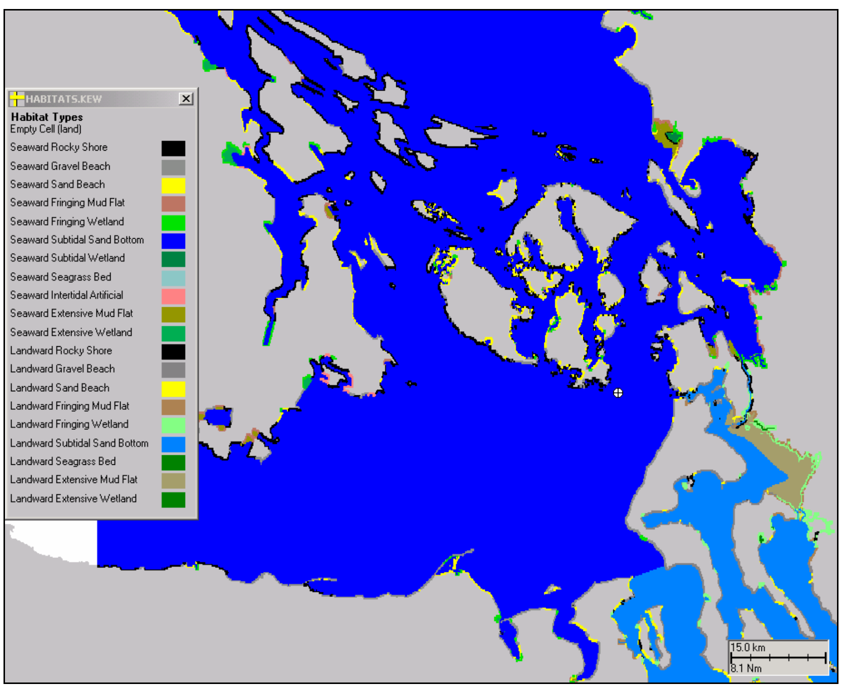


Figure XVIII.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XVIII.B-3. Gridded Depth Data

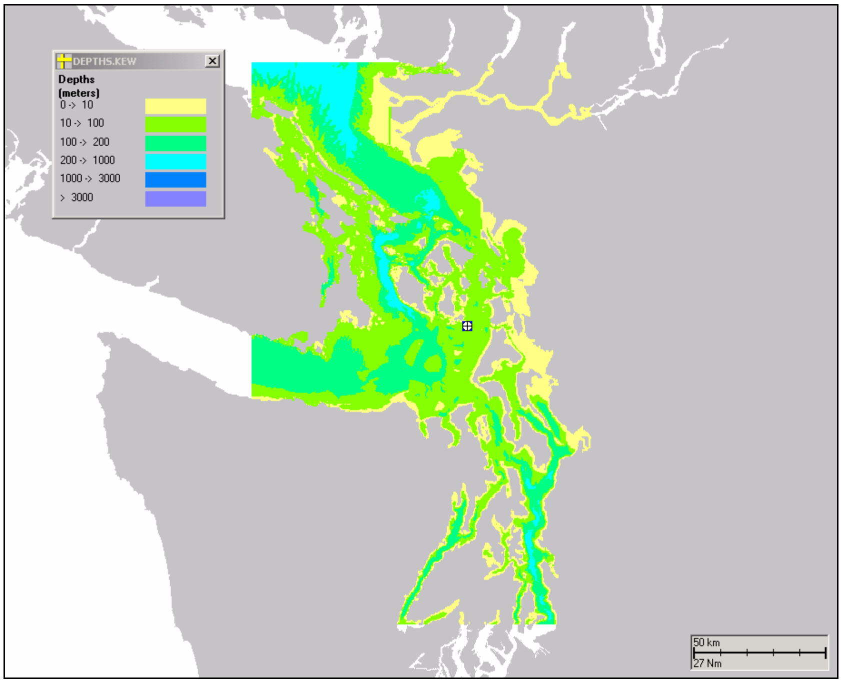


Figure XVIII.B.3-1 Depth grid used for modeling the potential spills.

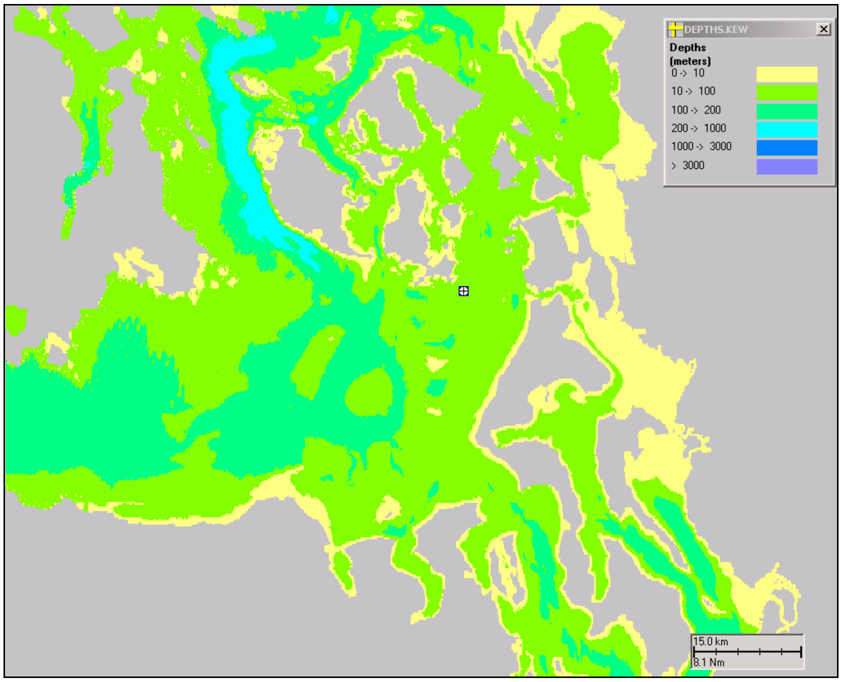


Figure XVIII.B.3-2 Depth grid used for modeling the potential spills (closer view).

XVIII.B-4. Areas Where Response Actions Assumed

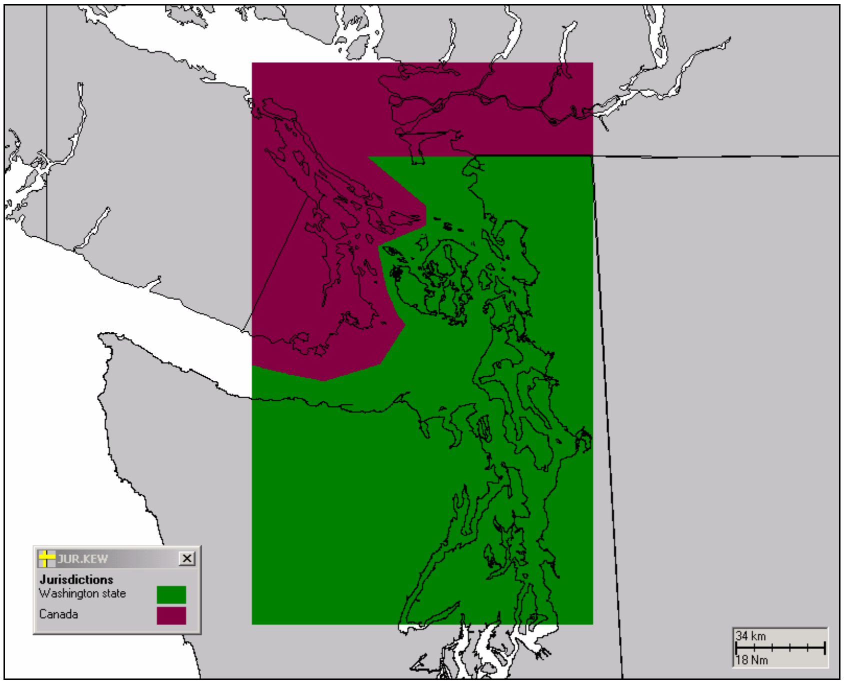


Figure XVIII.B.4-1 Jurisdictions in the area of the potential spills.

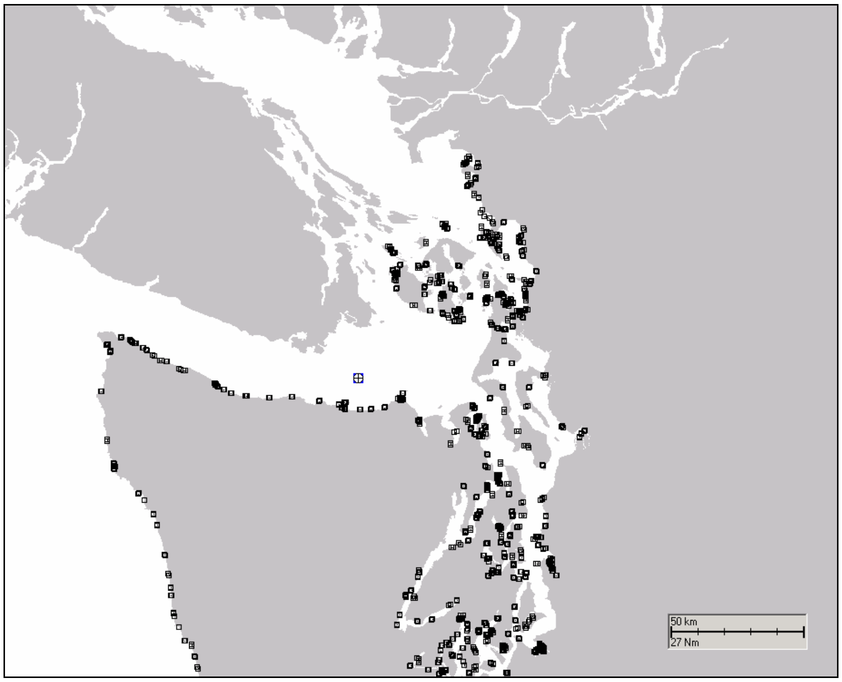


Figure XVIII.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

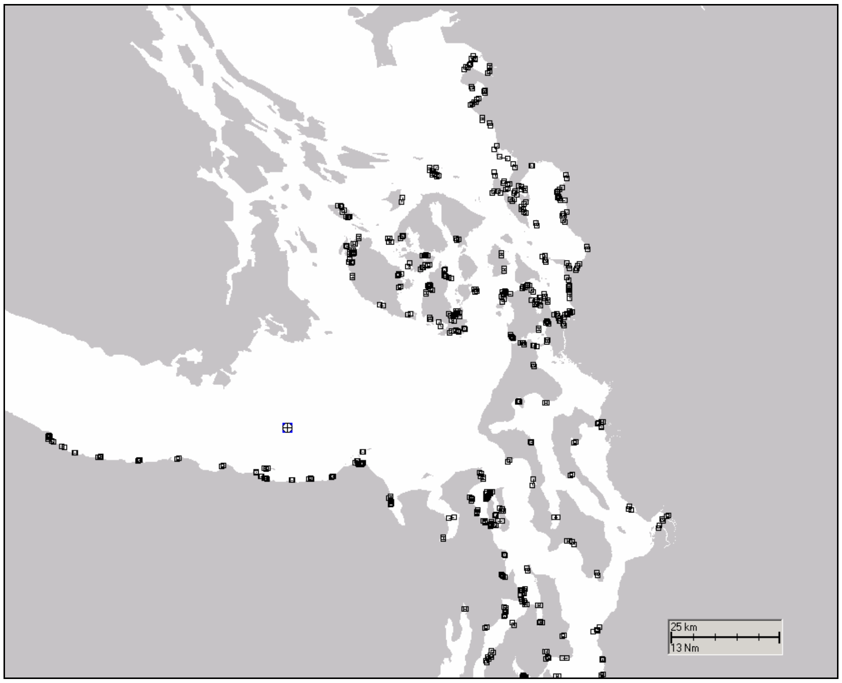


Figure XVIII.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

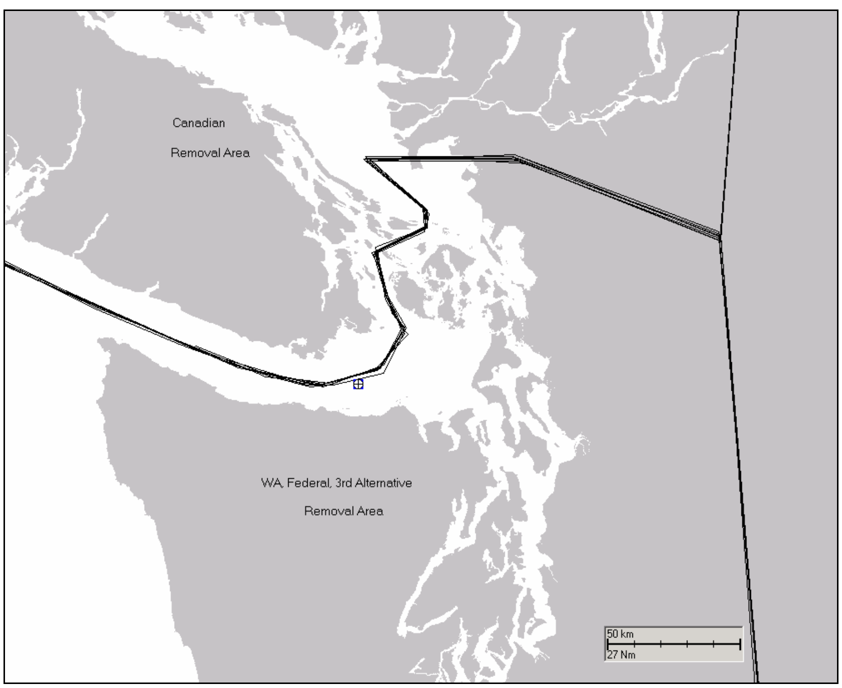


Figure XVIII.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

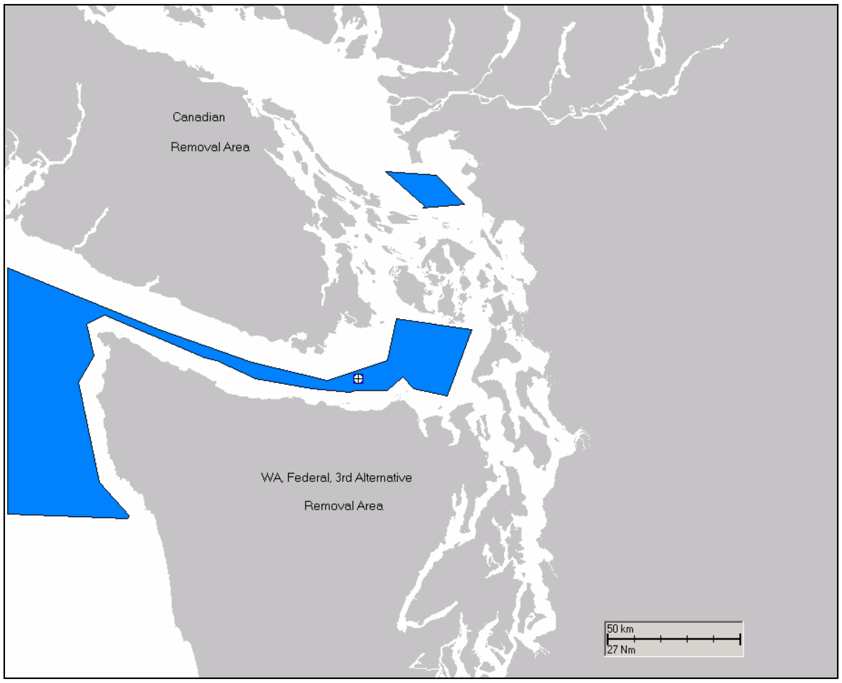


Figure XVIII.B.4-5 Areas where dispersant application was assumed to occur in modeling the potential spills.

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).

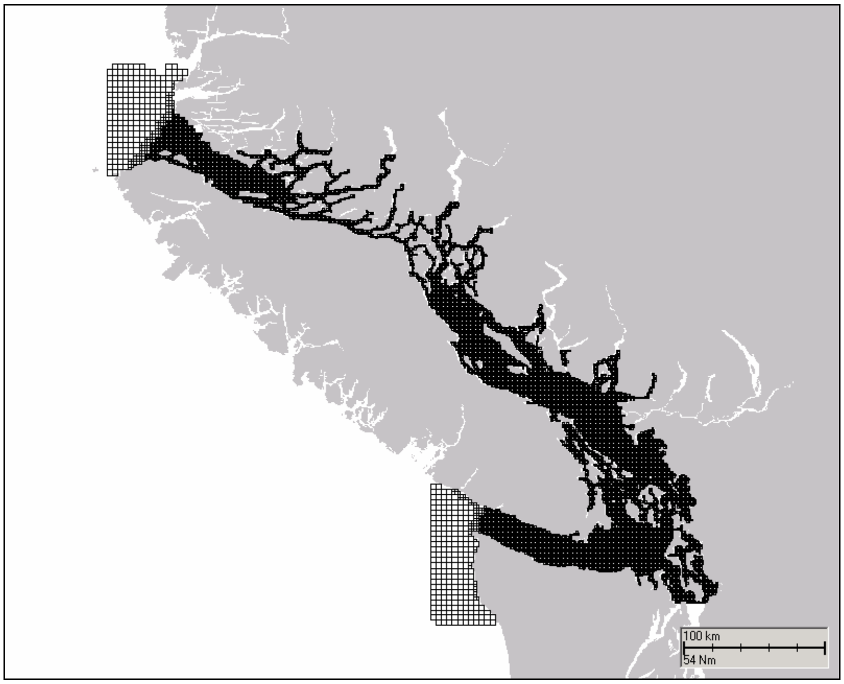


Figure XVIII.C.1-1 Grid used for the hydrodynamic model-generated current data.

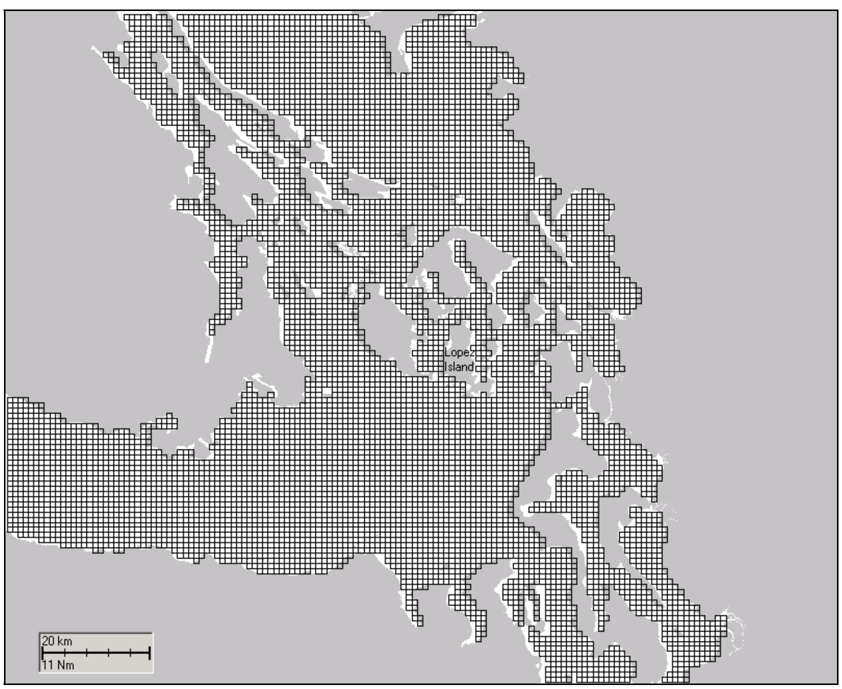


Figure XVIII.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island).

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.

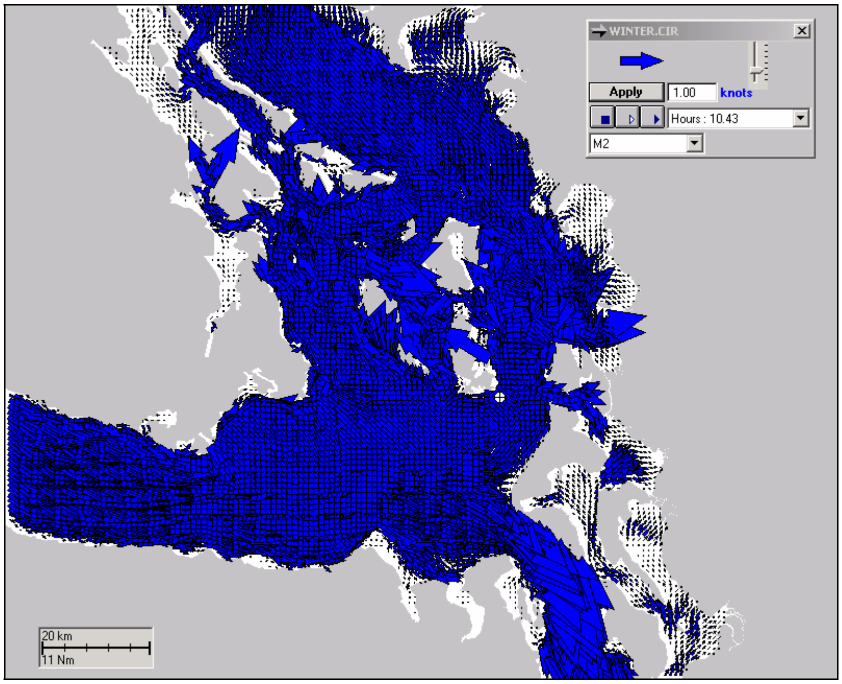


Figure XVIII.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Lopez Island.

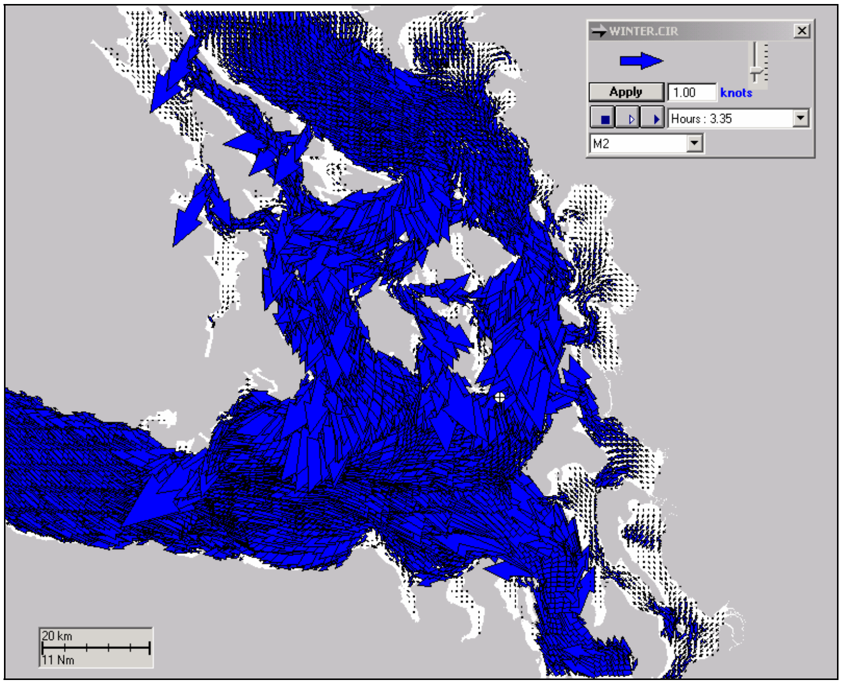


Figure XVIII.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Lopez Island.

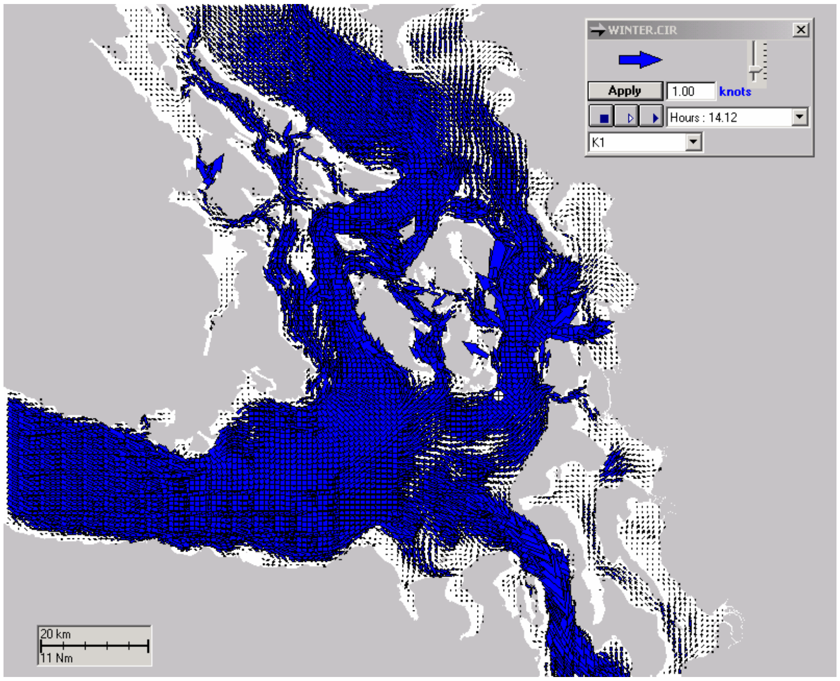


Figure XVIII.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Lopez Island.

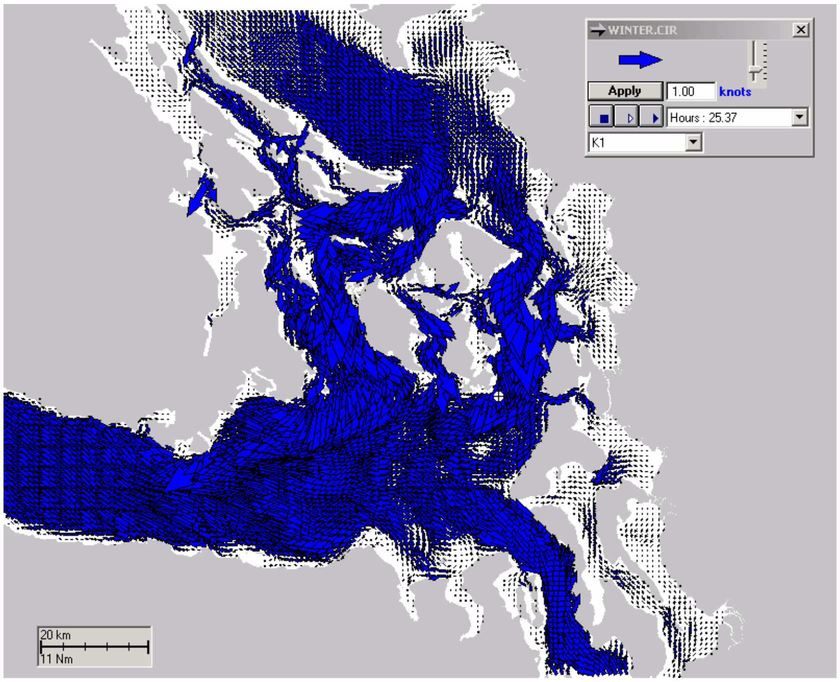


Figure XVIII.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Lopez Island.

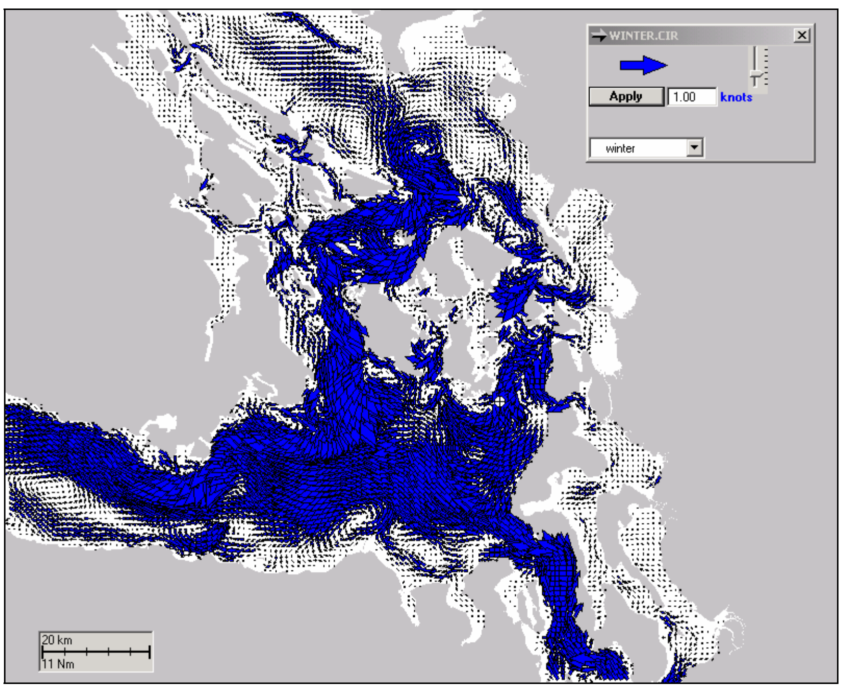


Figure XVIII.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction.

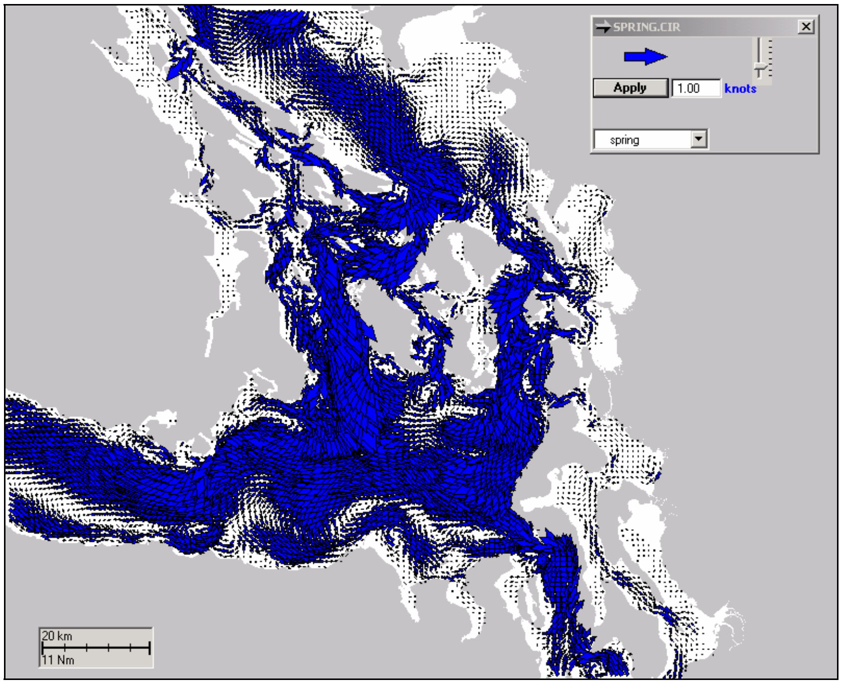


Figure XVIII.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction.

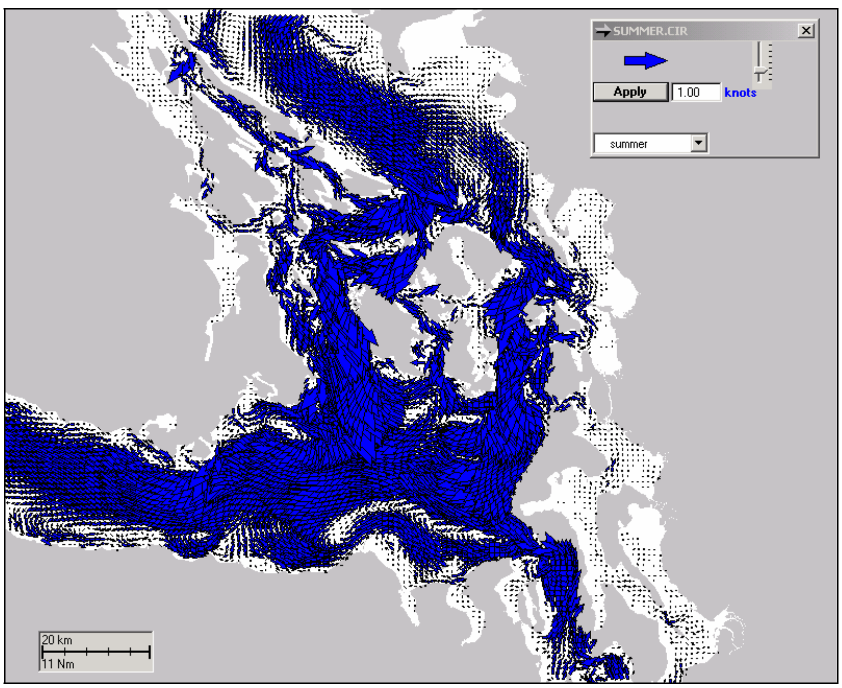


Figure XVIII.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.

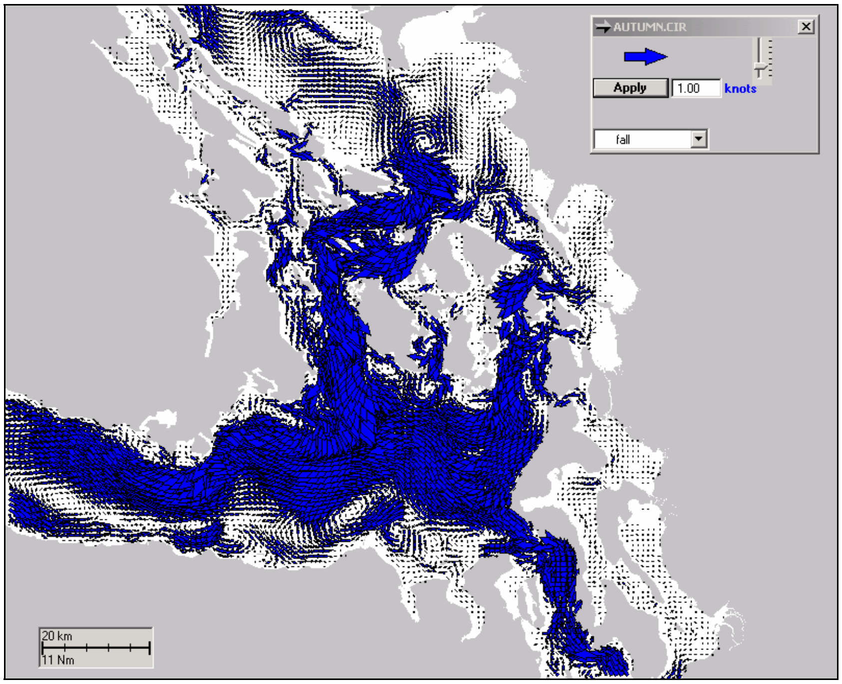


Figure XVIII.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction.

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

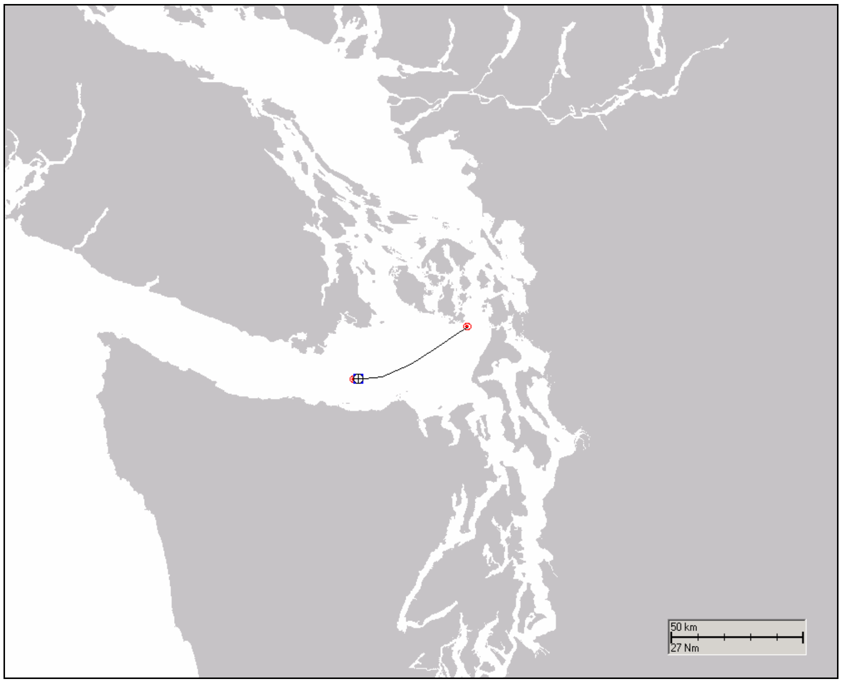


Figure XVIII.E-1 Varied range of spill site, from Port Angeles to the south end of Lopez Island.

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^{o} 57.76'W
Grid S edge	47^{o} 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.

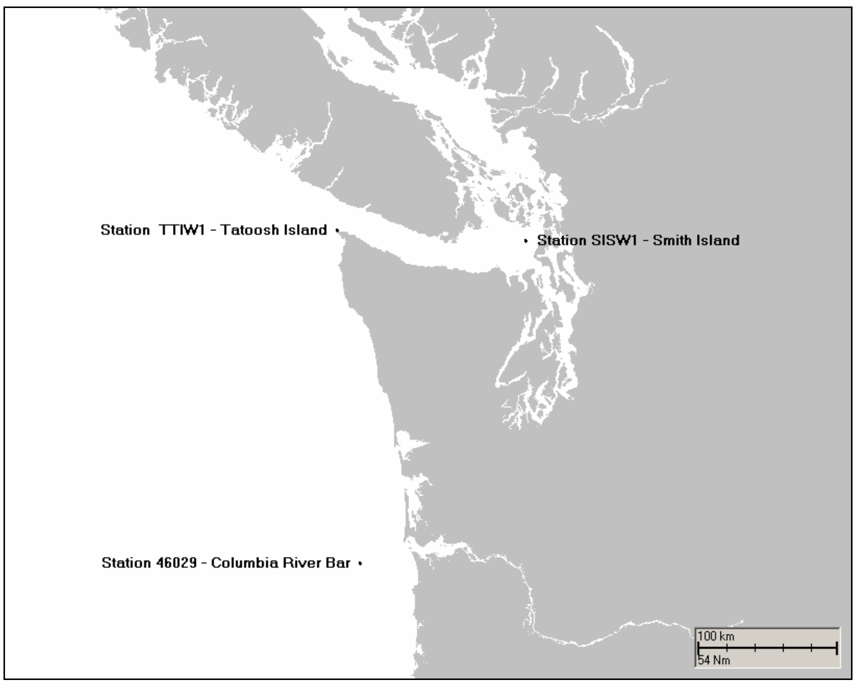


Figure XVIII.E-2 Wind Station Locations.

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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suàrez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

XIX.A. Introduction XIX-1
XIX.B. Maps of Exposure Probability, Time First Exposed, and Maximum Possible Contamination XIX-1
XIX.C. Rank Order Distributions for All Model Runs XIX-9
XIX.D. Shoreline Areas Exposed by Shore Type XIX-22
XIX.E. Exposure for Representative Individual Model Runs. XIX-26
XIX.F. Estimated Biological Impacts: Wildlife XIX-34
XIX.G. Estimated Biological Impacts: Fish and Invertebrates XIX-37
XIX.H. Estimated NRDA Costs: Habitat Restoration Costs XIX-40
XIX.I. Estimated NRDA Costs: Washington Compensation schedule XIX-45

List of Figures

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). XIX-2
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.... XIX-3
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). XIX-3
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.... XIX-4
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).... XIX-4
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).... XIX-5
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). ... XIX-5
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. .... XIX-6
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).... XIX-6
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. XIX-7
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).... XIX-7
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-8
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....XIX-9
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)....XIX-10
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)....XIX-10
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)....XIX-11
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)....XIX-11
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....XIX-12
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....XIX-13
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....XIX-13
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)....XIX-14
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 (%)....XIX-14
Figure XIX.C-12. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass mechanically removed. XIX-15
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....XIX-15
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)....XIX-16
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)....XIX-16

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). XIX-17
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). XIX-17
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). XIX-18
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. XIX-18
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. XIX-19
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. XIX-19
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). XIX-20
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 (%). XIX-20
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-21
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. XIX-26
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. XIX-27
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. XIX-27
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. XIX-28
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. XIX-28
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. XIX-29

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. XIX-29
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. XIX-30
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. XIX-30
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. XIX-31
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. XIX-31
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. XIX-32
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. XIX-32
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-33

List of Tables

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). XIX-22
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). XIX-23
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). XIX-23
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). . XIX-23
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). XIX-24
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). XIX-24
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). XIX-24
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). XIX-25
Table XIX.F-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost). XIX-35
Table XIX.F-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost). XIX-36
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). XIX-38
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). XIX-39
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. XIX-41
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. XIX-42

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. XIX-43
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$) for compensatory restoration. XIX-44
Table XIX.I-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. XIX-45
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. XIX-45

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 ≥ 1 ppb (1 mg/m^3)
- Subsurface oil (entrained in water): average over the water cell ≥ 10 ppb (10 mg/m^3)
- Sediment total hydrocarbons: average over the cell ≥ 0.0001 g/ m^2
- Sediment dissolved aromatic concentrations: average over the cell ≥ 0.0001 g/ m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10 cm, the assumed bioturbation zone)

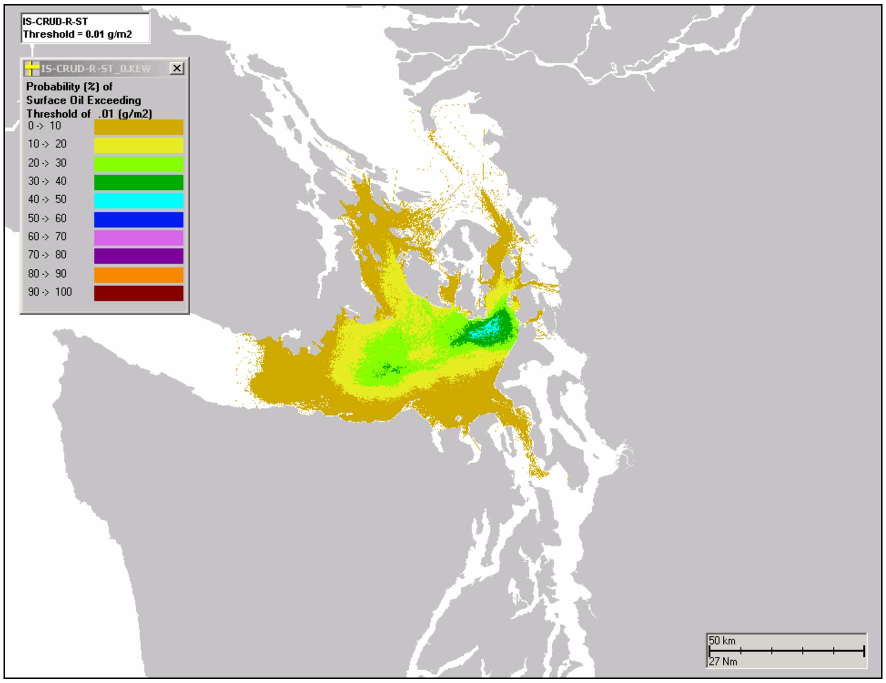


Figure XIX.B-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

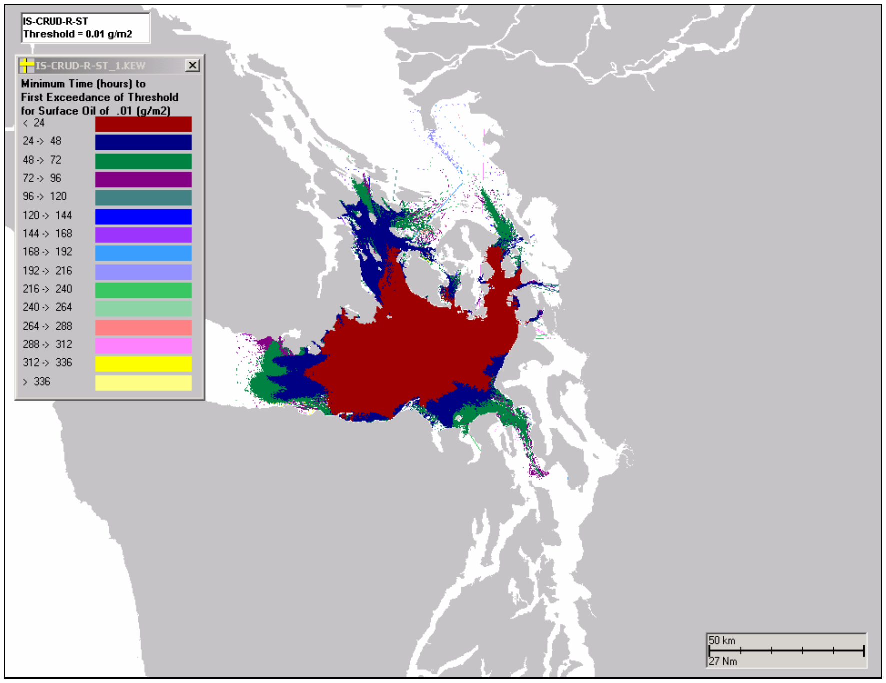


Figure XIX.B-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

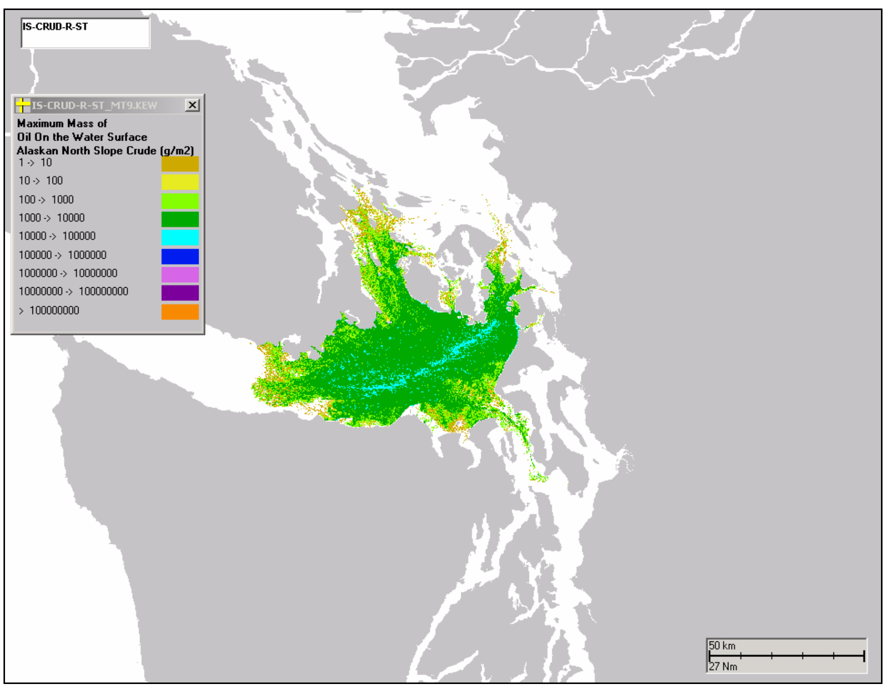


Figure XIX.B-3. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

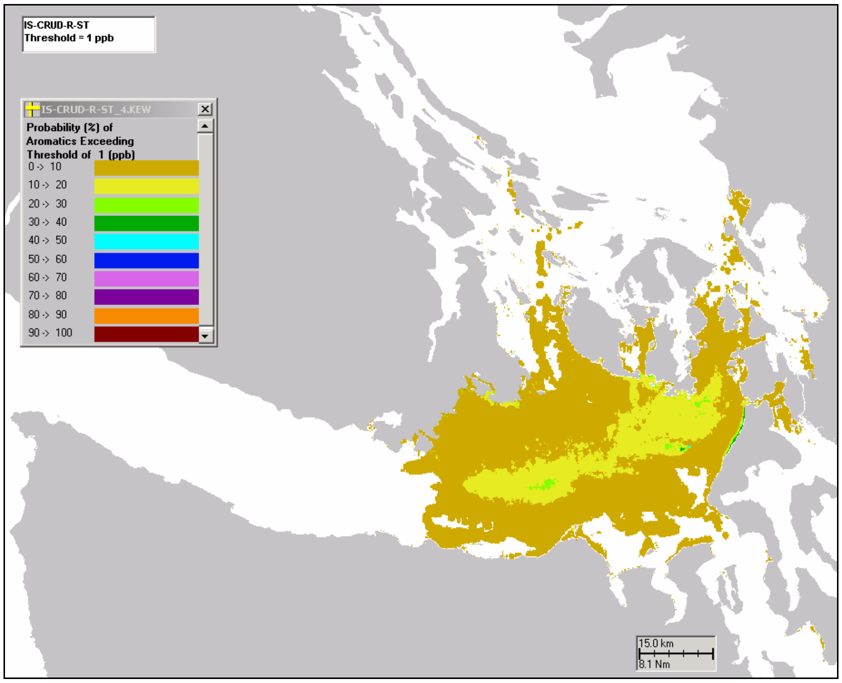


Figure XIX.B-4. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

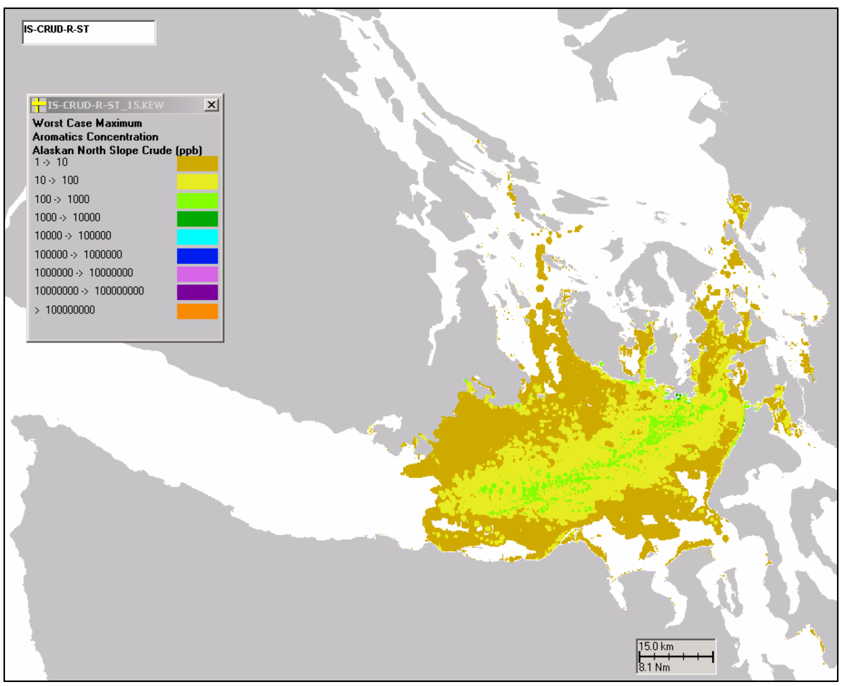


Figure XIX.B-5. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any 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).

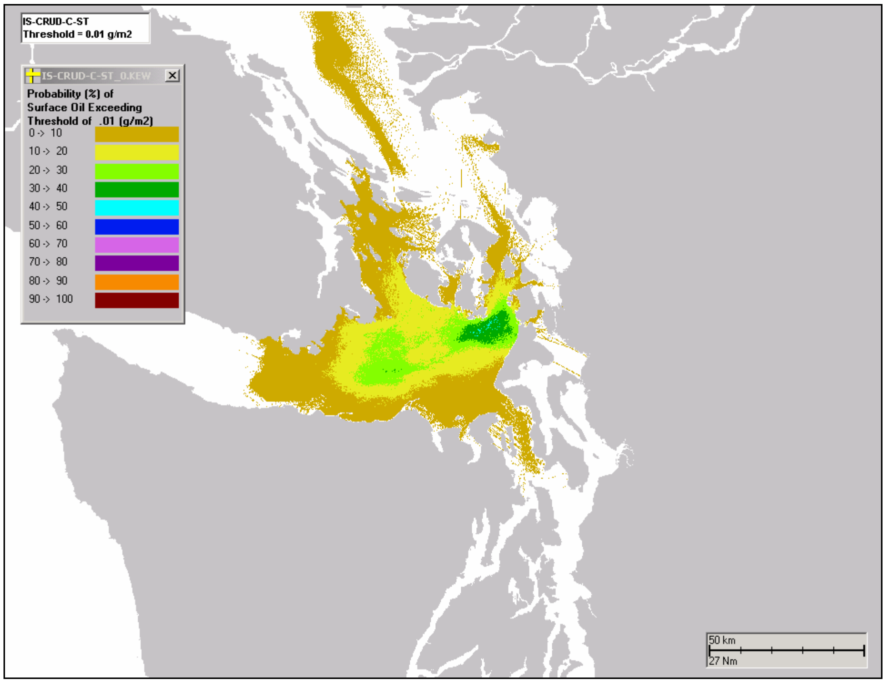


Figure XIX.B-7. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

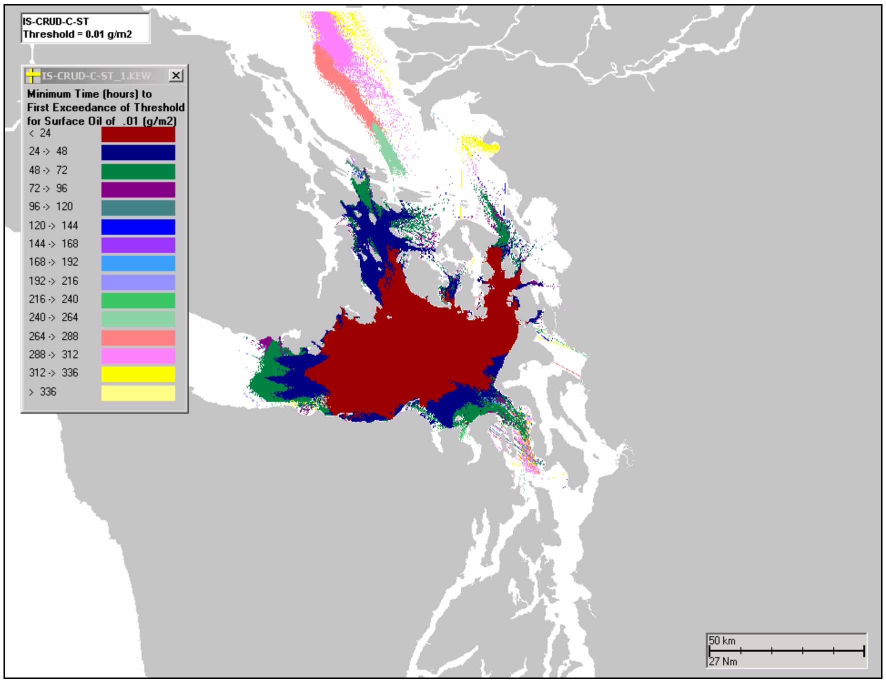


Figure XIX.B-8. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

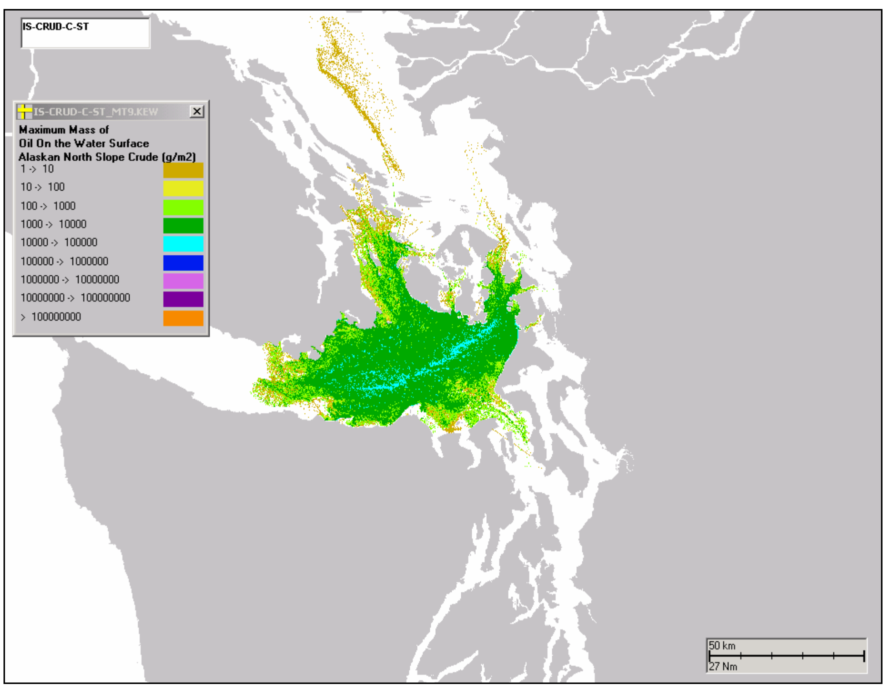


Figure XIX.B-9. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Peak water surface exposure to floating hydrocarbons (g/m^2) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum possible exposure under any conditions).

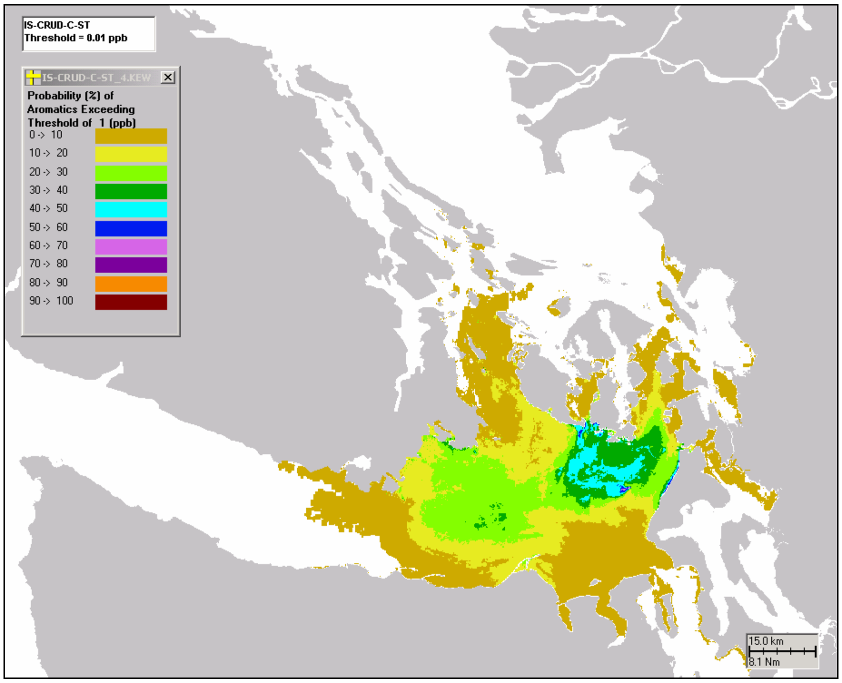


Figure XIX.B-10. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

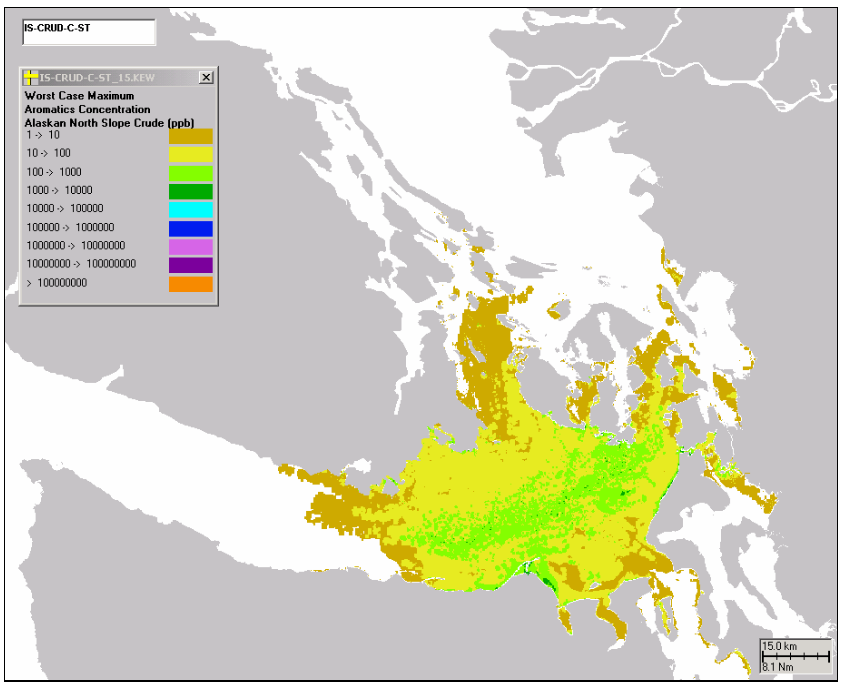


Figure XIX.B-11. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill under worst-case environmental conditions for each location (i.e., maximum 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).

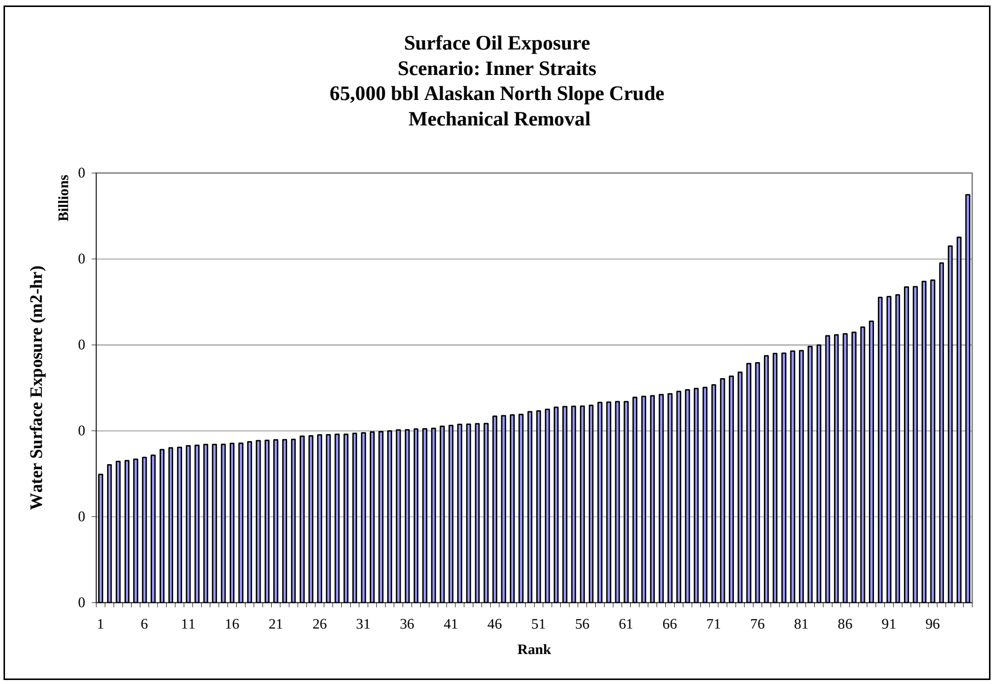


Figure XIX.C-1. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

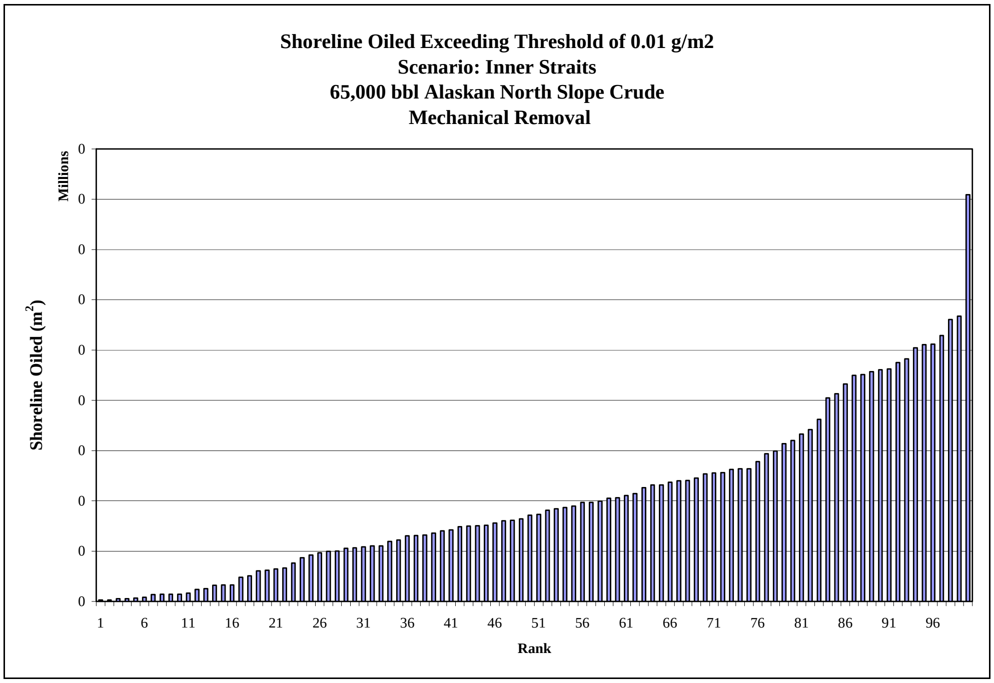


Figure XIX.C-2. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

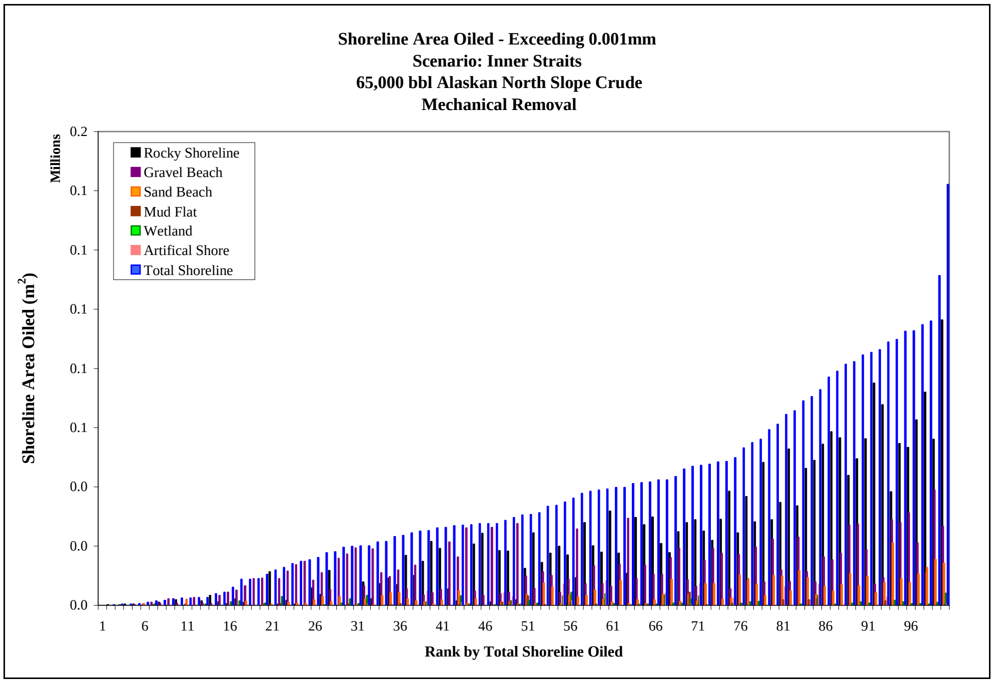


Figure XIX.C-3. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

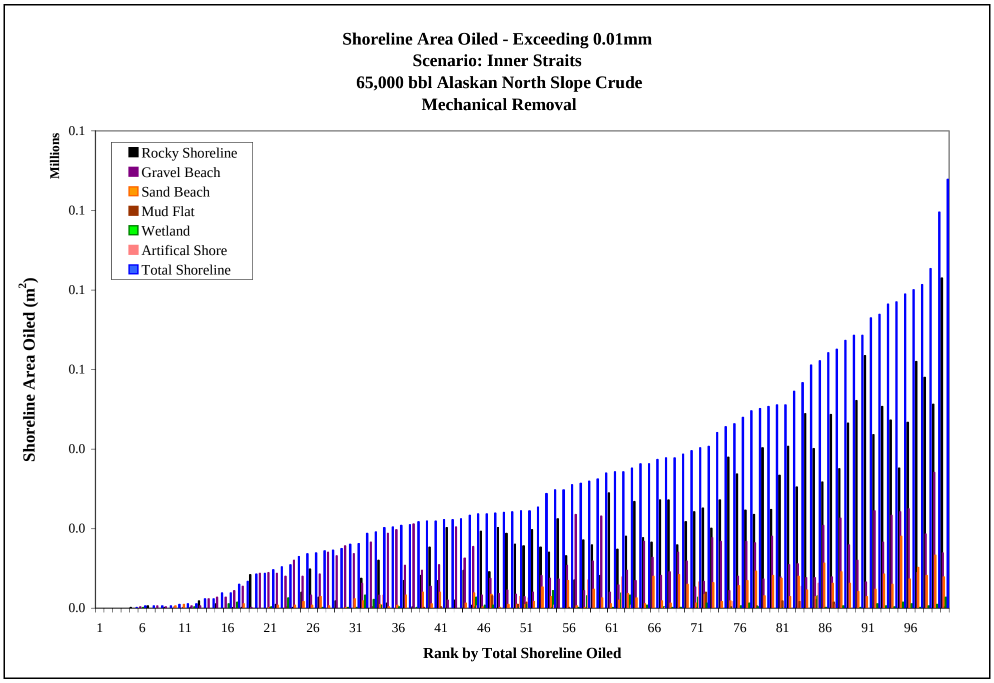


Figure XIX.C-4. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

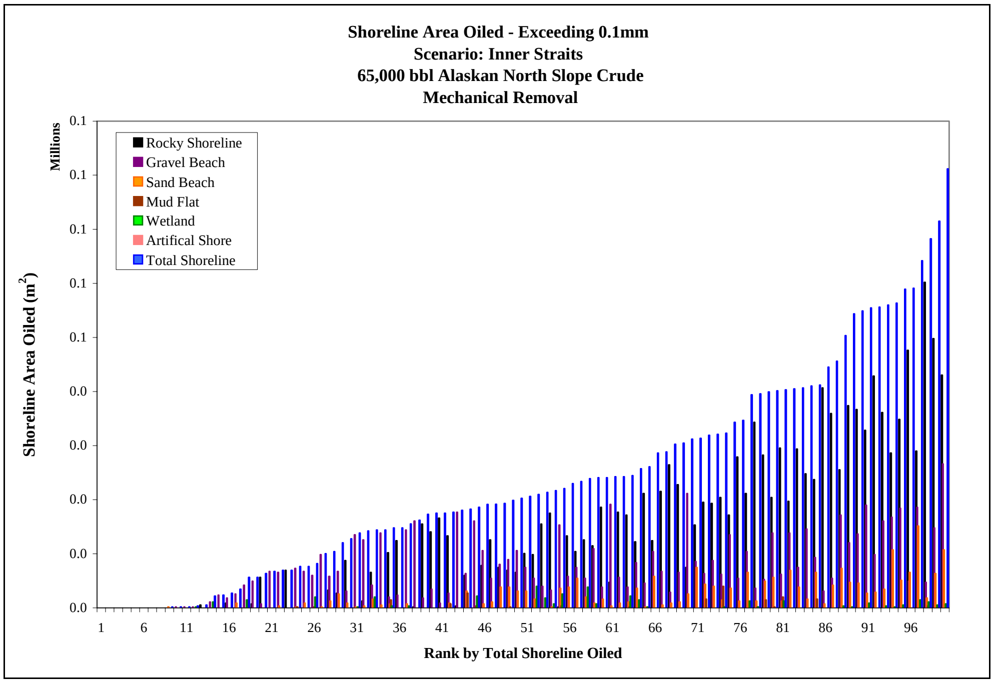


Figure XIX.C-5. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

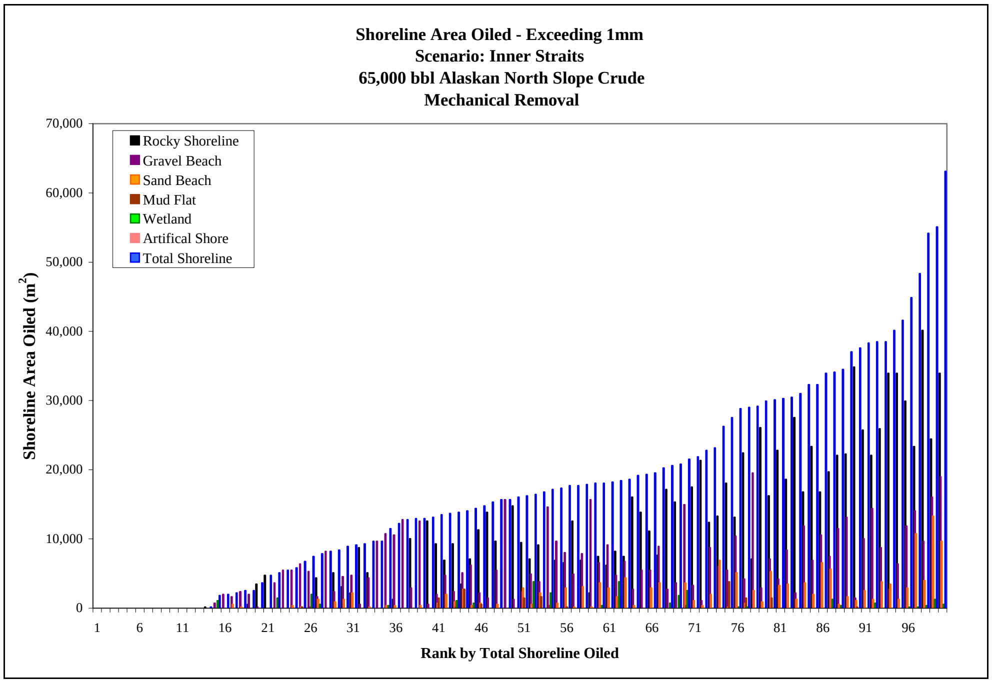


Figure XIX.C-6. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

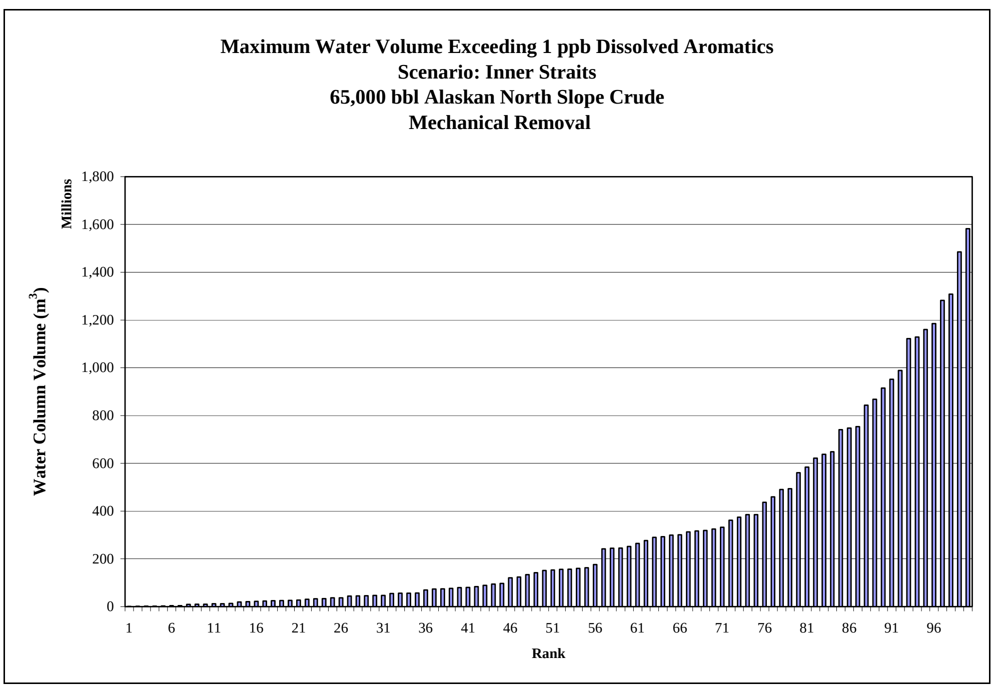


Figure XIX.C-7. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

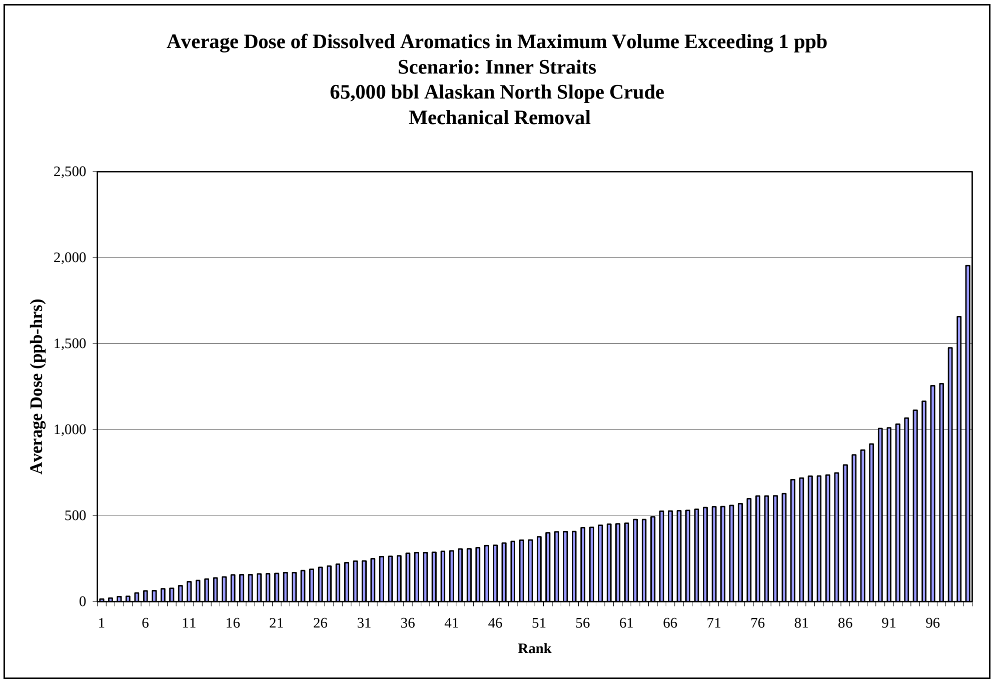


Figure XIX.C-8. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

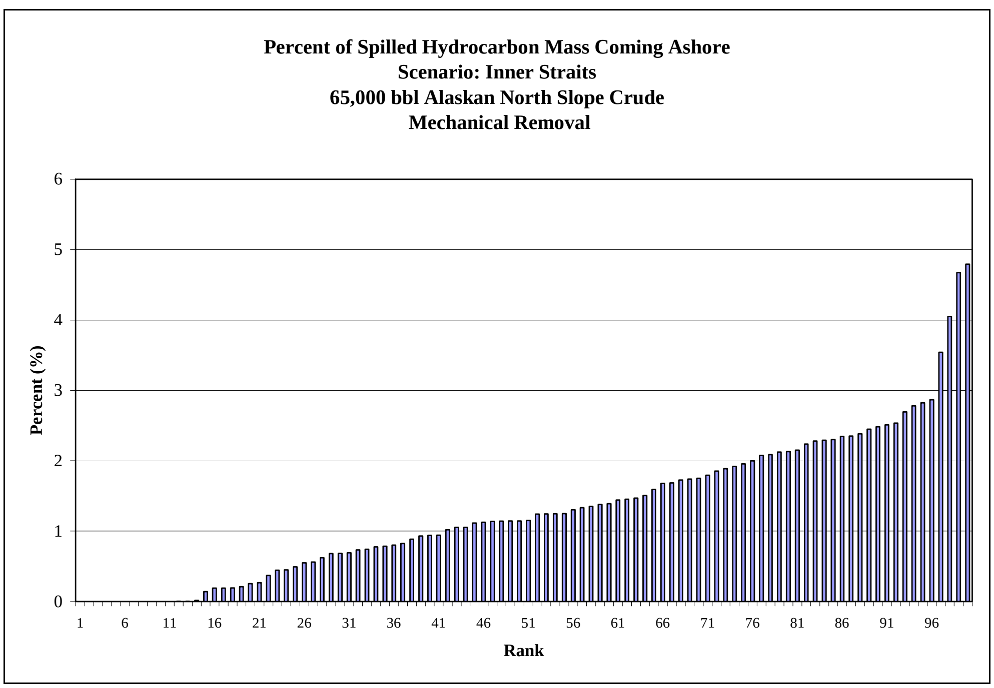


Figure XIX.C-9. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

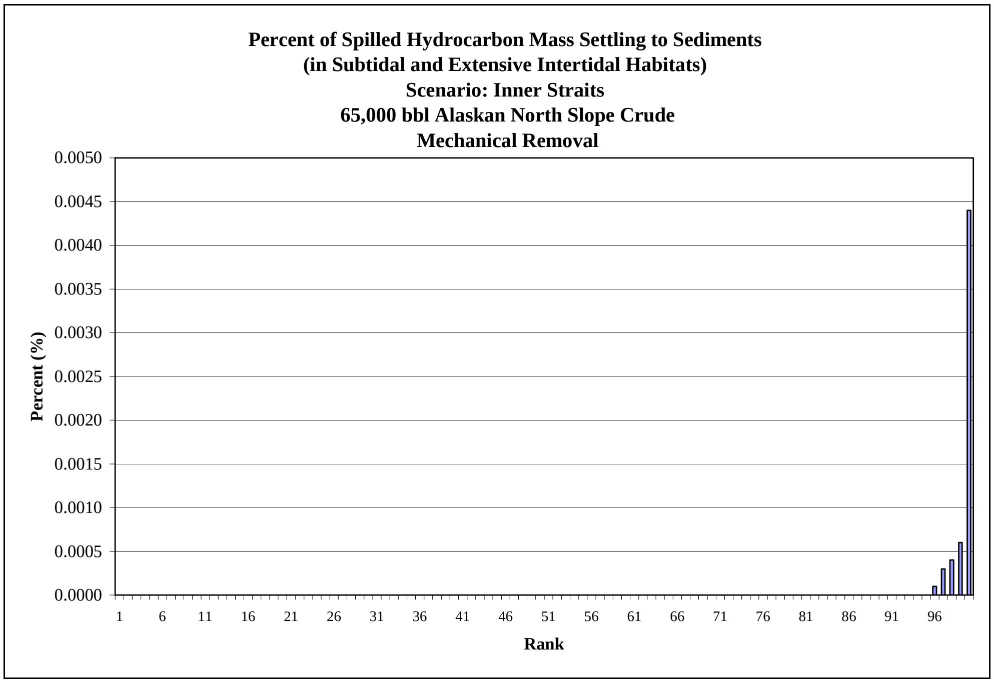


Figure XIX.C-10. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

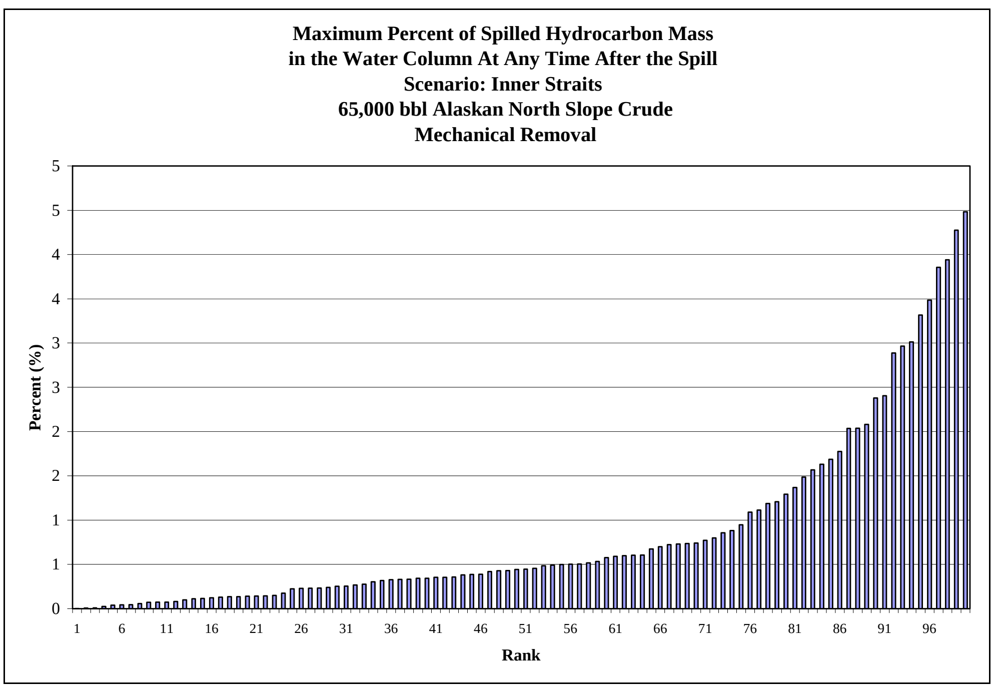


Figure XIX.C-11. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

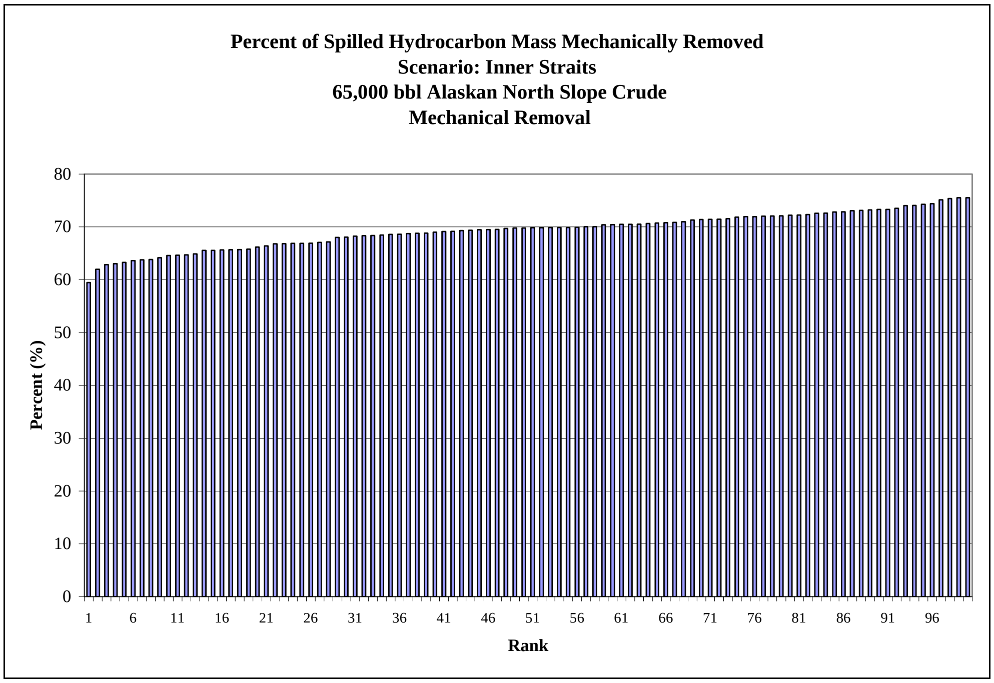


Figure XIX.C-12. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal: Percent of spilled hydrocarbon mass mechanically removed.

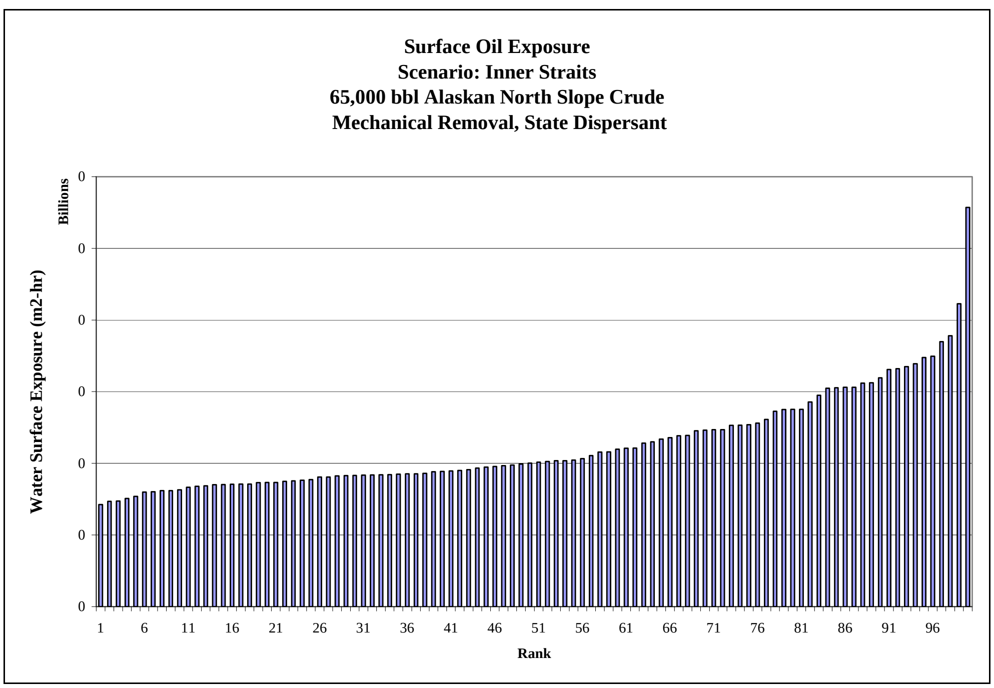


Figure XIX.C-13. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water surface exposed to floating hydrocarbons, as the sum of area covered by more than 0.01g/m^2 times duration of exposure.

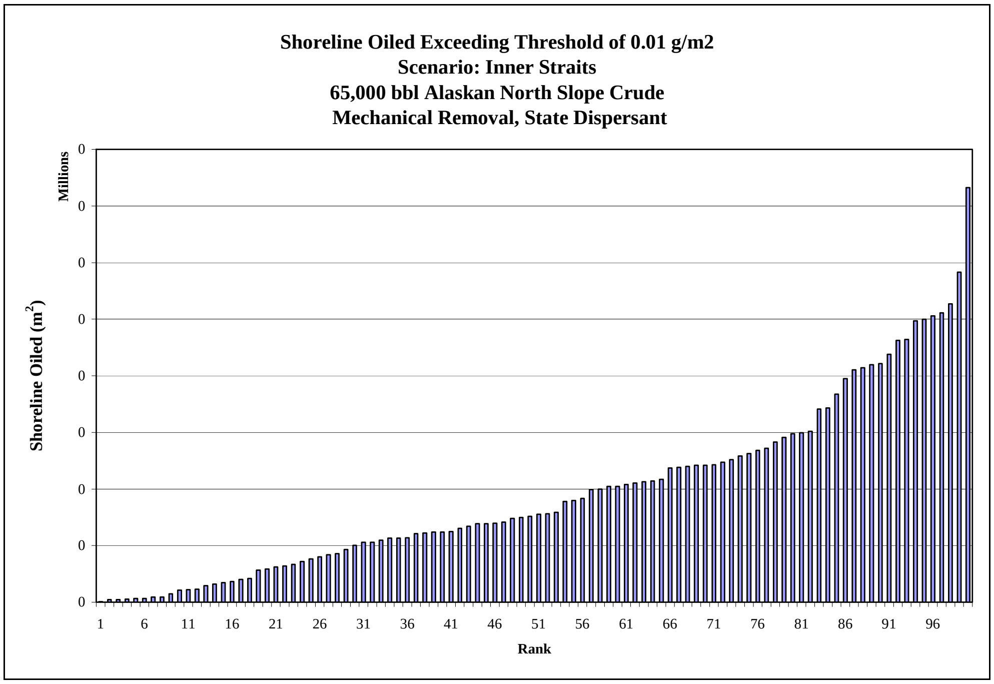


Figure XIX.C-14. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >0.01g/m^2 (about 0.00001mm thick).

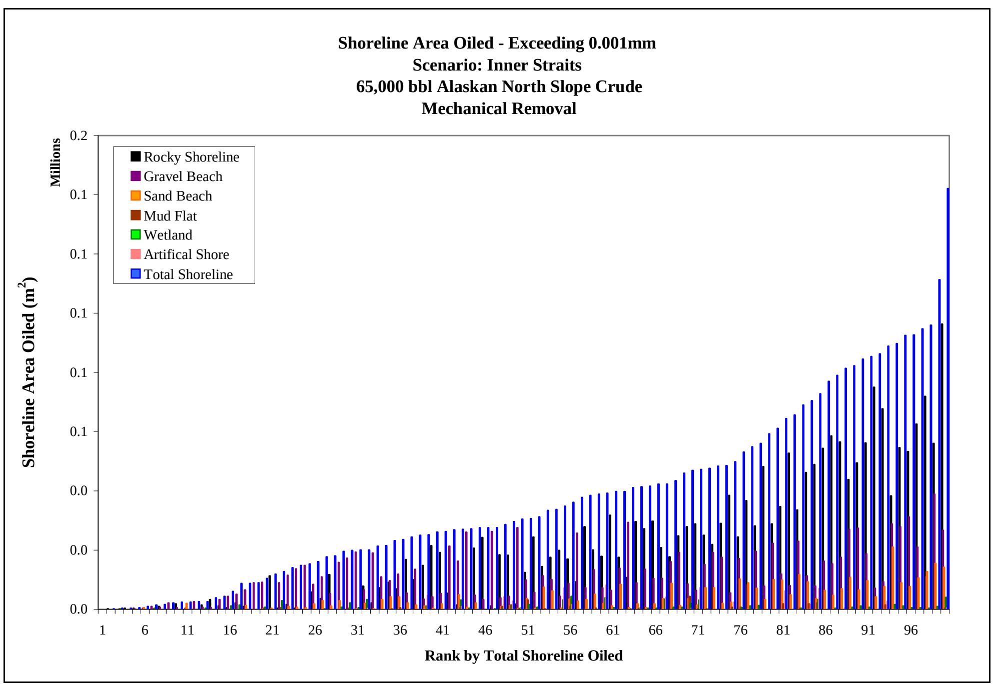


Figure XIX.C-15. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1g/m^2 (about 0.001mm thick).

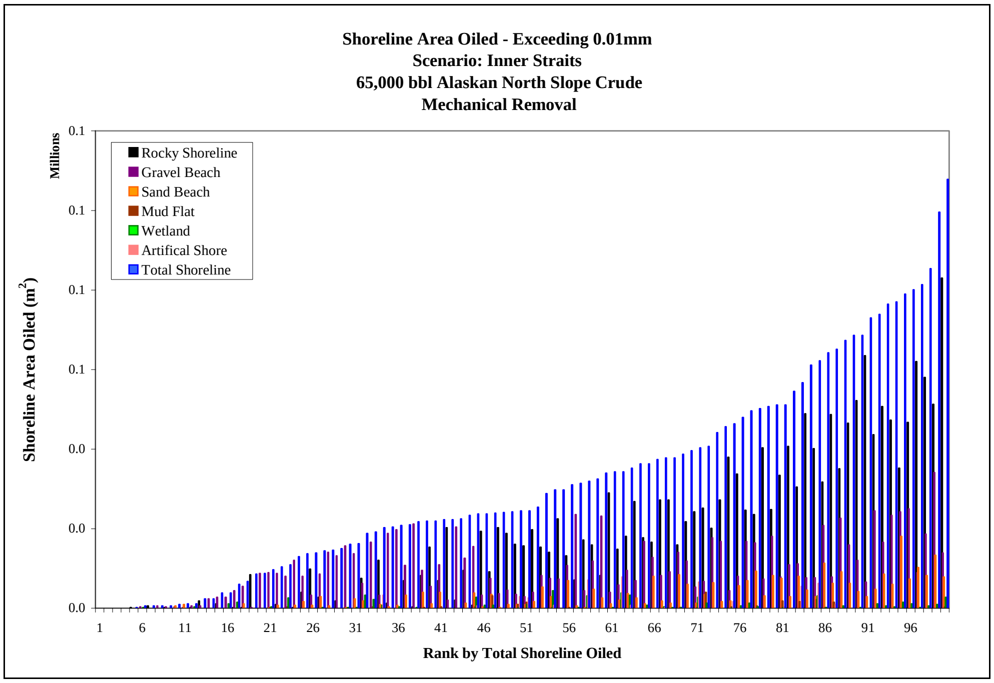


Figure XIX.C-16. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >10g/m^2 (about 0.01mm thick).

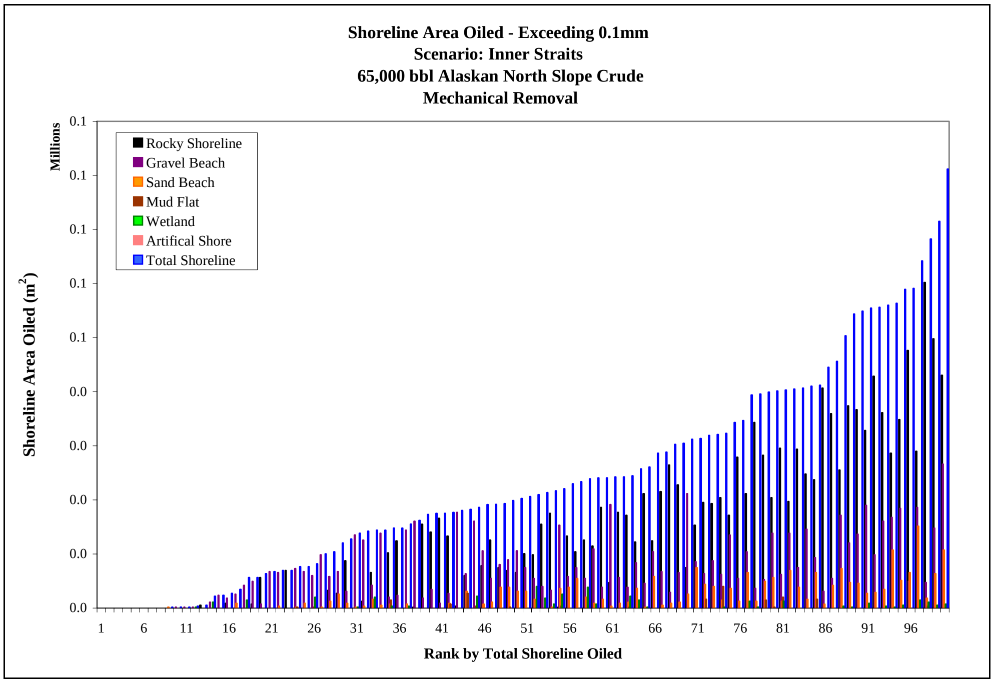


Figure XIX.C-17. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >100g/m^2 (about 0.1mm thick).

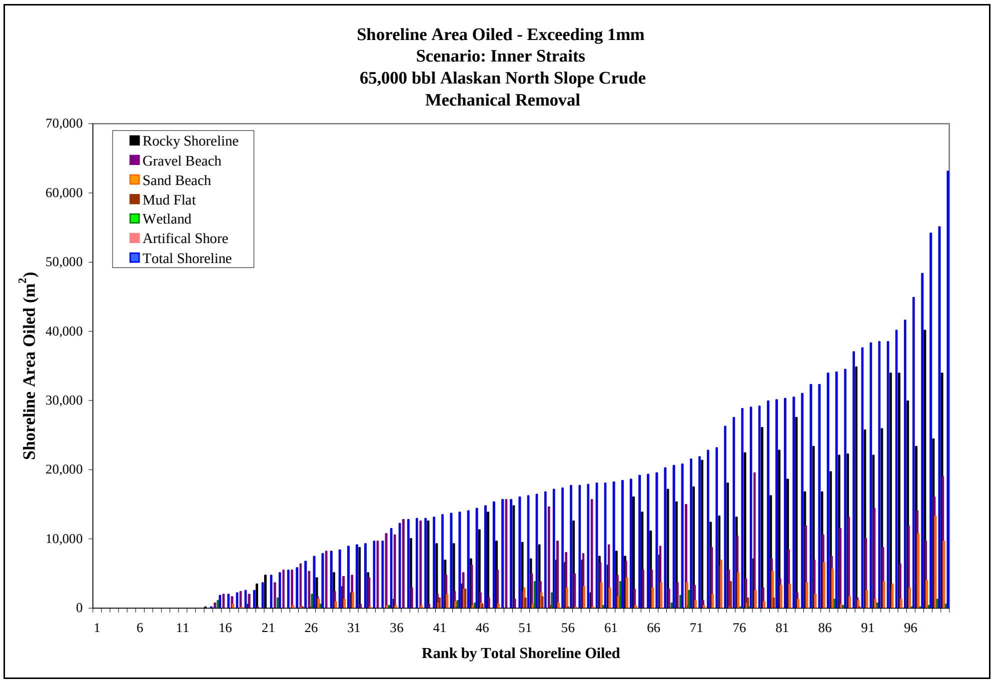


Figure XIX.C-18. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Shoreline area exposed to hydrocarbons of >1000g/m^2 (about 1mm thick).

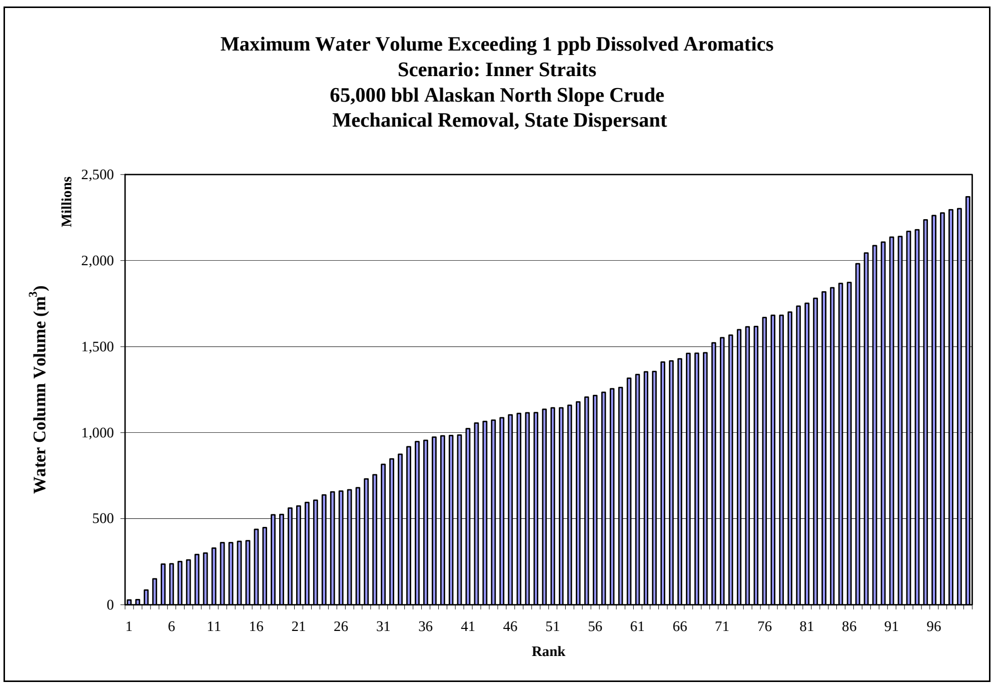


Figure XIX.C-19. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

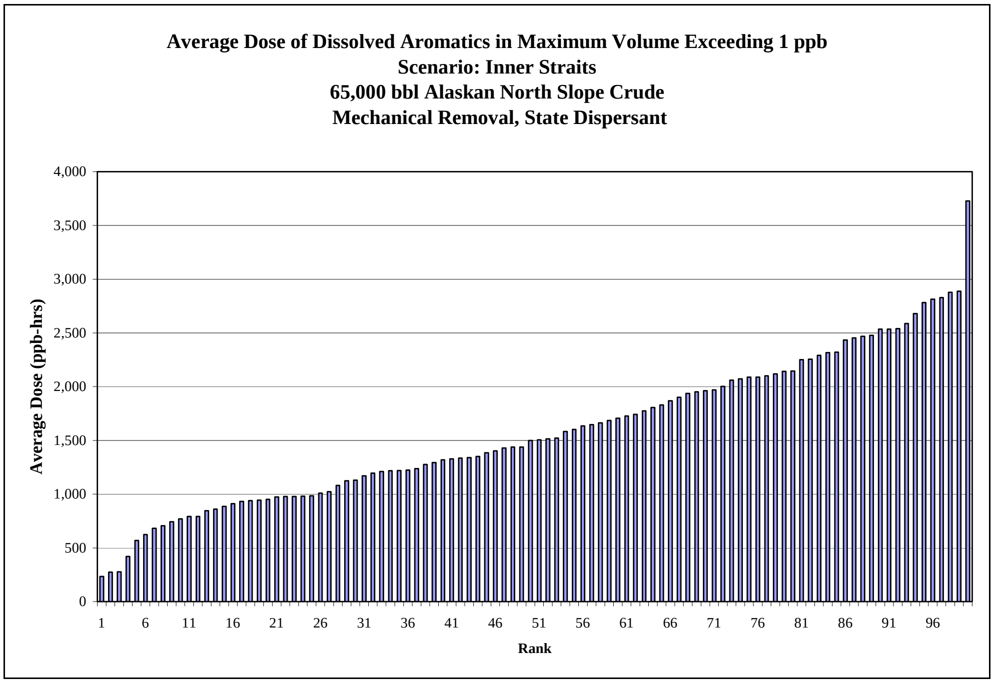


Figure XIX.C-20. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill.

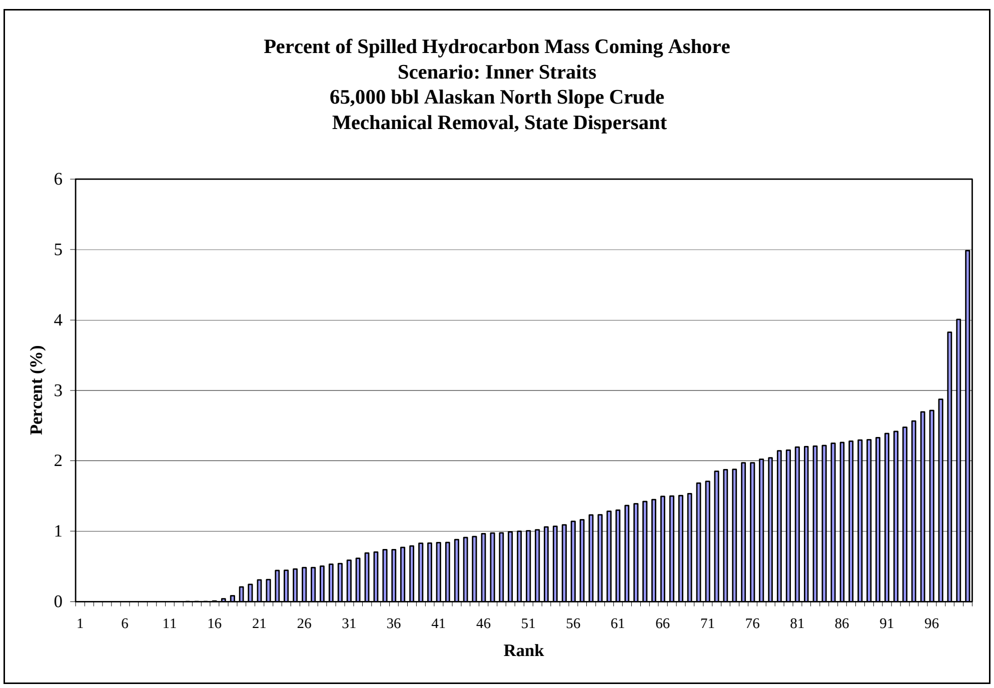


Figure XIX.C-21. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass surfacing and eventually going ashore.

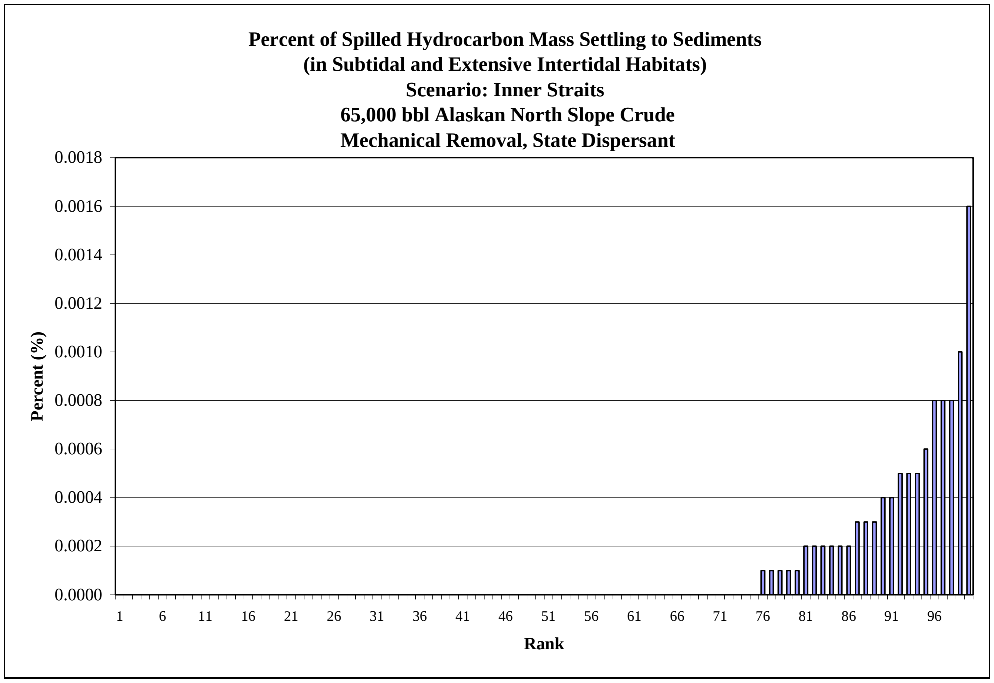


Figure XIX.C-22. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats).

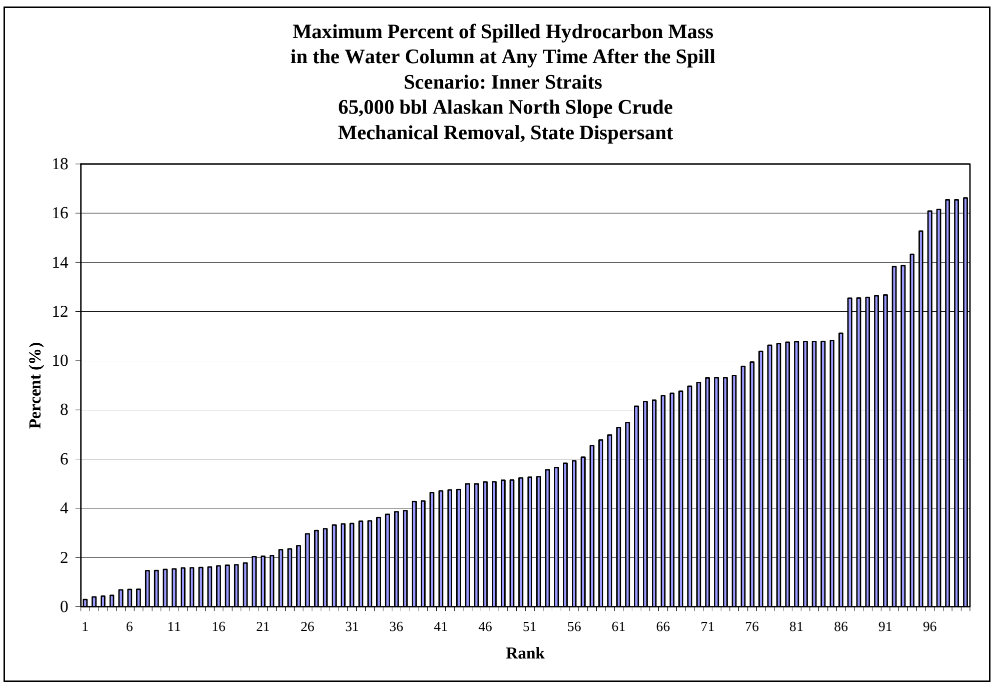


Figure XIX.C-23. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

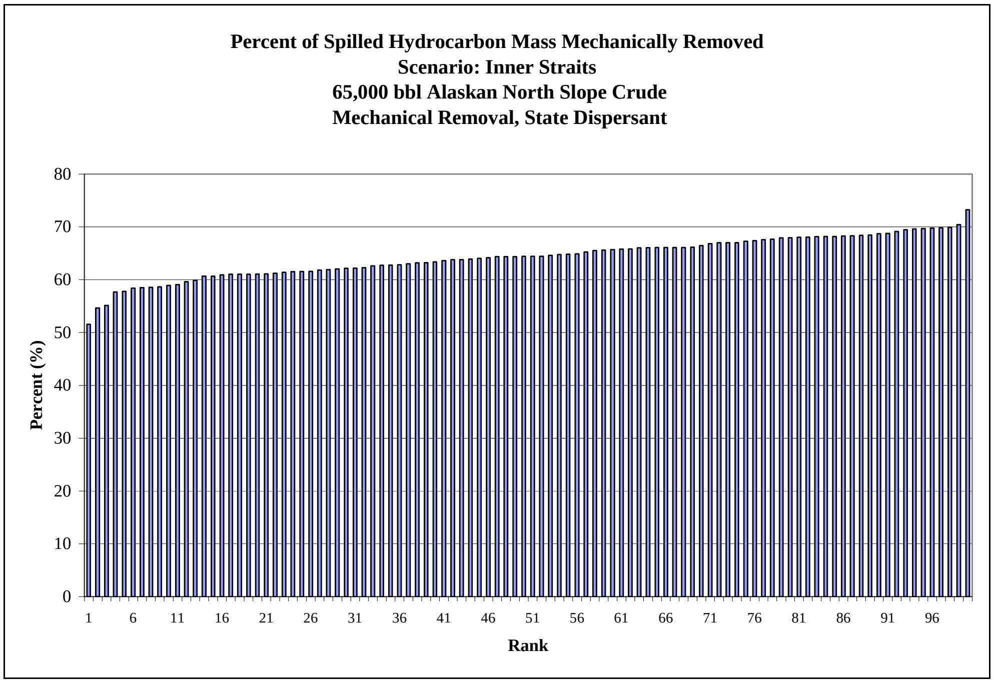


Figure XIX.C-24. Inner Straits/Puget Sound – Alaskan North Slope Crude, WA state mechanical removal and dispersant application: Percent of spilled hydrocarbon mass mechanically removed.

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

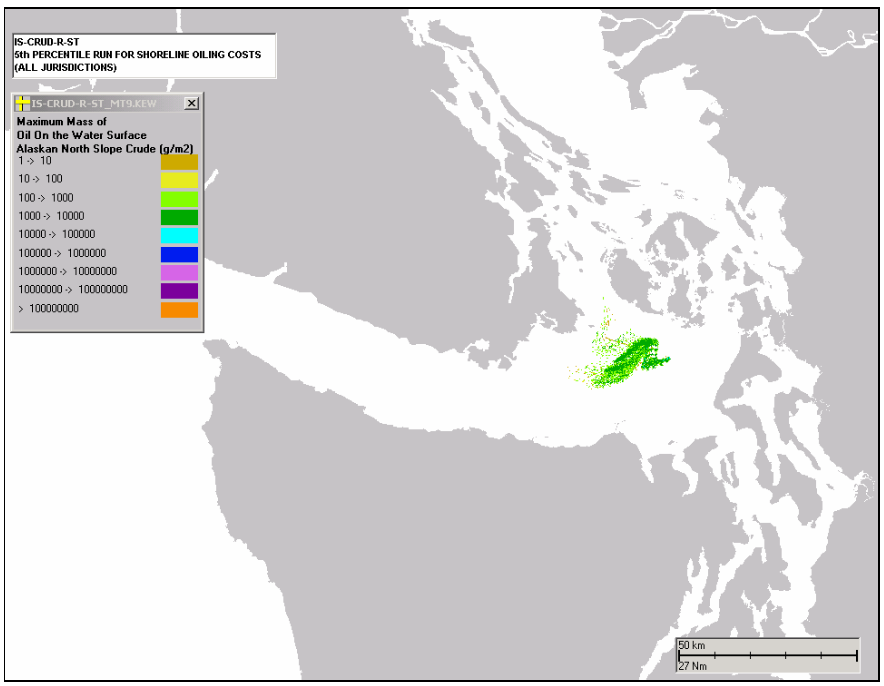


Figure XIX.E-1. Inner Straits/Puget Sound, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

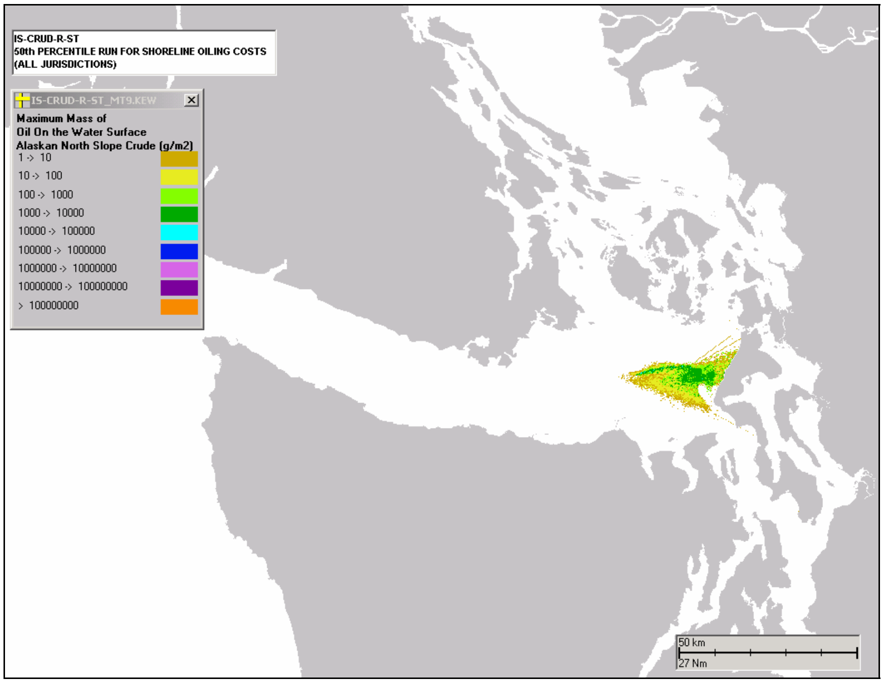


Figure XIX.E-2. Inner Straits/Puget Sound, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

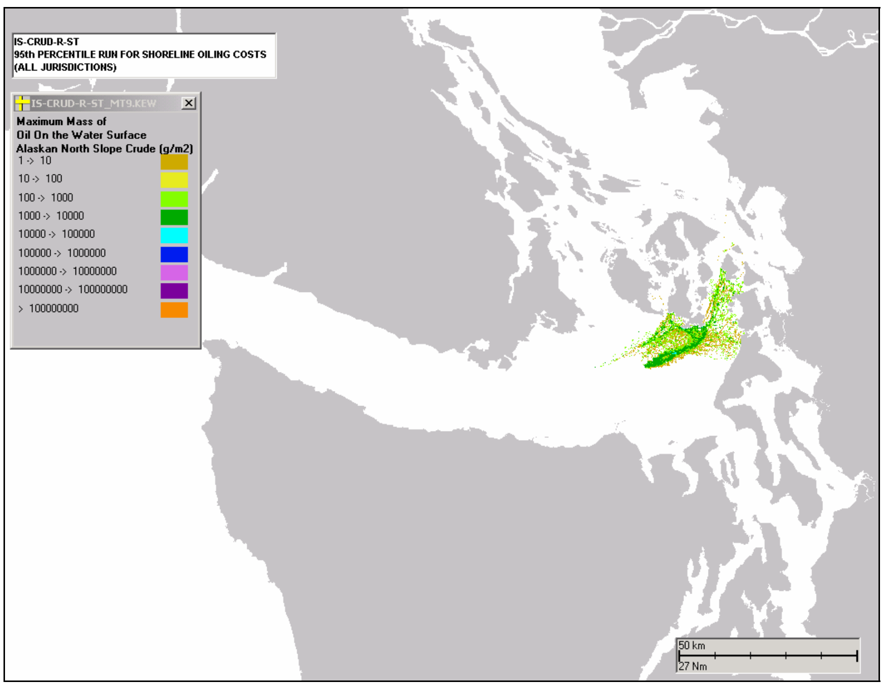


Figure XIX.E-3. Inner Straits/Puget Sound, WA state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

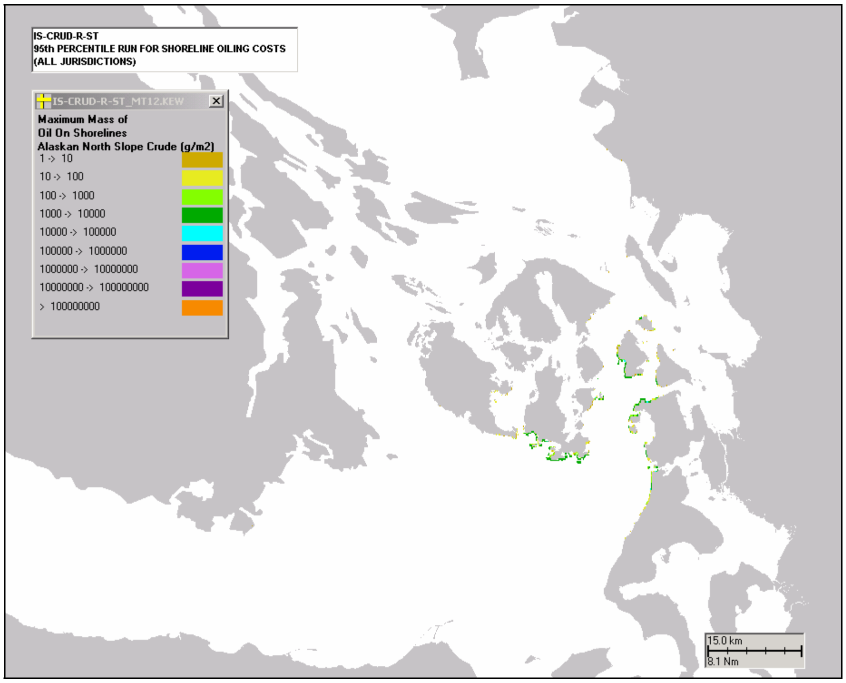


Figure XIX.E-4. Inner Straits/Puget Sound, WA state mechanical removal: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

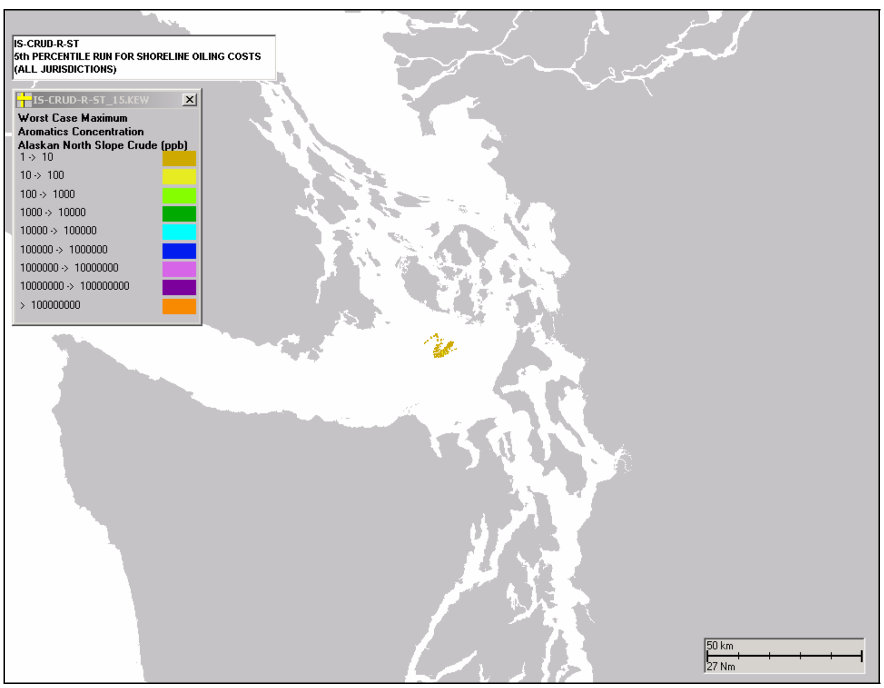


Figure XIX.E-5. Inner Straits/Puget Sound, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

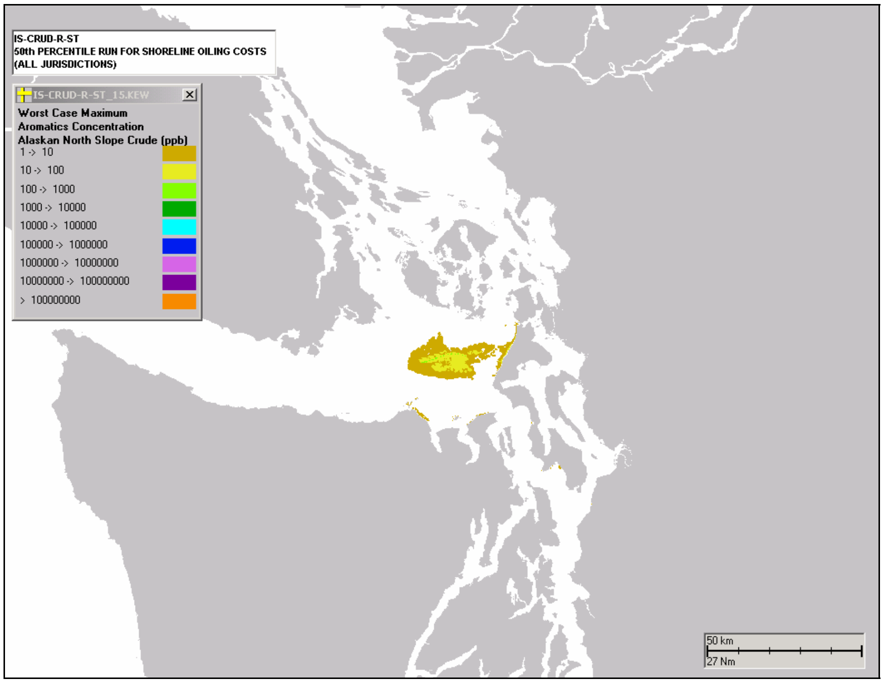


Figure XIX.E-6. Inner Straits/Puget Sound, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

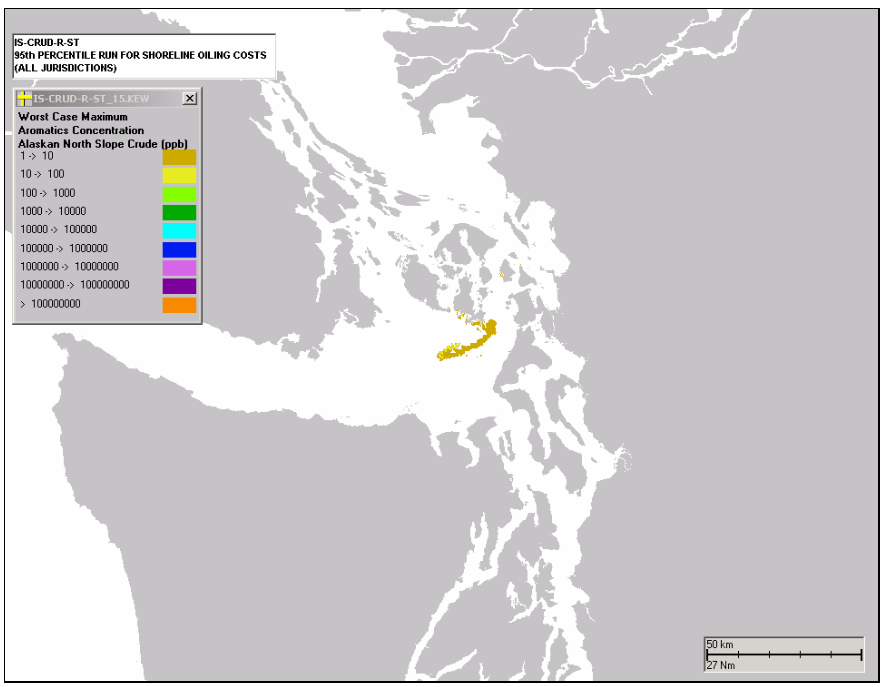


Figure XIX.E-7. Inner Straits/Puget Sound, WA state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

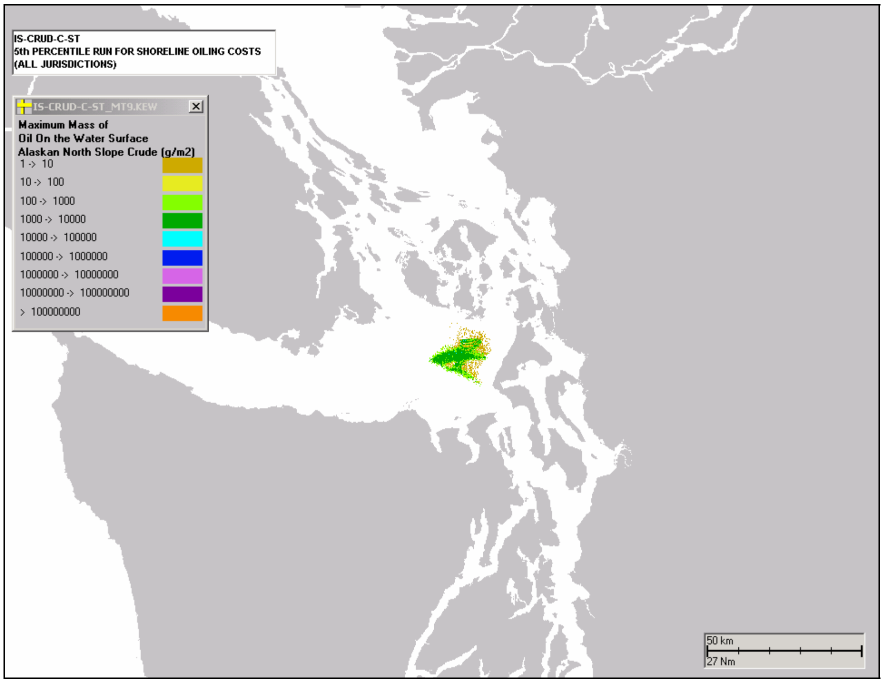


Figure XIX.E-8. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

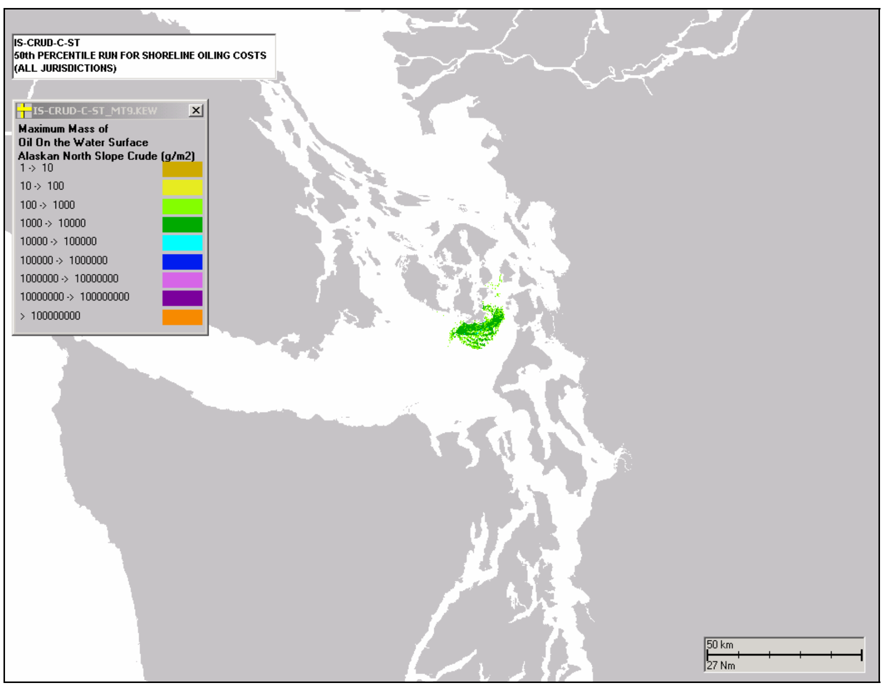


Figure XIX.E-9. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

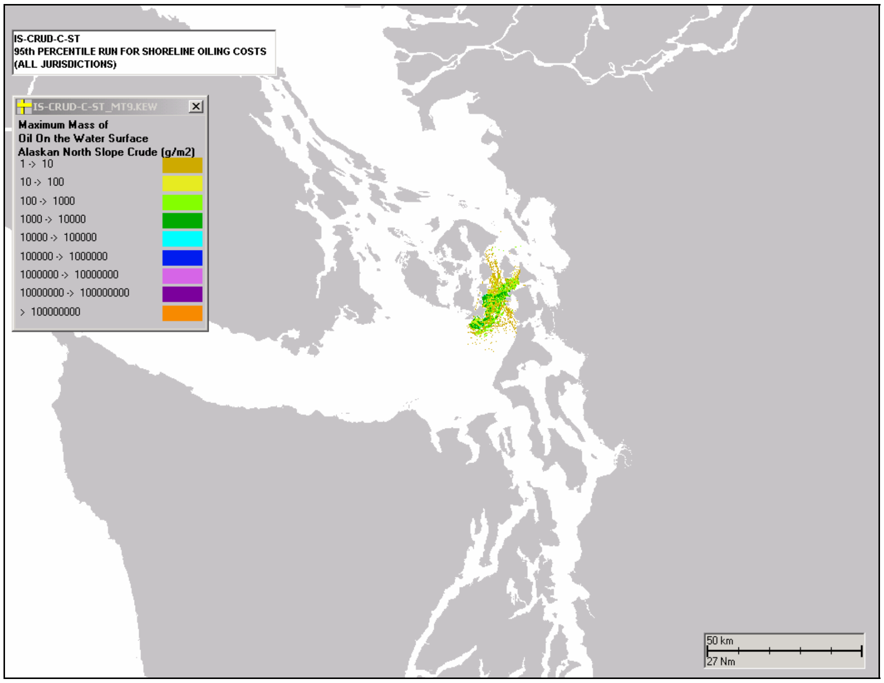


Figure XIX.E-10. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

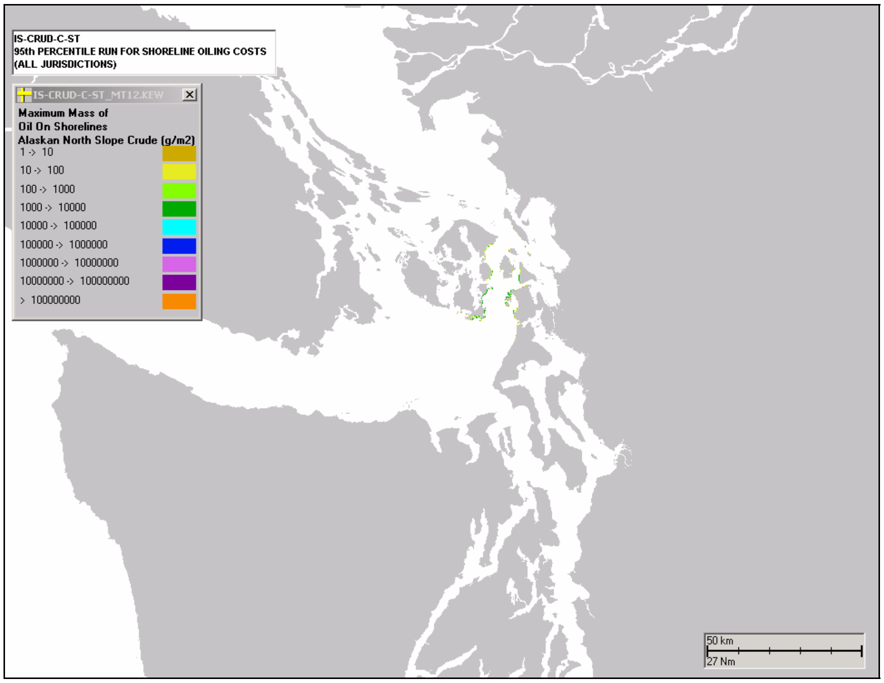


Figure XIX.E-11. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Shoreline exposure to hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

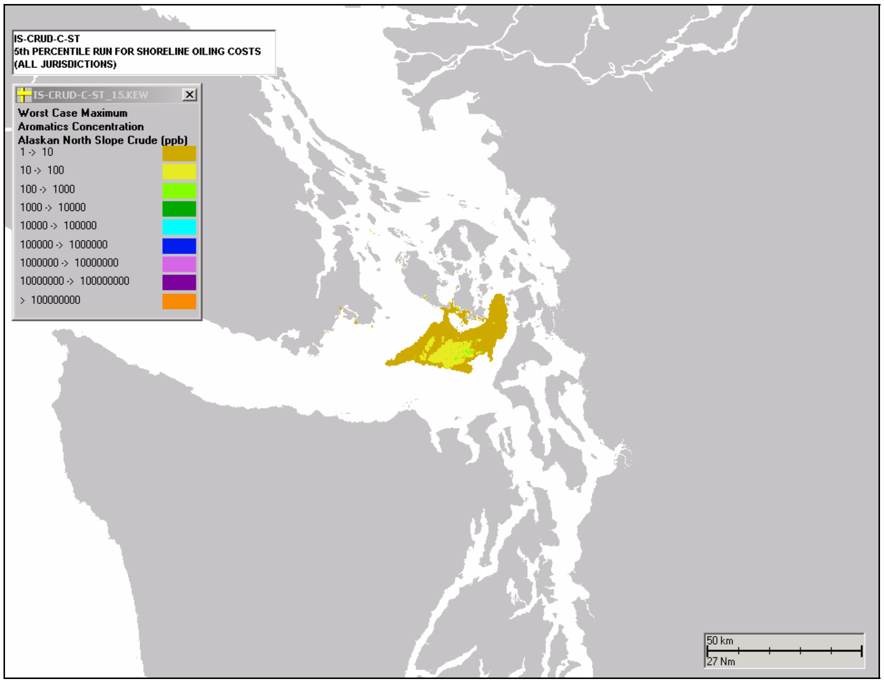


Figure XIX.E-12. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

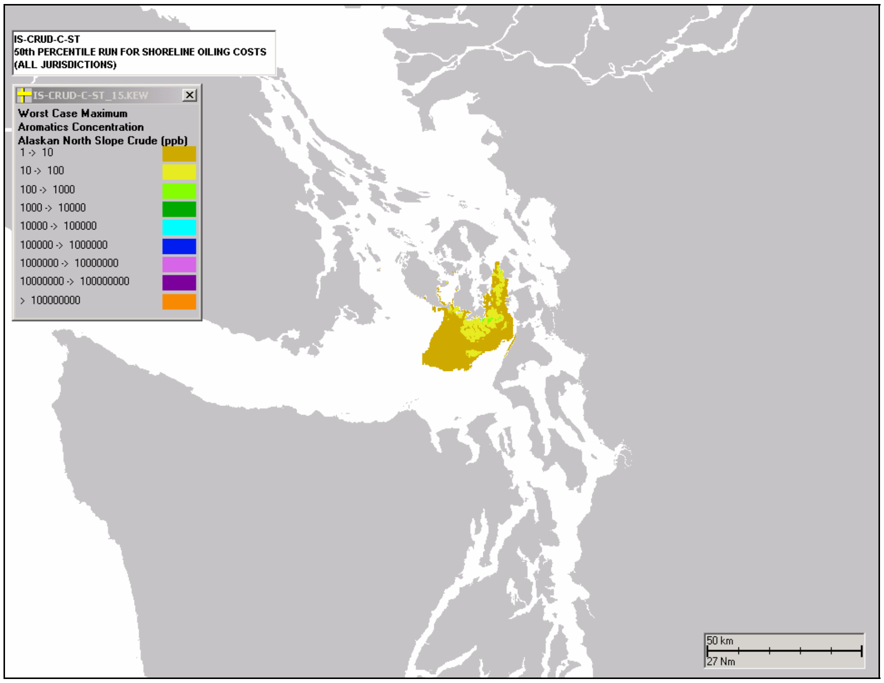


Figure XIX.E-13. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

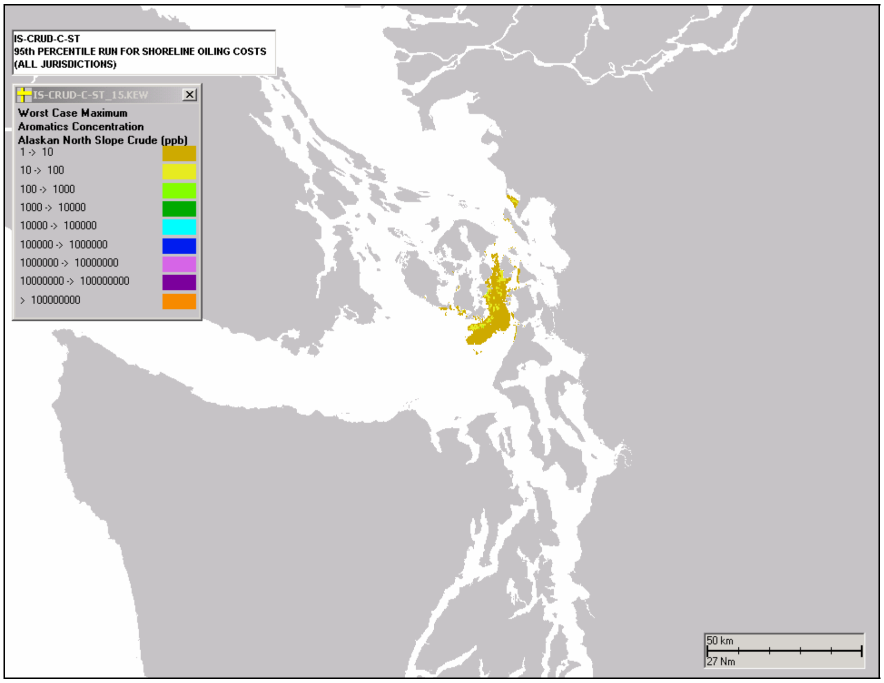


Figure XIX.E-14. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

XIX.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated for the 5^{th}, 50^{th} and 95^{th} 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 5^{th} to 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} or 95^{th} 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 5^{th}, 50^{th} or 95^{th} percentile result for that impact index (columns labeled 5th Percentile, 50th Percentile, and 95th Percentile), not the 5^{th}, 50^{th} or 95^{th} *runs based on shore costs*. The results for 5^{th}, 50^{th} or 95^{th} *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 5^{th}, 50^{th} or 95^{th} *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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier,
Subbayya Sankaranarayanan and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@appsci.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
November 2005

Table of Contents

XX.A. Introduction 1
XX.B. Exposure for Individual Model Runs 3
XX.B.1. No Removal, Scenario IS-Crud-N 3
XX.B.2. State Mechanical Removal, Scenario IS-Crud-R-ST 7
XX.B.3. Federal Mechanical Removal, Scenario IS-Crud-R-Fed 11
XX.B.4. 3rd Alternative Mechanical Removal, Scenario IS-Crud-R-3 15
XX.B.5. State Mechanical Removal and dispersant, Scenario IS-Crud-C-ST 19
XX.B.6. Federal Mechanical Removal and dispersant, Scenario IS-Crud-C-Fed 23
XX.B.7. 3rd Alternative Mechanical Removal and dispersant, Scenario IS-Crud-C-3. 27
XX.B.8. Oil Fate Over Time 31
XX.C. Estimated Biological Impacts: Wildlife 61
XX.D. Estimated Biological Impacts: Fish and Invertebrates 68
XX.E. Estimated NRDA Costs: Habitat Restoration Costs 75
XX.F. Estimated NRDA Costs: Washington Compensation schedule 83

List of Figures

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. 3

Figure XX.B.1-2. Inner Straits/Puget Sound, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50^{th} percentile run based on shoreline costs. 4

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. 4

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. 5

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 50^{th} percentile run based on shoreline costs. 5

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. 6

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. 7

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 50^{th} percentile run based on shoreline costs. 8

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. 8

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. 9

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 50^{th} percentile run based on shoreline costs. 9

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. 10

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. 11

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 50^{th} percentile run based on shoreline costs. 12

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. 12
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. 13
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. 13
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. 14
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. 15
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. 16
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. 16
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. 17
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. 17
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. 18
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. 19
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. 20
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. 20
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. 21

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 50^{th} percentile run based on shoreline costs. 21
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. 22
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........ 23
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 50^{th} percentile run based on shoreline costs........ 24
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........ 24
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. 25
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 50^{th} percentile run based on shoreline costs. 25
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. 26
Figure XX.B.7-1. Inner Straits/Puget Sound, crude oil, 3^{rd} alternative mechanical removal, dispersant: Inner Straits/Puget Sound, crude oil, 3^{rd} alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs........ 27
Figure XX.B.7-2. Inner Straits/Puget Sound, crude oil, 3^{rd} alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50^{th} percentile run based on shoreline costs........ 28
Figure XX.B.7-3. Inner Straits/Puget Sound, crude oil, 3^{rd} alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs........ 28
Figure XX.B.7-4. Inner Straits/Puget Sound, crude oil, 3^{rd} 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........ 29
Figure XX.B.7-5. Inner Straits/Puget Sound, crude oil, 3^{rd} 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. 29
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. 30
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)... 32
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). 32
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). 33
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). 33
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)..................................... 34
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)..................................... 34
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)..................................... 35
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)... 35
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). 36
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). 36
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). 37
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)................................... 37
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)................................... 38

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). 38
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).. 39
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). 39
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). 40
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). 40
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).................................. 41
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).................................. 41
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). 42
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. 43
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. 44
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. 45
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. 46
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. 47
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. 48
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. 49
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. 50
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. 51
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. 52
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. 53
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. 54
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. 55
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. 56
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. 57
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. 58
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. 59

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. 60

List of Tables

Table IXX.C-1 Inner Straits/Puget Sound, no removal: Wildlife injury (as numbers lost). 61
Table IXX.C-2 Inner Straits/Puget Sound, WA state mechanical removal: Wildlife injury (as numbers lost). 62
Table IXX.C-3 Inner Straits/Puget Sound, federal mechanical removal: Wildlife injury (as numbers lost). 63
Table IXX.C-4 Inner Straits/Puget Sound, 3rd alternative mechanical removal: Wildlife injury (as numbers lost). 64
Table IXX.C-5 Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Wildlife injury (as numbers lost). 65
Table IXX.C-6 Inner Straits/Puget Sound, federal mechanical removal and dispersant application: Wildlife injury (as numbers lost). 66
Table IXX.C-7 Inner Straits/Puget Sound, 3rd alternative mechanical removal and dispersant application: Wildlife injury (as numbers lost). 67
Table XX.D-1. Inner Straits/Puget Sound, no removal: Fish and invertebrate injury (as biomass lost in kg). 68
Table XX.D-2. Inner Straits/Puget Sound, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 69
Table XX.D-3. Inner Straits/Puget Sound, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 70
Table XX.D-4. Inner Straits/Puget Sound, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 71
Table XX.D-5. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg). 72
Table XX.D-6. Inner Straits/Puget Sound, federal mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg). 73
Table XX.D-7. Inner Straits/Puget Sound, 3rd alternative mechanical removal and dispersant application: Fish and invertebrate injury (as biomass lost in kg). 74
Table XX.E-1. Inner Straits/Puget Sound, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 76
Table XX.E-2. Inner Straits/Puget Sound, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 76
Table XX.E-3. Inner Straits/Puget Sound, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 77
Table XX.E-4. Inner Straits/Puget Sound, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 77
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. 78
Table XX.E-6. Inner Straits/Puget Sound, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 78
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. 79

Table XX.E-8. Inner Straits/Puget Sound, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 79
Table XX.E-9. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.. 80
Table XX.E-10. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.... 80
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.. 81
Table XX.E-12. Inner Straits/Puget Sound, federal mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration.... 81
Table XX.E-13. Inner Straits/Puget Sound, 3rd alternative mechanical removal and dispersant application: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.. 82
Table XX.E-14. Inner Straits/Puget Sound, 3rd alternative mechanical removal and dispersant application: Area and costs (in millions of 2004$) for compensatory restoration. 82
Table XX.F-1. Inner Straits/Puget Sound, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 83
Table XX.F-2. Inner Straits/Puget Sound, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule............ 83
Table XX.F-3. Inner Straits/Puget Sound, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule............ 83
Table XX.F-4. Inner Straits/Puget Sound, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 84
Table XX.F-5. Inner Straits/Puget Sound, WA state mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 84
Table XX.F-6. Inner Straits/Puget Sound, federal mechanical removal and dispersant application: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 84
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.. 84

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.

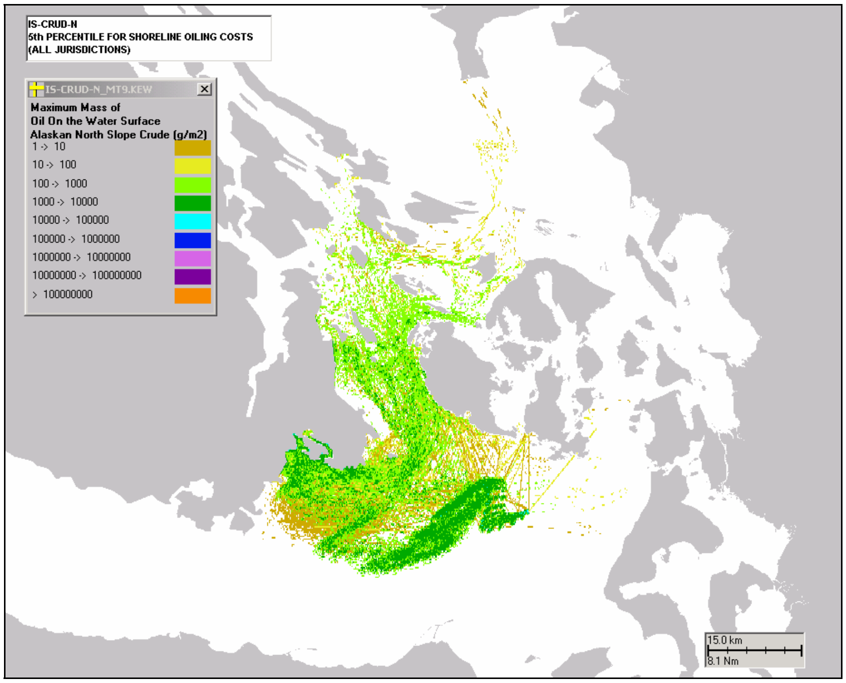


Figure XX.B.1-1. Inner Straits/Puget Sound, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

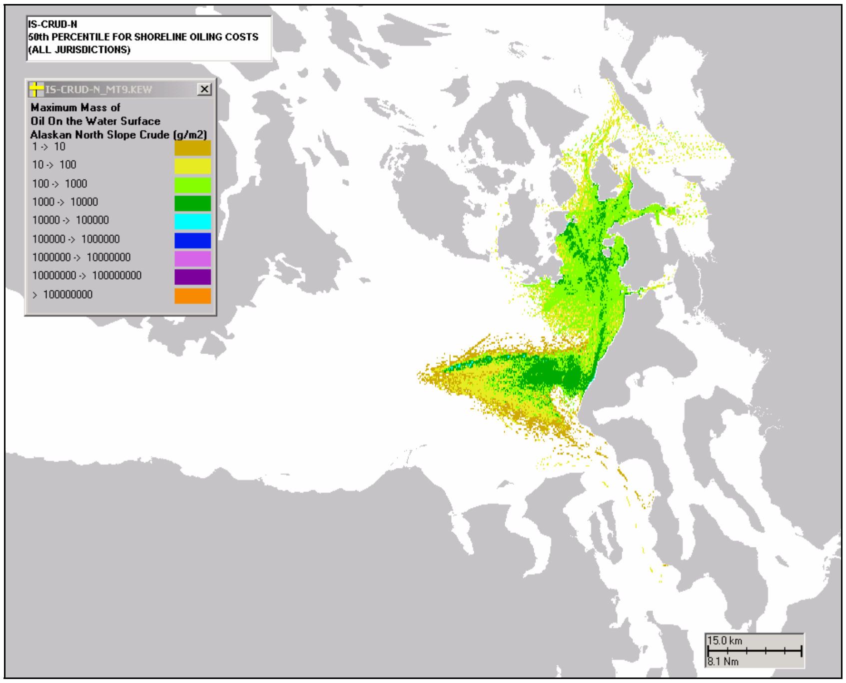


Figure XX.B.1-2. Inner Straits/Puget Sound, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50^{th} percentile run based on shoreline costs.

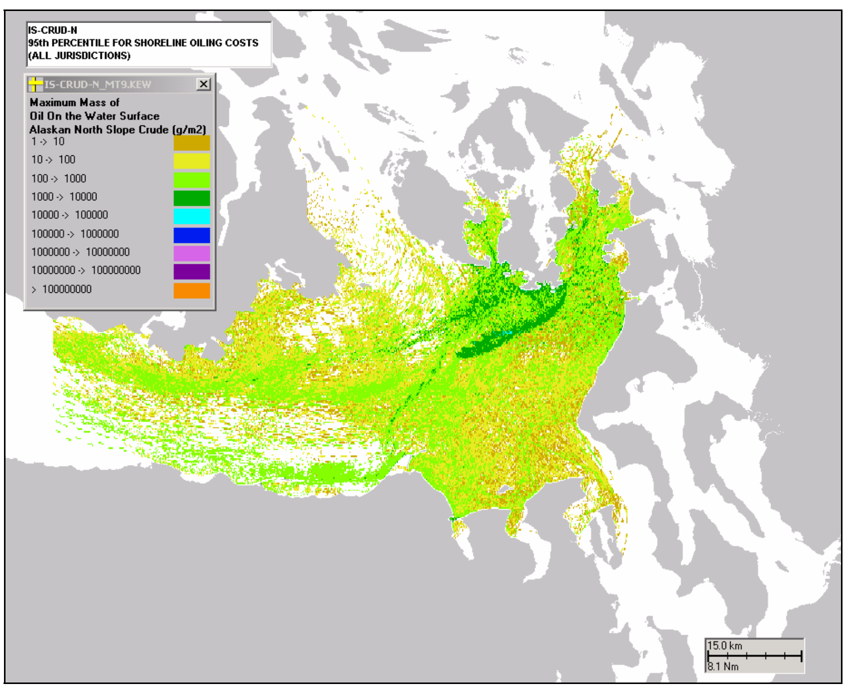


Figure XX.B.1-3. Inner Straits/Puget Sound, crude oil, no removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

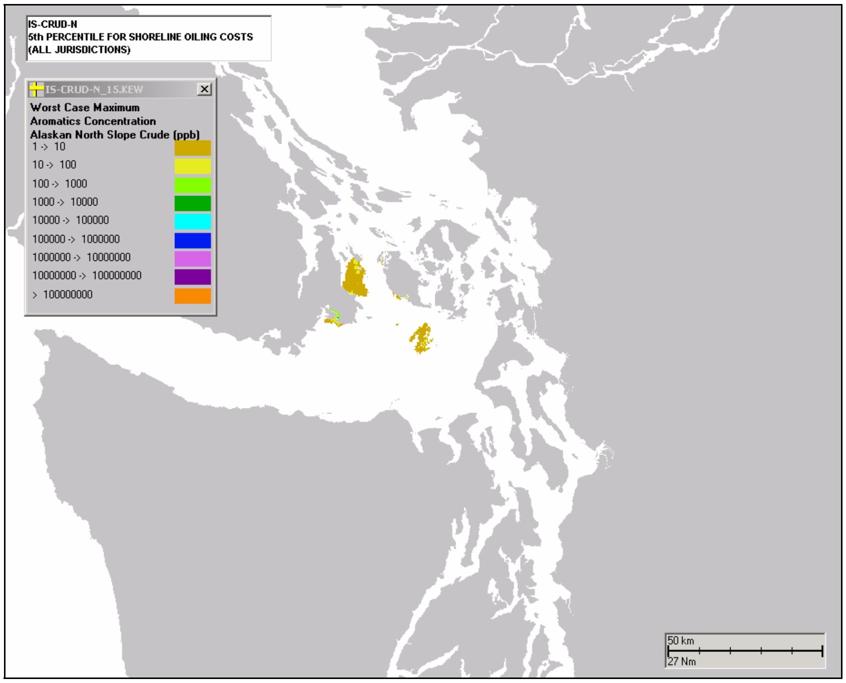


Figure XX.B.1-4. Inner Straits/Puget Sound, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

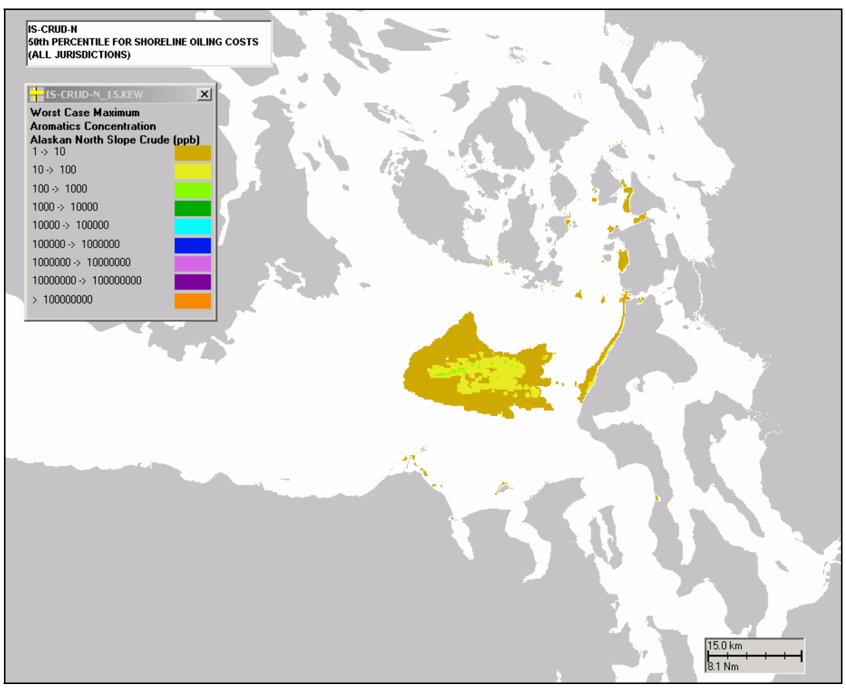


Figure XX.B.1-5. Inner Straits/Puget Sound, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

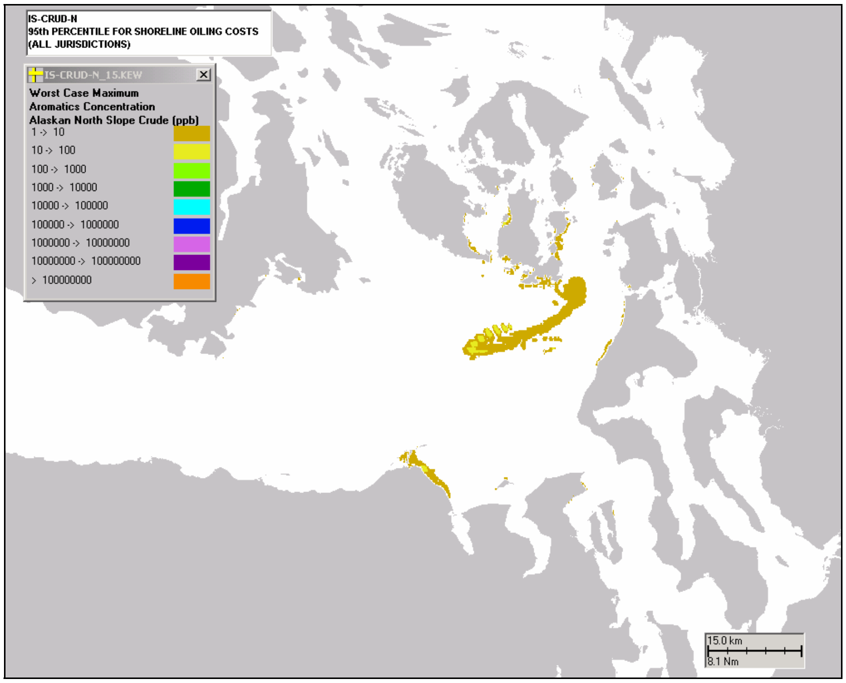


Figure XX.B.1-6. Inner Straits/Puget Sound, crude oil, no removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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".

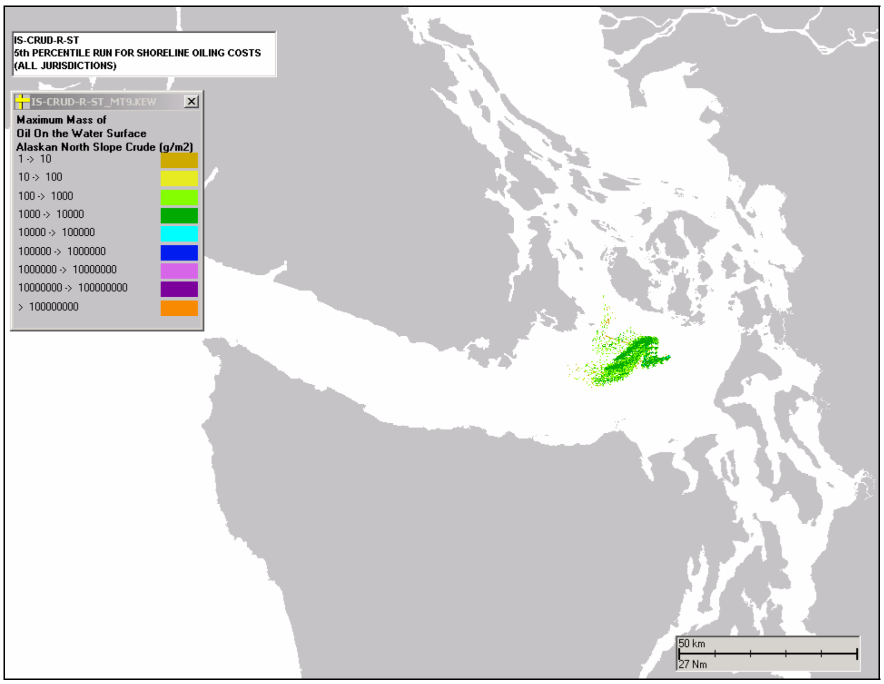


Figure XX.B.2-1. Inner Straits/Puget Sound, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

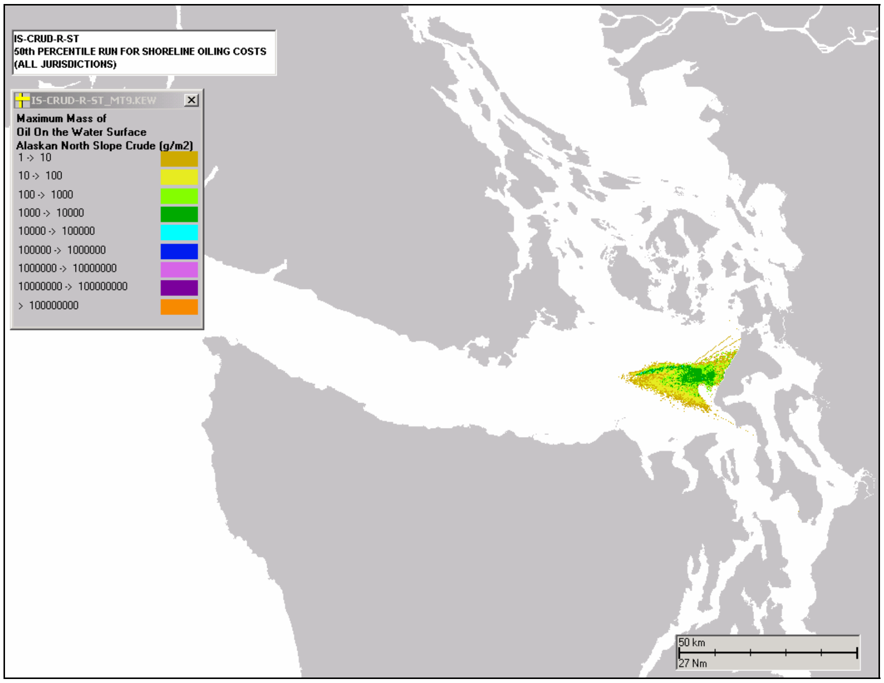


Figure XX. B.2-2. Inner Straits/Puget Sound, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

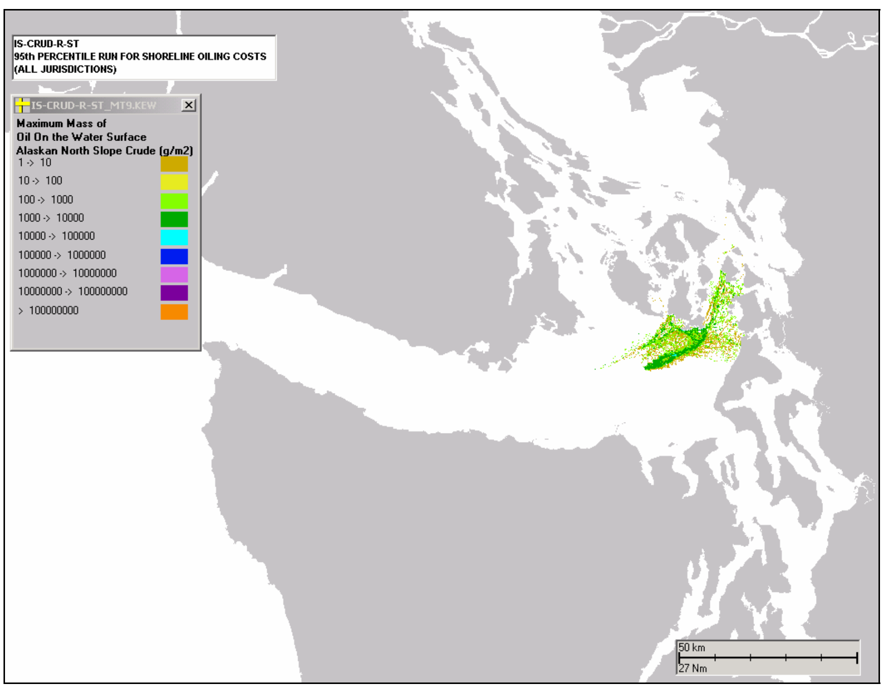


Figure XX. B.2-3. Inner Straits/Puget Sound, crude oil, state mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

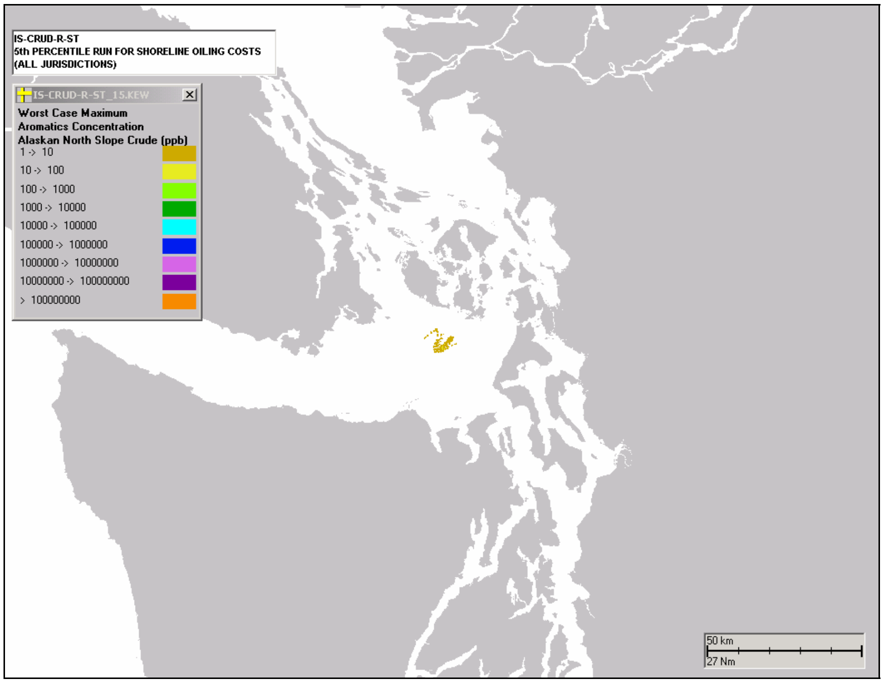


Figure XX. B.2-4. Inner Straits/Puget Sound, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

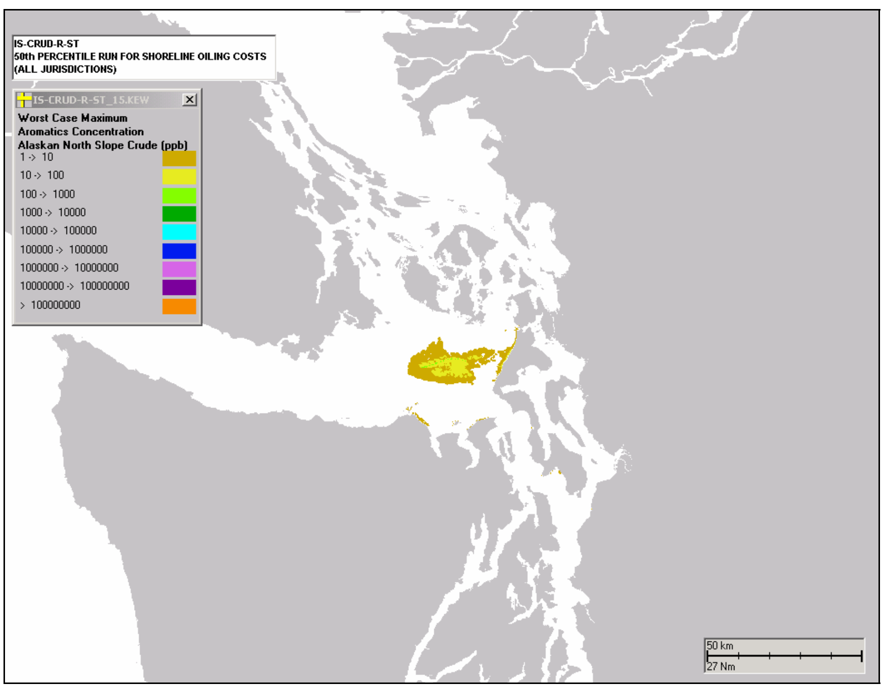


Figure XX. B.2-5. Inner Straits/Puget Sound, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

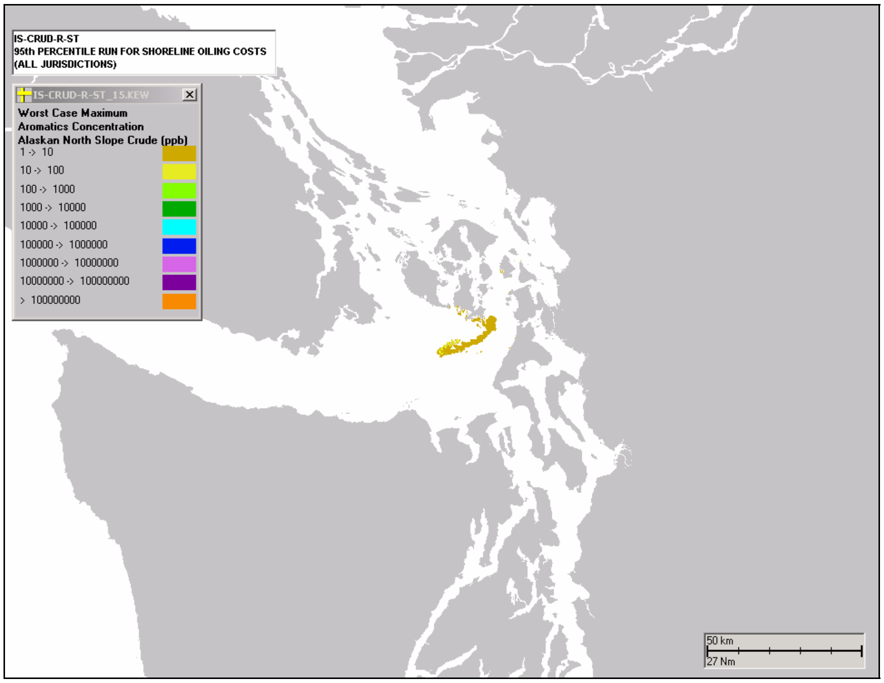


Figure XX. B.2-6. Inner Straits/Puget Sound, crude oil, state mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

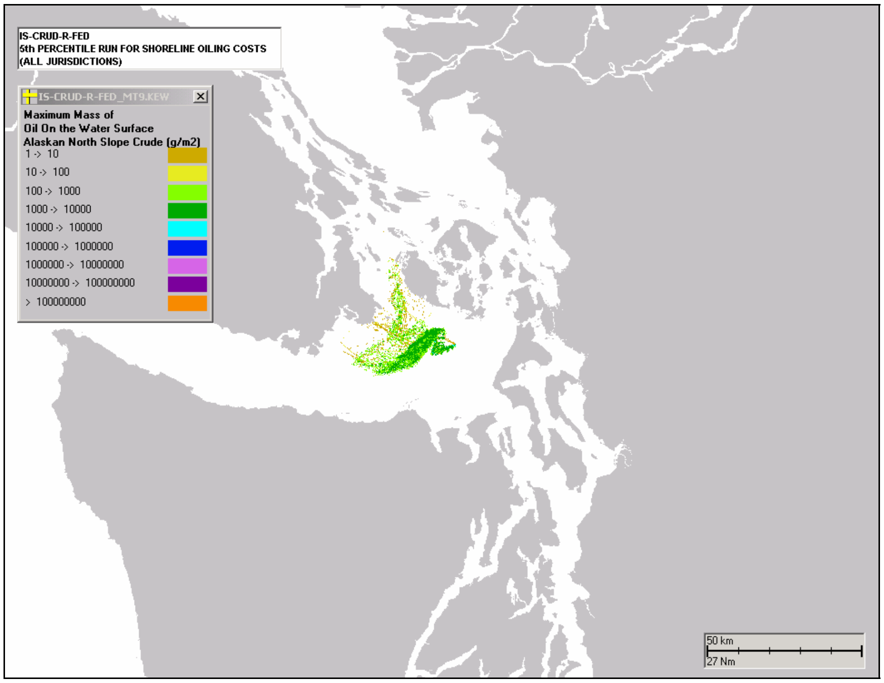


Figure XX.B.3-1. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

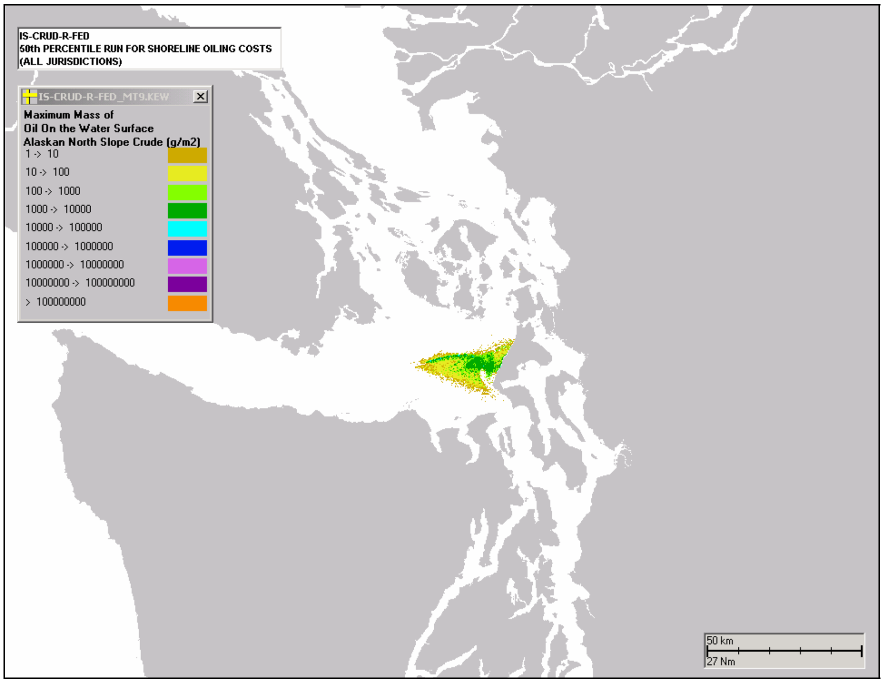


Figure XX. B.3-2. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

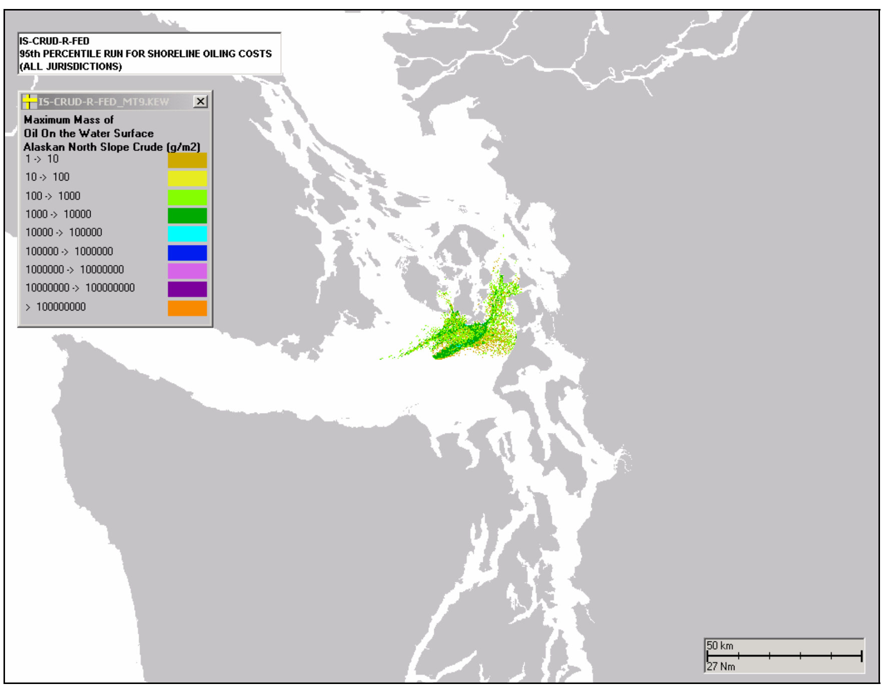


Figure XX. B.3-3. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

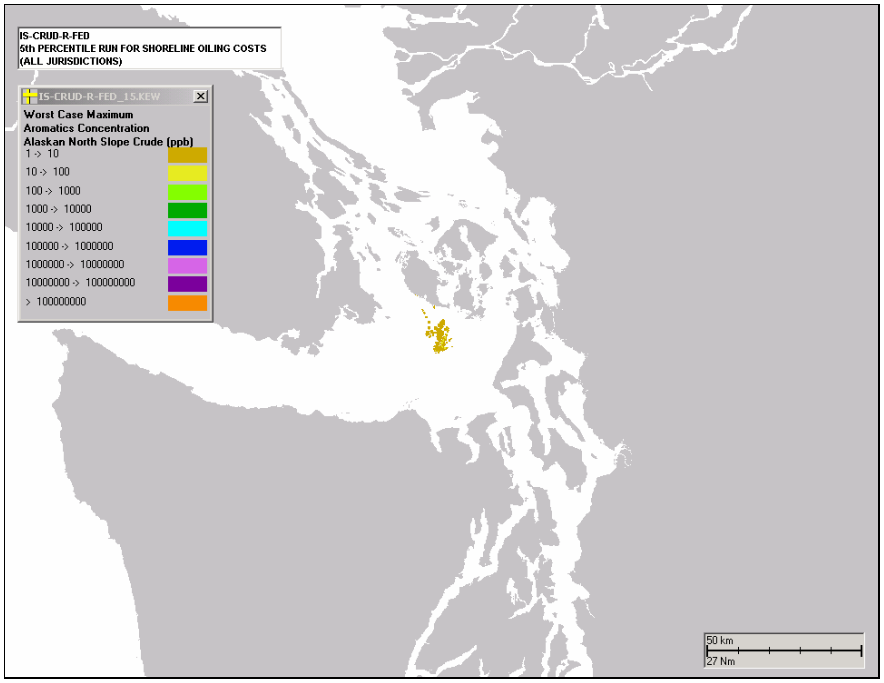


Figure XX.B.3-4. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

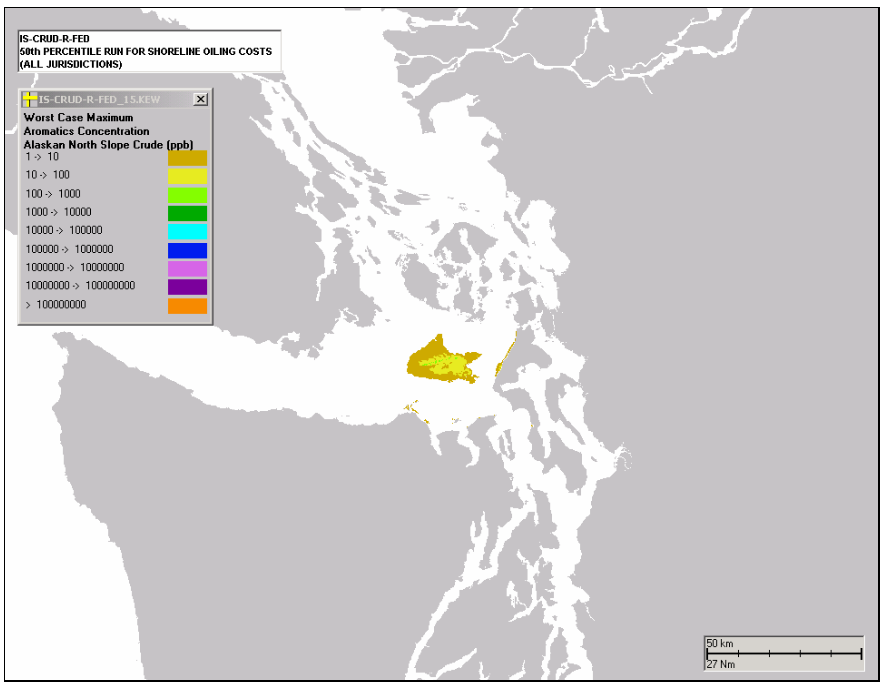


Figure XX.B.3-5. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

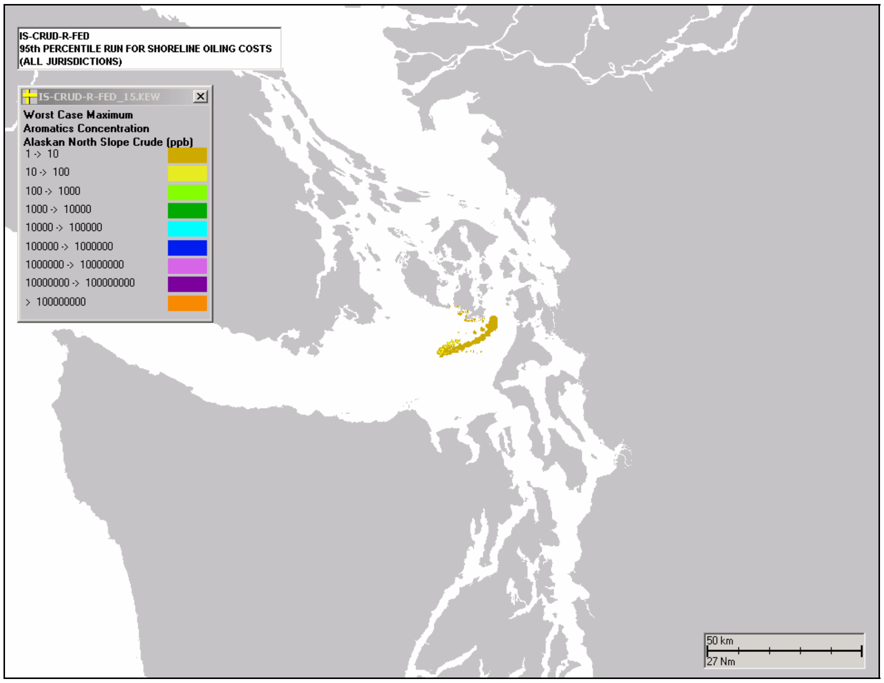


Figure XX.B.3-6. Inner Straits/Puget Sound, crude oil, federal mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

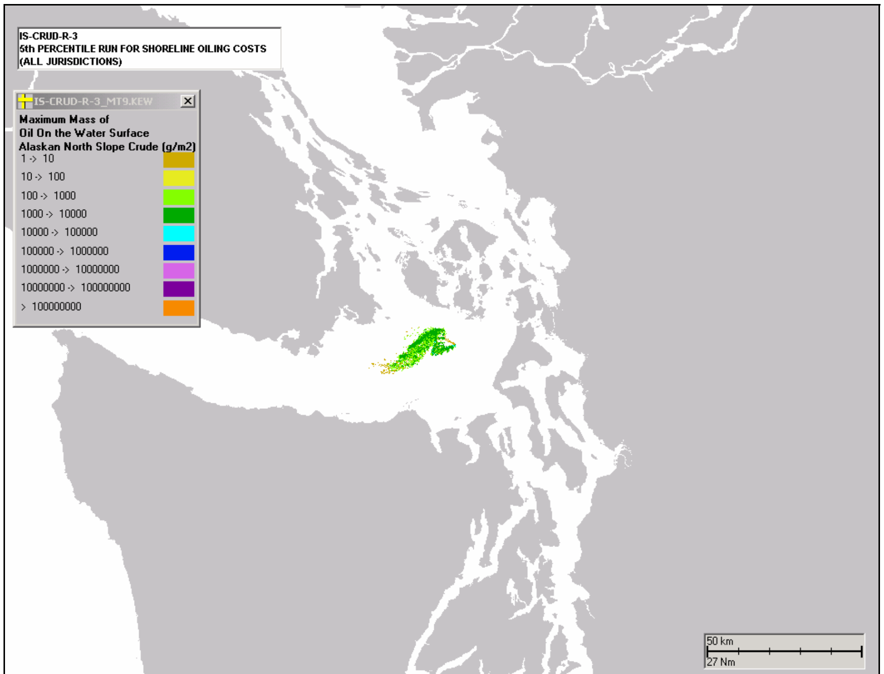


Figure XX.B.4-1. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

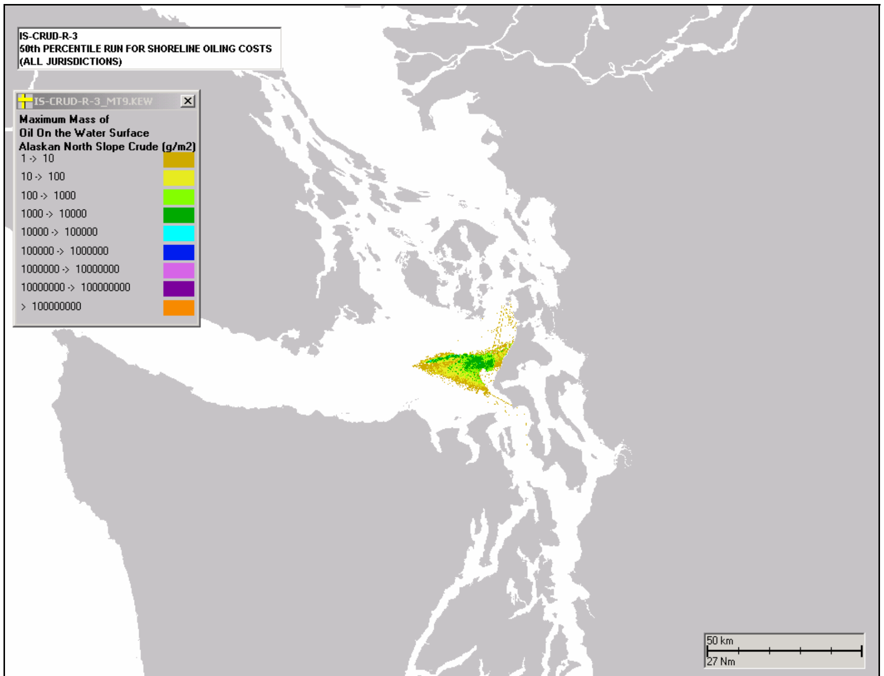


Figure XX.B.4-2. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

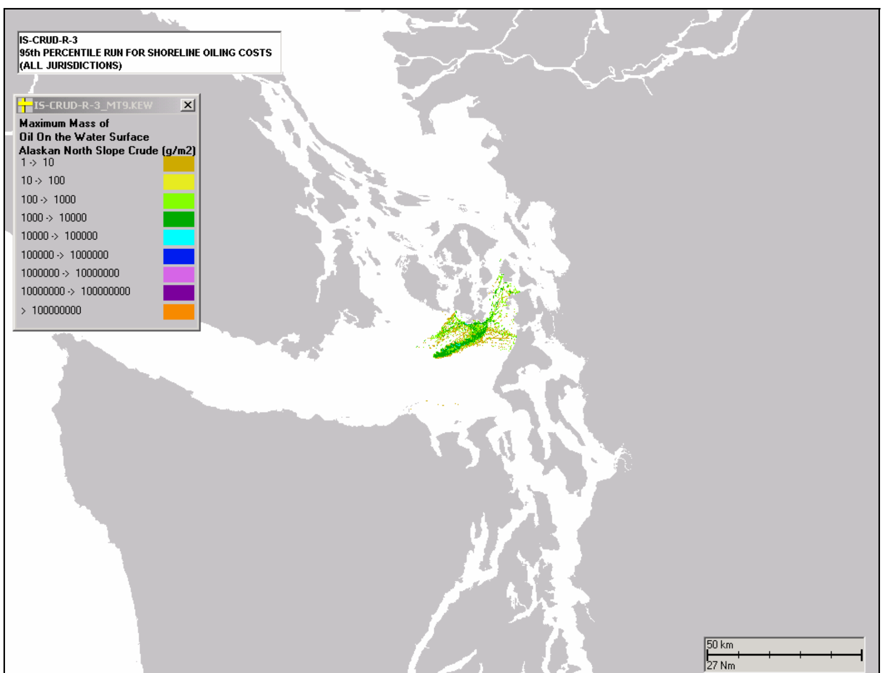


Figure XX.B.4-3. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

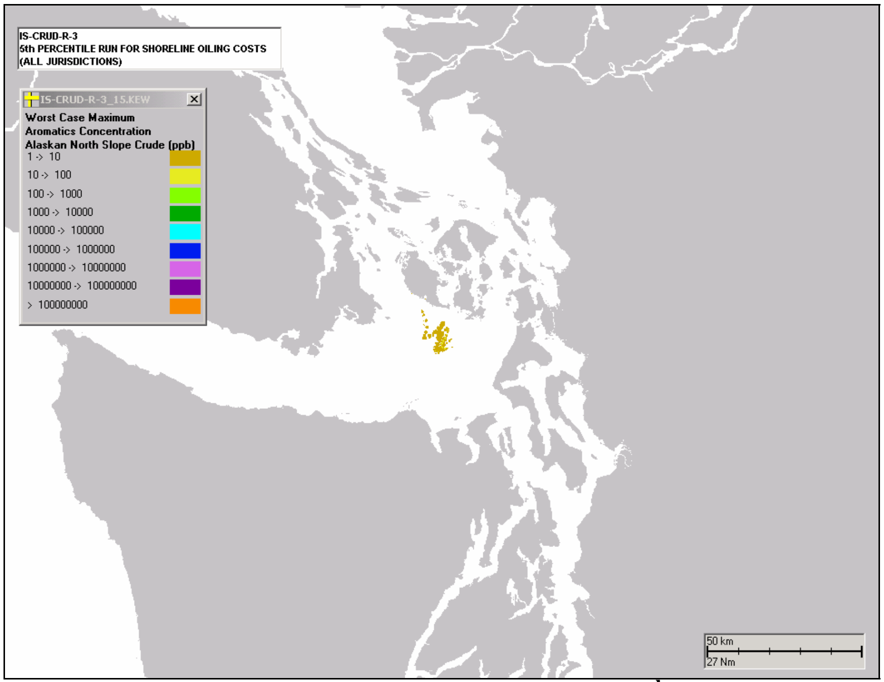


Figure XX.B.4-4. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

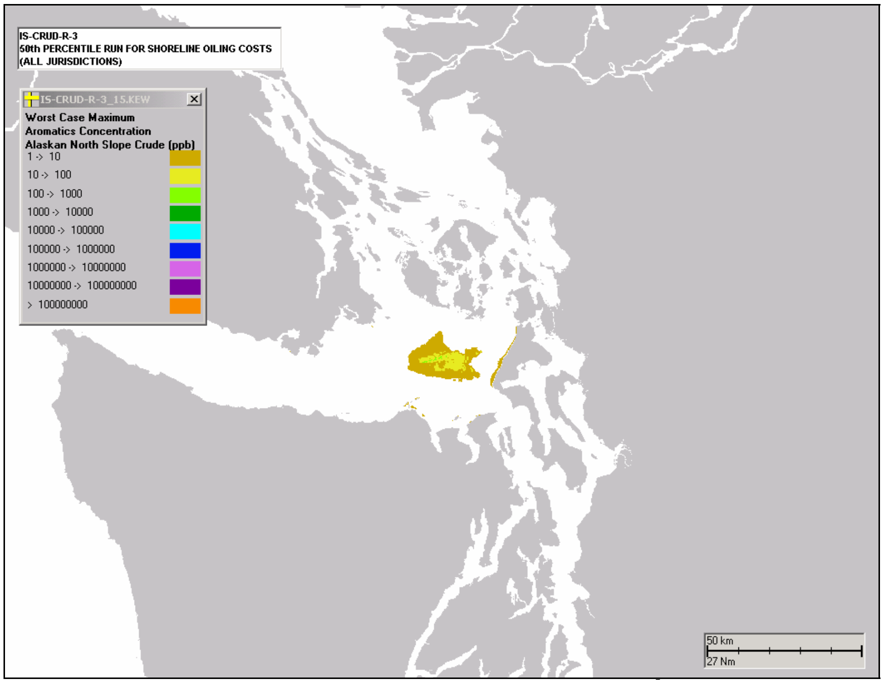


Figure XX.B.4-5. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

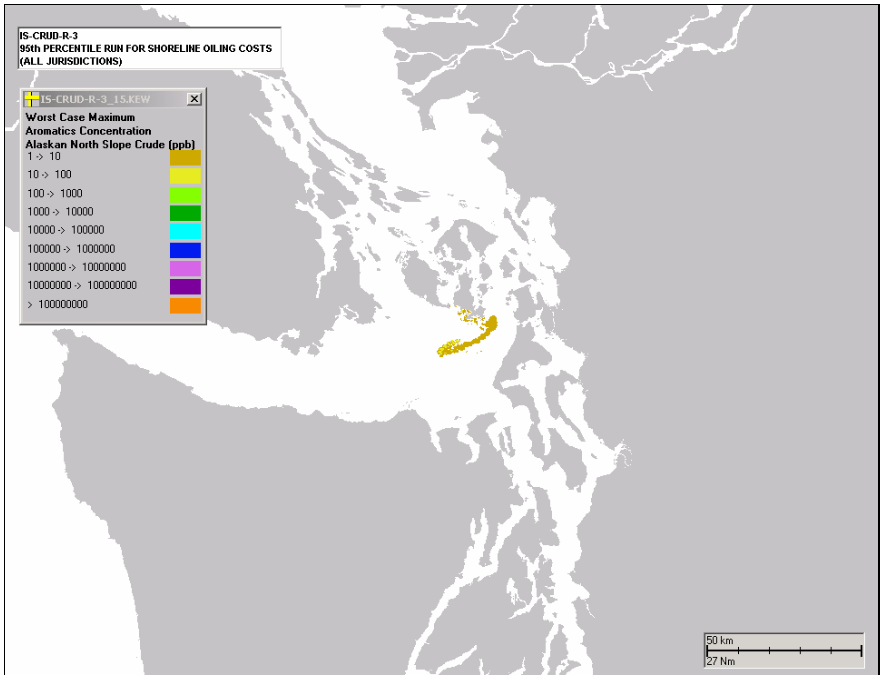


Figure XX.B.4-6. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

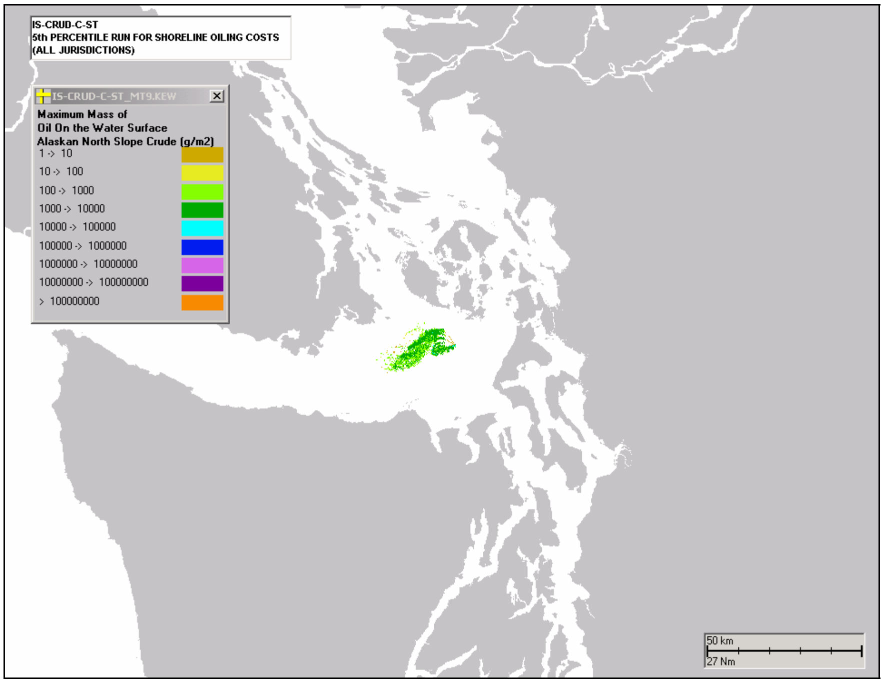


Figure XX.B.5-1. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

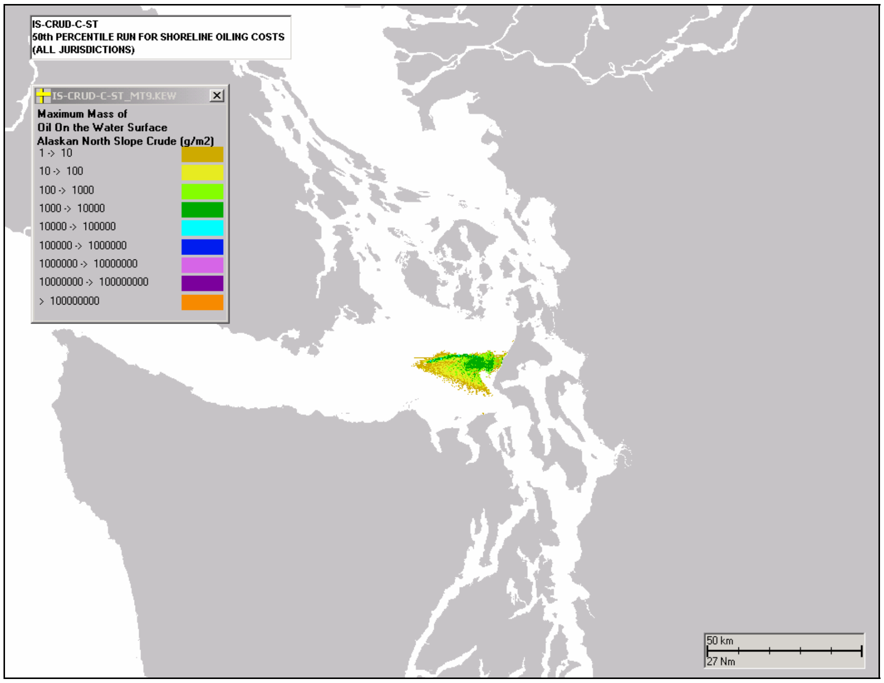


Figure XX.B.5-2. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

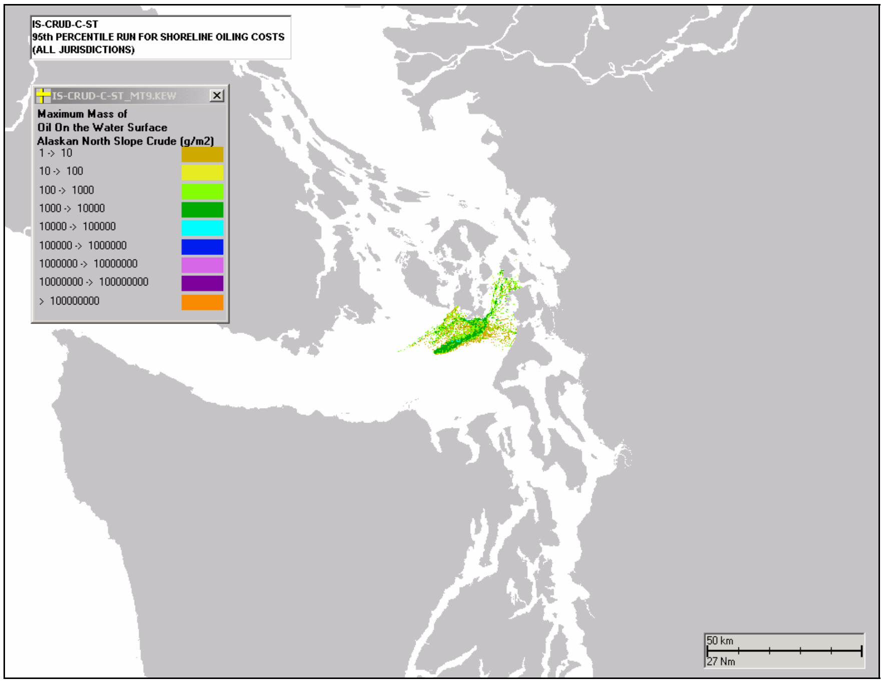


Figure XX.B.5-3. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

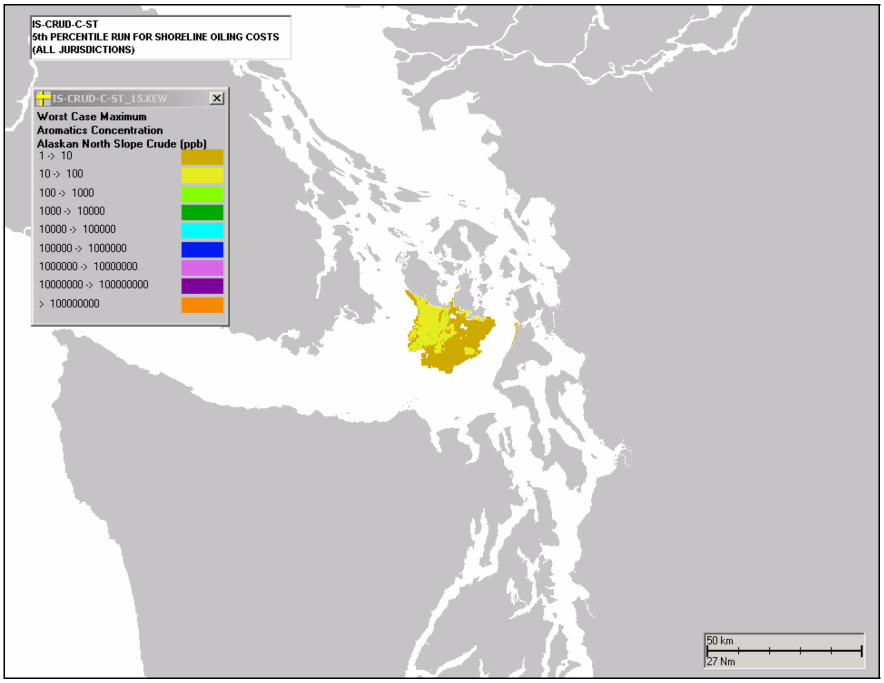


Figure XX.B.5-4. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

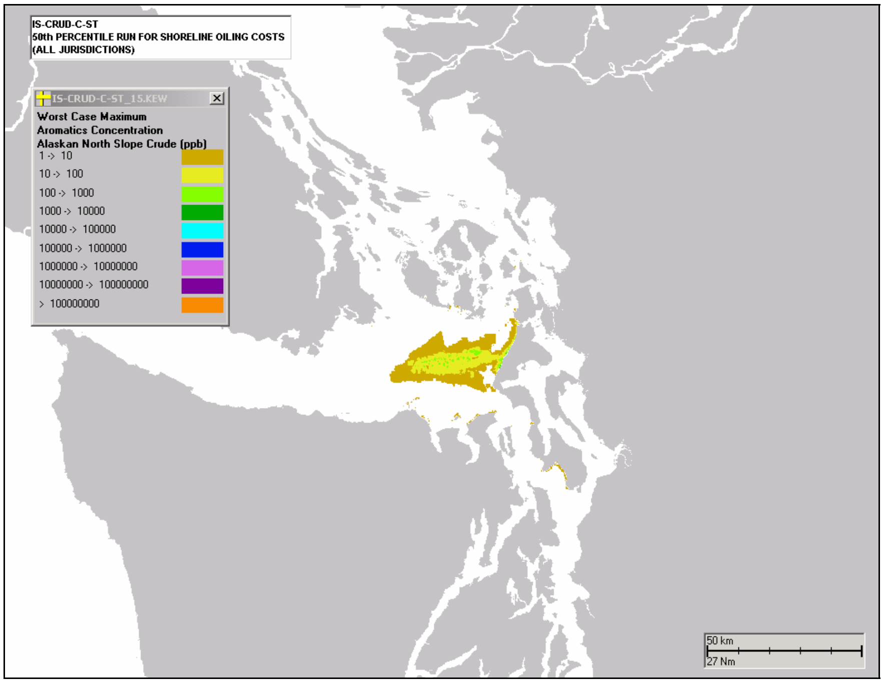


Figure XX.B.5-5. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

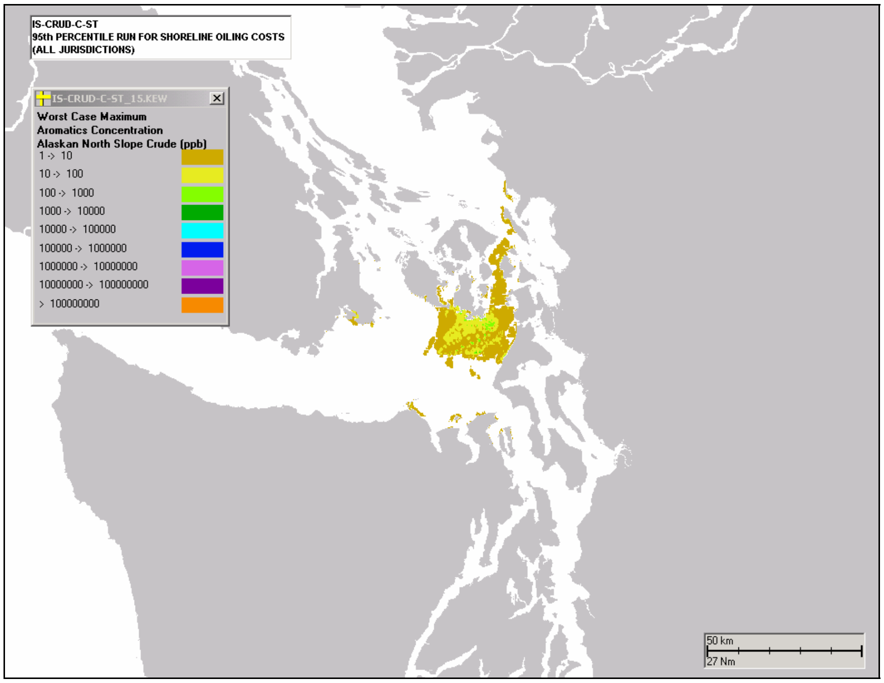


Figure XX.B.5-6. Inner Straits/Puget Sound, crude oil, state mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

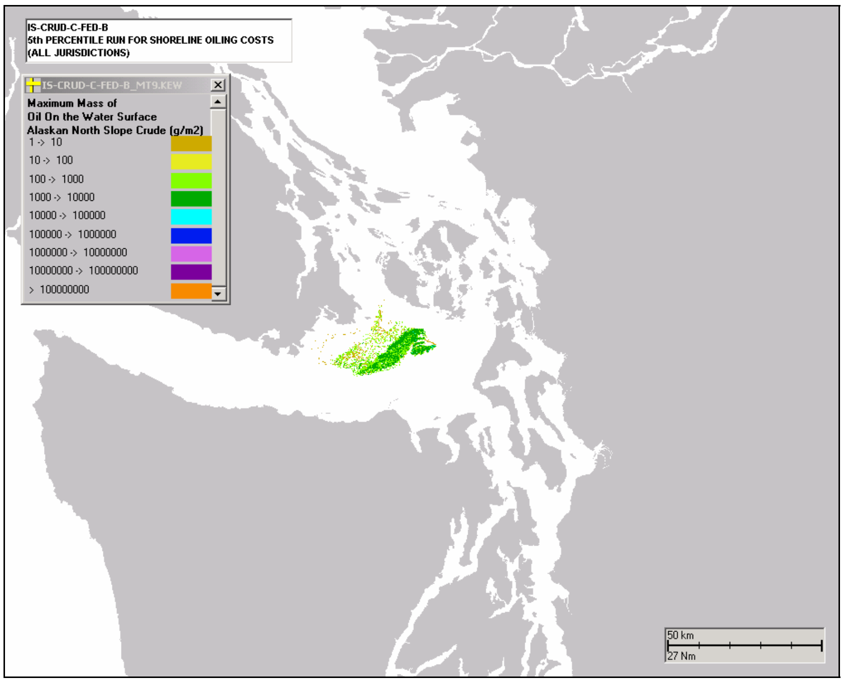


Figure XX.B.6-1. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

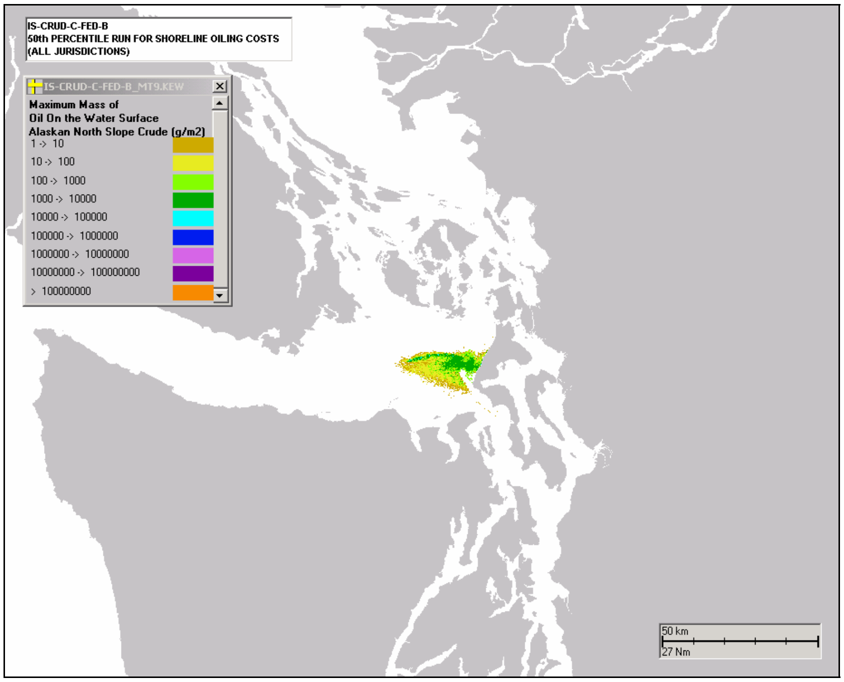


Figure XX.B.6-2. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

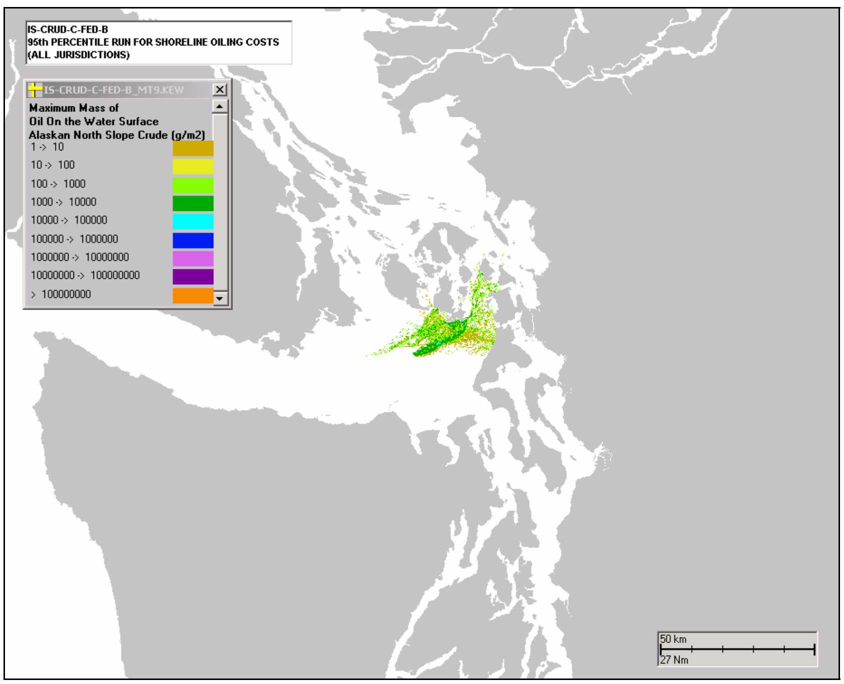


Figure XX.B.6-3. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

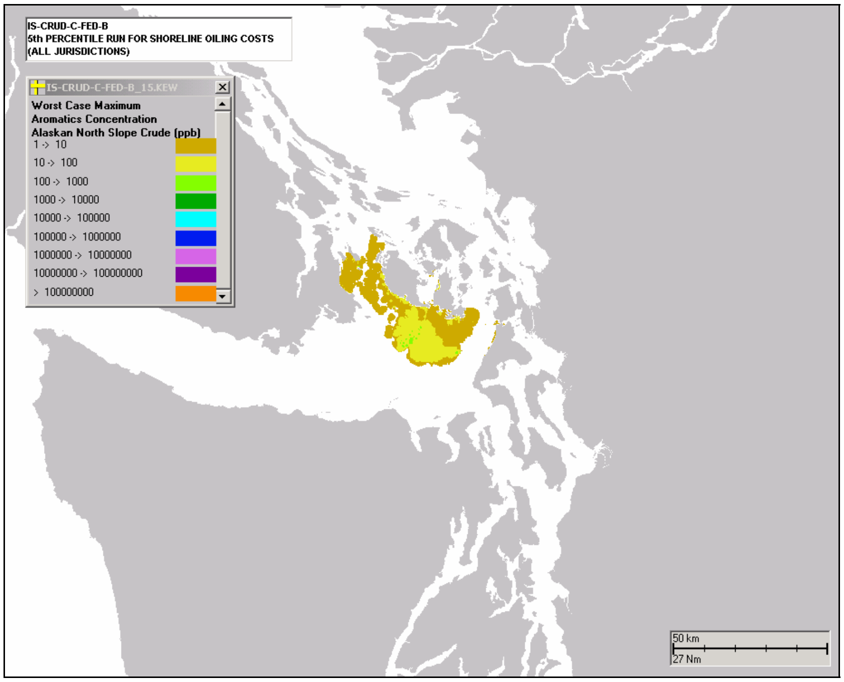


Figure XX.B.6-4. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

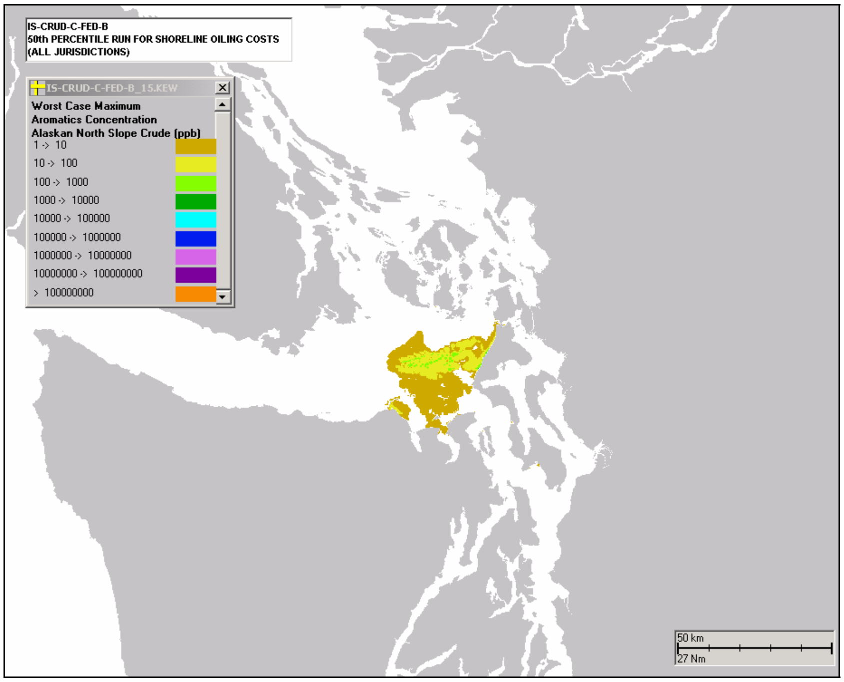


Figure XX.B.6-5. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

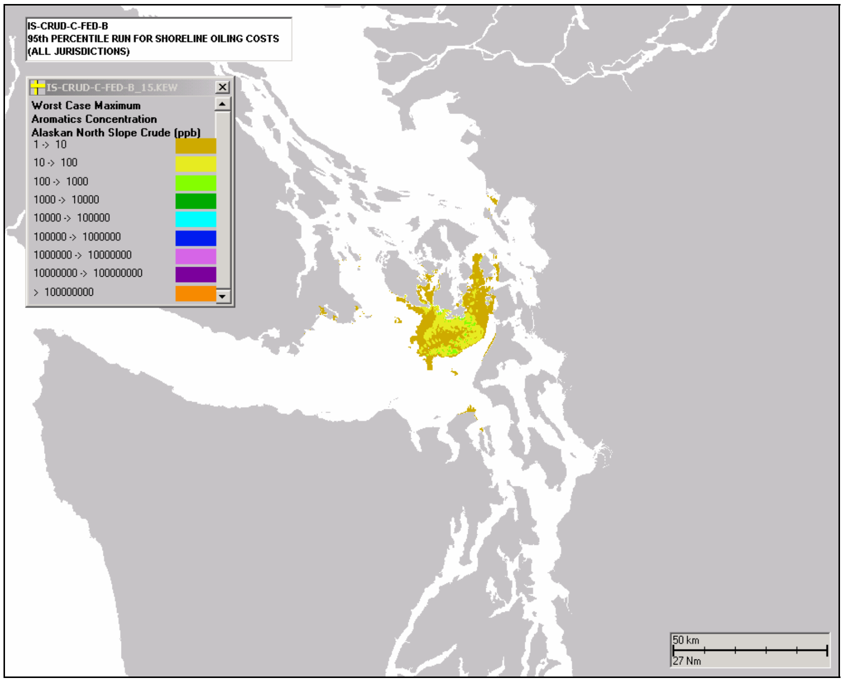


Figure XX.B.6-6. Inner Straits/Puget Sound, crude oil, federal mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

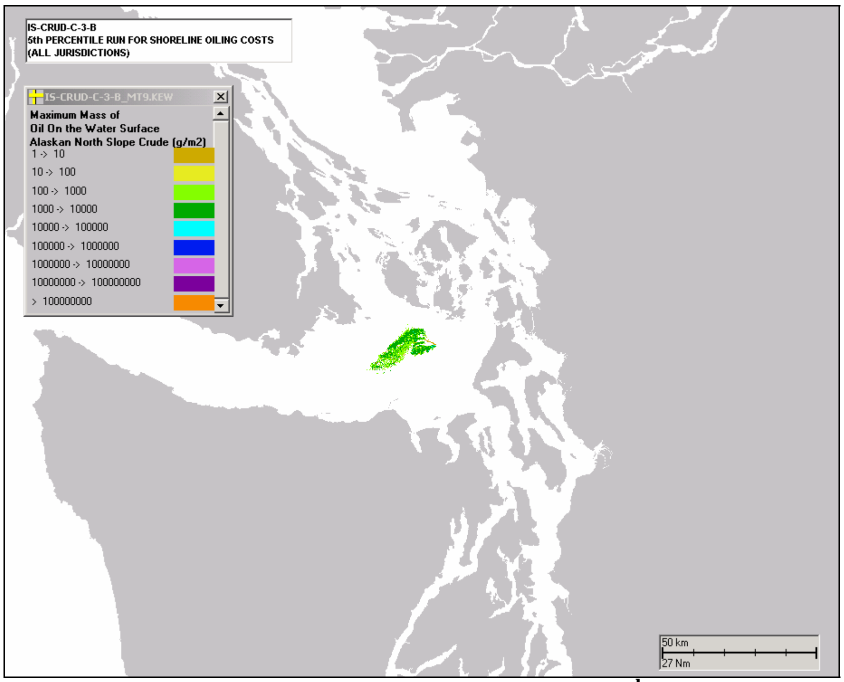


Figure XX.B.7-1. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 5th percentile run based on shoreline costs.

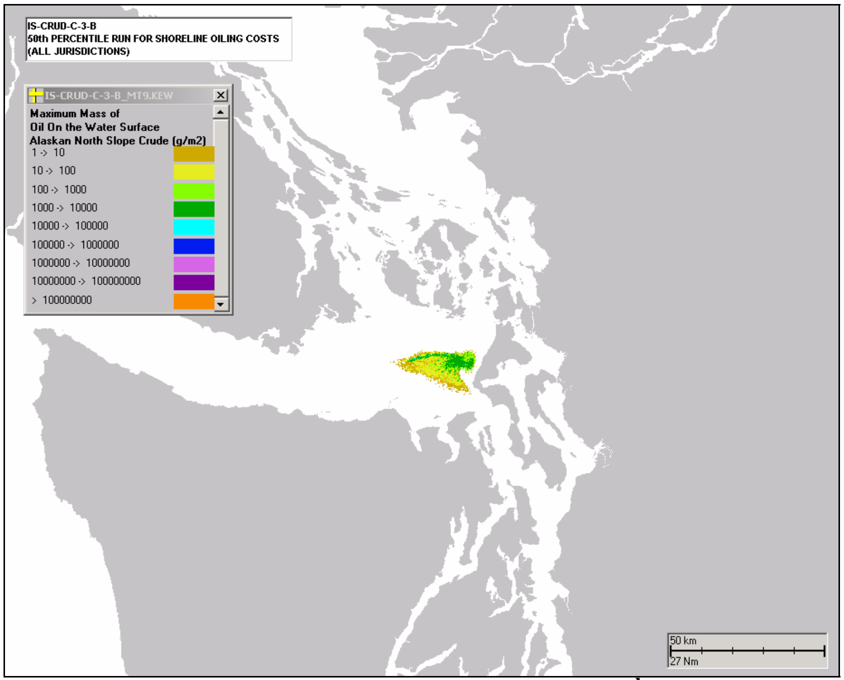


Figure XX.B.7-2. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

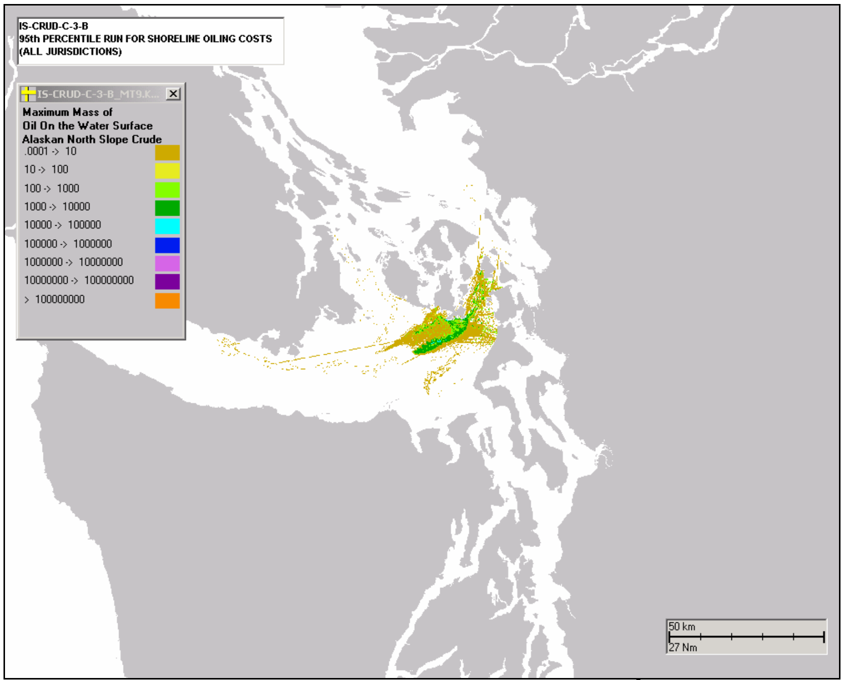


Figure XX.B.7-3. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Water surface exposure to floating hydrocarbons (g/m^2) for the 95th percentile run based on shoreline costs.

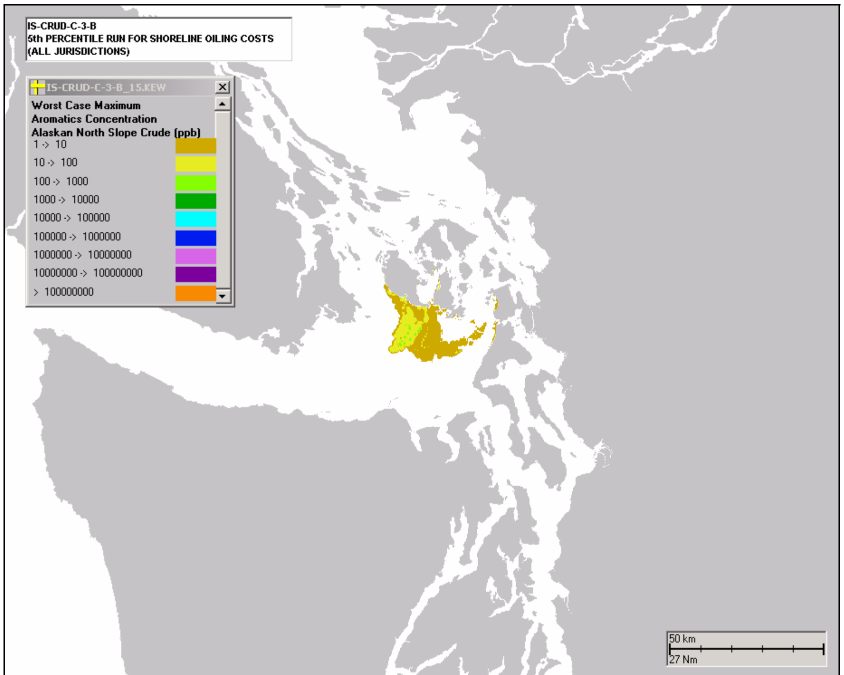


Figure XX.B.7-4. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 5th percentile run based on shoreline costs.

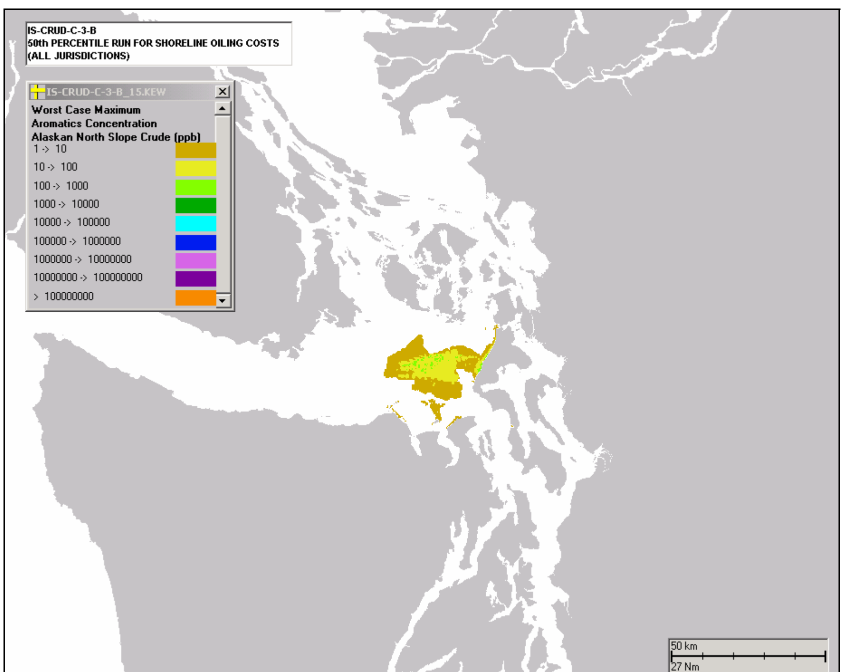


Figure XX.B.7-5. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 50th percentile run based on shoreline costs.

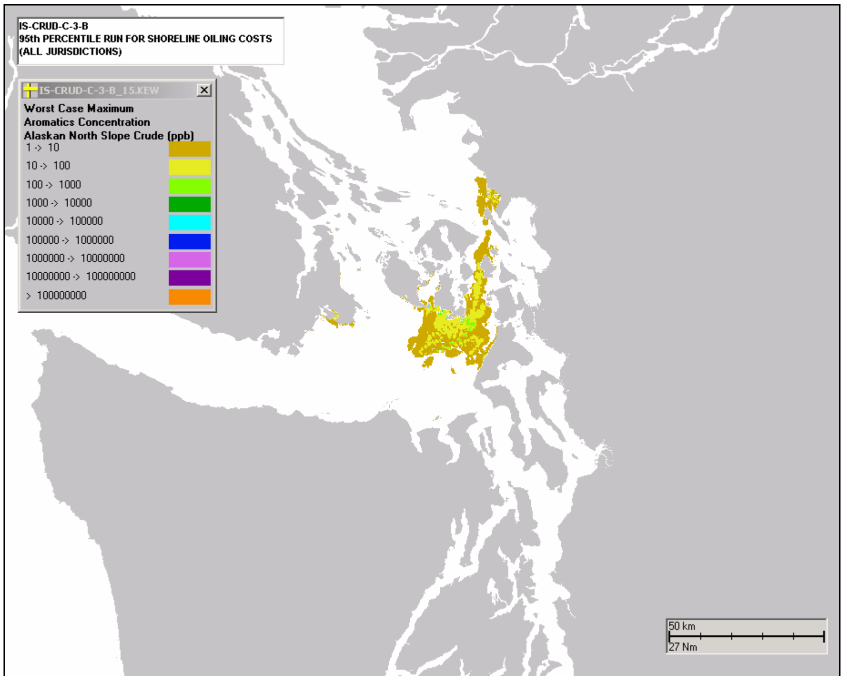


Figure XX.B.7-6. Inner Straits/Puget Sound, crude oil, 3rd alternative mechanical removal, dispersant: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the 95th percentile run based on shoreline costs.

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.

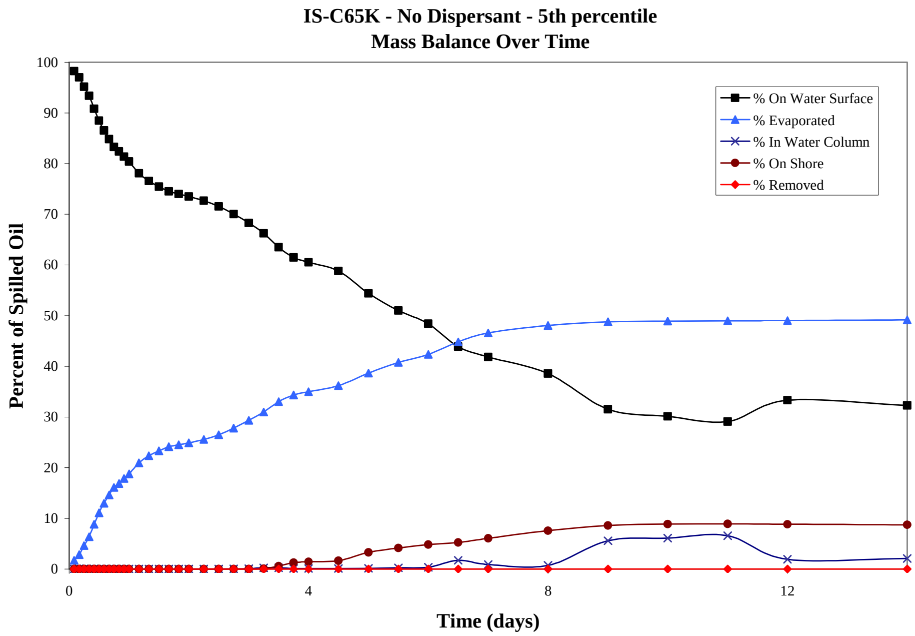


Figure XX.B.8-1 Inner Straits/Puget Sound - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

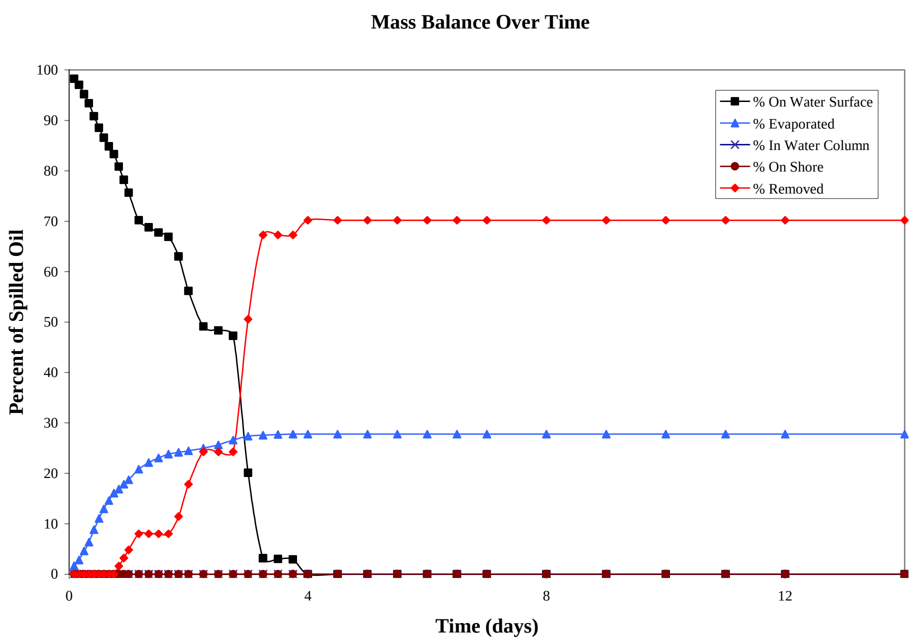


Figure XX.B.8-2 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

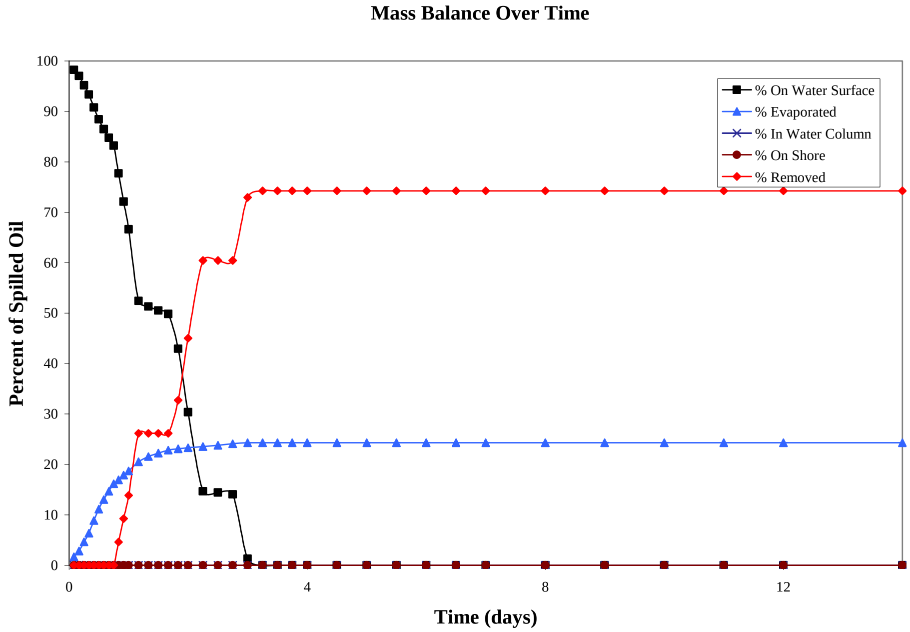


Figure XX.B.8-3 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

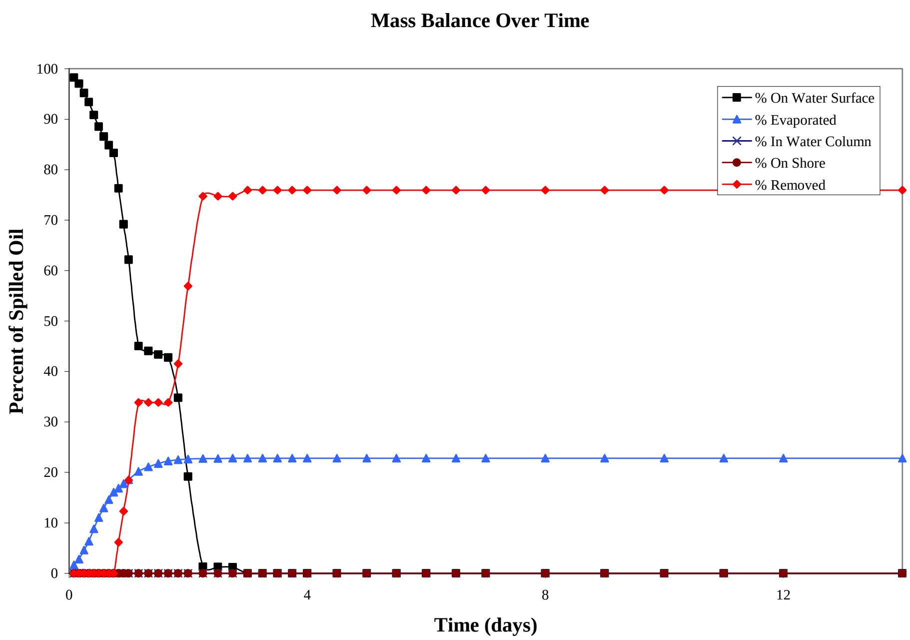


Figure XX.B.8-4 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

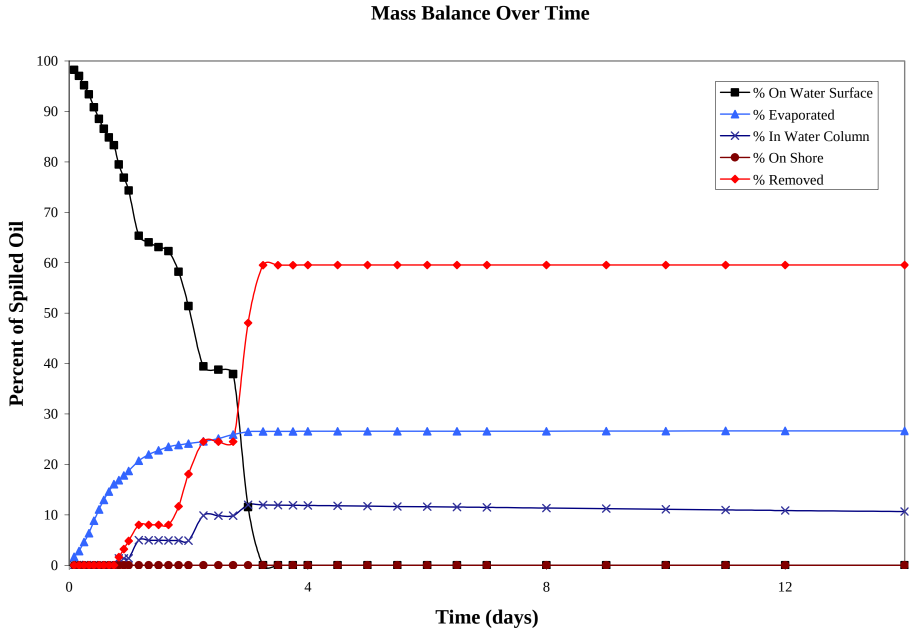


Figure XX.B.8-5 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

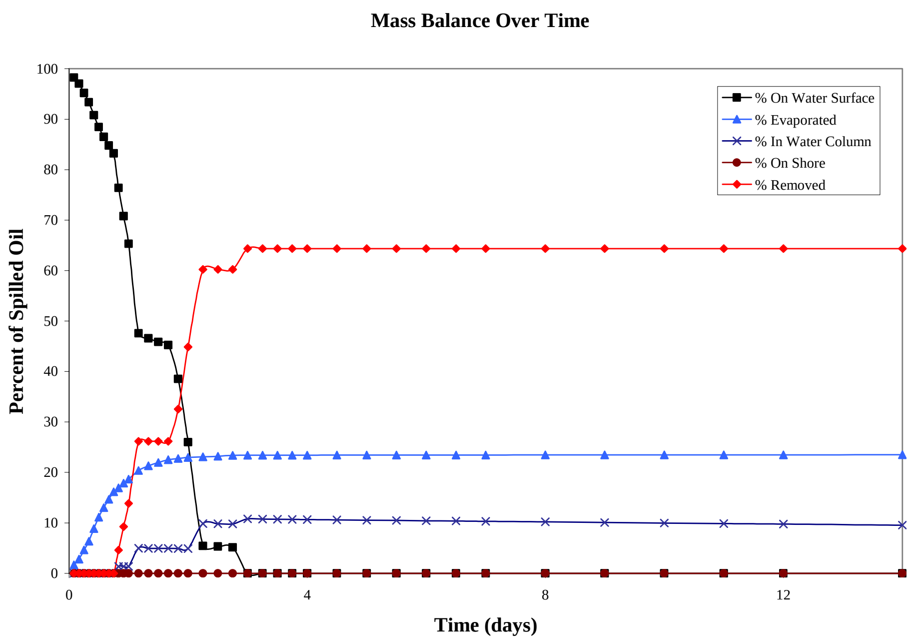


Figure XX.B.8-6 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

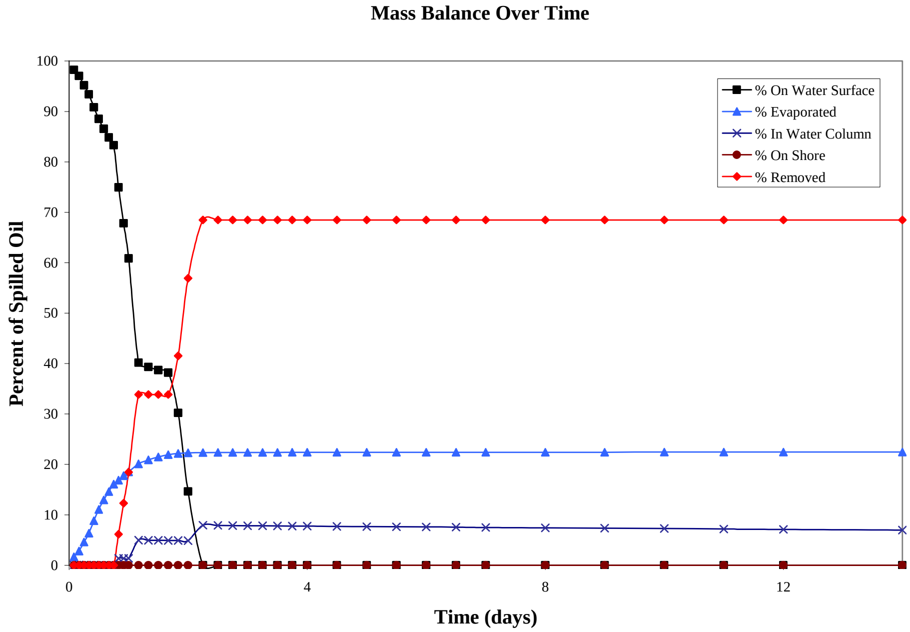


Figure XX.B.8-7 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 5th percentile run (based on shore cost).

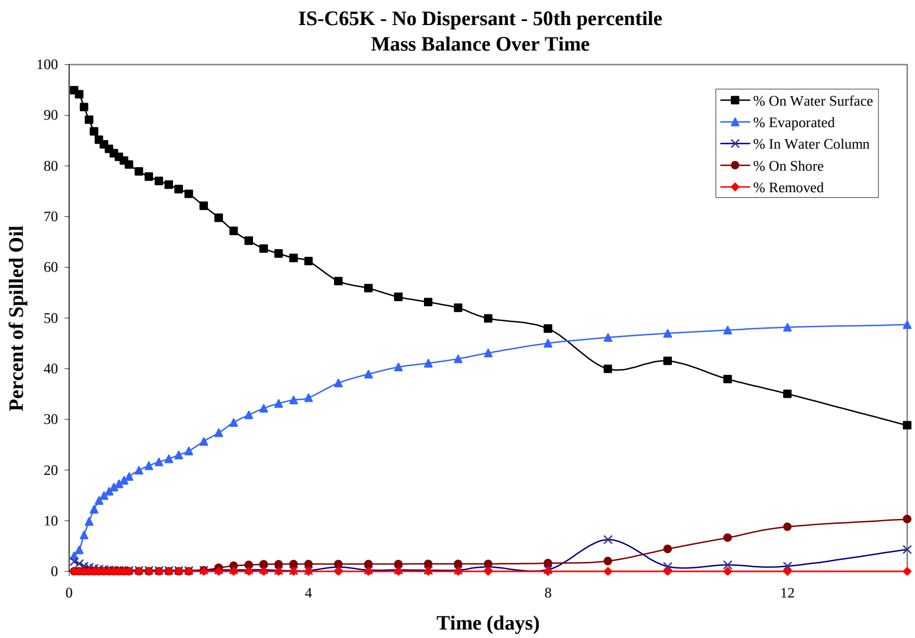


Figure XX.B.8-8 Inner Straits/Puget Sound - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

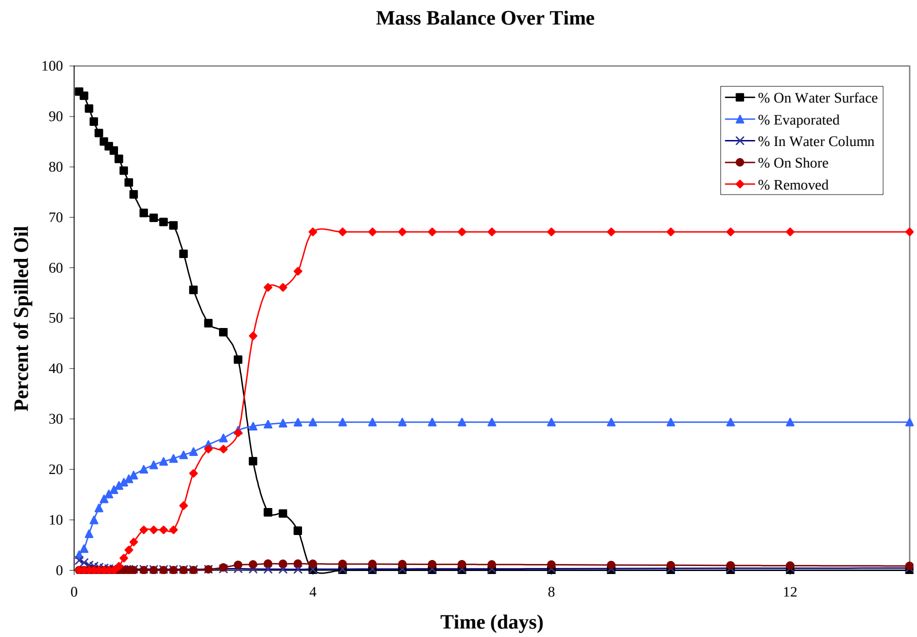


Figure XX.B.8-9 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

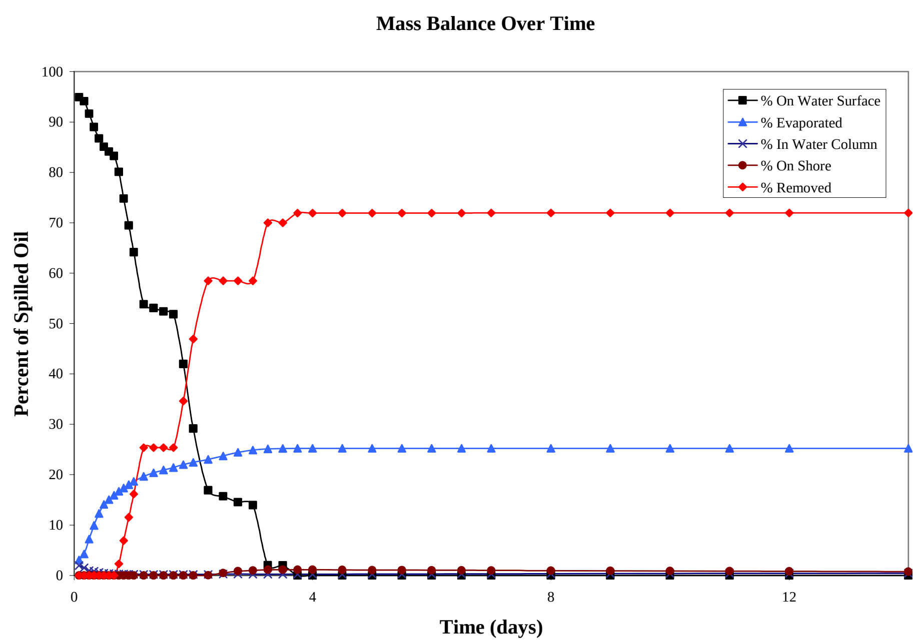


Figure XX.B.8-10 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

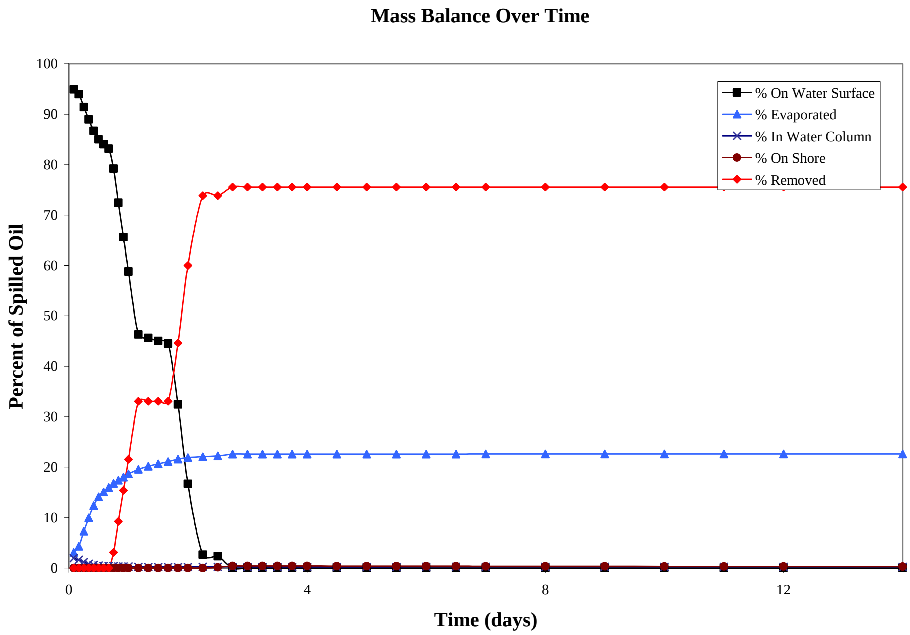


Figure XX.B.8-11 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

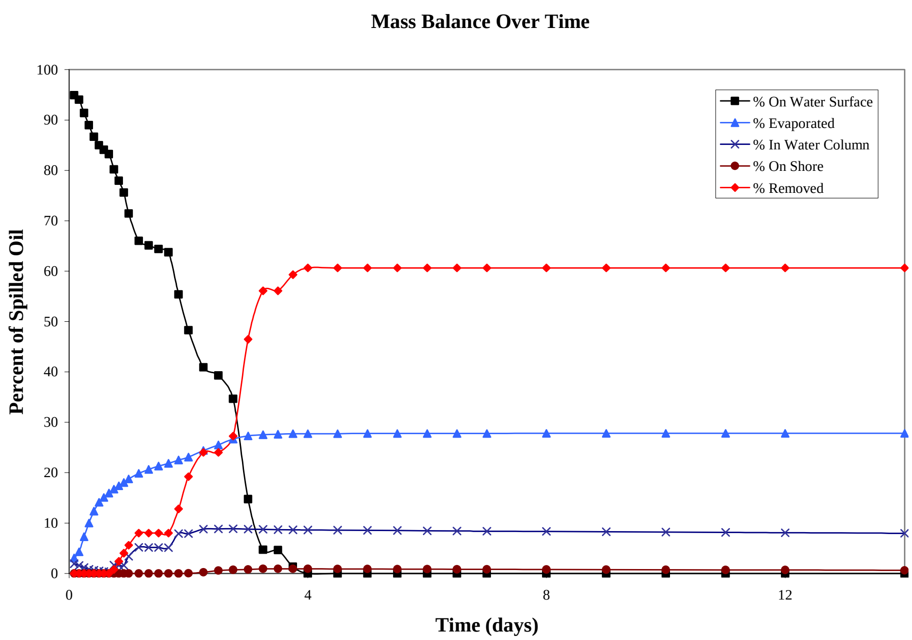


Figure XX.B.8-12 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

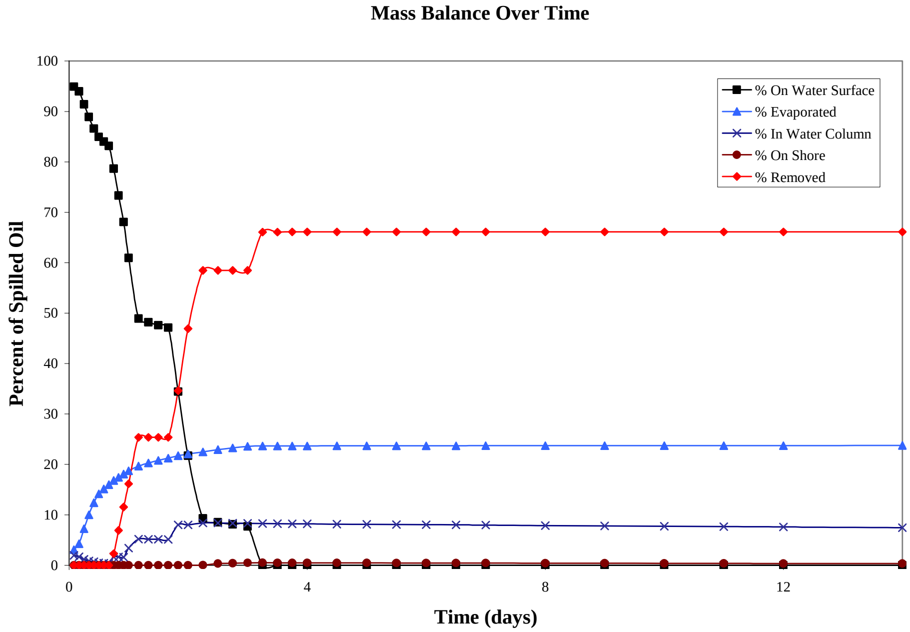


Figure XX.B.8-13 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

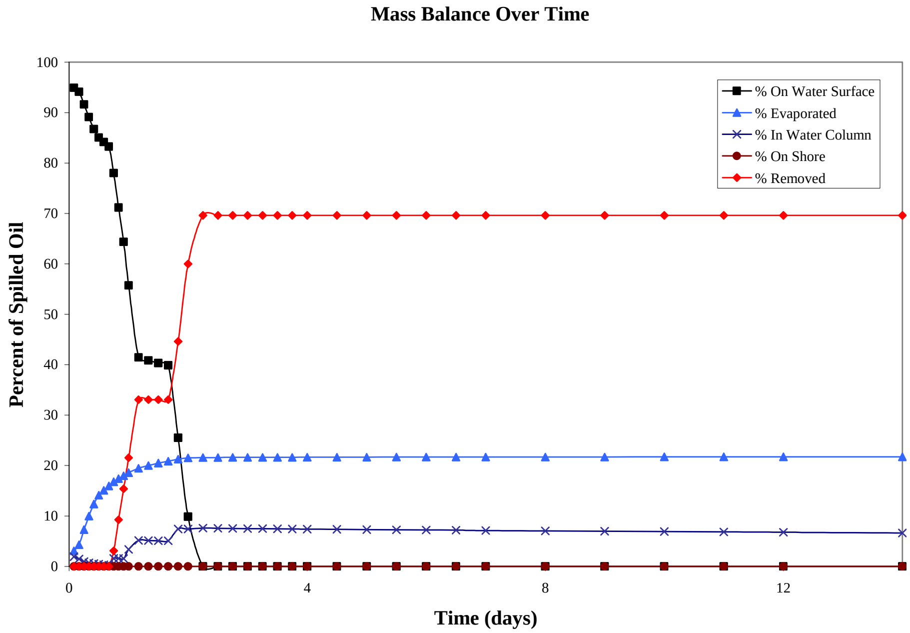


Figure XX.B.8-14 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

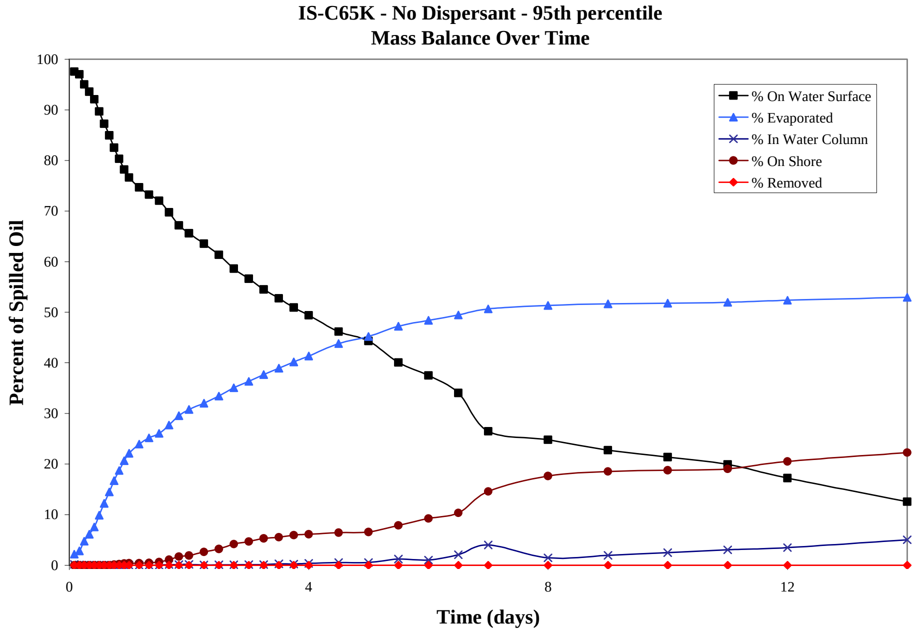


Figure XX.B.8-15 Inner Straits/Puget Sound - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

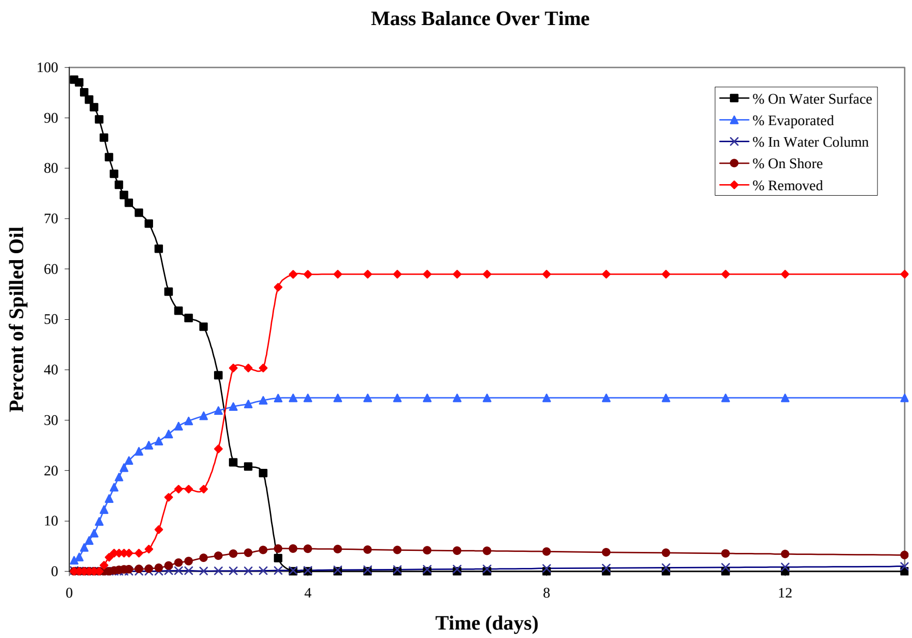


Figure XX.B.8-16 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

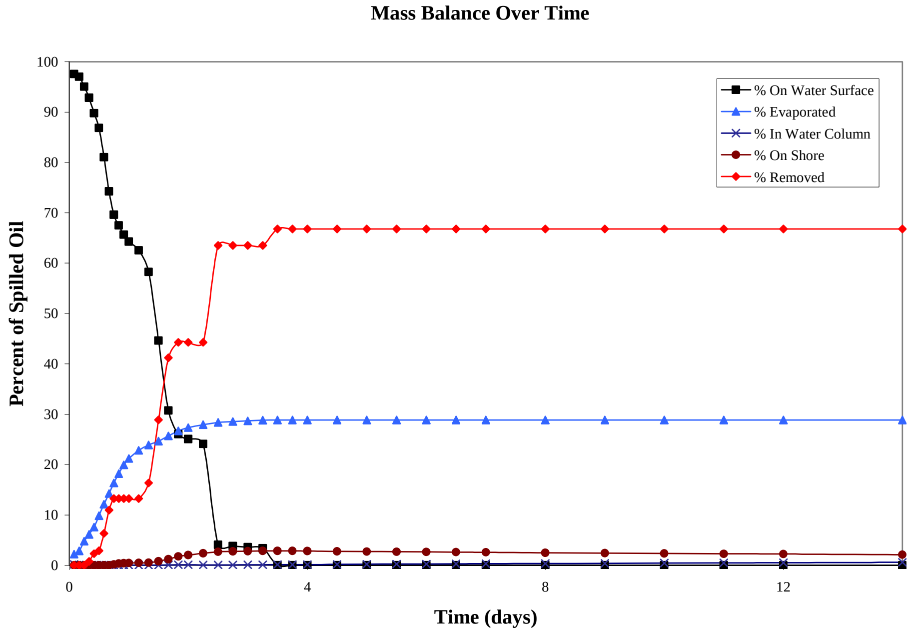


Figure XX.B.8-17 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

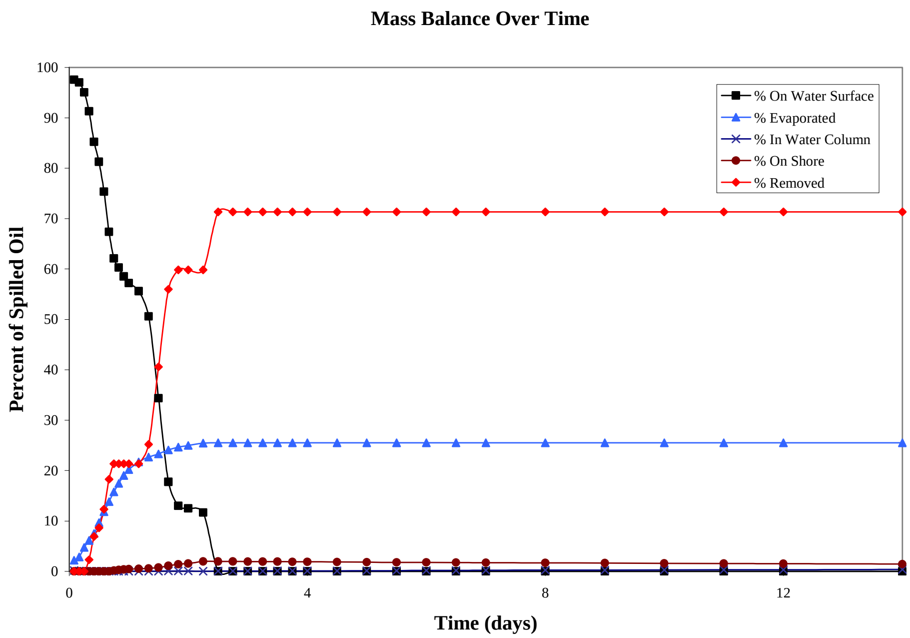


Figure XX.B.8-18 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

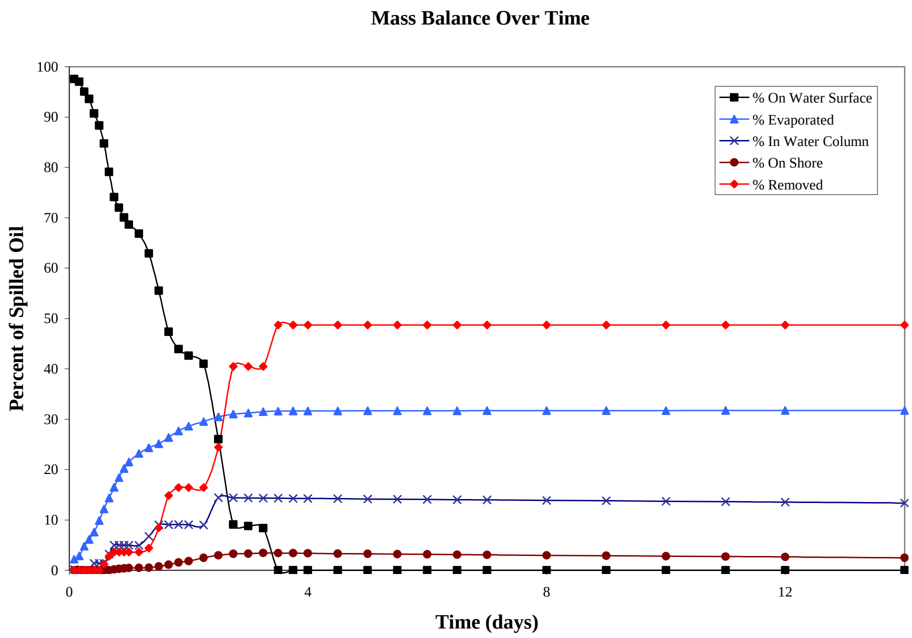


Figure XX.B.8-19 Inner Straits/Puget Sound - Alaskan North Slope Crude, federal mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

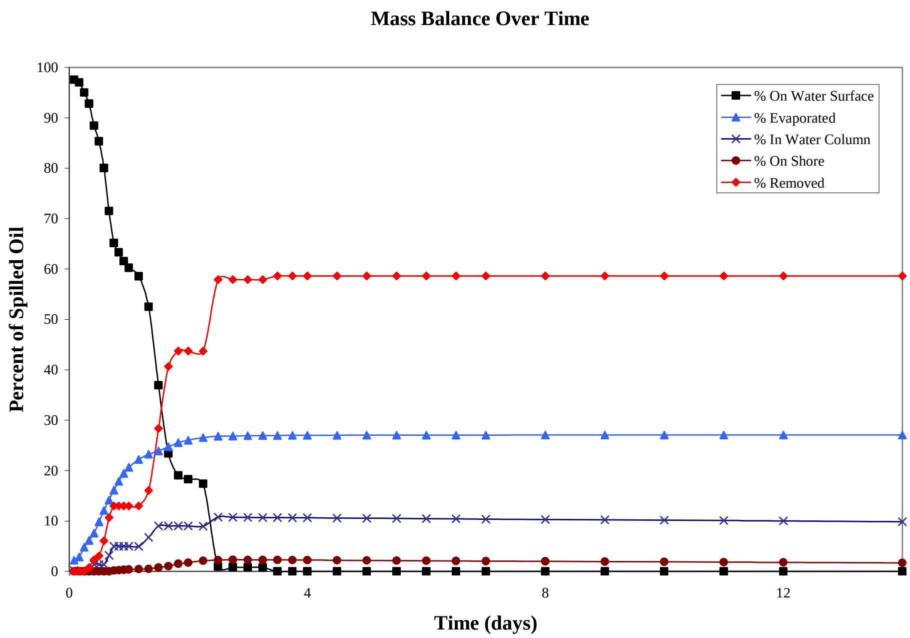


Figure XX.B.8-20 Inner Straits/Puget Sound - Alaskan North Slope Crude, WA state mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).

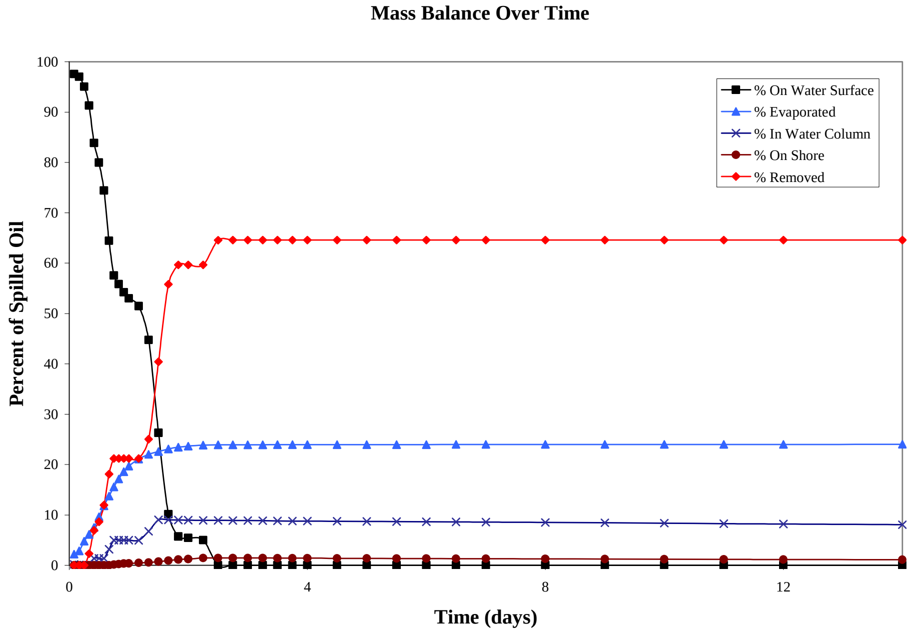
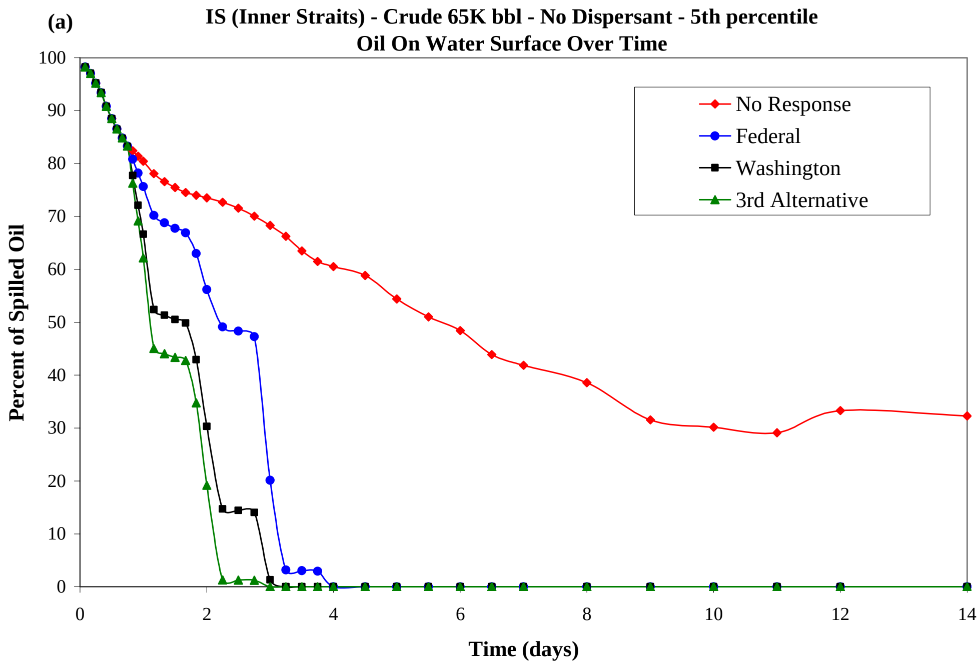


Figure XX.B.8-21 Inner Straits/Puget Sound - Alaskan North Slope Crude, 3rd alternative mechanical removal and dispersant use: Mass balance of oil over time (percent of spilled oil) for the 95th percentile run (based on shore cost).



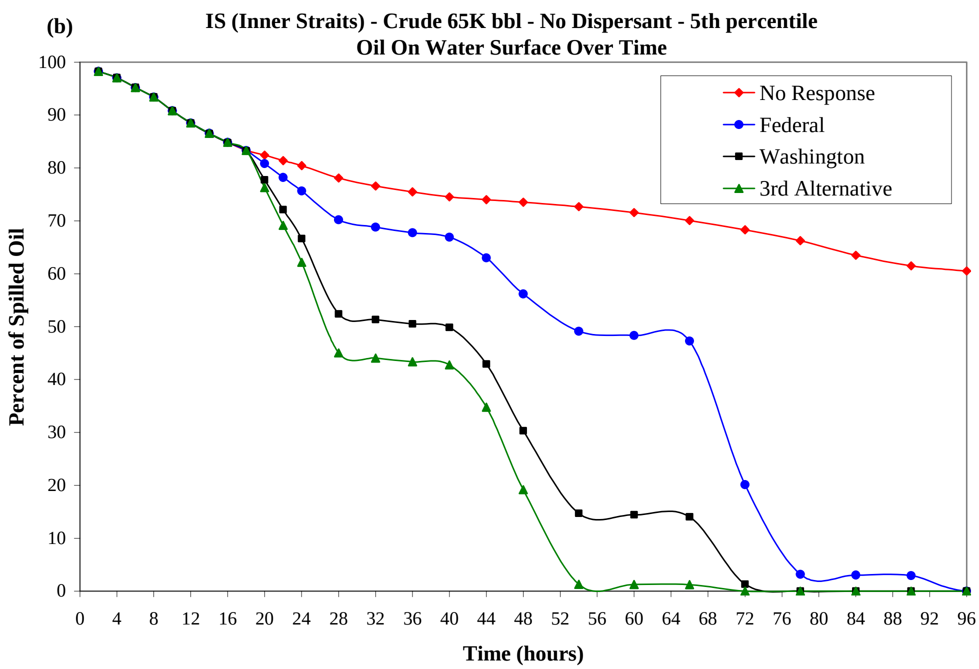


Figure XX.B.8-22 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.

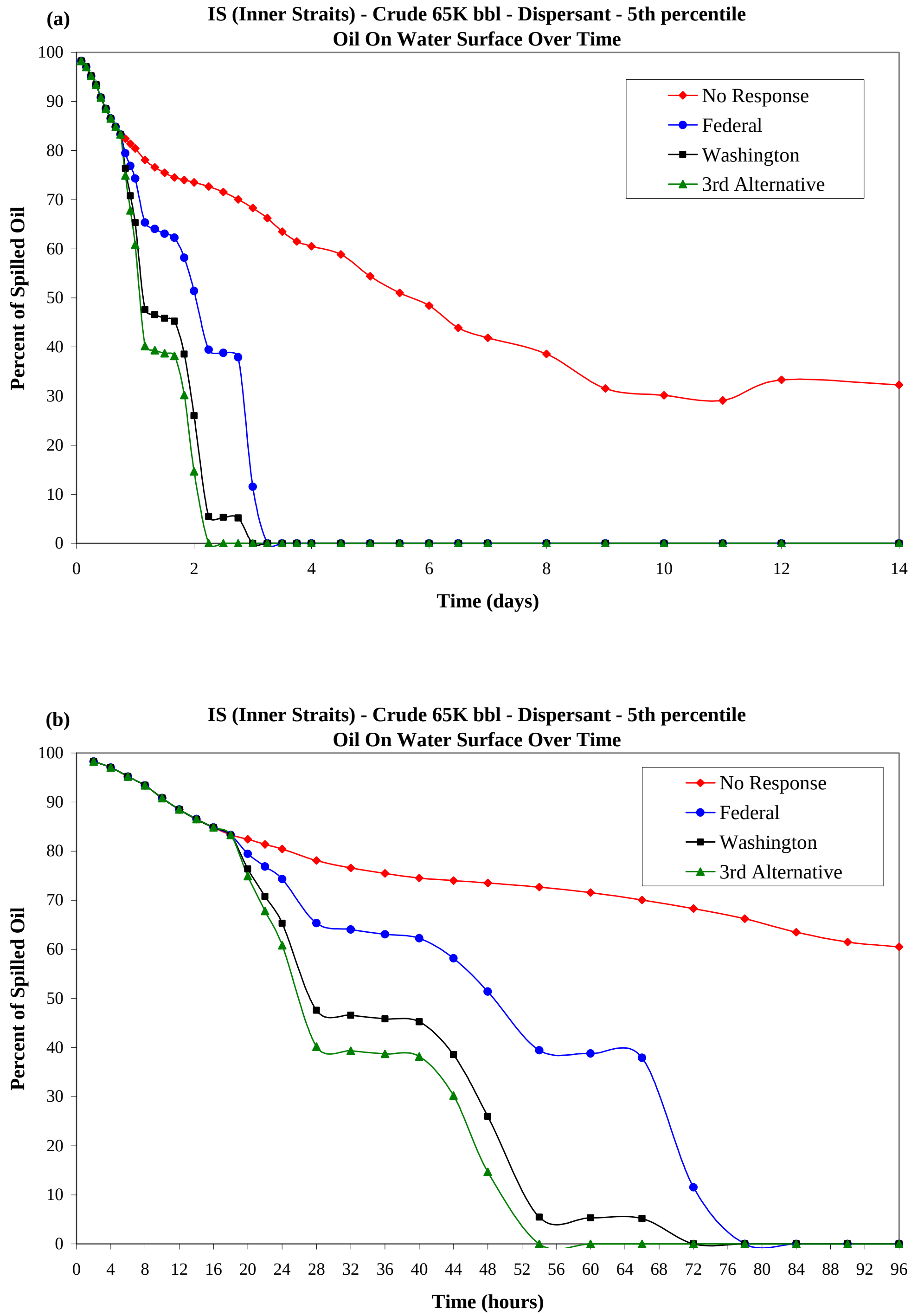


Figure XX.B.8-23 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.

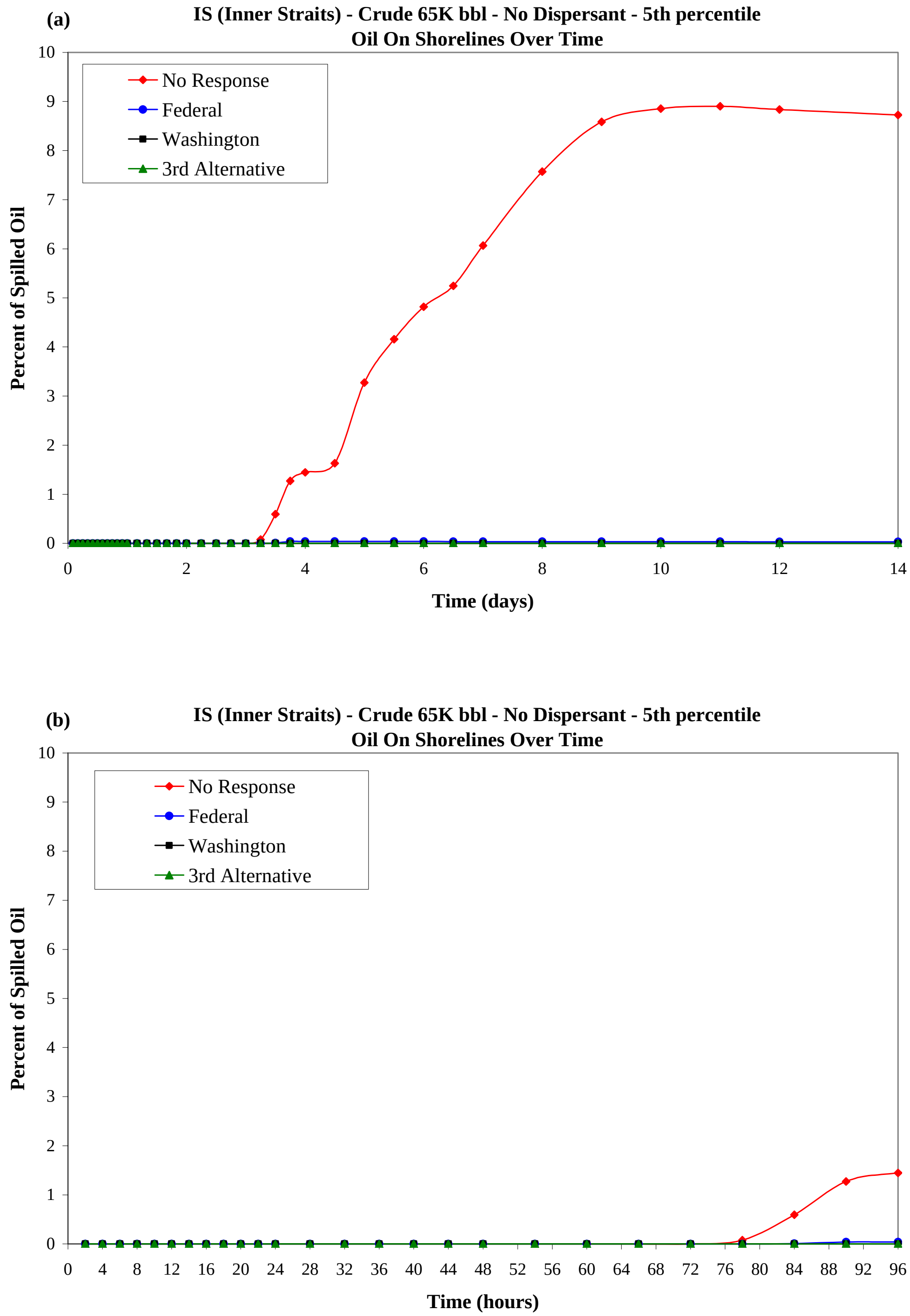


Figure XX.B.8-24 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b is a subset of Part a.

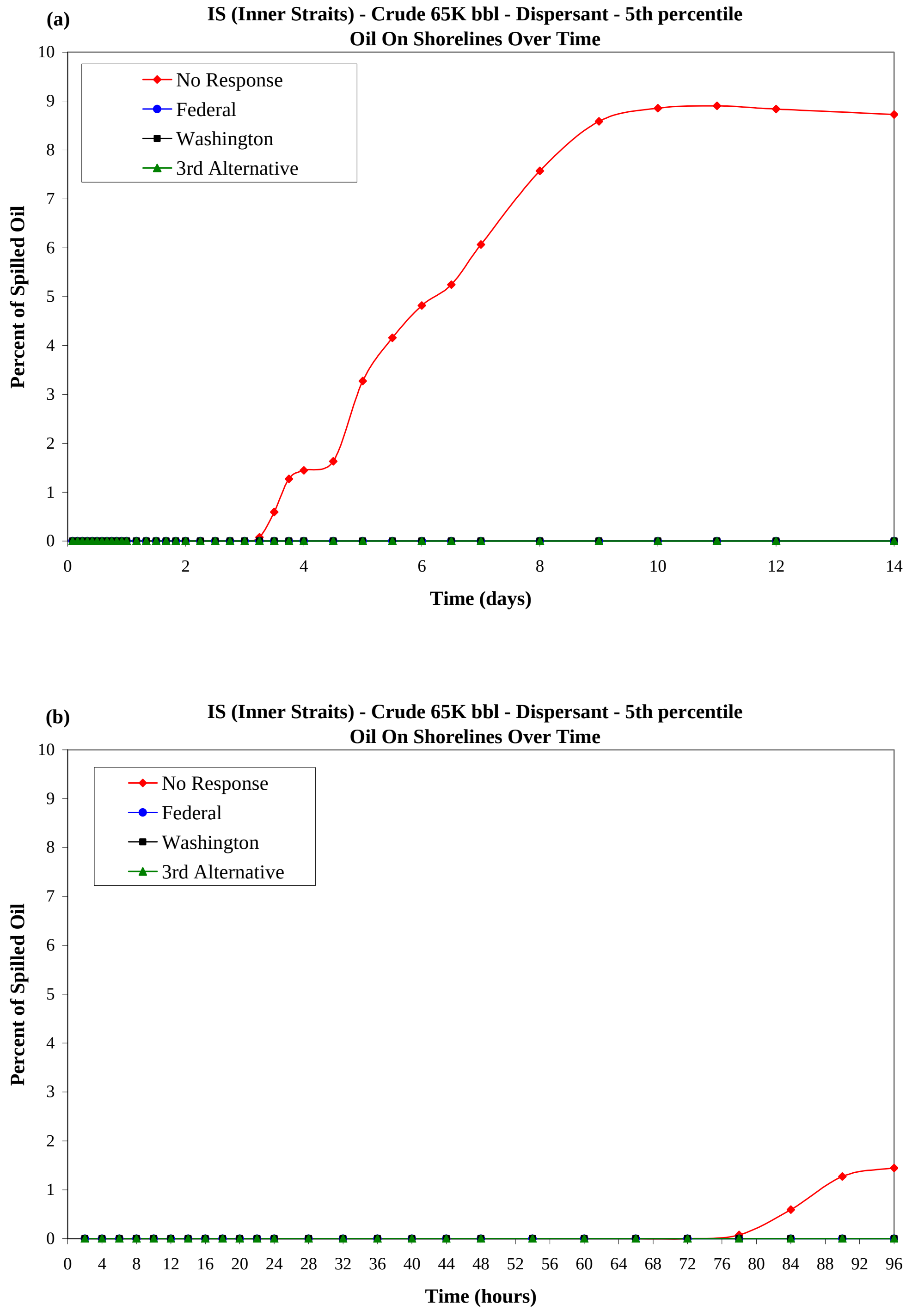
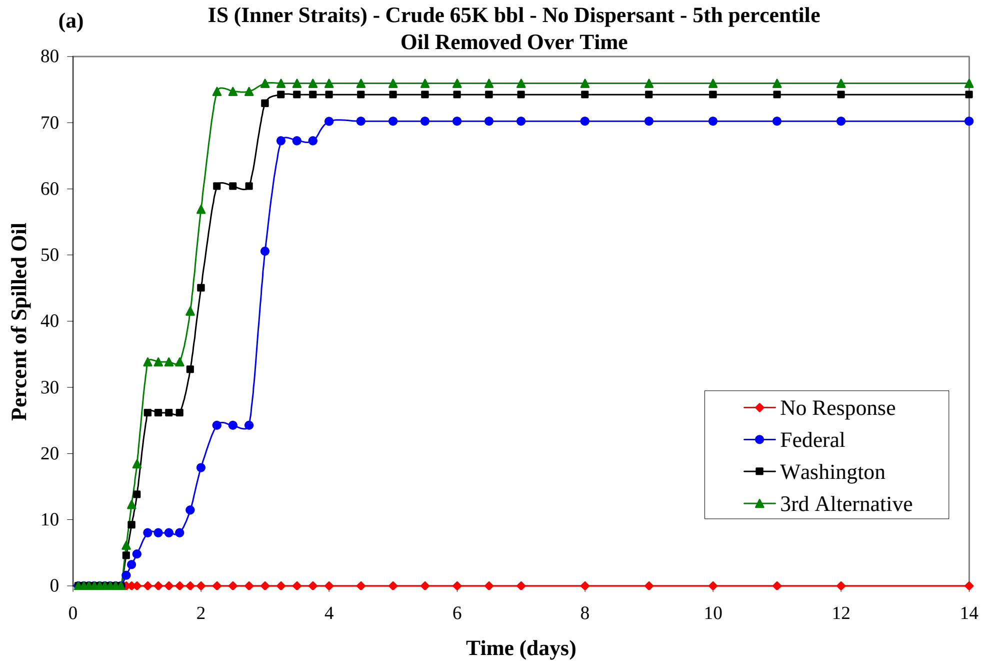


Figure XX.B.8-25 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



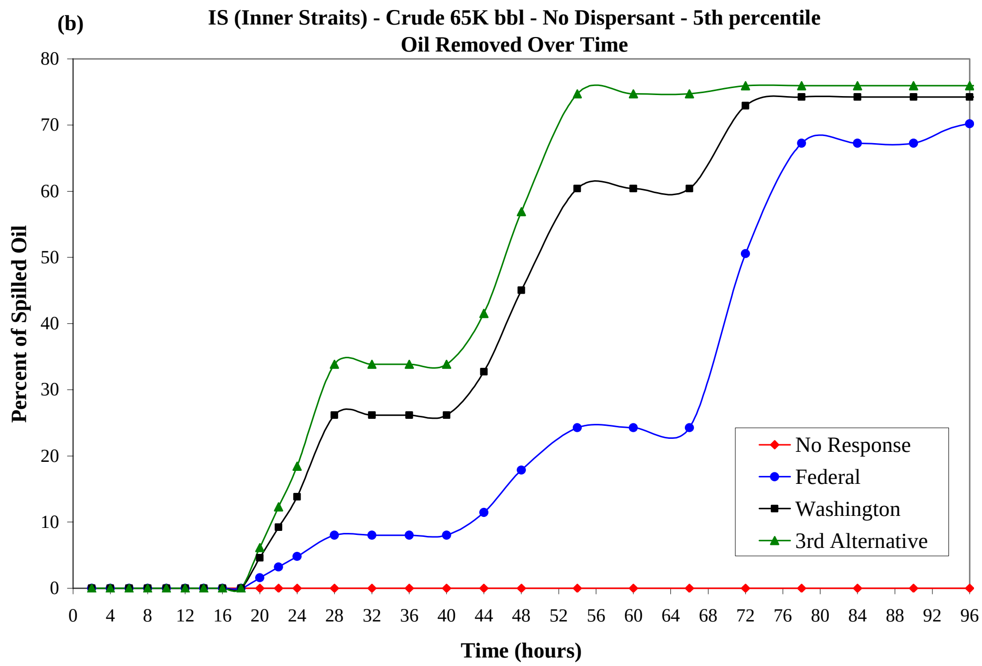
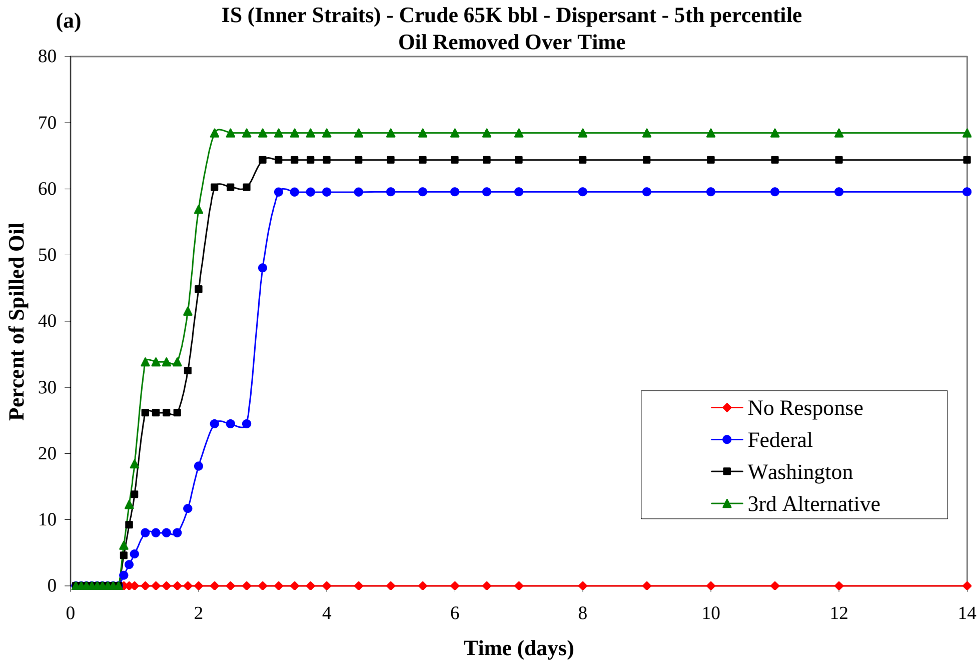


Figure XX.B.8-26 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



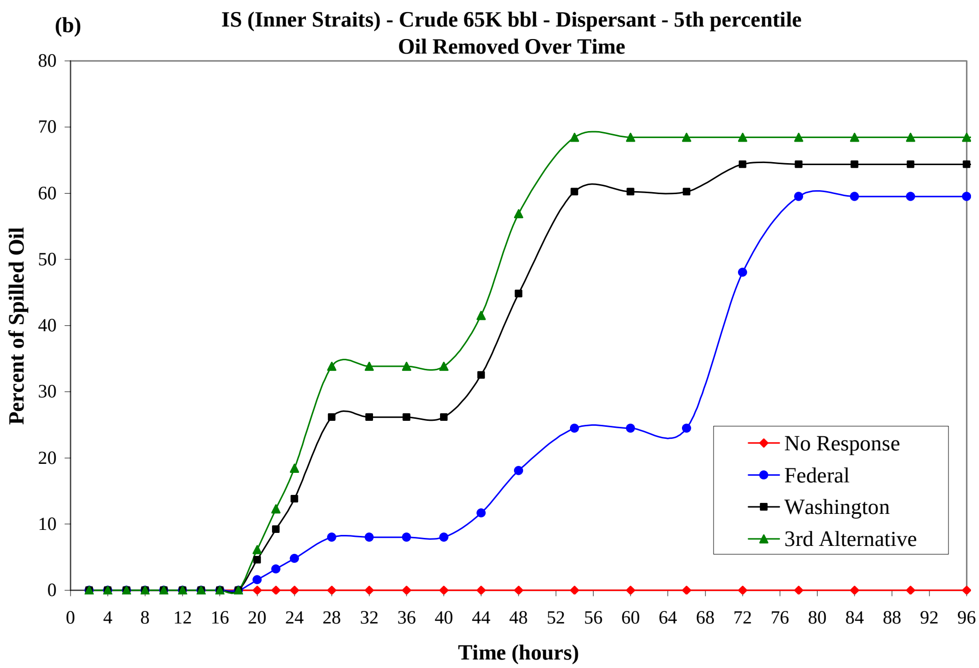
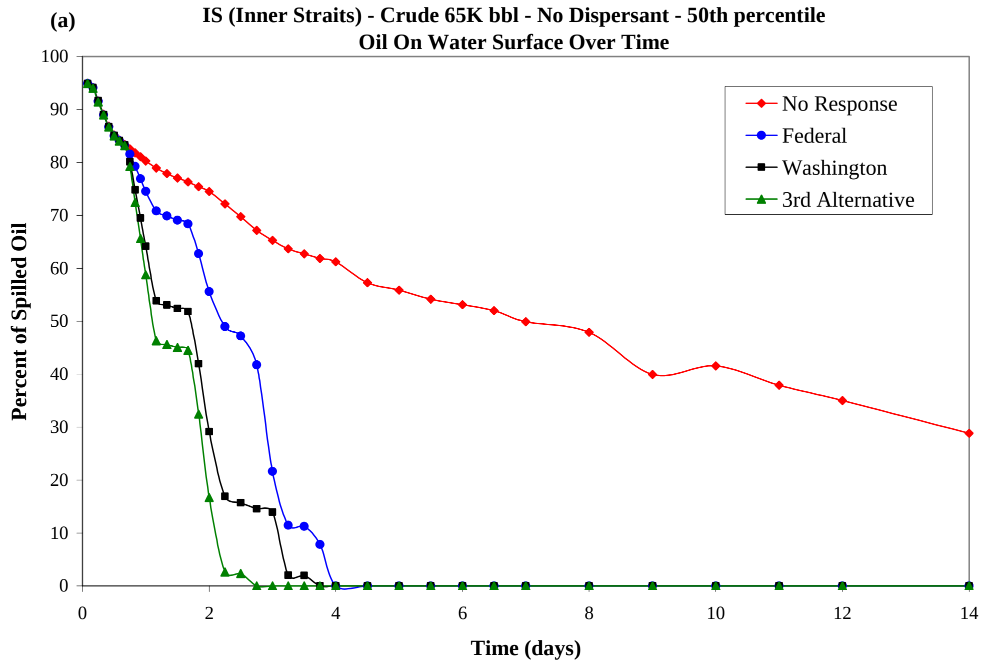


Figure XX.B.8-27 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 5th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



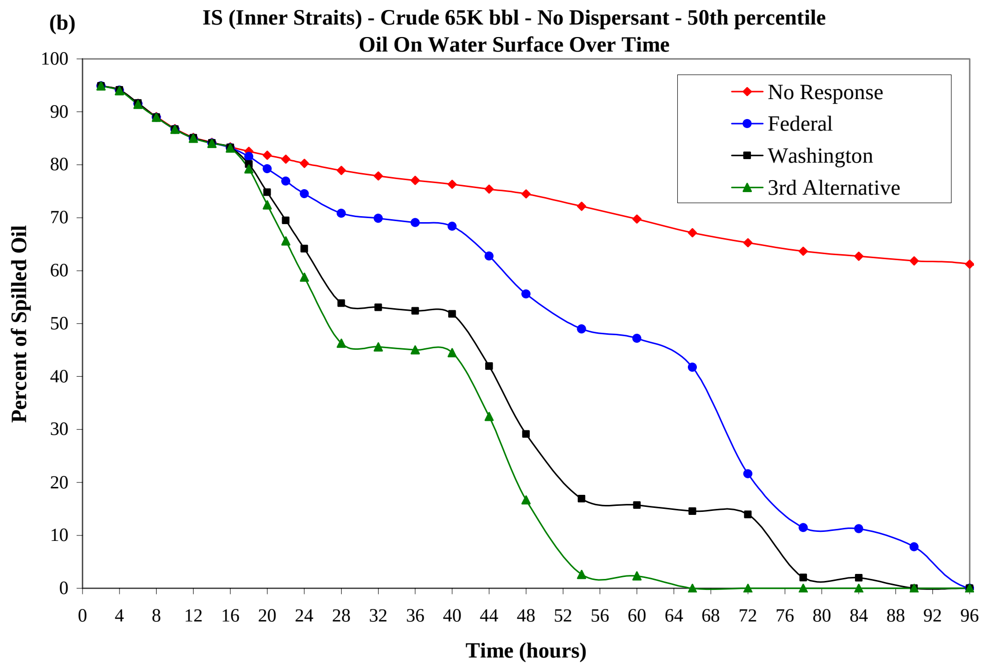
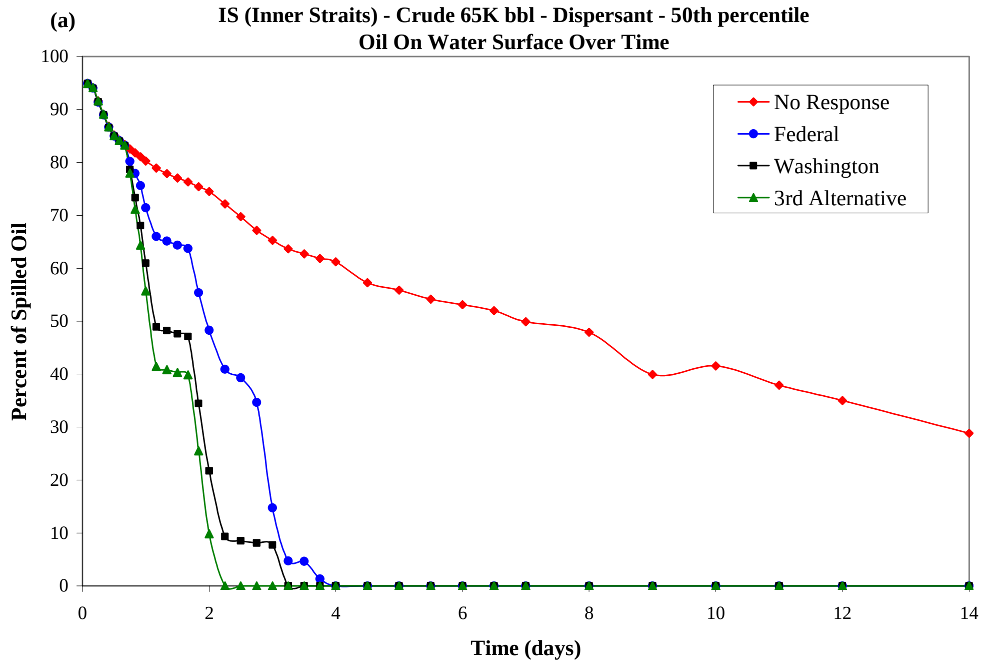


Figure XX.B.8-28 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



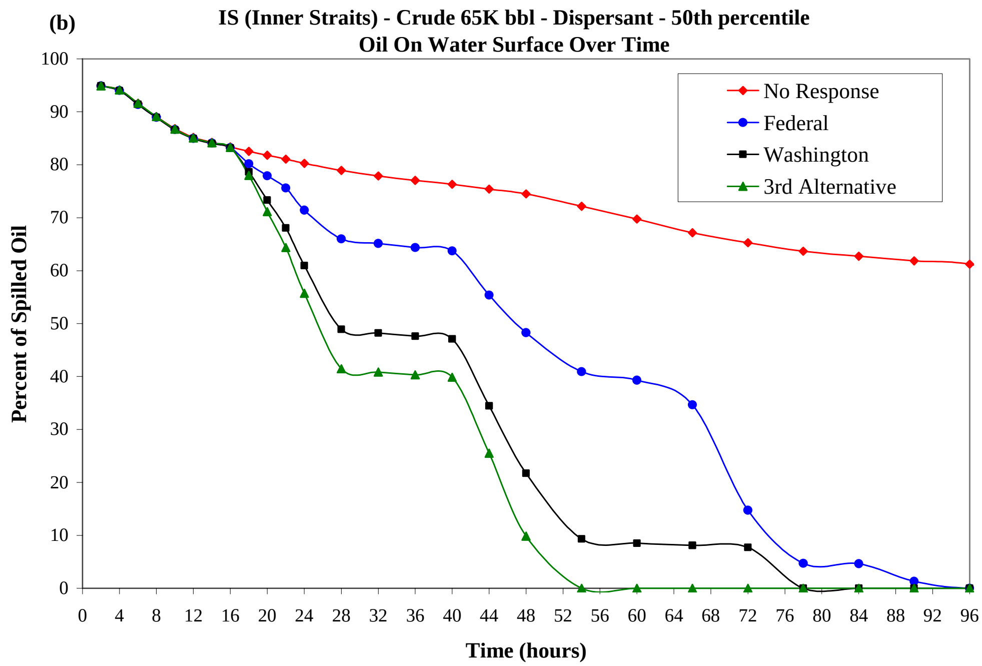
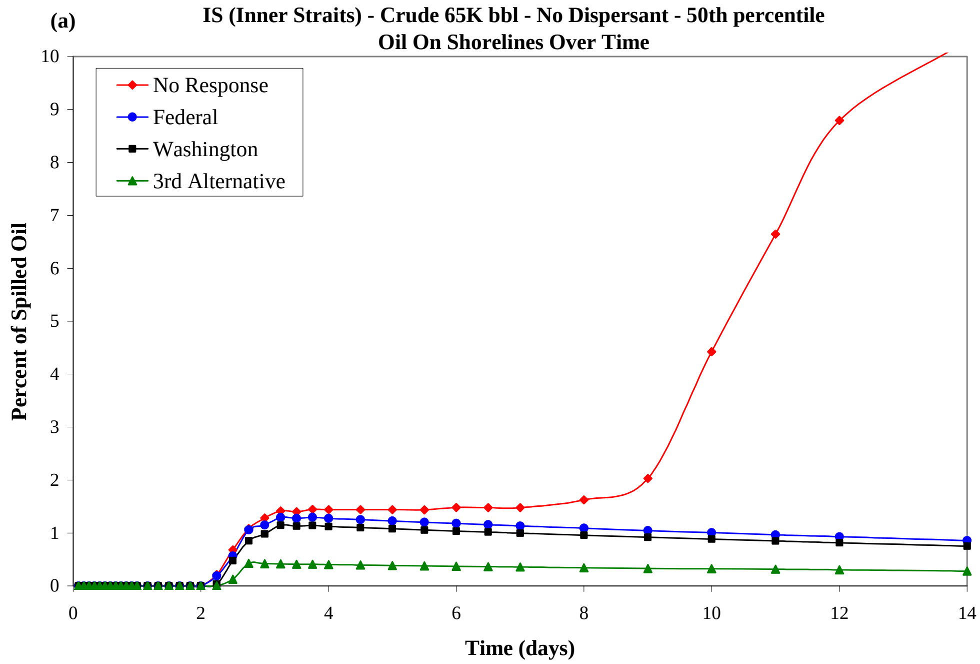


Figure XX.B.8-29 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



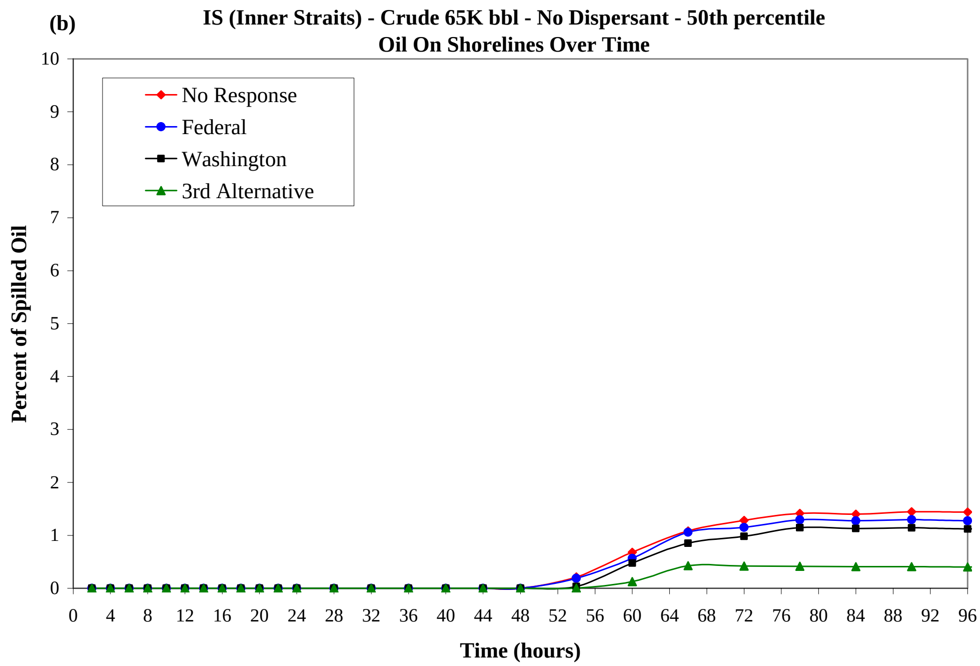
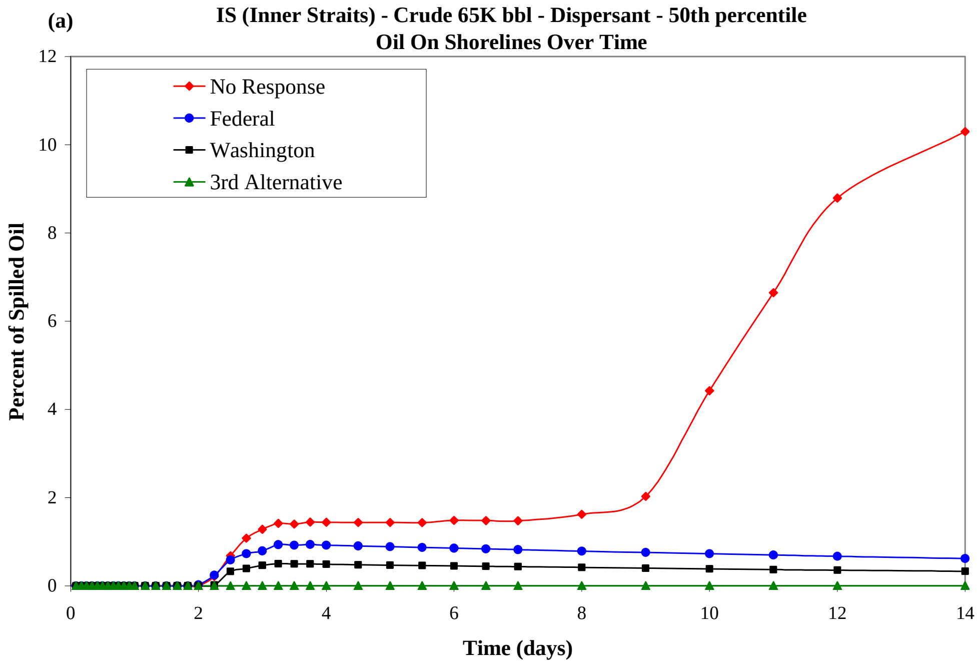


Figure XX.B.8-30 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



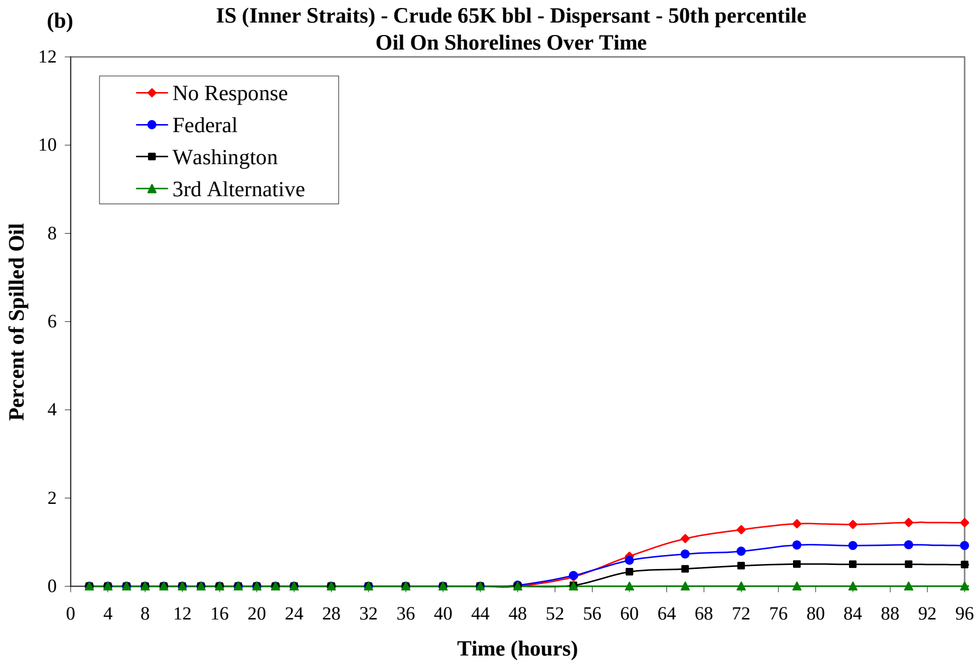
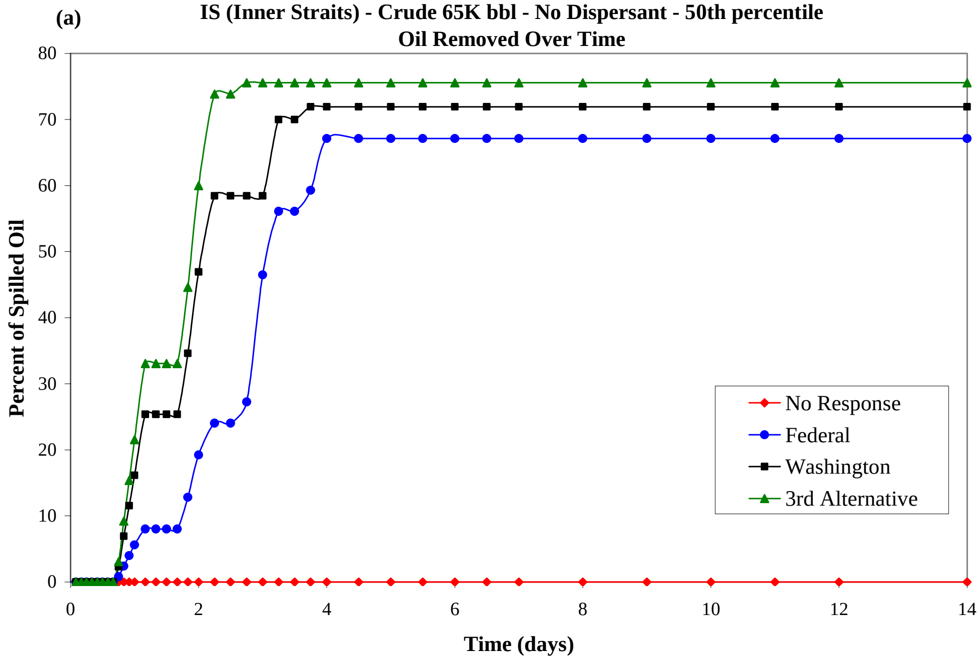


Figure XX.B.8-31 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



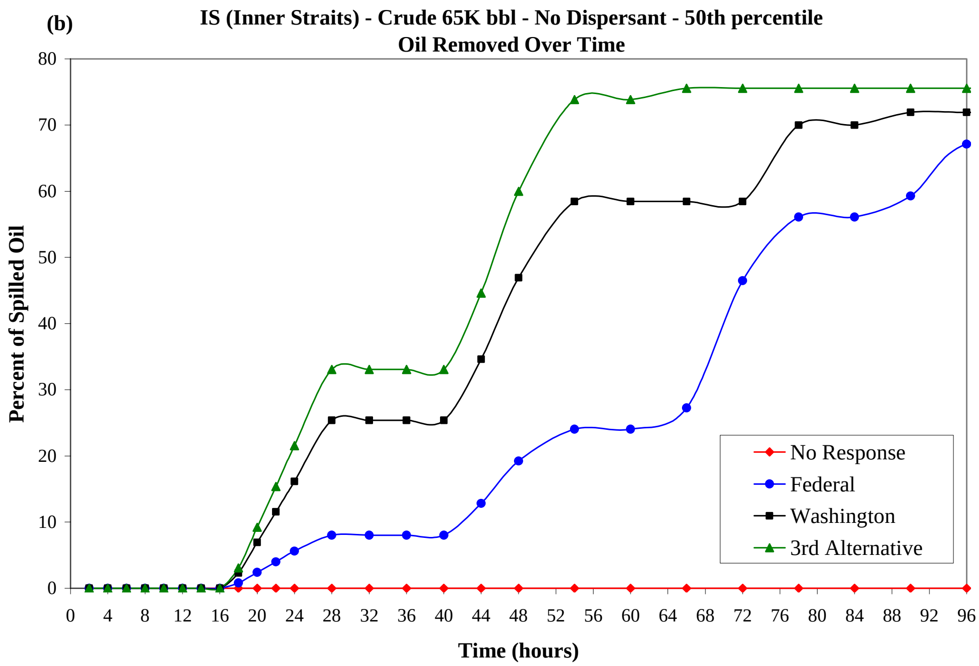
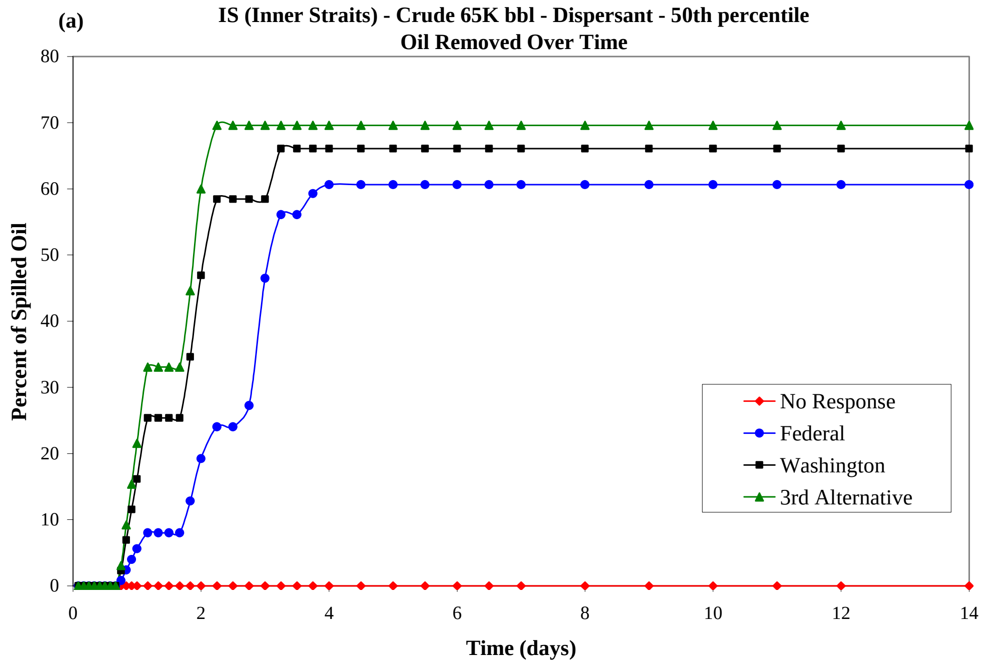


Figure XX.B.8-32 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



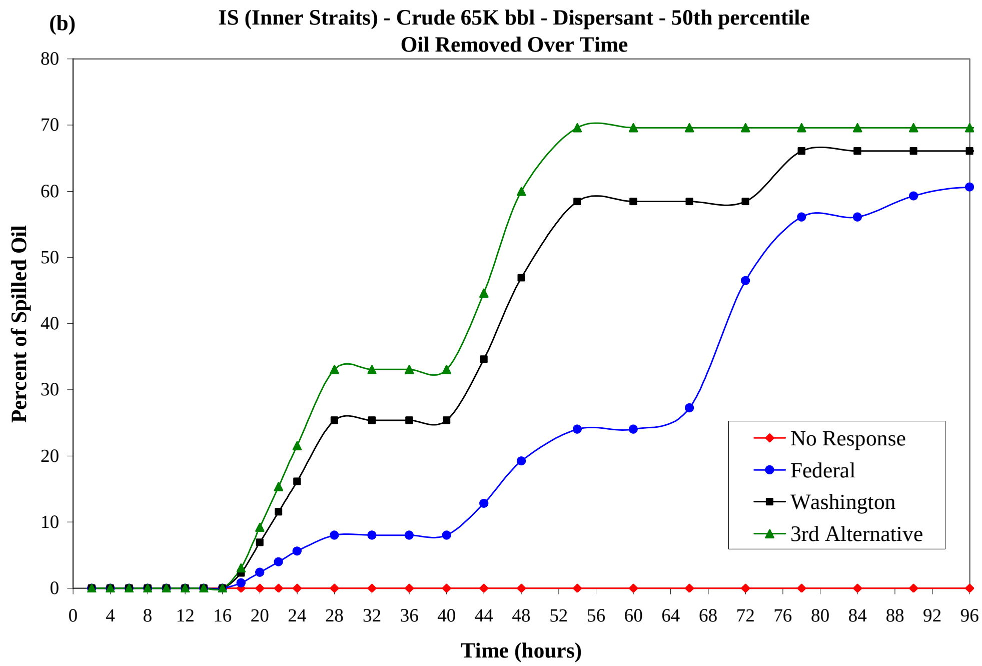
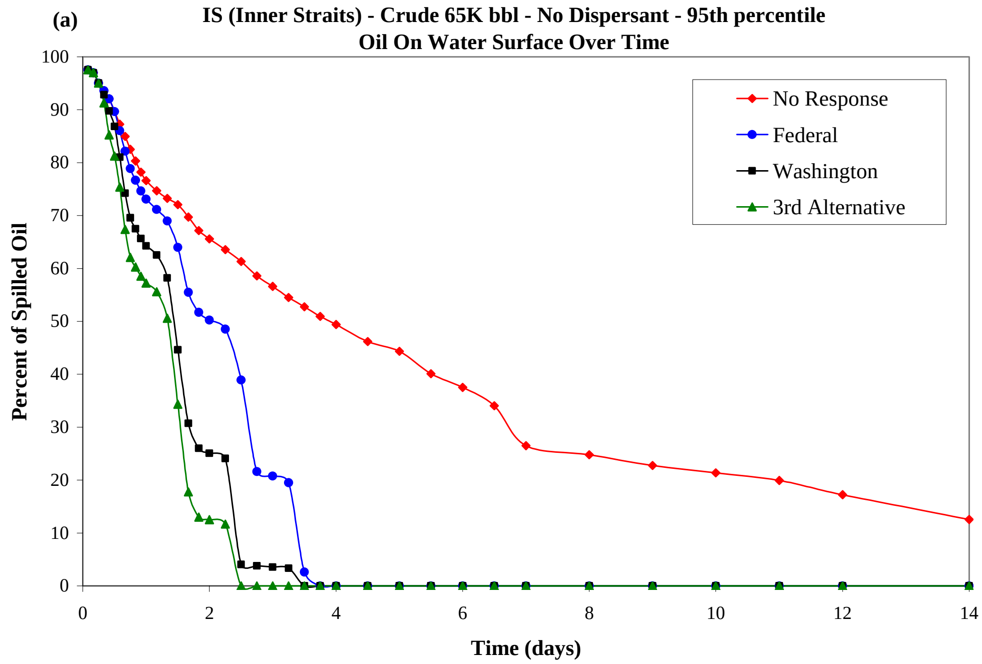


Figure XX.B.8-33 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 50th percentile run (based on shore cost). Part b is a subset of Part a.



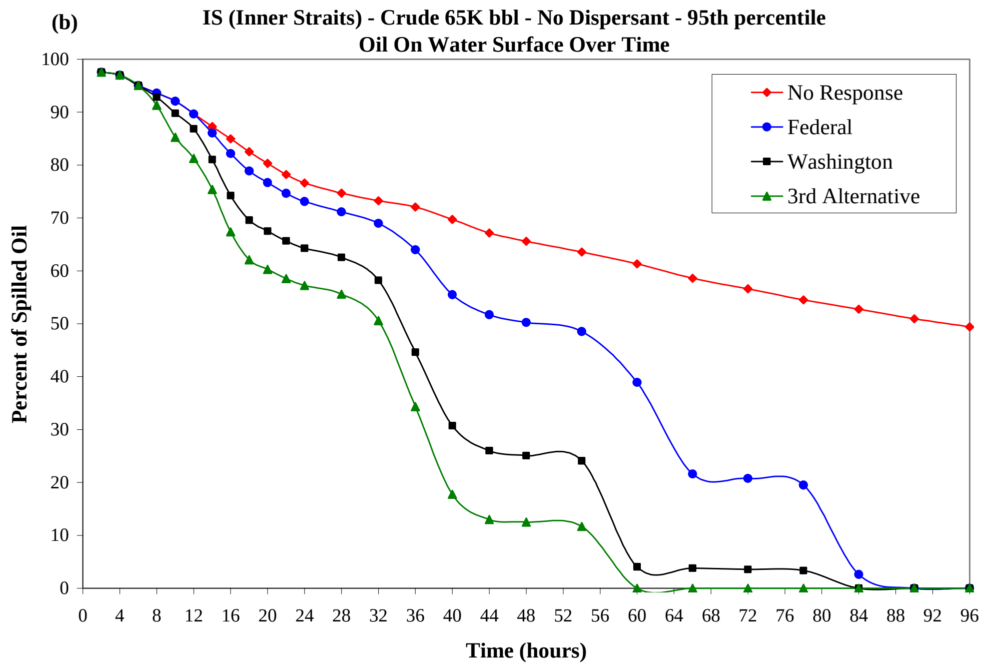


Figure XX.B.8-34 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.

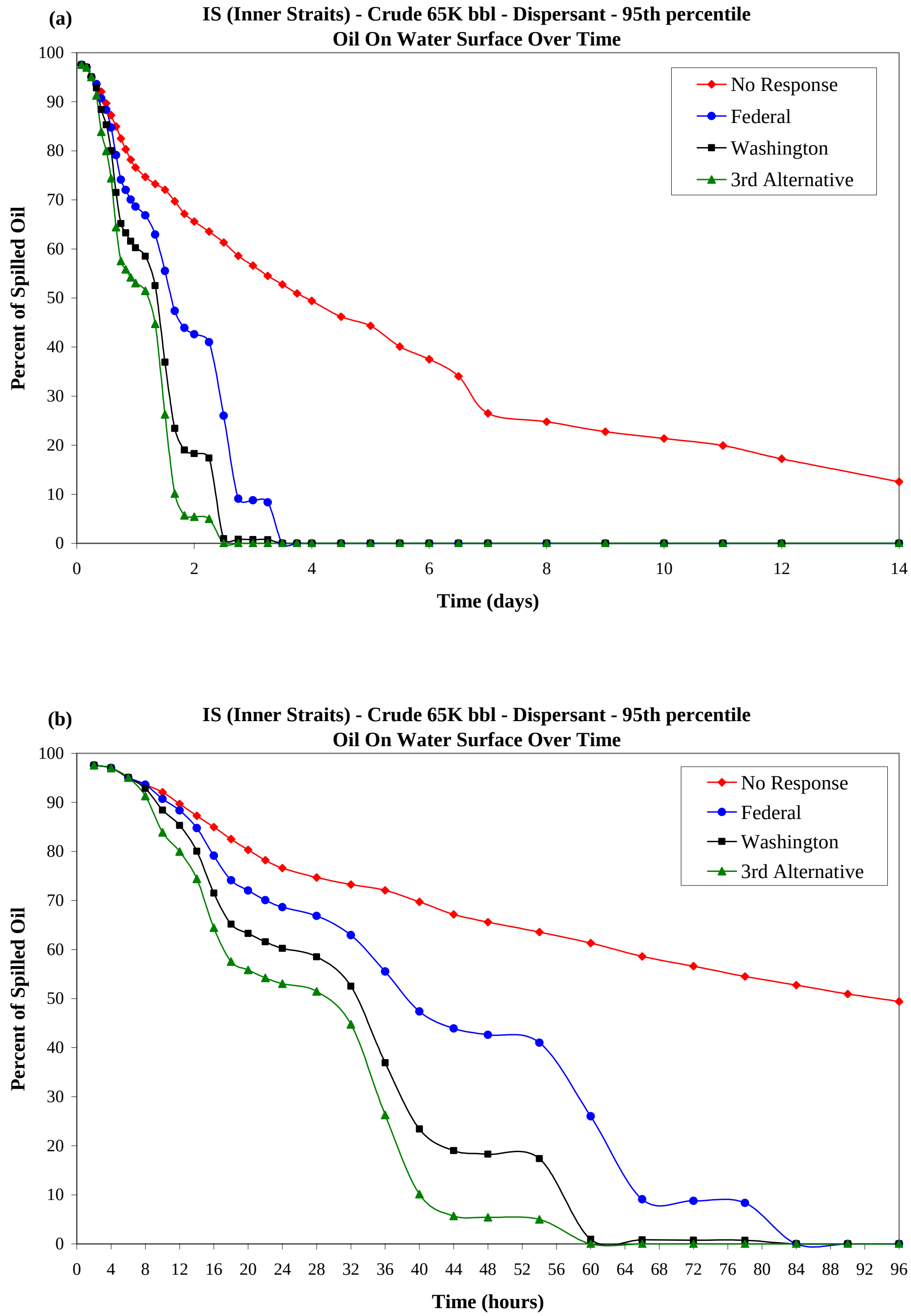
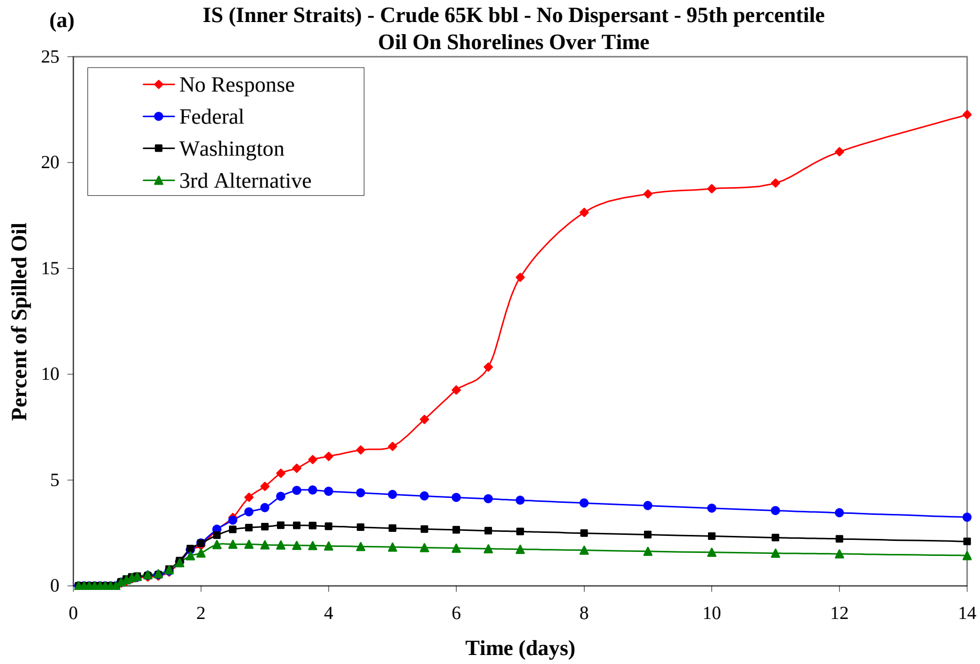


Figure XX.B.8-35 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



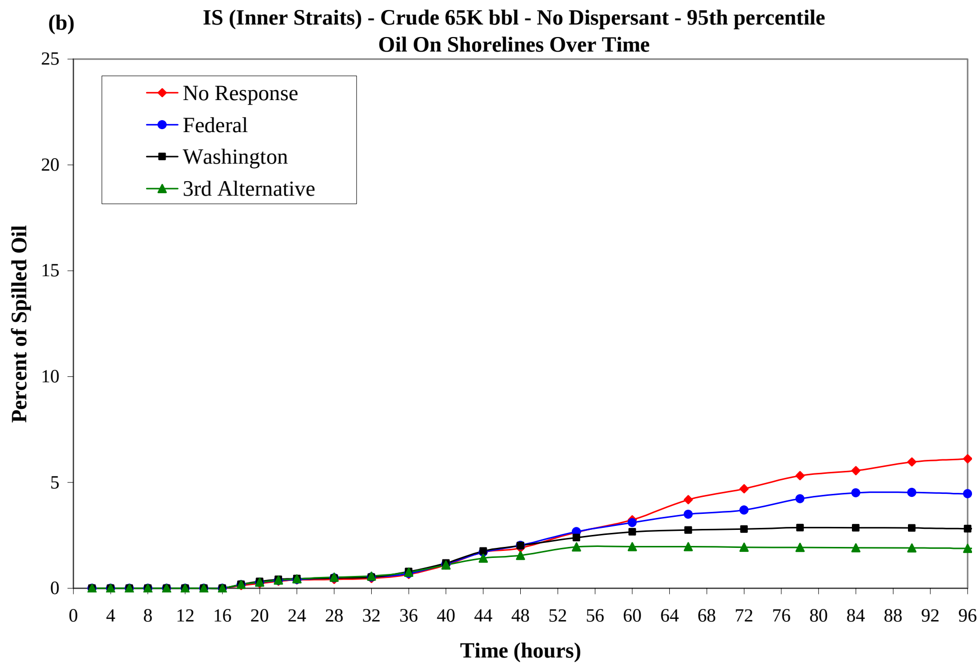
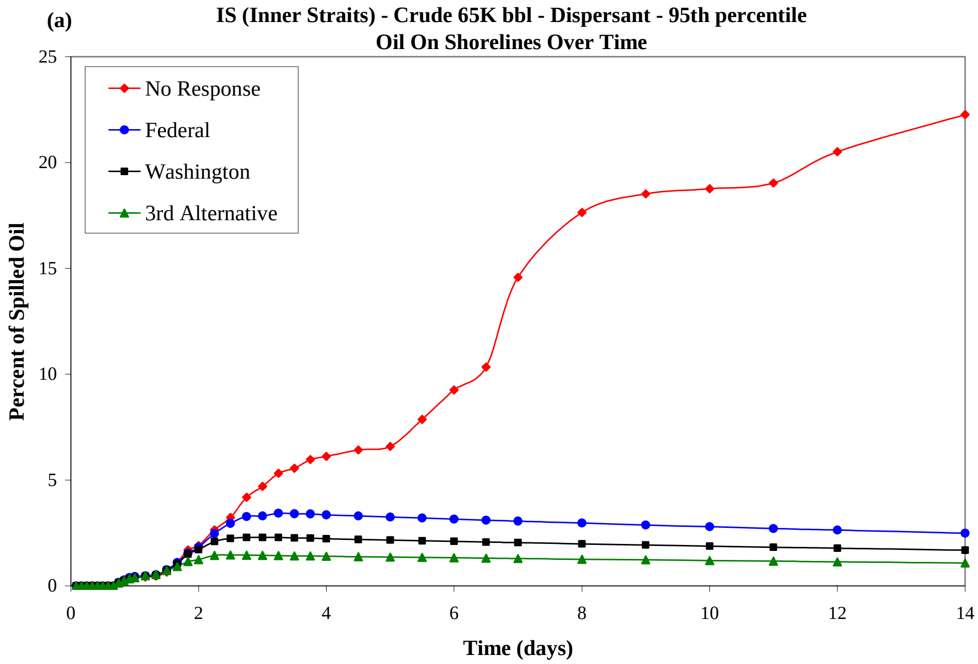


Figure XX.B.8-36 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



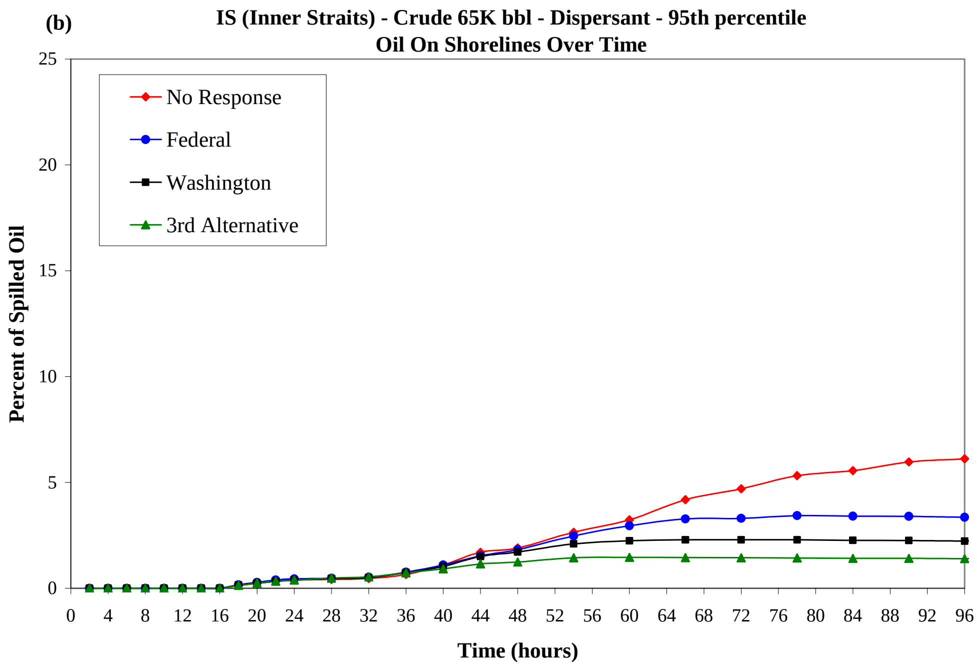
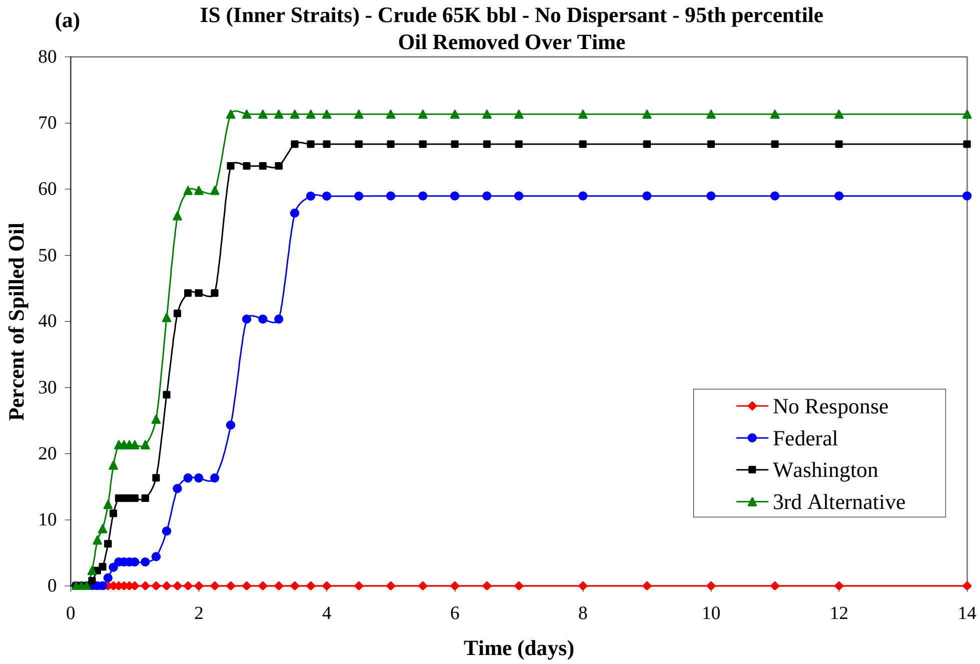


Figure XX.B.8-37 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



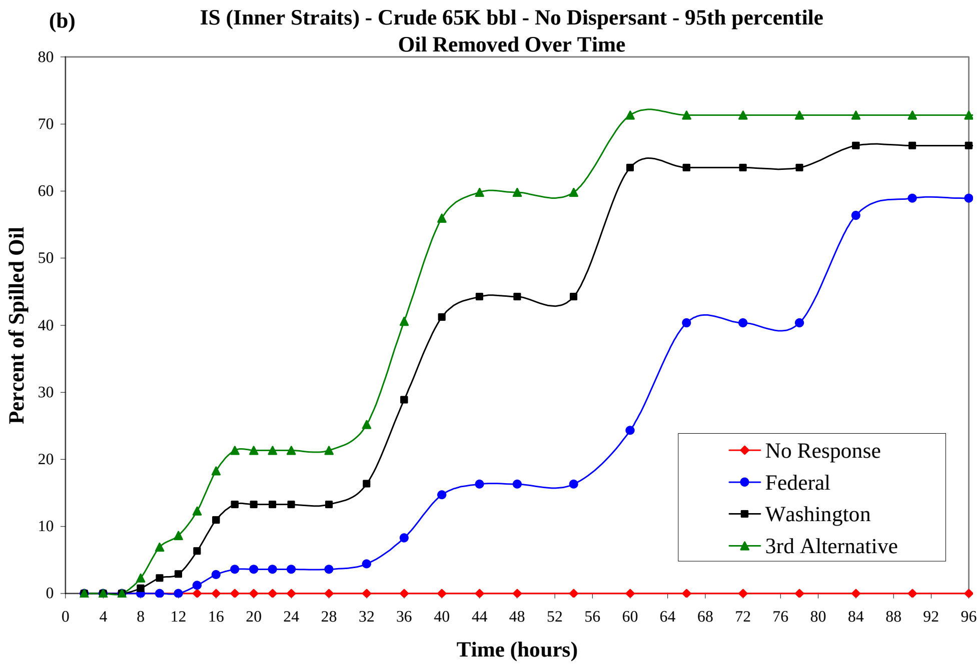
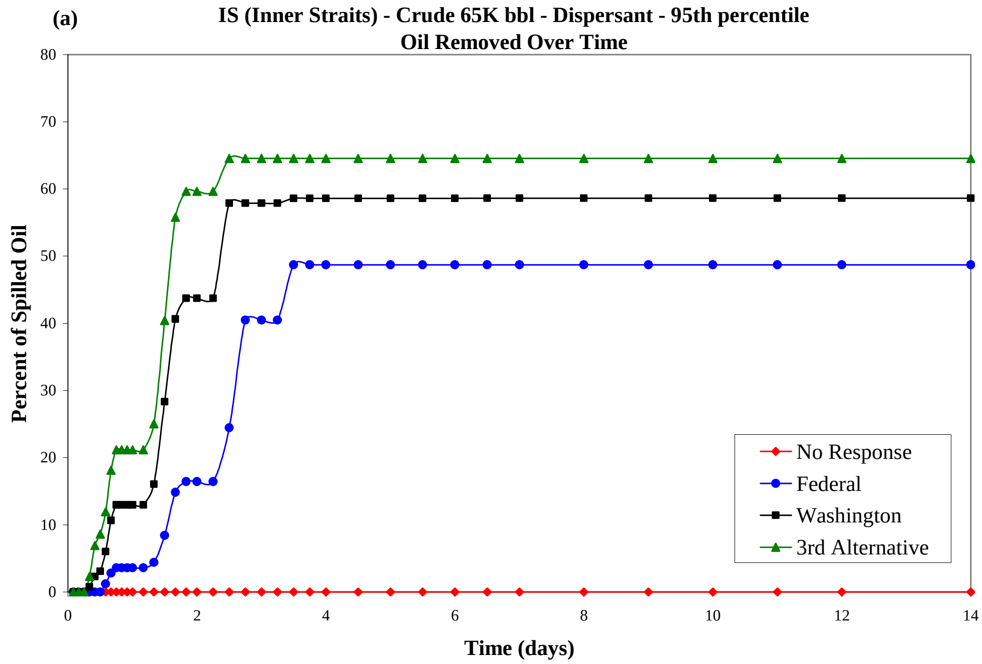


Figure XX.B.8-38 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal only) for the 95th percentile run. Part b is a subset of Part a.



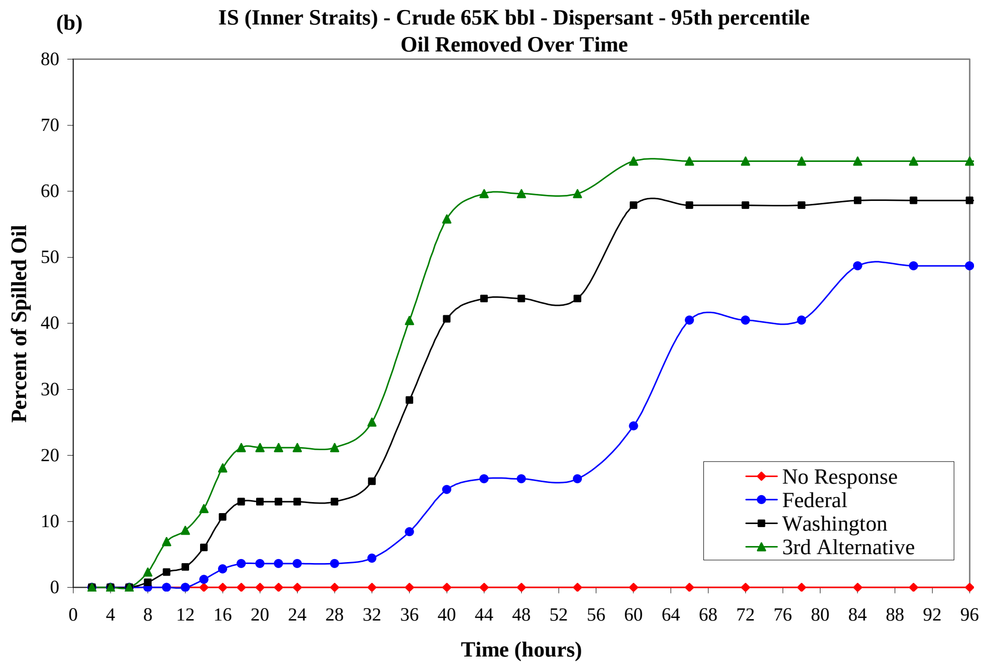


Figure XX.B.8-39 Inner Straits/Puget Sound - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios (mechanical removal and dispersant use) for the 95th percentile run. Part b is a subset of Part a.

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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan, Ann Borowik, and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrenchmccay@asascience.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
May 2006

List of Volumes

Volume I: Model Description, Approach, and Analysis
Volume II: Summary of Results for All Scenarios

Volume III: Model Inputs for Outer Coast (OC) Scenarios at Duntz Rock off Cape Flattery – Alaskan North Slope Crude
Volume IV: Model Results for Runs Assuming No Response for Outer Coast (OC) Scenarios at Duntz Rock off Cape Flattery – Alaskan North Slope Crude
Volume V: Results of Alternative Response Scenarios for Outer Coast (OC) Scenarios at Duntz Rock off Cape Flattery – Alaskan North Slope Crude
Volume VI: Model Inputs for Strait of Juan de Fuca – Bunker C
Volume VII: Model Results for Runs Assuming No Response for Strait of Juan de Fuca – Bunker C
Volume VIII: Results of Alternative Response Scenarios for Strait of Juan de Fuca – Bunker C
Volume IX: Model Inputs for Strait of Juan de Fuca – Diesel
Volume X: Model Results for Runs Assuming No Response for Strait of Juan de Fuca – Diesel
Volume XI: Results of Alternative Response Scenarios for Strait of Juan de Fuca – Diesel
Volume XII: Model Inputs for Strait of Juan de Fuca – Alaskan North Slope Crude
Volume XIII: Model Results for Runs Assuming No Response for Strait of Juan de Fuca – Alaskan North Slope Crude
Volume XIV: Results of Alternative Response Scenarios for Strait of Juan de Fuca – Alaskan North Slope Crude
Volume XV: Model Inputs for San Juan Islands – Alaskan North Slope Crude
Volume XVI: Model Results for Runs Assuming No Response for San Juan Islands – Alaskan North Slope Crude
Volume XVII: Results of Alternative Response Scenarios for San Juan Islands – Alaskan North Slope Crude
Volume XVIII: Model Inputs for Lower Columbia River – Bunker C
Volume XIX: Model Results for Runs Assuming No Response for Lower Columbia River – Bunker C
Volume XX: Results of Alternative Response Scenarios for Lower Columbia River – Bunker C
Volume XXI: Model Inputs for Upper Columbia River – Bunker C
Volume XXII: Model Results for Runs Assuming No Response for Upper Columbia River – Bunker C
Volume XXIII: Results of Alternative Response Scenarios for Upper Columbia River – Bunker C
Volume XXIV: Model Inputs for Outer Coast Sea Lanes – Bunker C
Volume XXV: Model Results for Runs Assuming No Response for Outer Coast Sea Lanes – Bunker C
Volume XXVI: Results of Alternative Response Scenarios for Outer Coast Sea Lanes – Bunker C
Volume XXVII: Model Inputs for Grays Harbor – Bunker C

Volume XXVIII: Model Results for Runs Assuming No Response for Grays Harbor – Bunker C
Volume XXIX: Results of Alternative Response Scenarios for Grays Harbor – Bunker C

Volume I: Table of Contents

Executive Summary 1

1. Introduction 12

2. SIMAP Model Description 21
- 2.1 Physical Fates Model 22
- 2.2 Biological Effects Model 25
  - 2.2.1 Wildlife 26
  - 2.2.2 Fish and Invertebrates 28
  - 2.2.3 Validation of the Biological Effects Model 30
  - 2.2.4 Quantification of Fish and Invertebrate Impacts as Lost Production 30
- 2.3 Stochastic Modeling 32
  - 2.3.1 Approach 32

3. Model Input Data 36
- 3.1 Geographical and Model Grid 36
- 3.2 Environmental Data 38
- 3.3 Currents 39
  - 3.3.1 Tidal and Other Currents 39
  - 3.3.2 Wind-driven Surface Currents 42
- 3.4 Oil Properties, Toxicity, and Impact Thresholds 42
  - 3.4.1 Whole oil 43
  - 3.4.2 Low molecular weight aromatics 43
  - 3.4.3 Toxicity Thresholds of Concern 44
- 3.5 Shoreline Oil Retention 45
- 3.6 Scenarios 46
- 3.7 Biological Abundance 50

4. Oil Fates Model Results 72
- 4.1 Explanation of Model Outputs 72
  - 4.1.1 Stochastic Output to Estimate Probabilities and Degrees of Exposure 72
  - 4.1.2 Estimated Exposure for the Sampled Range of Environmental Conditions 73
  - 4.1.3 Exposure Results for Individual Runs 75
- 4.2 Stochastic Model Results 75
- 4.3 Results for Individual Scenarios 85

5. Biological Effects Model Results 93
- 5.1 Intertidal Habitats 93
- 5.2 Wildlife 94
- 5.3 Fish and Invertebrates 96

6. Potential Natural Resource Damages 99
- 6.1 NRD Based on Restoration Costs 99
  - 6.1.1 Saltmarsh Restoration 102
  - 6.1.2 Seagrass Bed Restoration 103
- 6.2 Washington State Compensation Schedule 106

7. Discussion and Conclusions 108
- 7.1 Use of the Probabilistic Approach – Stochastic Modeling 108

7.2 Oil Recovery Rates 108
7.3 Differences in Impacts with Alternative Response Scenarios 109
7.4 Biological Impacts 109
7.5 Natural Resource Damages... 110

8. References.. 112

Contents of Volume II

II.1. Introduction
II.2. Summary of Impact statistics for the No-Response Stochastic Scenarios
II.3. Comparison of Alternative Responses: Outer Coast at Duntz Rock off Cape Flattery – Alaskan North Slope Crude
II.4. Comparison of Alternative Responses: Strait of Juan de Fuca – Bunker C
II.5. Comparison of Alternative Responses: Strait of Juan de Fuca – Diesel
II.6. Comparison of Alternative Responses: Strait of Juan de Fuca – Alaskan North Slope Crude
II.7. Comparison of Alternative Responses: San Juan Islands – Alaskan North Slope Crude
II.8. Comparison of Alternative Responses: Lower Columbia River – Bunker C
II.9. Comparison of Alternative Responses: Upper Columbia River – Bunker C
II.10. Comparison of Alternative Responses: Outer Coast Sea Lanes – Bunker C
II.11. Comparison of Alternative Responses: Grays Harbor – Bunker C

Contents of Volumes III, VI, IX, XII, XV, XVIII, XXI, XXIV, and XXVII

III.A. Introduction
III.B. Geographical Data
    III.B.1. Maps of the Vicinity of the Modeled Spill Locations
    III.B.2. Gridded Habitat Mapping
    III.B.3. Gridded Depth Data
    III.B.4. Areas Where Response Actions Assumed
III.C. Current Data
    III.C.1. Basis of Current Data
    III.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations
III.D: Oil Properties
III.E: Inputs to the SIMAP Physical Fates Model

Contents of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII

IV.A. Introduction
IV.B. Maps of Exposure Probability and Time First Exposed
IV.C. Statistics for All Model Runs
IV.D. Shoreline Areas Exposed by Shore Type
IV.E. Exposure for Representative Individual Model Runs.
IV.F. Estimated Biological Impacts: Wildlife
IV.G. Estimated Biological Impacts: Fish and Invertebrates
IV.H. Estimated NRDA Costs: Habitat Restoration Costs
IV.I. Estimated NRDA Costs: Washington Compensation schedule

Contents for Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX

V.A. Introduction
V.B. Oil Fate Over Time
V.C. Estimated Biological Impacts: Wildlife
V.D. Estimated Biological Impacts: Fish and Invertebrates
V.E. Estimated NRDA Costs: Habitat Restoration Costs
V.F. Estimated NRDA Costs: Washington Compensation schedule

Volume I: List of Figures

Figure 1-1. Shipping route segments where the hypothetical spills are assumed to occur: Straits and Outer Coast at Duntz Rock scenarios. 18
Figure 1-2. Shipping route segments where the hypothetical spills are assumed to occur: Outer Coast-Sea Lanes and Grays Harbor scenarios. 18
Figure 1-3. Shipping route segments where the hypothetical spills are assumed to occur: Columbia River scenarios. 19
Figure 2-1. Simulated oil fates processes in open water... 24
Figure 2-2. LC50 of dissolved PAH mixtures from oil, as a function of exposure duration and temperature.. 28
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). 76
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). 77
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). 77
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). 78
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). 78
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). 79
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). 79
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).. 80
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)............................ 80
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).. 89
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)........................ 89
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)................................ 90

Volume I: List of Tables

Table E-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed. 7
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). 10
Table E-3. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled. 10
Table E-4. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled. 10
Table E-5. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates. 11
Table E-6. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (clams). 11
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. 11
Table 1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed. 15
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). 23
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. 27
Table 2-3. Biological resource types and exposure measure by which the resource is most affected. 34
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.) 37
Table 3-2. Default fringing intertidal habitat type, given adjacent subtidal or extensive intertidal habitat type. 38
Table 3-3. LC50s for fuel components and varying exposure times. 45
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). 45
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). 48
Table 3-6. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Strait of Juan de Fuca Spill 25,000 bbl Bunker (Etkin, 2005b). 48
Table 3-7. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Strait of Juan de Fuca Spill 65,000 bbl Diesel (Etkin, 2005b). 48
Table 3-8. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Strait Juan de Fuca Spill 250,000 bbl ANS Crude (Etkin, 2005b). 49

Table 3-9. Modeled mechanical Spill Response Capability (bbl/day recovery rate): San Juan Islands Spill 250,000 bbl ANS Crude (Etkin, 2005b). 49
Table 3-10. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Columbia River Spill 25,000 bbl Bunker (Etkin, 2005b). 49
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). 50
Table 3-12. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Grays Harbor Spill 25,000 bbl Bunker (Etkin et al., 2006). 50
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. 52
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. 53
Table 3-15. Wildlife densities assumed for the lower Columbia River, as seasonal means in number per km^2. 55
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] 56
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. 58
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. 60
Table 3-19. Fish and invertebrate densities (kg/km^2) assumed for the lower Columbia River, as seasonal mean by habitat. 61
Table 3-20. Fish and invertebrate densities (kg/km^2) assumed for the upper Columbia River, as seasonal mean by habitat. 62
Table 3-21. Fish and invertebrate taxonomic grouping used in modeling. 64
Table 3-22. Fish and invertebrate taxa codes for species in Strait of Juan de Fuca, San Juan Islands, and Puget Sound. 64
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). 65
Table 3-24. Fish and invertebrate taxa codes for species for the lower Columbia River. 65
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. 67
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. 68
Table 3-28. Fish and invertebrate young-of-the-year densities ($\#/km^2$) assumed for the lower Columbia River, as seasonal means by habitat. 69
Table 3-29. Fish and invertebrate young-of-the-year densities ($\#/km^2$) assumed for the upper Columbia River, as seasonal means by habitat. 70

Table 3-30. Intertidal invertebrate densities (kg/km^2) by location. 71
Table 4-1. Oil thickness (microns ~ g/m^2) and appearance on water (NRC, 1985). 73
Table 4-2. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass coming ashore (%). 81
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). 82
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, %). 82
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 (%).. 83
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.. 83
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. 84
Table 4-8. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Outer Coast spills of crude oil at Duntz Rock. 85
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. 86
Table 4-10. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel. 86
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. 86
Table 4-12. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for San Juan Island spills of crude oil. 87
Table 4-13. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Lower Columbia River spills of Bunker C fuel. 87
Table 4-14. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Upper Columbia River spills of Bunker C fuel. 87
Table 4-15. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Outer Coast-Sea Lanes spills of Bunker C fuel. 88
Table 4-16. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Grays Harbor spills of Bunker C fuel. 88
Table 5-1. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to intertidal invertebrates (clams)... 94
Table 5-2. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled. 95
Table 5-3. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled.. 95
Table 5-4. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates... 97
Table 5-5. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal and intertidal fish and invertebrates. 98
Table 6-1. Assumed ecological efficiencies for one trophic step. 100

Table 6-2 Composite ecological efficiency relative to benthic invertebrate production by trophic group. 101
Table 6-3. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. 103
Table 6-4. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is wetland creation. 103
Table 6-5. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming seagrass bed creation. 105
Table 6-6. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is seagrass bed creation. 105
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. 107

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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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 5^{th} to 95^{th} percentile run by shore cost. The actual 5^{th}, 50^{th} and 95^{th} 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.

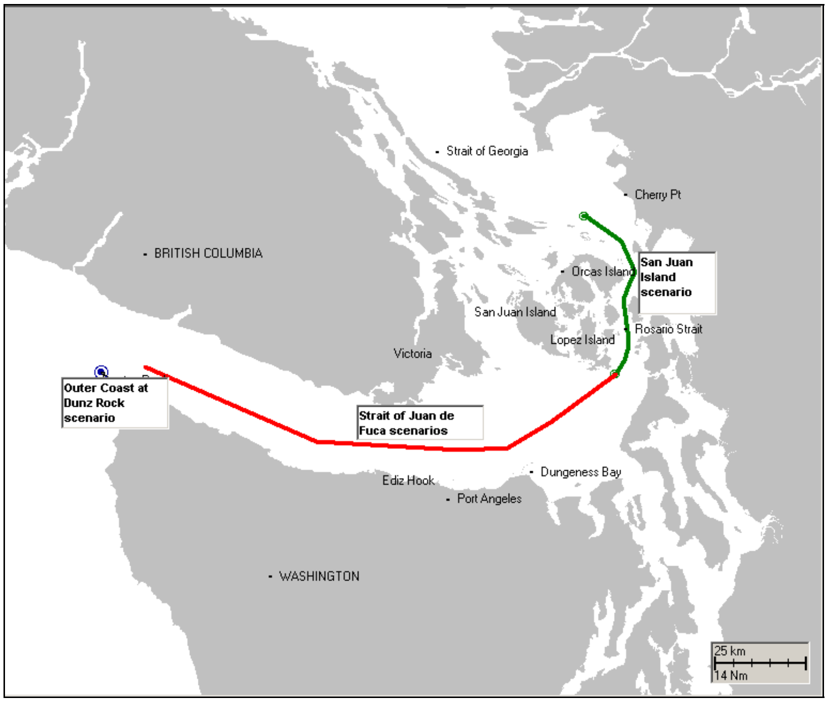


Figure 1-1. Shipping route segments where the hypothetical spills are assumed to occur: Straits and Outer Coast at Duntz Rock scenarios.

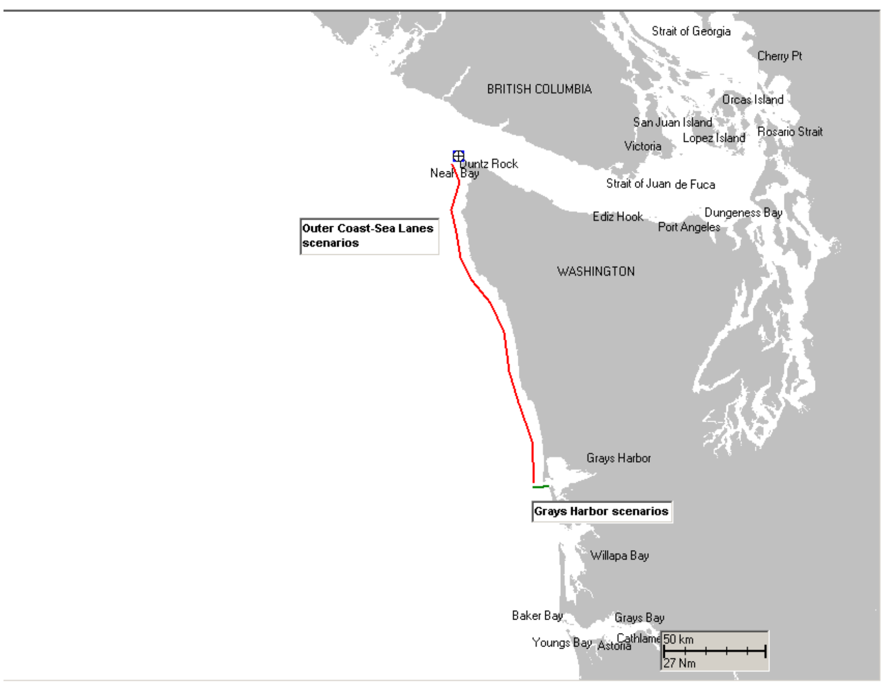


Figure 1-2. Shipping route segments where the hypothetical spills are assumed to occur: Outer Coast-Sea Lanes and Grays Harbor scenarios.

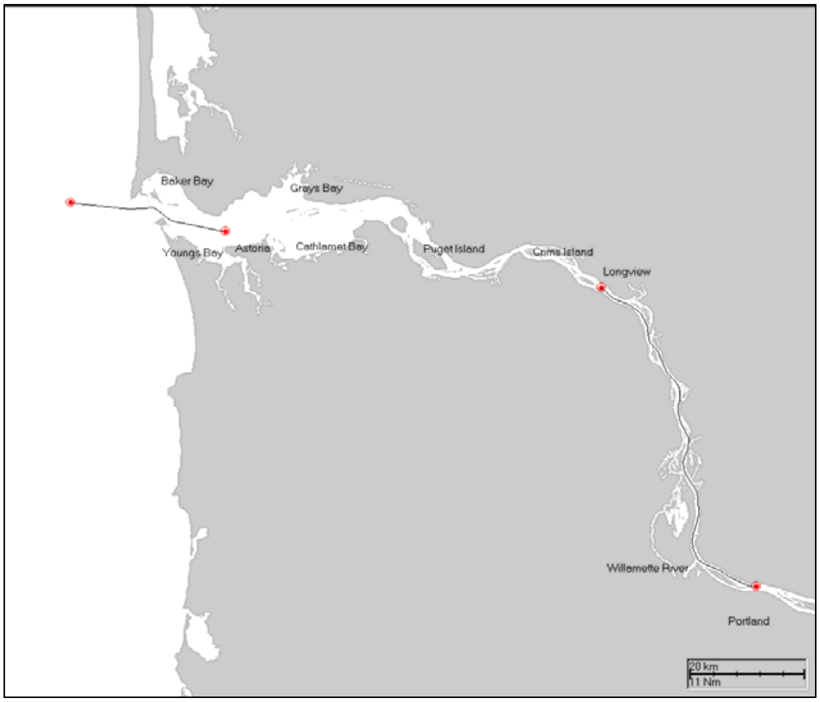


Figure 1-3. Shipping route segments where the hypothetical spills are assumed to occur: Columbia River scenarios.

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
$\mathrm{Log}(K_{ow})$	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.

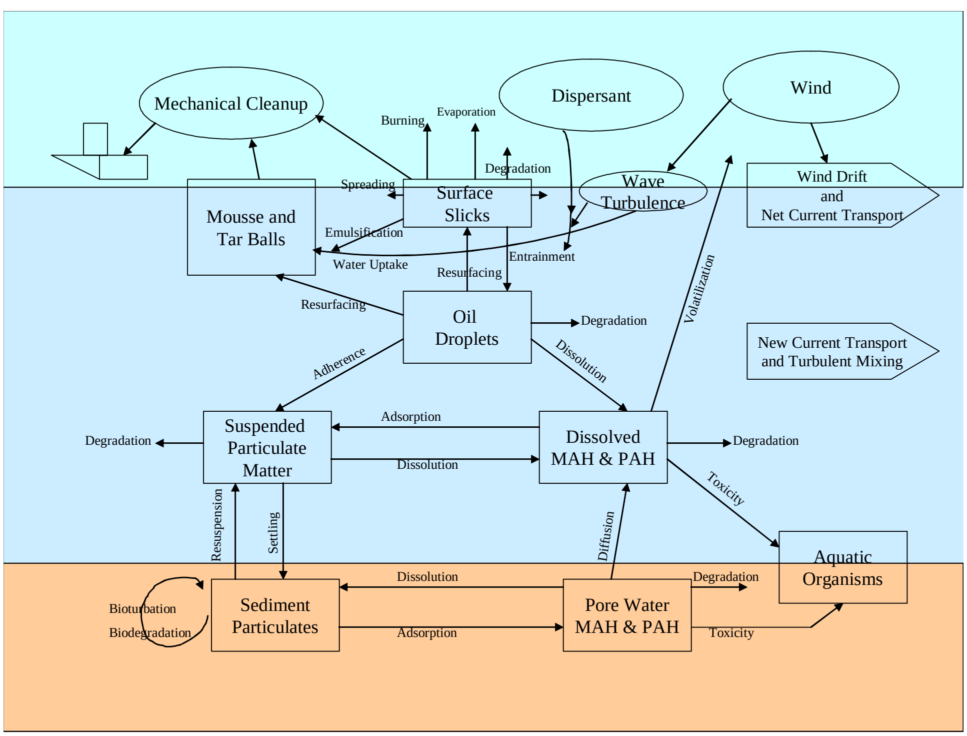


Figure 2-1. Simulated oil fates processes in open water

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.

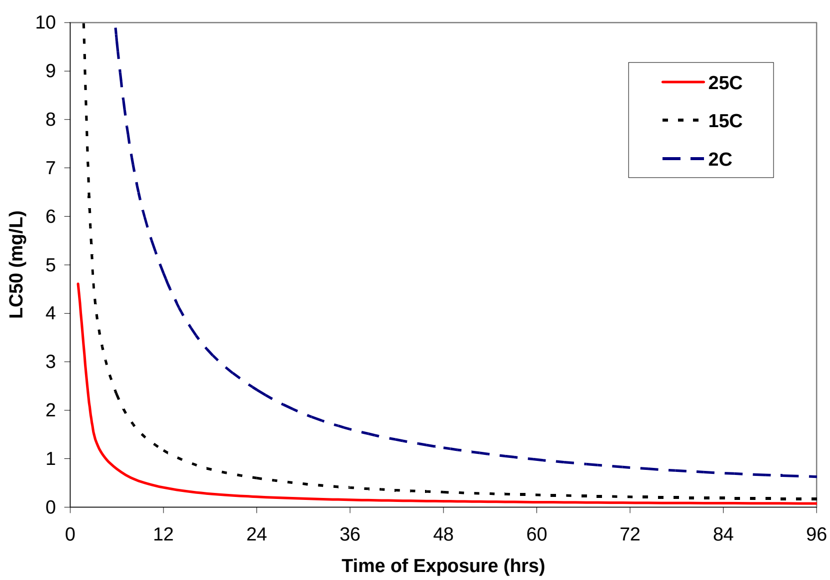


Figure 2-2. LC50 of dissolved PAH mixtures from oil, as a function of exposure duration and temperature.

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 50^{th} (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., 99^{th} 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).

- 5^{th}, 50^{th} and 95^{th} percentile runs based on shore cost, including shorelines of all jurisdictions for all scenarios except the Outer Coast – Sea Lanes and Grays Harbor;
- 5^{th}, 30^{th}, 50^{th}, 65^{th}, 80^{th} and 95^{th} percentile runs based on shore cost, including shorelines of all jurisdictions for the Outer Coast – Sea Lanes and Grays Harbor scenarios only;
- 5^{th}, 50^{th} and 95^{th} 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);
- 5^{th}, 30^{th}, 50^{th}, 65^{th}, 80^{th} and 95^{th} 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^{o}-30^{o} 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^{o}-30^{o} 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 (5^{th} percentile) and average (50^{th} 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.

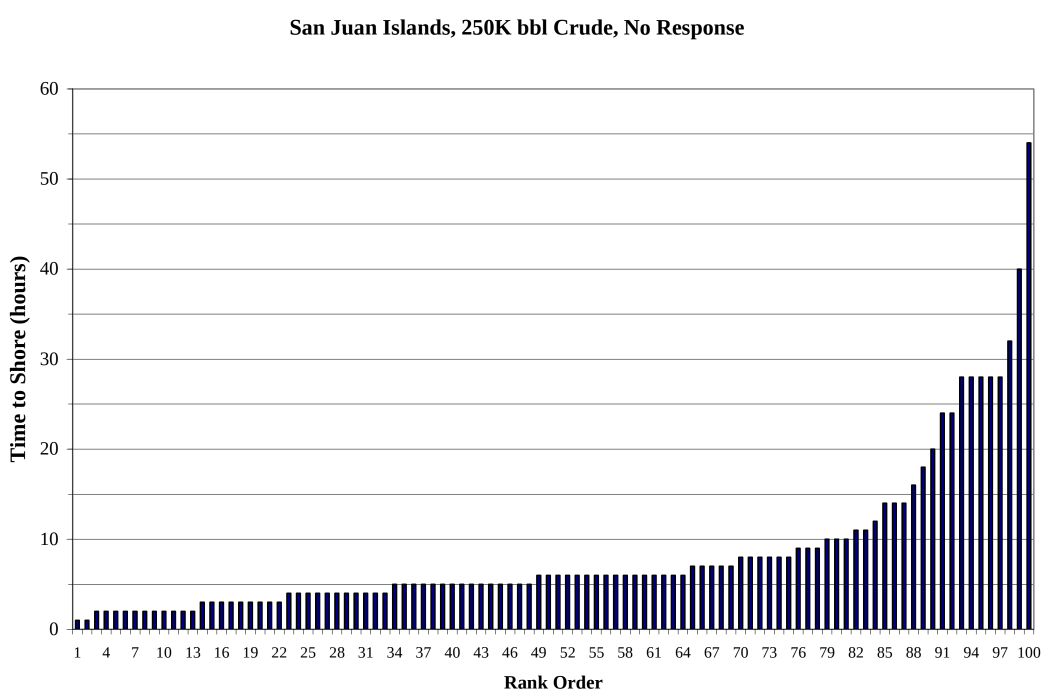


Figure 4-1. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the San Juan Island crude oil spill (no response assumed).

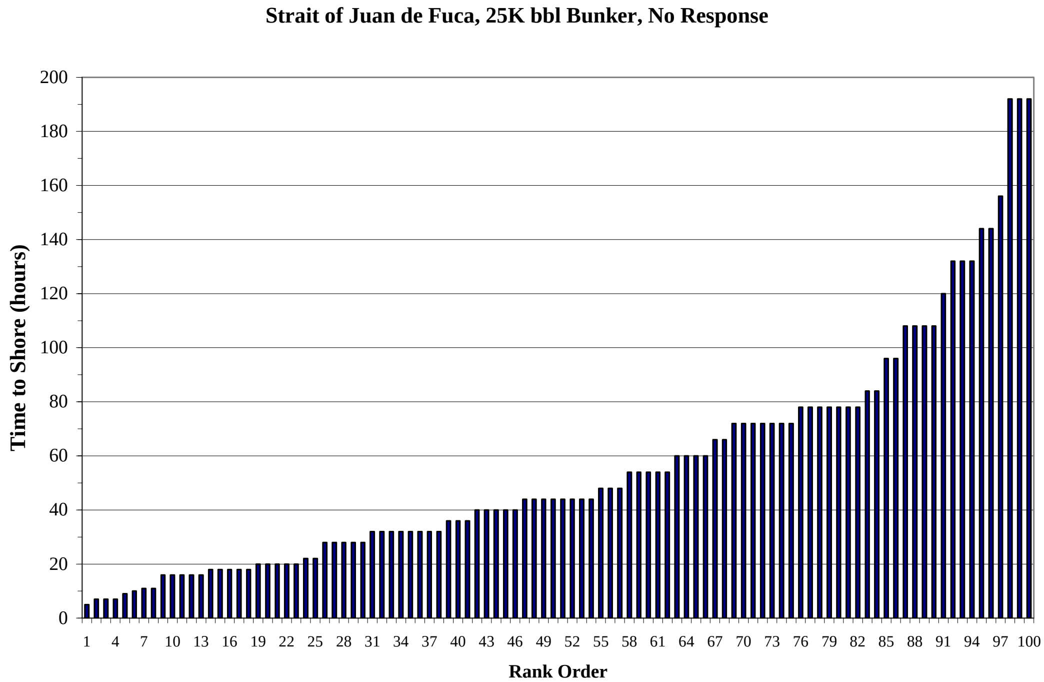


Figure 4-2. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Strait of Juan de Fuca bunker fuel spill (no response assumed).

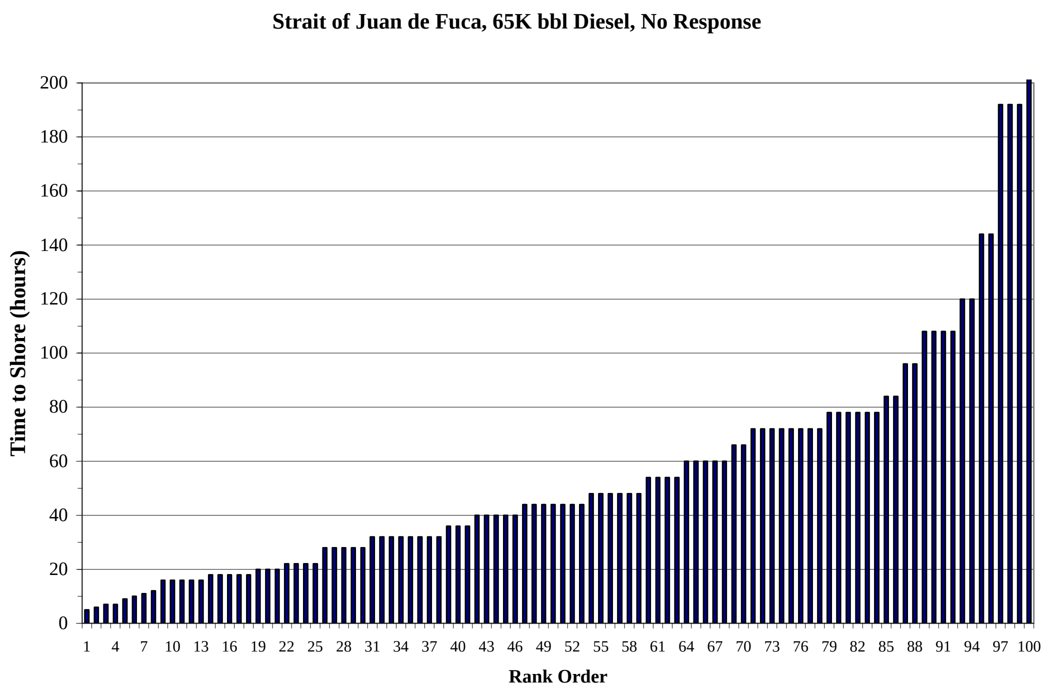


Figure 4-3. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Strait of Juan de Fuca diesel fuel spill (no response assumed).

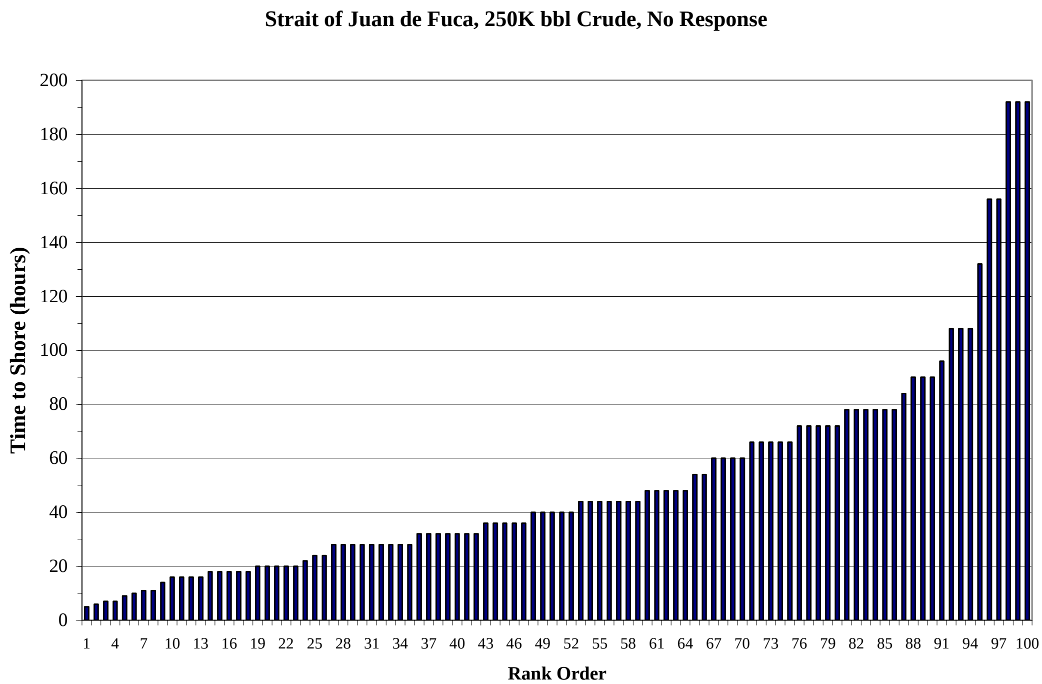


Figure 4-4. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Strait of Juan de Fuca crude oil spill (no response assumed).

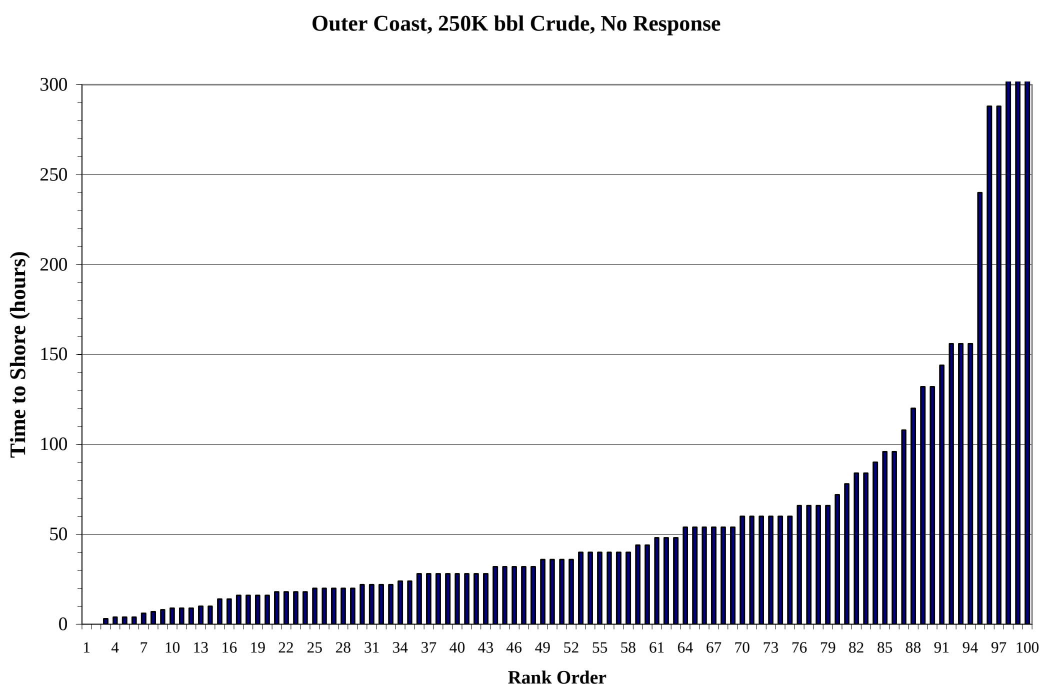


Figure 4-5. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Outer Coast at Duntz Rock crude oil spill (no response assumed).

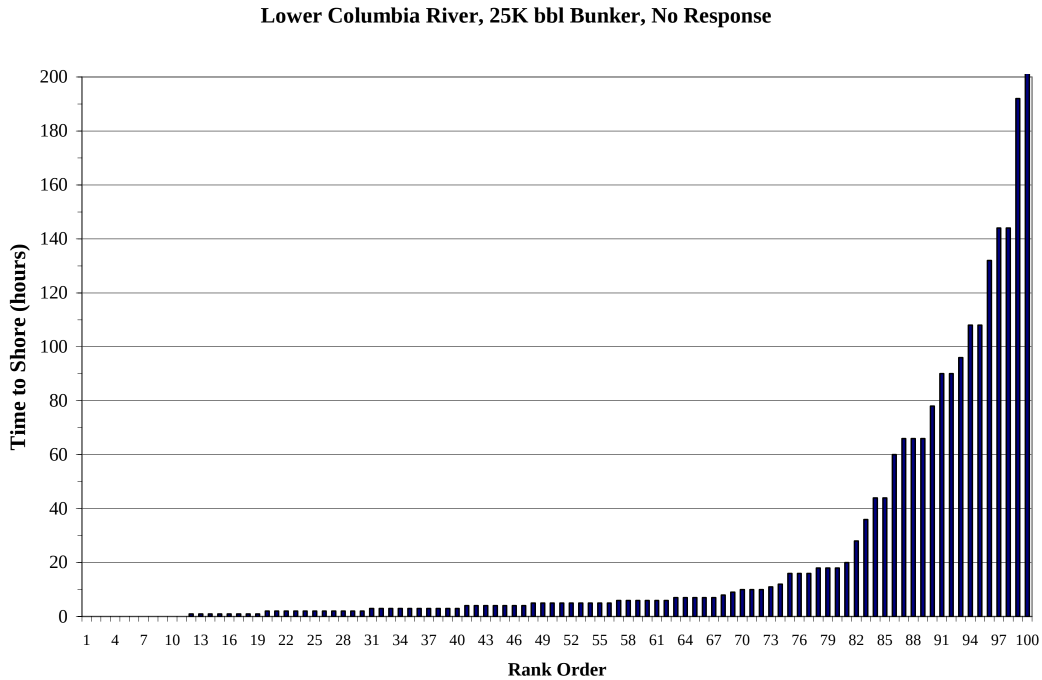


Figure 4-6. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Lower Columbia River bunker fuel spill (no response assumed).

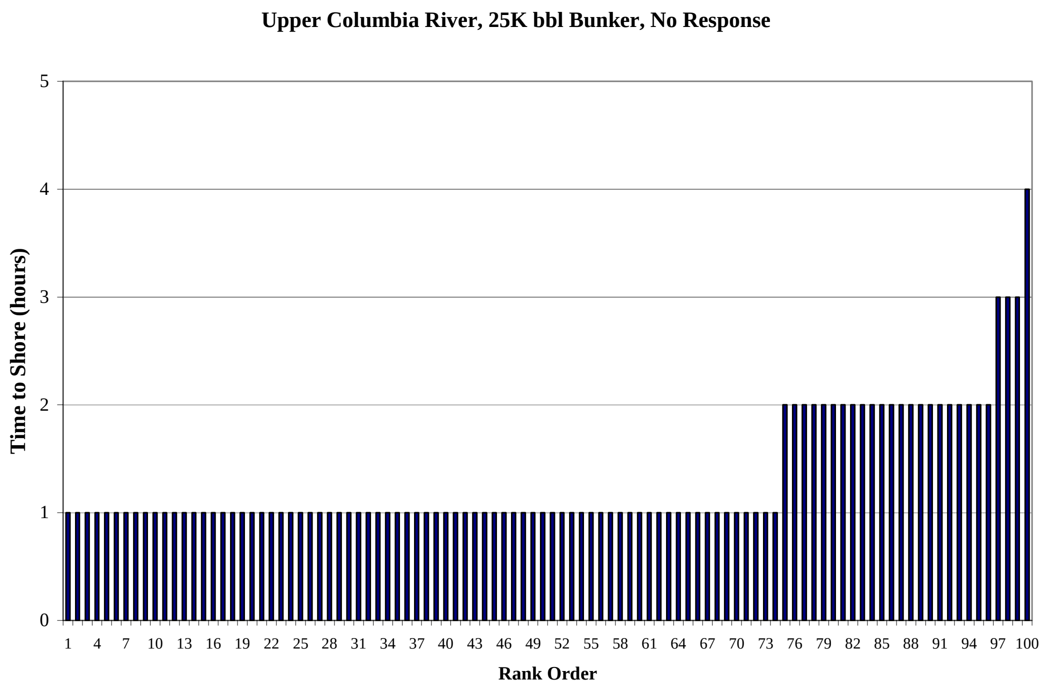


Figure 4-7. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Upper Columbia River bunker fuel spill (no response assumed).

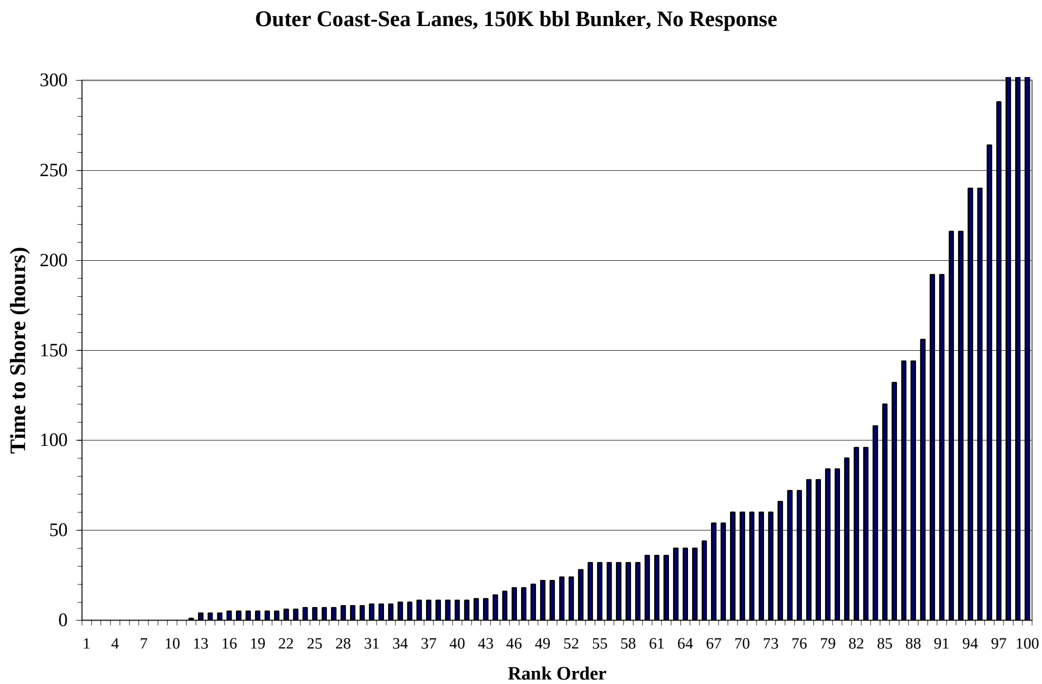


Figure 4-8. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Outer Coast-Sea Lanes bunker spill (no response assumed).

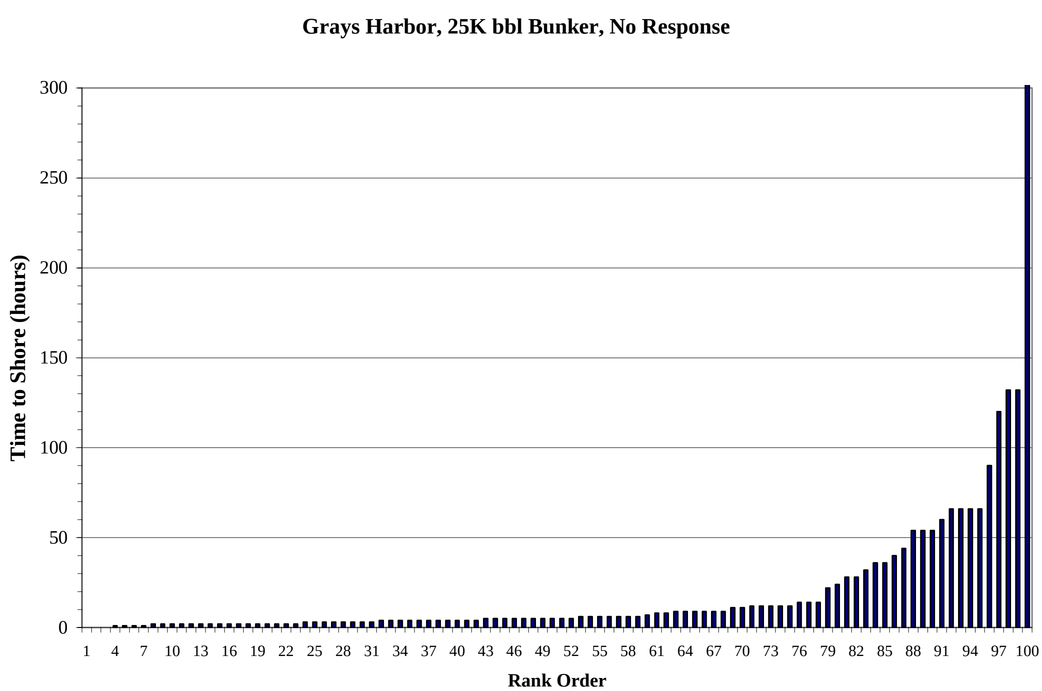


Figure 4-9. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Grays Harbor spill (no response assumed).

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.

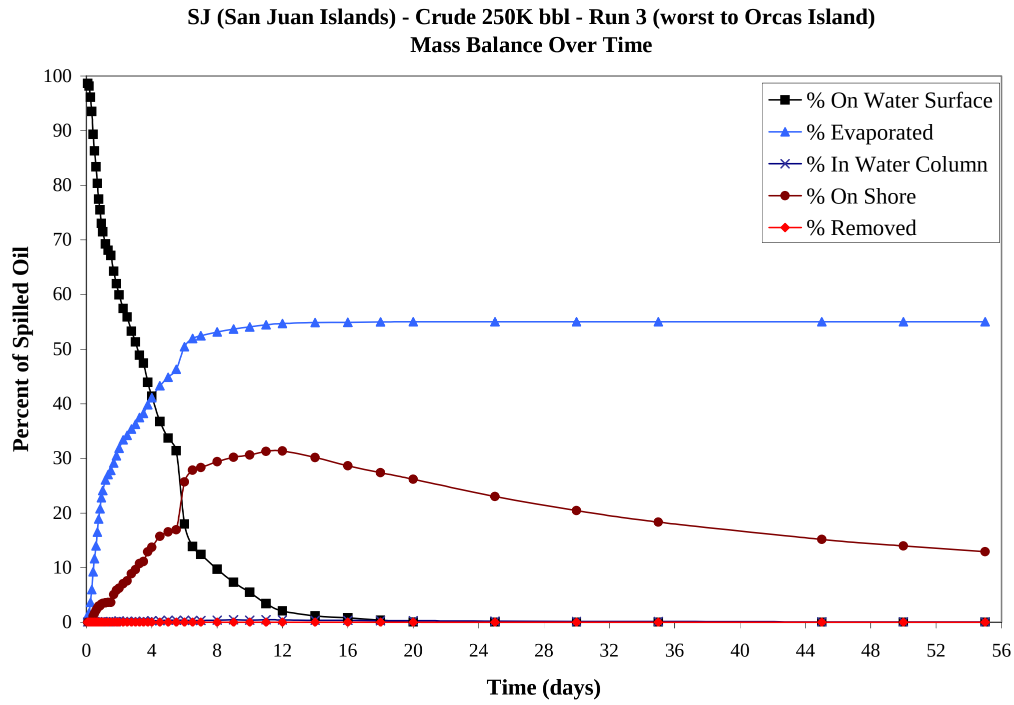


Figure 4-10. Mass balance over time for a crude oil spill simulation in the San Juan Island location (worst run for impacts on Orcas Island).

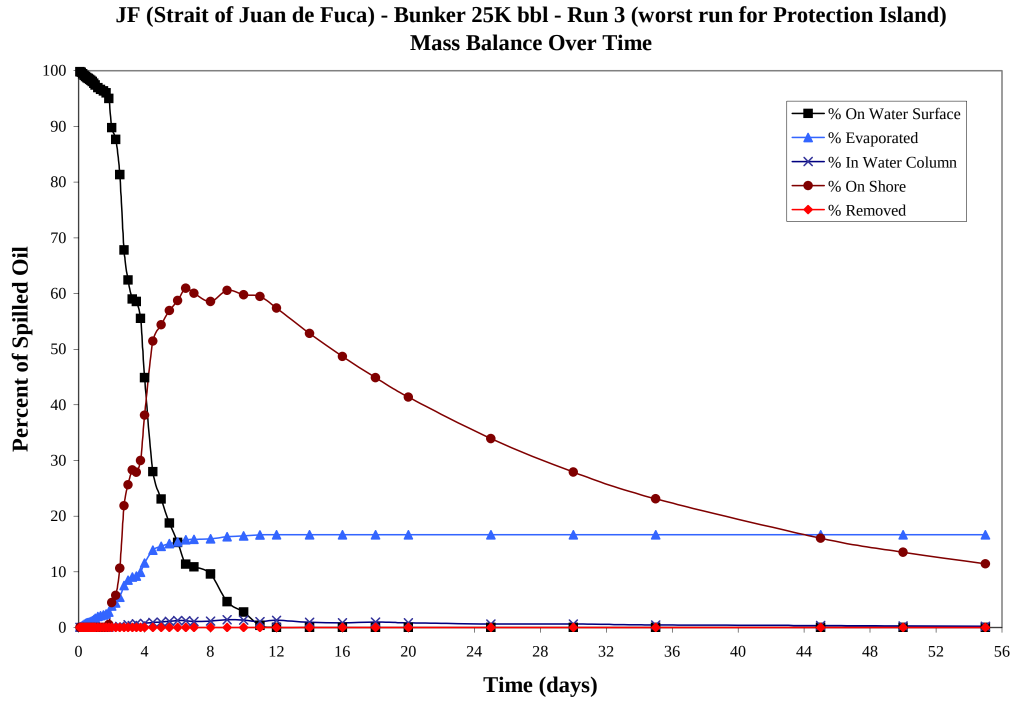


Figure 4-11. Mass balance over time for a bunker fuel spill simulation in the Strait of Juan de Fuca location (worst run for impacts on Protection Island).

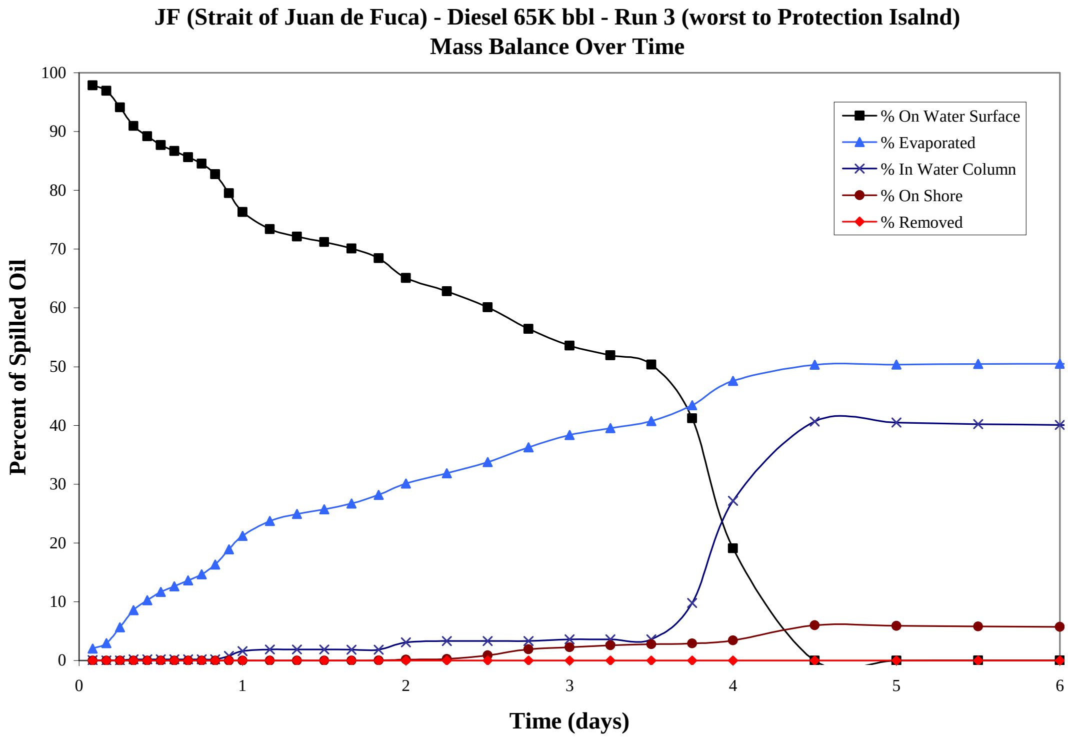


Figure 4-12. Mass balance over time for a diesel fuel spill simulation in the Strait of Juan de Fuca location (worst run for impacts on Protection Island).

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.

8. REFERENCES

A.D. Little, 1996. Reference samples measured during North Cape damage assessment, (A.D. Little, personal communication)

Anderson, J.W., 1985. Toxicity of dispersed and undispersed Prudhoe Bay crude oil fractions to shrimp, fish, and their larvae. American Petroleum Institute Publication No. 4441, Washington, D.C., USA, August 1985, 52p.

American Petroleum Institute (API), National Oceanic and Atmospheric Administration (NOAA), U.S. Coast Guard (USCG), and U.S. Environmental Protection Agency (USEPA), 2001. Characteristics of Response Strategies: A Guide for Spill Response Planning in Marine Environments. Joint Publication of API, NOAA, USCG, and USEPA, June 2001, 80p.

ASCE Task Committee on Modeling Oil Spills, 1996. State-of-the-art Review of Modeling Transport and Fate of Oil Spills, Water Resources Engineering Division, ASCE, Journal of Hydraulic Engineering 122(11): 594-609.

Call, D.J., L.T. Brooke, M.L. Knuth, S.H. Poirier, and M.D. Hoglund, 1985. Fish subchronic toxicity prediction model for industrial organic chemicals that produce narcosis. Environmental Toxicology and Chemistry 4:335-341.

Coastal Engineering Research Center (CERC), 1984. Shore Protection Manual, Vol. I. Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi, 1,105p. plus 134p. in appendices.

Continental Shelf Associates, Inc., 1991. A Comparison of Marine Productivity Among Outer Continental Shelf Planning Areas. Supplement An Evaluation of Benthic Habitat Primary Productivity. A final report for the U.S. Department of the Interior,. Minerals Management Service, Herndon, VA. OCS Study MMS 91 0001. Contract No. 14 35 0001 30487. 245 pp. + app.

Defant, A. (1961) Physical Oceanography. Vol. 2. Pergamon Press, New York.

DiToro, D.M., J.A. McGrath and D.J. Hansen, 2000. Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. I. Water and tissue. Environmental Toxicology and Chemistry 19(8): 1951-1970.

DiToro, D.M. and J.A. McGrath, 2000. Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. II. Mixtures and sediments. Environmental Toxicology and Chemistry 19(8): 1971-1982.

Egbert, G. D., A. F. Bennett, and M.G.G. Foreman, 1994. TOPEX/POSEIDON tides estimated using global inverse model. J. Geophys. Res. 99(C12): 24821-24852.

Etkin, D.S., 2004a. Response Cost Modeling For Washington State Oil Spill Scenarios: Executive Summary. Draft Report Submitted to Washington Department of Ecology, Lacey, WA, June 30, 2004.

Etkin, D.S., 2004b. Socioeconomic Cost Modeling For Washington State Oil Spill Scenarios. Summary Report Submitted to Washington Department of Ecology, Lacey, WA, July 21, 2004.

Etkin, D.S., D. French McCay, J. Rowe, N. Whittier, S. Sankaranarayanan, and L. Pilkey-Jarvis, 2005a. Modeling Impacts of Response Method and Capability on Oil Spill Costs and Damages for Washington State Spill Scenarios. Proceedings, 2005 International Oil Spill Conference, Paper 299, Miami, Florida, American Petroleum Institute, Washington, DC.

Etkin, D.S., 2005b. Response Cost Modeling For Washington State Oil Spill Scenarios: Part II. Submitted to Washington Department of Ecology, Lacey, WA, October 2005.

Etkin, D.S., 2005c. Socioeconomic Cost Modeling For Washington State Oil Spill Scenarios: Part II. Submitted to Washington Department of Ecology, Lacey, WA, October 2005.

Etkin, D.S. and D. French-McCay, 2005. Summary of Modeling Assumptions and Results For Washington State Oil Spill Scenarios Phases I and II. Submitted to Washington Department of Ecology, Lacey, WA, October 2005.

Etkin, D.S., D. French-McCay, J.Rowe, N. Whittier, S. Sankaranarayanan, R.Asch, A. Borowik, C. Suárez. 2006. Modeling of Washington State Oil Spill Scenarios Phase III: Outer Coast/Grays Harbor. Submitted to Washington Department of Ecology, Lacey, WA, February 2006.

Fonseca, M. S., W. J., Kenworthy and G. W. Thayer, 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA’s Coastal Ocean Program, Decision Analysis Series No. 12, November 1998.

French, D.P., S. Pavignano, A. Keller, D. Gifford, S. Puckett, S. Feng, M. Reed, M. Welsh and R. Bishop, 1993. Compensation formula for natural resource damage assessments under OPA: Oil spills into inland (freshwater) waters, Vol. I - Technical Documentation. Report to the National Oceanic and Atmospheric Administration, Rockville, MD, March 1993.

French, D.P., S. Pavignano, A. Keller and D. Gifford, 1993. Compensation formula for natural resource damage assessments under OPA: Oil spills into inland (freshwater) waters, Vol. II - Biological database: Inland waters other than the Great Lakes. Report to the National Oceanic and Atmospheric Administration, Rockville, MD, April 1993.

French, D., M. Reed, K. Jayko, S. Feng, H. Rines, S. Pavignano, T. Isaji, S. Puckett, A. Keller, F. W. French III, D. Gifford, J. McCue, G. Brown, E. MacDonald, J. Quirk, S. Natzke, R. Bishop, M. Welsh, M. Phillips and B.S. Ingram, 1996a. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), Technical Documentation, Vol. I - Model Description. Final Report, submitted to the Office of Environmental Policy and Compliance, U.S. Dept. of the Interior, Washington, DC, April, 1996, Contract No. 14-0001-91-C-11.

French, D., M. Reed, S. Feng and S. Pavignano, 1996b. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), Technical Documentation, Vol. III - Chemical and Environmental Databases. Final Report , Submitted to the Office of Environmental Policy and Compliance, U.S. Dept. of the Interior, Washington, DC, April, 1996, Contract No. 14-01-0001-91-C-11.

French, D., S. Pavignano, H. Rines, A. Keller, F.W. French III and D. Gifford, 1996c. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), Technical Documentation, Vol.IV - Biological Databases. Final Report , Submitted to the Office of Environmental Policy and Compliance, U.S. Dept. of the Interior, Washington, DC, April, 1996, Contract No. 14-01-0001-91-C-11.

French, D.P., and H. Rines, 1997. Validation and use of spill impact modeling for impact assessment. Proceedings, 1997 International Oil Spill Conference, Fort Lauderdale, Florida, American Petroleum Institute Publication No. 4651, Washington, DC, pp-829-834.

French, D.P., H. Rines and P. Masciangioli, 1997. Validation of an Orimulsion spill fates model using observations from field test spills. *Proceedings, Twentieth Arctic and Marine Oil Spill Program Technical Seminar*, Vancouver, Canada, June 10-13, 1997.

French, D., H. Schuttenberg, and T. Isaji, 1999. Probabilities of Oil Exceeding Thresholds of Concern: Examples from an Evaluation for Florida Power and Light. In: Proceedings of the 22nd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, June 2-4, 1999, Calgary, Alberta, Environment Canada, pp.243-270.

French, D. P., C.A. Manen, M. Gibson, and J. Catena, 2001. Quantifying the scale of restoration required to compensate for the impacts of the North Cape oil spill on fish and invertebrates. Proceedings of the 2001 International Oil Spill Conference & Exposition, American Petroleum Institute, March 26-29, 2001, Tampa, Florida.

French McCay, D.P., 2002. Development and Application of an Oil Toxicity and Exposure Model, OilToxEx. Environmental Toxicology and Chemistry 21(10): 2080-2094.

French McCay, D.P., 2003. Development and Application of Damage Assessment Modeling: Example Assessment for the North Cape Oil Spill. Marine Pollution Bulletin, Volume 47, Issues 9-12, September-December 2003, pp. 341-359.

French McCay, D.P., 2004. Oil spill impact modeling: Development and validation. Environmental Toxicology and Chemistry 23(10): 2441-2456.

French McCay, D.P., and J.J. Rowe, 2003. Habitat restoration as mitigation for lost production at multiple trophic levels. Mar Ecol Prog Ser 264:235-249.

French McCay, D.P., and J.J. Rowe, 2004. Evaluation of Bird Impacts in Historical Oil Spill Cases Using the SIMAP Oil Spill Model. In Proceedings of the 27th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, pp. 421-452.

French McCay, D., N. Whittier, S. Sankaranarayanan, J. Jennings, and D. S. Etkin, 2002. Modeling Fates and Impacts for Bio-Economic Analysis of Hypothetical Oil Spill Scenarios in San Francisco Bay. In Proceedings of the Twenty Fifth Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Environment Canada, Calgary, AB, Canada, 2002, p. 1051-1074.

French McCay, D.P., C.H. Peterson, J.T. DeAlteris and J. Catena, 2003a. Restoration that targets function as opposed to structure: replacing lost bivalve production and filtration. Mar Ecol Prog Ser 264:197-212.

French McCay, D., N. Whittier, T. Isaji, and W.Saunders, 2003b. Assessment of the Potential Impacts of Oil Spills in the James River, Virginia. In Proceedings of the 26th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, p. 857-878.

French McCay, D., J. J. Rowe, and N. Whittier, 2003c. Final Report, Estimation of Natural Resource Damages for 23 Florida Cases Using Modeling of Physical Fates and Biological Injuries. (23 volumes). Prepared for Florida Department of Environmental Protection, May 2003.

French McCay, D., N. Whittier, S. Sankaranarayanan, J. Jennings, and D. S. Etkin, 2004a. Estimation of Potential Impacts and Natural Resource Damages of Oil. J. Hazardous Materials 107/1-2:11-25.

French McCay, D, J. Rowe, N. Whittier, S. Sankaranarayanan, C. Suàrez, and D. Schmidt Etkin, 2004b. Evaluation of the Consequences of Various Response Options Using

Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters. Draft Report (26 volumes), Submitted to Washington Department of Ecology, Lacey, WA, July 8, 2004.

French-McCay, D.P, J. J. Rowe, N. Whittier, S. Sankaranarayanan, D. S. Etkin, and L. Pilkey-Jarvis, 2005a. Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA Costs of Oil Spills into Washington Waters. Proceedings, 2005 International Oil Spill Conference, Paper 395, Miami, Florida, American Petroleum Institute, Washington, DC.

French McCay, D, J. Rowe, N. Whittier, S. Sankaranarayanan, C. Suàrez, and D. Schmidt Etkin, 2005b. Evaluation of the Consequences of Various Response Options Using Modeling of Fate, Effects and NRDA costs for Oil Spills into Washington Waters. Phase I, Final Report (26 volumes), Submitted to Washington Department of Ecology, Lacey, WA, November 2005.

Exxon Valdez Oil Spill Trustee Council. 1989. *State/Federal Natural Resource Damage Assessment Plan for the Exxon Valdez Oil Spill, August 1989*. Public Review Draft, Juneau, AK.

Geise, B. S., and Jay, D. A. (1989) Modeling tidal energetic of the Columbia River Estuary, Estuarine, Coastal and Shelf Science, 29, pp.549-571.

Giesy, J.P., and R. Graney, 1989. Recent developments in and intercomparisons of acute and chronic bioassays and bioindicators. Hydrobiologia 188/189: 21-60.

Gobas, F.A.P.C. 1989. A model for exposure and toxicological impact assessment of aromatic hydrocarbon spills in the aquatic environment. Proceedings of the 12th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, June 7-9, 1989, Calgary, Alberta, p.279-296.

Gundlach, E.R., 1987. Oil Holding Capacities and Removal Coefficients for Different Shoreline Types to Computer Simulate Spills in Coastal Waters, in Proceedings of the 1987 Oil Spill conference, pp. 451-457.

Haines, J.R., and R.M. Atlas, 1982. In situ microbial degradation of Prudhoe Bay crude oil in Beaufort sea sediments. Marine Environmental Research 7:91-102.

Hickey, B. M. 1998. Coastal Oceanography of western North America from the tip of Baja California to Vancouver Island, The Sea, Vol. 11, edited by Allan R. Robinson, and Kenneth H. Brink, John Wiley & Sons.

Hodgins, D.O., 1998. Marine sewage outfall assessment for the capital regional district, British Columbia, using nested three-dimensional models. Water Science and Technology 38(10): 301–308.

Isaji T., E. Howlett, C. Dalton, and E. Anderson. 2001. Stepwise-Continuous-Variable-Rectangular Grid Hydrodynamic Model, Environment Canada's 24th Arctic and Marine Oilspill (AMOP) Technical Seminar.

Isaji T., E. Howlett, C. Dalton, and E. Anderson. 2002. Stepwise-Continuous-Variable-Rectangular Grid Hydrodynamic Model, Proceedings of the Seventh International Conference on Estuarine and Coastal Modeling, Nov 5-7, 2001 at St. Petersburg, Florida, pp.519-534.

Jokuty, P., S. Whiticar, Z. Wang, M. Fingas, P. Lambert, B. Fieldhouse, and J. Mullin, 1996. A catalogue of crude oil and oil product properties (1996 edition), Report # EE-157, Emergencies Science Division, Environment Canada, Ottawa, Canada (http://www.etcentre.org/spills)

Jokuty, P., S. Whiticar, Z. Wang, M. Fingas, P. Lambert, B. Fieldhouse, and J. Mullin, 1999. A catalogue of crude oil and oil product properties (1999 edition), Report # EE-165, Emergencies Science Division, Environment Canada, Ottawa, Canada.

Jones, R.K., 1997. A Simplified Pseudo-Component of Oil Evaporation Model, in Proceedings of the 20th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Environment Canada, pp. 43-61.

Kim, H.S. and J. C. Swanson, 2001. Modeling of double flood currents in the Sakonnet River. Submitted for publication in 7th Annual International Conference on Estuarine and Coastal Modeling (ECM 7), St. Petersburg Beach, Florida, November 5-7, 2001. American Society of Civil Engineers, Reston, Virginia, pp. 418-433.

Kolpack, R.L., Plutchak, N.B. and R. W. Stearns, 1977. Fate of oil in a water environment - Phase II, a dynamic model of the mass balance for released oil. University of Southern California, prepared for American Petroleum Institute, API Publication 4313, Washington, D.C.

Kullenberg, G. (ed.), 1982. Pollutant transfer and transport in the sea. Volume I. CRC Press, Boca Raton, Florida. 227 p.

Lee et al., 1992, Environ. Sci. Technol. 26:2104-2110.

Lehr, W.J., D. Wesley, D. Simecek-Beatty, R. Jones, G. Kachook and J. Lankford, 2000. Algorithm and interface modifications of the NOAA oil spill behavior model. Proceedings of the 23rd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Vancouver, BC, Environmental Protection Service, Environment Canada, pp. 525-539.

Lunel, T. 1993a. Dispersion: Oil droplet size measurements at sea. in Proceedings of the 16th Arctic Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada, Calgary, Alberta, June 7-9, 1993, pp. 1023-1056.

Lunel, T. 1993b. Dispersion: Oil droplet size measurements at sea. in Proceedings of the 1993 Oil Spill Conference, pp. 794-795.

Mackay, D.,S. Paterson and K. Trudel, 1980. A mathematical model of oil spill behavior, Department of Chemical and Applied Chemistry, University of Toronto, Canada, 39p.

Mackay, D., W.Y. Shiu, and K.C. Ma, 1992a. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. I, Monoaromatic Hydrocarbons, Chlorobenzenes, and PCBs. Lewis Publ., Chelsea, Michigan, 668p.

Mackay, D., W.Y. Shiu, and K.C. Ma, 1992b. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. II, Polynuclear Aromatic Hydrocarbons, Polychlorinated Dioxins, and Dibenzofurans. Lewis Publ., Chelsea, Michigan, 566p.

Mackay, D., W.Y. Shiu, and K.C. Ma, 1992c. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. III, Volatile Organic Chemicals. Lewis Publ., Chelsea, Michigan, 885p.

Mackay, D., W.Y. Shiu and D.C. Ma, 1992d. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals. Volume IV Oxygen, Nitrogen, and Sulfur containing compounds. Lewis Publishers, Inc. Chelsea, Michigan, 930p.

Malins, D.C. and H.O. Hodgins, 1981. Petroleum and marine fishes: a review of uptake, disposition, and effects. Envir. Science & Technology 15(11):1272-1280.

Maltrud, M. E., R. D. Smith, A. J. Semtner, R. C. Malone, 1998. Global eddy resolving ocean simulations driven by 1985-1995 atmospheric winds, J. Geophys. Res., 103, C13, 30825-30853.

Markarian, R.K., J.P. Nicolette, T.R. Barber, and L.H. Giese, 1993. A critical review of toxicity values and evaluation of the persistence of petroleum products for use in natural resource damage assessments. Prepared by Entrix, Inc. for the American Petroleum Institute, Washington, DC, 126 pp plus appendices.

McAuliffe, C.D., 1987. Organism exposure to volatile/soluble hydrocarbons from crude oil spills – a field and laboratory comparison. Proceedings of the 1987 Oil Spill Conference, API, p. 275-288.

Mendelsohn, D., S. Peene, E. Yassuda, and S. Davie, 1999. A hydrodynamic model calibration study of the Savannah River Estuary with an examination of factors affecting salinity intrusion. Estuarine and Coastal Modeling 6 (ECM6), New

Orleans, Louisiana, 3-5 November 1999. American Society of Civil Engineers, Reston, Virginia, pp. 663-685.

Mendelsohn, D.L., Yassuda, E.A., S.J. Peene, 2001. A simplified method for marsh inundation modeling in hydrodynamic and water quality models with application to the Cooper River Estuary (SC). Proceedings of the Seventh American Society of Civil Engineers (ASCE) International Estuarine and Coastal Modeling Conference. St. Petersburg (FL), November 5-7, 2001.

Morrison, J., M. Quick and M.G.G. Foreman, 2002. Climate change in the Fraser river watershed: flow and temperature projections. Journal of Hydrology 263: 230-244.

Muin, M., 1993. A Three-Dimensional Boundary Fitted Circulation Model in Spherical Coordinates, Ph.D. Dissertation, Department of Ocean Engineering, University of Rhode Island, Kingston, RI.

Muin, M. and M. Spaulding, 1997a. Three-dimensional boundary-fitted circulation model. Journal of Hydraulic Engineering, Vol. 123, No. 1, January 1997, p2-12.

Muin, M. and M. Spaulding, 1997b. Application of three-dimensional boundary-fitted circulation model to the Providence River. J. of Hydraulic Engineering, Vol. 123, No. 1, January 1997, p.13-20.

National Oceanic and Atmospheric Administration (NOAA), 2000. ADIOS Oil Database, NOAA HAZMAT, 2000 Version 2.0 (http://response.restoration.noaa.gov)

National Research Council, 1985. Oil in the Sea: Inputs, Fates and Effects, National Academy Press, Washington, D.C. 601p.

National Research Council, 2002. Oil in the Sea III: Inputs, Fates and Effects, National Academy Press, Washington, D.C. 446p.

Neff, J.M., J.W. Anderson, B.A. Cox, R.B. Laughlin, Jr., S.S. Rossi, and H.E. Tatem, 1976. Effects of petroleum on survival respiration, and growth of marine animals. p. 515-539 In: Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Am. Institute of Biological Sciences, Washington, DC.

Neff, J.M. and J.W. Anderson, 1981. Response of Marine Animals to Petroleum and Specific Petroleum Hydrocarbons. Applied Science Publishers Ltd., London and Halsted Press Division, John Wiley & Sons, NY. 177p.

Neff, J.M., and W. A. Burns, 1996. Estimation of polycyclic aromatic hydrocarbon concentrations in the water column based on tissue residues in mussels and salmon: an equilibrium partitioning approach, Environmental Toxicology and Chemistry 15: 2240-2253.

Nysewander,D. R., J. R. Evenson, B. L. Murphie, and T. A. Cyra. 2001. Status and trends for a suite of key diving marine bird species characteristic of Greater Puget Sound, as examined by the Marine Bird Component, Puget Sound Ambient Monitoring Program (PSAMP). Puget Sound Research 2001.

Odum, E.P., 1971. Fundamentals of Ecology, W.B. Saunders Co., Philadelphia, 574 p.

Okubo, A. 1971. Oceanic diffusion diagrams. Deep-Sea Research 8:789-802.

Okubo, A. and R.V. Ozmidov, 1970. Empirical dependence of the coefficient of horizontal turbulent diffusion in the ocean on the scale of the phenomenon in question atmospheric and ocean physics 6(5):534-536.

Ostazeski, S.A., S.C. Macomber, L.G. Roberts, A.D. Uhler, and K.R. Bitting, 1997. The environmental behavior of Orimulsion spilled on water, In: Proceedings of the 1997 International Oil Spill Conference, American Petroleum Institute, Fort Lauderdale, Florida, Publication No. 4651, pp. 469-478.

Pacific Estuarine Research Laboratory, 1990. A manual for assessing restored and natural coastal wetlands with examples from southern California. California Sea Grant Report No. T-CSGCP-021. La Jolla, California.

Parker, B. B., 1977. Tidal hydrodynamics in the Straits of Juan de Fuca – Strait of Georgia, NOAA Tech. Rep. TR-NOS 69, U.S. Dept. of Commerce, Washington, DC, 56pp.

Payne, J.R., B.E. Kirstein, G.D. McNabb, Jr., J.L. Lambach, R. Redding R.E. Jordan, W. Hom, C. deOliveria, G.S. Smith, D.M. Baxter, and R. Gaegel, 1984. Multivariate analysis of petroleum weathering in the marine environment – sub Arctic , Environmental Assessment of the Alaskan Continental Shelf, OCEAP, Final Report of Principal Investigators, Vol. 21 and 22, Feb. 1984, 690p.

Payne, J.R., B.E. Kirstein, J.R. Clayton, Jr., C. Clary, R. Redding, G.D. McNabb, Jr., and G. Farmer, 1987. Integration of suspended particulate matter and oil transportation study. Final Report. Minerals Management Service, Environmental Studies Branch, Anchorage, AK. Contract No. 14-12-0001-30146, 216 p.

Peene, S.J., E.A. Yassuda, and D.L. Mendelsohn, 1997. Development of a waste load allocation model within the Charleston Harbor Estuary. Part I: Barotropic circulation. Proceedings of the Fifth American Society of Civil Engineers (ASCE) International Estuarine and Coastal Modeling Conference. Alexandria, Virginia, October 22nd to 24th, 1997.

Phillips, R.C., 1984. The ecology of eelgrass meadows in the Pacific Northwest: A community profile. U.S. Fish Wildl. Serv. FWS/OBS-84/24. 85 pp.

Piatt, JF, Lensink CJ, Butler W, Kendziorek M, Nysewander DR. 1990. Immediate impact of the Exxon Valdez oil spill on marine birds. *The Auk* 107:387 397.

Rice, S.D., J.W. Short and J.F. Karinen, 1977. Comparative oil toxicity and comparative animal sensitivity. p. 78-94 In: D.A. Wolfe (ed.)., Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. Pergamon Press, NY.

Ricker, W.E., 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.

Sankaranarayanan, S. and D. French McCay, 2003a. Application of a two- dimensional depth-averaged hydrodynamic tidal model. Journal of Ocean Engineering 30(14), 1807-1832.

Sankaranarayanan, S. and D. French McCay, 2003b. Three-dimensional modeling of tidal circulation in Bay of Fundy. Journal of Waterway, Port, Coastal, and Ocean Engineering, ASCE, Vol. 129(3), May/June 2003, p.114-123.

Sankaranarayanan, S., and M. L. Spaulding, 2003. A study of the effects of grid non-orthogonality on the solution of shallow water equations in boundary-fitted coordinate systems. Journal of Computational Physics 184(1):299-320.

Seneca, E. D. And S. W. Broome, 1992. Restoring tidal marshes in North Carolina and France. Chapter 2 In: G.W. Thayer (editor), Restoring the Nation's Marine Environment. Maryland Sea Grant, College Park, MD, p. 53-78.

Spaulding, M.L., 1984. A vertically averaged circulation model using boundary-fitted coordinates, J. Phys. Oceanography, 14, 973.

Spaulding, M. L., D. Mendelsohn, and J. C. Swanson, 1999a. WQMAP: An integrated three-dimensional hydrodynamic and water quality model system for estuarine and coastal applications, Marine Technology Society Journal, invited paper, Special issue on state of the art in ocean and coastal modeling, Vol. 33, No. 3, p. 38-54.

Spaulding, M., J.C. Swanson, and D. Mendelsohn, 1999b. Application of quantitative model – data calibration measures to assess model performance. Estuarine and Coastal Modeling 6 (ECM6), New Orleans, Louisiana, 3-5 November 1999. American Society of Civil Engineers, Reston, Virginia, pp. 843-867.

Stiver, W. and D. Mackay, 1984. Evaporation rate of oil spills of hydrocarbons and petroleum mixtures. Environmental Science and Technology 18: 834-840.

Swanson, J.C., D. Mendelsohn, H. Rines, and H. Schuttenberg, 1998. Mount Hope Bay hydrodynamic model calibration and confirmation. Report to New England Power Company, Applied Science Associates, Narragansett, Rhode Island, Project No. ASA-96-076.

Swartz, R.C., D.W. Schults, R.J. Ozretich, J.O. Lamberson, F.A. Cole, T.H. DeWitt, M.S. Redmond, and S.P. Ferraro, 1995. ∑PAH: A Model to Predict the Toxicity of Polynuclear Aromatic Hydrocarbon Mixtures in Field-Collected Sediments, Journal of Environmental Toxicology and Chemistry 14(11): 1977-1987.

Thompson, C.W., 1999. Distribution and Abundance of Marbled Murrelets and Common Murres on the Outer Coast of Washington – Summer 1998 through Winter 1998-1999. Washington Department of Fish and Wildlife, Wildlife Research. http://wdfw.wa.gov/wlm/research/papers/murrelet/murrelets.pdf

Wang, Z., M.F. Fingas, M. Landriault, L. Sigouin, and N. Xu, "Identification of Alkyl Benzenes and Direct Determination of BTEX and (BTEX + C3-Benzenes) in Oils by GC/MS", in Proceedings of the Eighteenth Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Edmonton, AB, Canada, pp. 141-164, 1995.

Whiticar, S., M. Bobra, M. Fingas, P. Jokuty, P. Liuzzo, S. Callaghan, F. Ackerman and J. Cao, 1992. A catalogue of crude oil and oil product properties 1992 (edition), Report # EE-144, Environment Canada, Ottawa, Canada, 643p.

Yassuda, E.A., S.J. Peene, S.R. Davie, D.L. Mendelsohn, and T. Isaji, 2000a. Development of a waste load allocation model within the Charleston Harbor Estuary. Part II: Water quality estuarine, coastal and shelf science special issue on visualization in coastal marine science. Vol.50, No. 1, January 2000. Academic Press.

Yassuda, E.A., S.J. Peene, S.R. Davie, and D.L. Mendelsohn, 2000b. Development of a waste load allocation model with Sixth American Society of Civil Engineers (ASCE) International Estuarine and Coastal Modeling Conference. New Orleans, Louisiana, November 3-5,1999.

Youssef, M., 1993. The behavior of the near ocean surface under the combined action of waves and currents in shallow water. PhD Dissertation, Department of Ocean Engineering, University of Rhode Island, Narragansett, RI, 212p.

Youssef, M. and M. L. Spaulding, 1993. Drift current under the action of wind waves, Proceedings of the 16th Arctic and Marine Oil Spill Program Technical Seminar, Calgary, Alberta, Canada, pp. 587-615.

Youssef, M. and M.L. Spaulding, 1994. Drift Current Under the Combined Action of Wind and Waves in Shallow Water, in Proceedings of the 17th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Vancouver, British Columbia, June 8-10, 1994, pp. 767-784.

Zedler, J. B., 1992. Restoring cordgrass marshes in Southern California. Chapter 1 In: G.W. Thayer (editor), Restoring the Nation's Marine Environment. Maryland Sea Grant, College Park, MD, p.7-52.

Zigic, S., M. Zapata, T. Isaji, B. King, and C. Lemckert. 2003. Modeling of Moreton Bay using ocean coastal circulation model, Coasts and Ports, Australasian Conference, Paper No. 170, 9-12 September 2003, Auckland, NZ.

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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan, Ann Borowik, and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrenchmccay@asascience.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
May 2006

Table of Contents

II.1. Introduction 1
II.2. Summary of Impact statistics for the No-Response Stochastic Scenarios 7
II.3. Comparison of Alternative Responses: Outer Coast at Duntz Rock off Cape Flattery – Alaskan North Slope Crude 33
II.4. Comparison of Alternative Responses: Strait of Juan de Fuca – Bunker C.............. 47
II.5. Comparison of Alternative Responses: Strait of Juan de Fuca – Diesel................... 61
II.6. Comparison of Alternative Responses: Strait of Juan de Fuca – Alaskan North Slope Crude.. 75
II.7. Comparison of Alternative Responses: San Juan Islands – Alaskan North Slope Crude.. 89
II.8. Comparison of Alternative Responses: Lower Columbia River – Bunker C 102
II.9. Comparison of Alternative Responses: Upper Columbia River – Bunker C.......... 116
II.10. Comparison of Alternative Responses: Outer Coast-Sea Lanes – Bunker C........ 129
II.11. Comparison of Alternative Responses: Grays Harbor – Bunker C....................... 143

List of Tables

Table II.1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed. 4
Table II.2-1. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass coming ashore (%). 8
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, %). 9
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 (%).......... 10
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.] 11
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.......... 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. 13
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). 14
Table II.2-8. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 100 g/m^2. 15
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). 16
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). 17
Table II.2-11. Summary of results for all stochastic scenarios of 100 runs each: Cost (2003$) for shoreline cleanup (per area costs only).......... 18
Table II.2-12. Summary of results for all stochastic scenarios of 100 runs each: Total number of waterfowl oiled. 19
Table II.2-13. Summary of results for all stochastic scenarios of 100 runs each: Total number of seabirds oiled. 20
Table II.2-14. Summary of results for all stochastic scenarios of 100 runs each: Total number of wading birds and shorebirds oiled. 21
Table II.2-15. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled. 22
Table II.2-16. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled. 23
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. 24
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).......... 25

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). 26
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). 27
Table II.2-21. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation. 28
Table II.2-22. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation. 29
Table II.2-23. Summary of results for all stochastic scenarios of 100 runs each: Compensatory restoration area (acres) assuming eelgrass bed creation. 30
Table II.2-24. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. 31
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. 32
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 (%). 34
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, %). 34
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 (%). 35
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 (%). 35
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. 36
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. 36
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). 37
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. 37
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). 38
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). 38

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). 39
Table II.3-12. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of waterfowl oiled. 39
Table II.3-13. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of seabirds oiled. 40
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. 40
Table II.3-15. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of birds oiled. 41
Table II.3-16. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of mammals oiled. 41
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. 42
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). 42
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). 43
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). 43
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. 44
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. 44
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. 45
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. 45
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. 46
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 (%). 48

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, %). 48
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 (%). 49
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 (%)... 49
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. 50
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. 50
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). 51
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.............. 51
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). 52
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). 52
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). 53
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. 53
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. 54
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. . 54
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. 55
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............................... 55
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. 56
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). 56

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). 57
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)....... 57
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. 58
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$), assuming compensatory restoration is wetland creation. 58
Table II.4-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. 59
Table II.4-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. 59
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. 60
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 (%).62
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, %). 62
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 (%). 63
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 (%).......... 63
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. 64
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. 64
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). 65
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. 65
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). 66

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). 66
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). 67
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. 67
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. 68
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. 68
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. 69
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. 69
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. 70
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). 70
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). 71
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). 71
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. 72
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. 72
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. 73
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. 73
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. 74
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 (%). 76

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, %). 76
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 (%). 77
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 (%)... 77
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. 78
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. 78
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). 79
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. 79
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). 80
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). 80
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). 81
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. 81
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. 82
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. .. 82
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.. 83
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. 83
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. 84
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). 84

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). 85
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)....... 85
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. 86
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$), assuming compensatory restoration is wetland creation. 86
Table II.6-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. 87
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. 88
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 (%). 89
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, %). 90
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 (%). 90
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 (%). 91
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. 91
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. 92
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). 92
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. 93
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). 93
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). 94

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). 94
Table II.7-12. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of waterfowl oiled. 95
Table II.7-13. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of seabirds oiled. 95
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. 96
Table II.7-15. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of birds oiled. 96
* 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. 96
Table II.7-16. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of mammals oiled. 97
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. 97
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). 98
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). 98
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). 99
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. 99
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. 100
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. 100
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. 101
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. 101
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 (%). 103

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, %). 103
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 (%). 104
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 (%).. 104
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. 105
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. 105
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). 106
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. 106
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). 107
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). 107
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). 108
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. 108
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. 109
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. 109
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. 110
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............................ 110
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. 111
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). 111

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). 112
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)..... 112
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. 113
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$), assuming compensatory restoration is wetland creation. 113
Table II.8-23. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation. 114
Table II.8-24. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation. 114
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. 115
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 (%)... 117
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, %). 117
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 (%). 118
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 (%).. 118
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. 119
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. 119
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). 120
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. 120

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). ... 121
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). ... 121
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). ... 122
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. ... 122
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. ... 123
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. ... 123
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. ... 124
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. ... 124
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. ... 125
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). ... 125
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). ... 126
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). ... 126
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. ... 127
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. ... 127
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. ... 128
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. ... 128

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 (%). 130
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, %). 130
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 (%). 131
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 (%). 131
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. 132
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. 132
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). 133
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. 133
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). 134
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). 134
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). 135
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. 135
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. 136
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. 136
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. 137
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. 137
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. 138
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)........ 138
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). 139
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). 139
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........ 140
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$), assuming compensatory restoration is wetland creation........ 140
Table II.10-23. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation........ 141
Table II.10-24. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation........ 141
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........ 142
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 (%). 144
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, %). 144
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 (%)........ 145
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 (%). ... 145
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........ 146
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........ 146
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). 147

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. 147
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). 148
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). 148
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). 149
Table II.11-12. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of waterfowl oiled. 149
Table II.11-13. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of seabirds oiled. 150
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. 150
Table II.11-15. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of birds oiled.. 151
Table II.11-16. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of mammals oiled. 151
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. 152
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). 152
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). 153
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). 153
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.. 154
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... 154
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.. 155
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.. 155

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. 156

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 5^{th}, 50^{th} and 95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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	5^{th} Percentile	50^{th} Percentile	95^{th} 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 (99^{th} 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 (99^{th} 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 (99^{th} 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 (99^{th} 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 (99^{th} 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 (99^{th} 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 (99^{th} 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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan, Ann Borowik, and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrenchmccay@asascience.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
May 2006

Table of Contents

XV.A. Introduction 1
XV.B. Geographical Data 2
  XV.B.1. Maps of the Vicinity of the Modeled Spill Locations 2
  XV.B.2. Gridded Habitat Mapping 3
  XV.B-3. Gridded Depth Data 4
  XV.B-4. Areas Where Response Actions Assumed 5
XV.C. Current Data 7
  XV.C.1. Basis of Current Data 7
  XV.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations 8
XV.D: Oil Properties 13
XV.E: Inputs to the SIMAP Physical Fates Model 16

List of Figures

Figure XV.B.1-1 Map of the vicinity of the potential spill locations. 2
Figure XV.B.2-1 Habitat grid used for modeling the potential spills................................ 3
Figure XV.B.2-2 Habitat grid used for modeling the potential spills (closer view)........... 3
Figure XV.B.3-1 Depth grid used for modeling the potential spills................................. 4
Figure XV.B.3-2 Depth grid used for modeling the potential spills (closer view)............ 4
Figure XV.B.4-1 Jurisdictions in the area of the potential spills...................................... 5
Figure XV.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 5
Figure XV.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 6
Figure XV.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 6
Figure XV.C.1-1 Grid used for the hydrodynamic model-generated current data. 7
Figure XV.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island)... 7
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. 8
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. 9
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. 9
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. 10
Figure XV.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction. 10
Figure XV.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction. 11
Figure XV.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.......................... 11
Figure XV.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction. 12
Figure XV.E-1 Varied range of spill site, Rosario Strait/Georgia Strait from the south end of Lopez Island to off Cherry Point. 19
Figure XV.E-2 Wind Station Locations.. 23

List of Tables

Table XV.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling. 13
Table XV.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil.... 14
Table XV.E-1. Inputs to the Fates Model for Stochastic Scenarios 16
Table XV.E-2. Time, date and location inputs for each of the 100 stochastic runs. 20
Table XV.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 22
Table XV.E-4. Water temperature by month of the year (from French et al., 1996b). ... 22
Table XV.E-5. Wind data sources and records used. 23

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

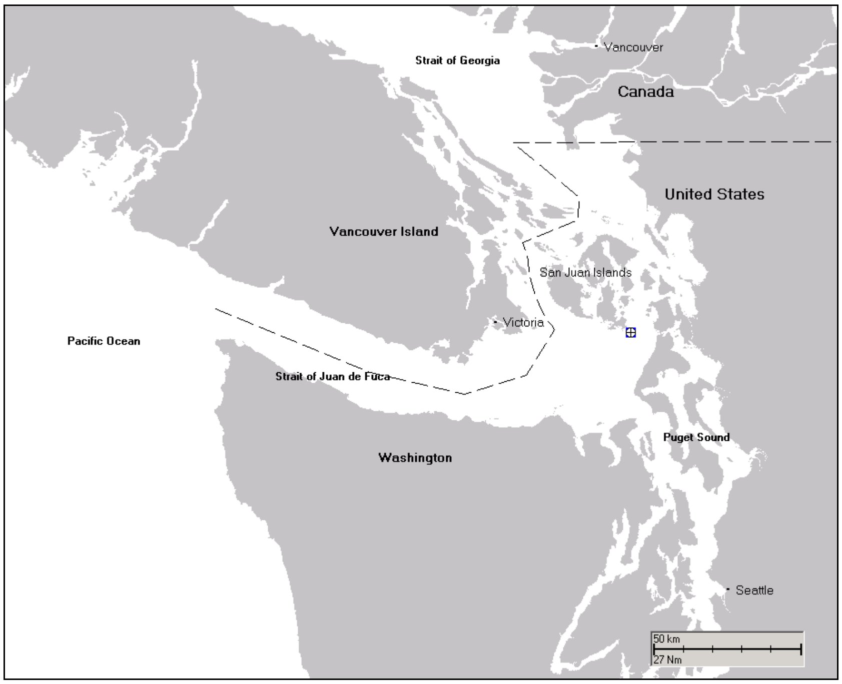


Figure XV.B.1-1 Map of the vicinity of the potential spill locations.

XV.B.2. Gridded Habitat Mapping

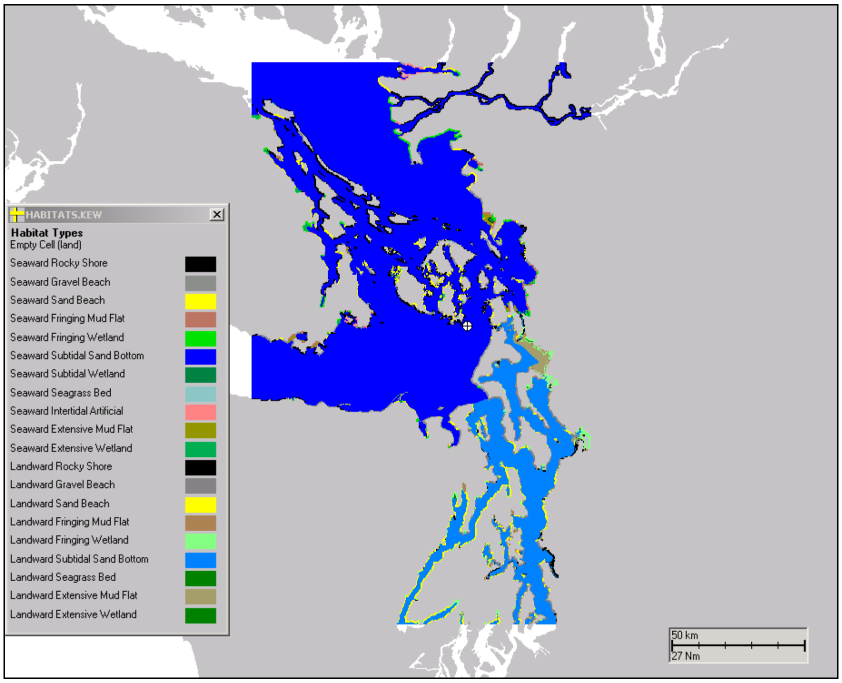


Figure XV.B.2-1 Habitat grid used for modeling the potential spills.

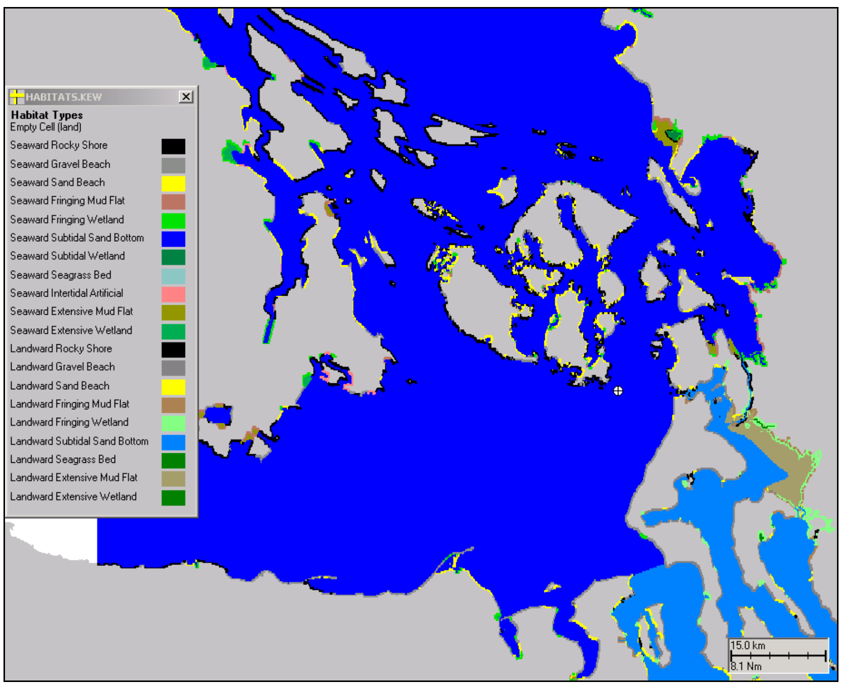


Figure XV.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XV.B-3. Gridded Depth Data

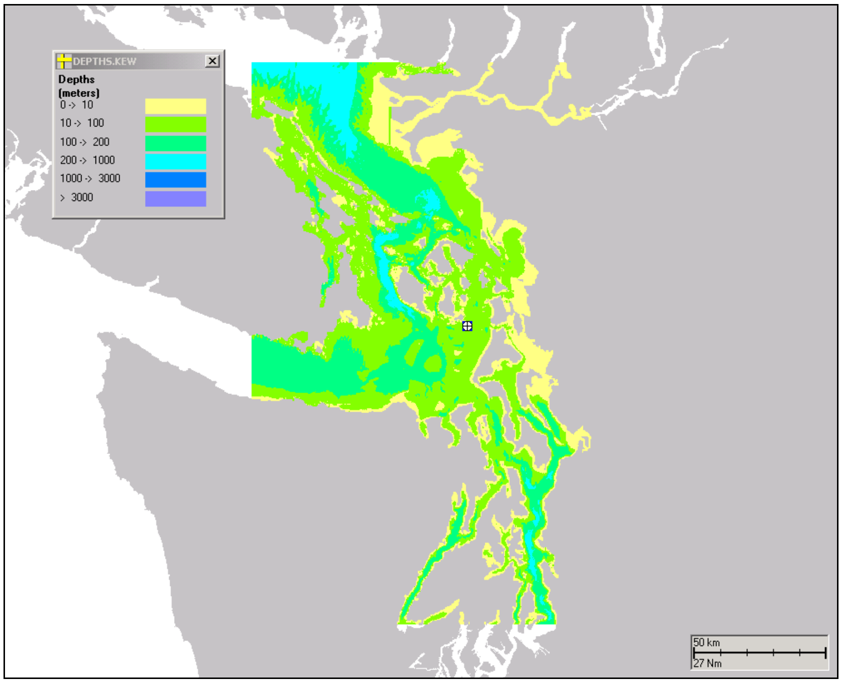


Figure XV.B.3-1 Depth grid used for modeling the potential spills.

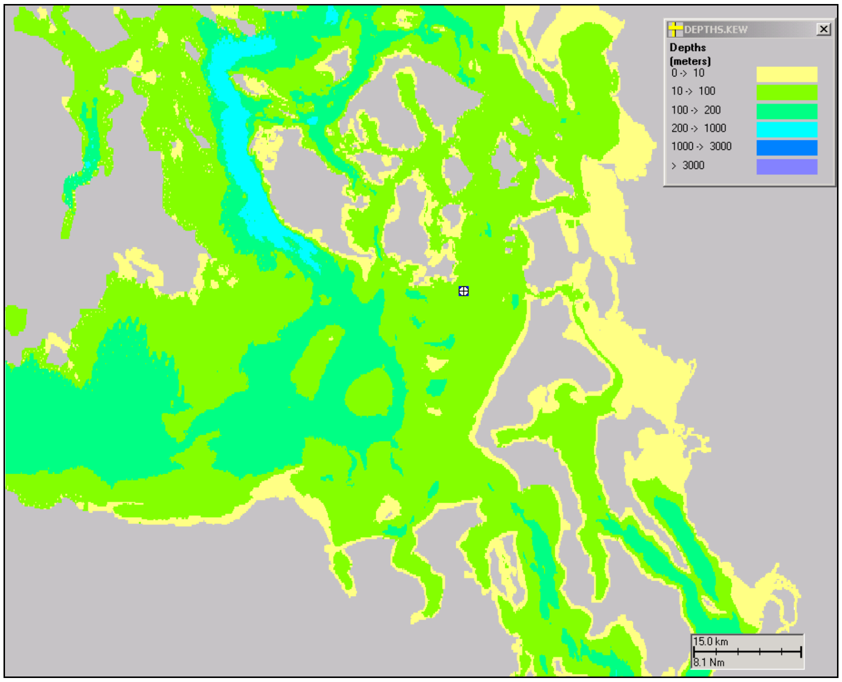


Figure XV.B.3-2 Depth grid used for modeling the potential spills (closer view).

XV.B-4. Areas Where Response Actions Assumed

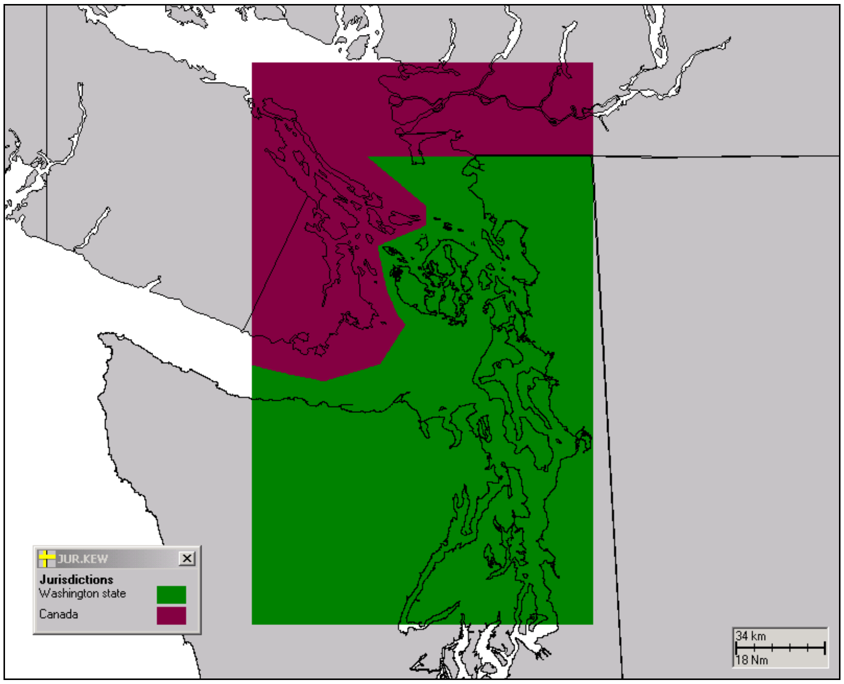


Figure XV.B.4-1 Jurisdictions in the area of the potential spills.

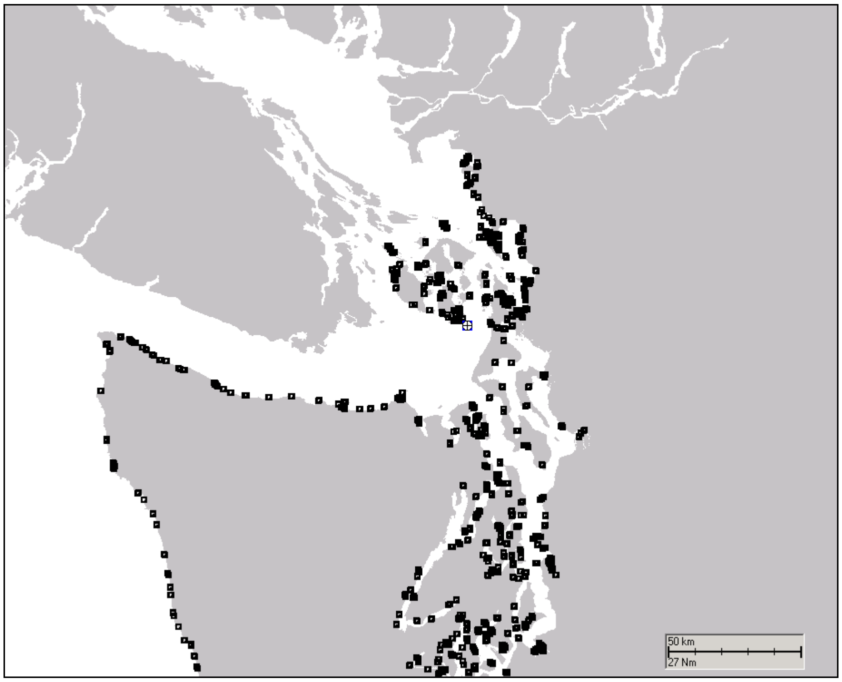


Figure XV.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

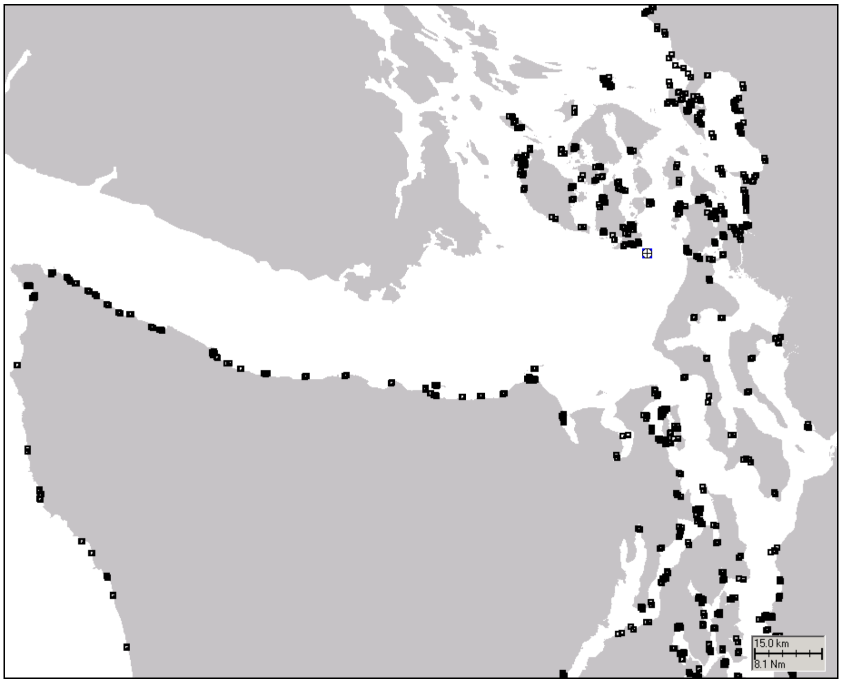


Figure XV.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

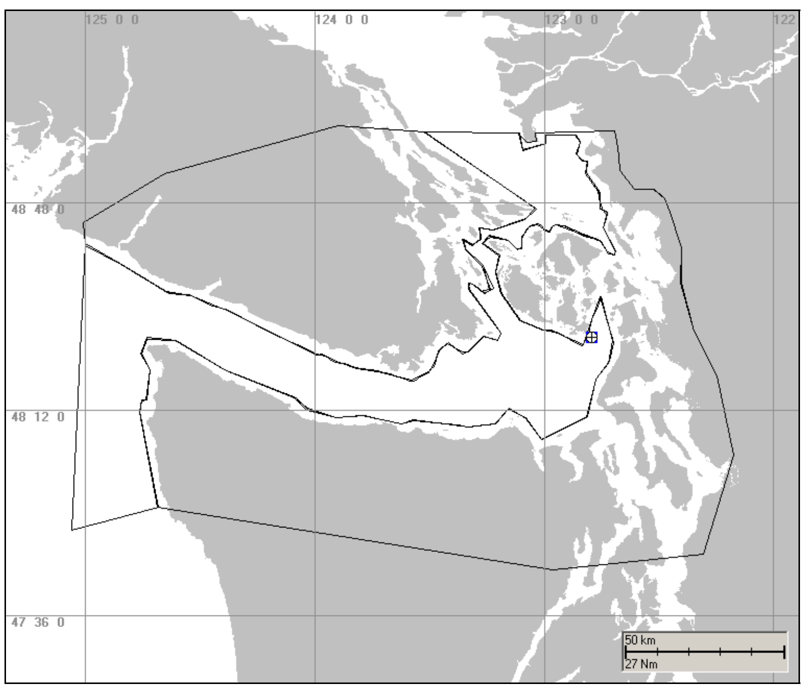


Figure XV.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

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).

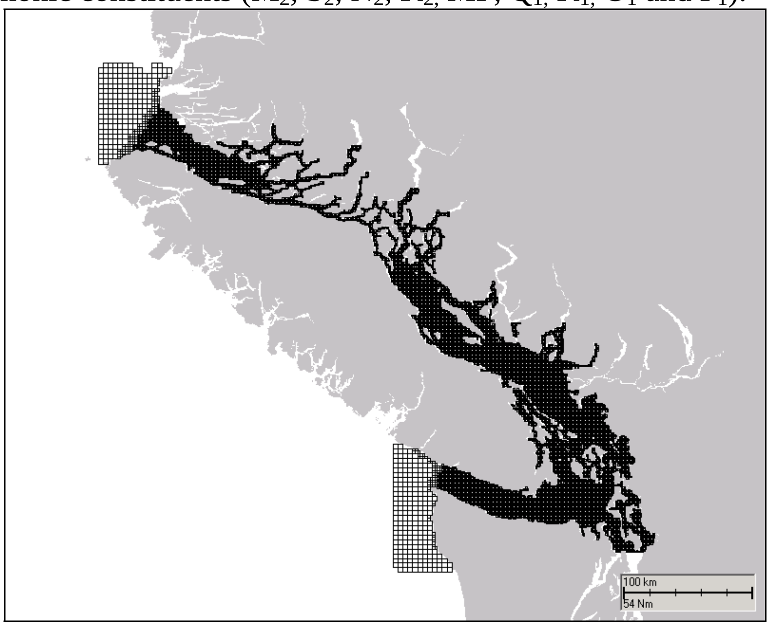


Figure XV.C.1-1 Grid used for the hydrodynamic model-generated current data.

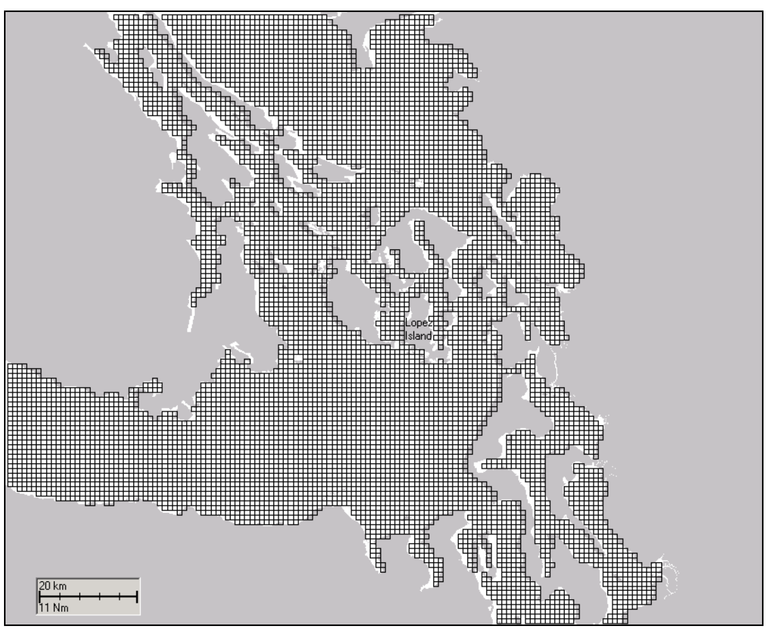


Figure XV.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island).

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.

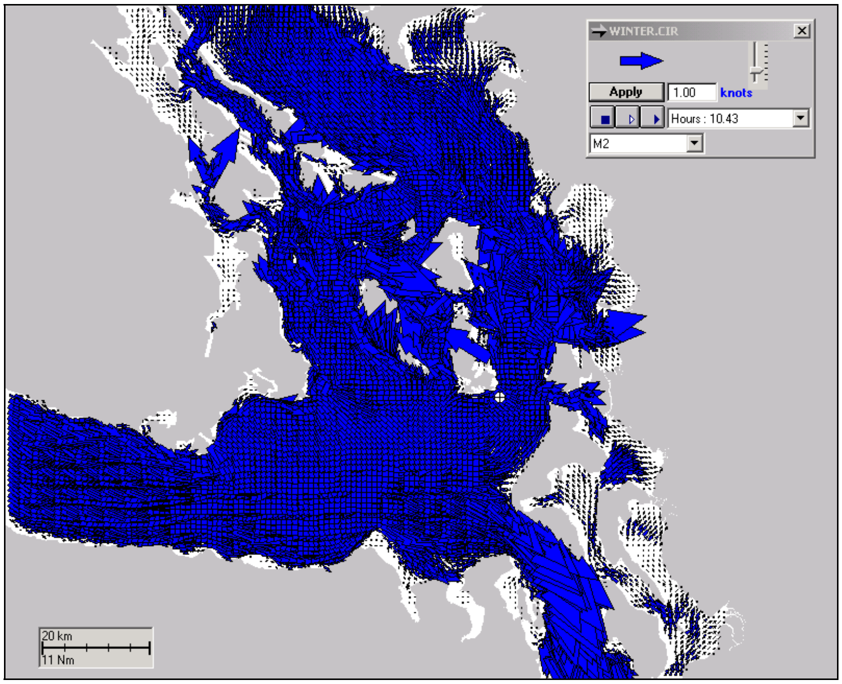


Figure XV.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Lopez Island.

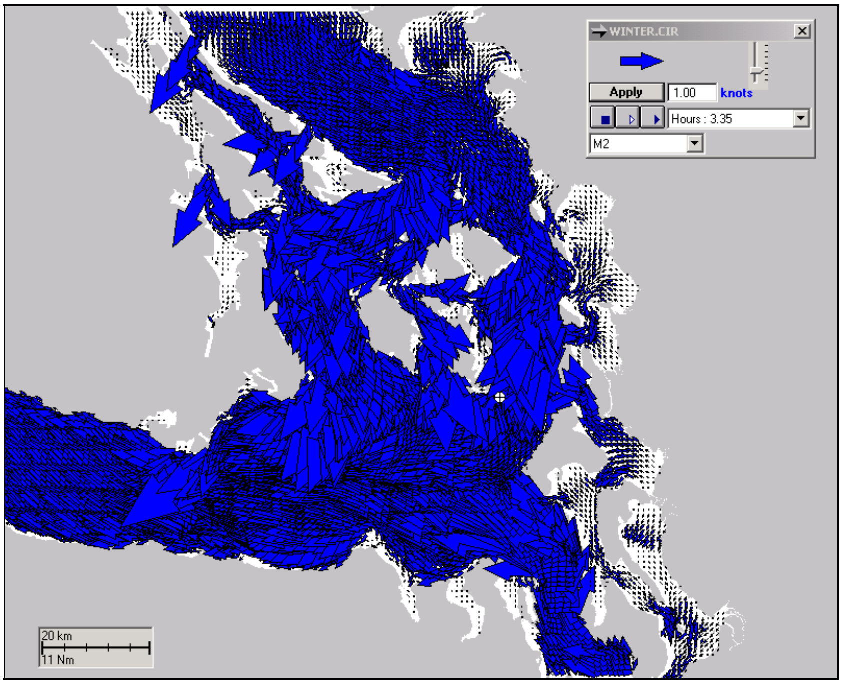


Figure XV.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Lopez Island.

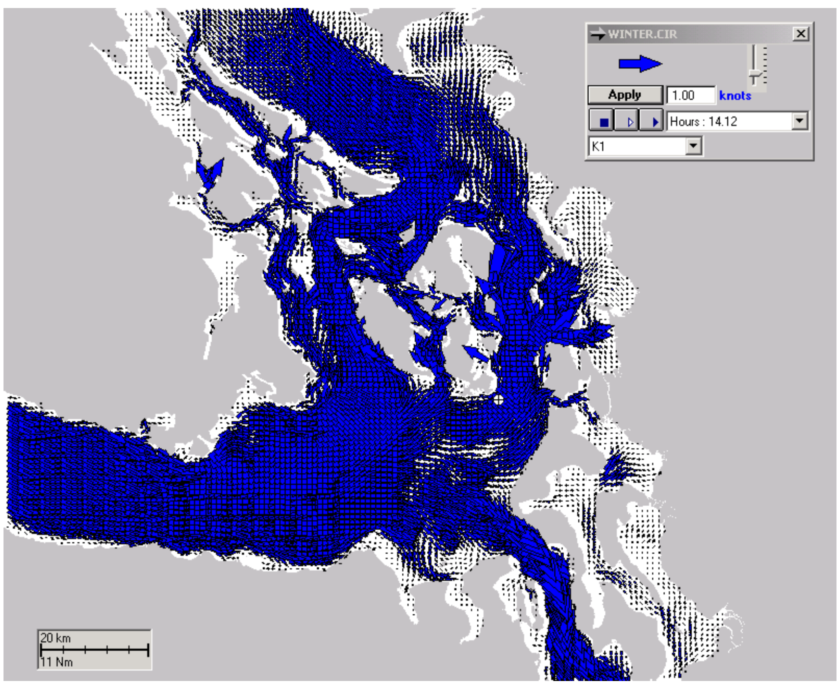


Figure XV.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Lopez Island.

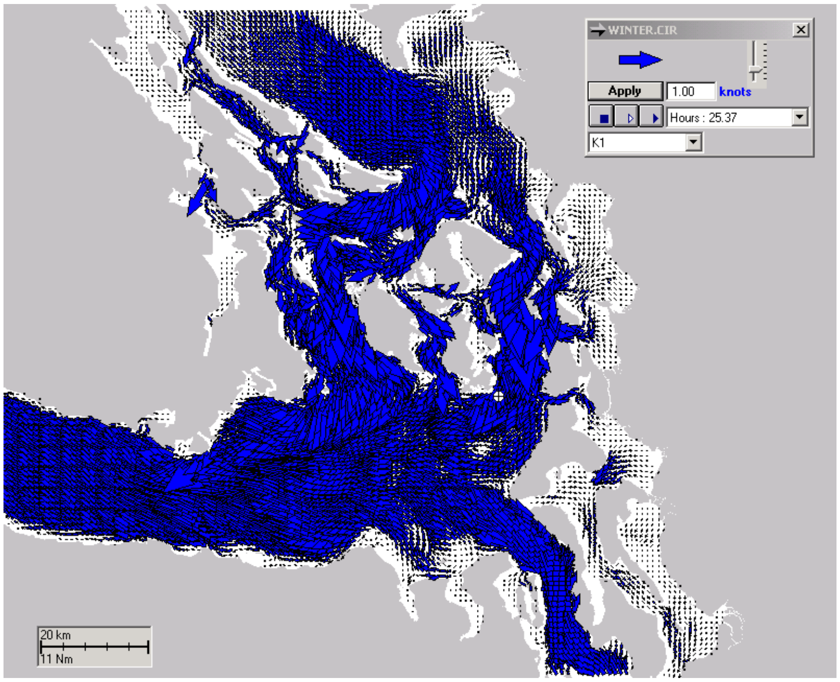


Figure XV.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Lopez Island.

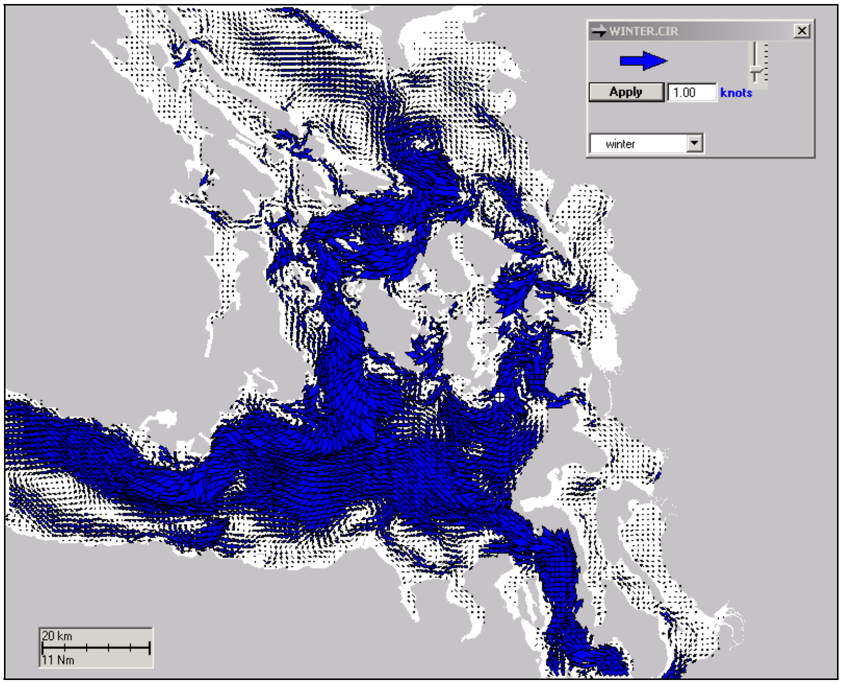


Figure XV.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction.

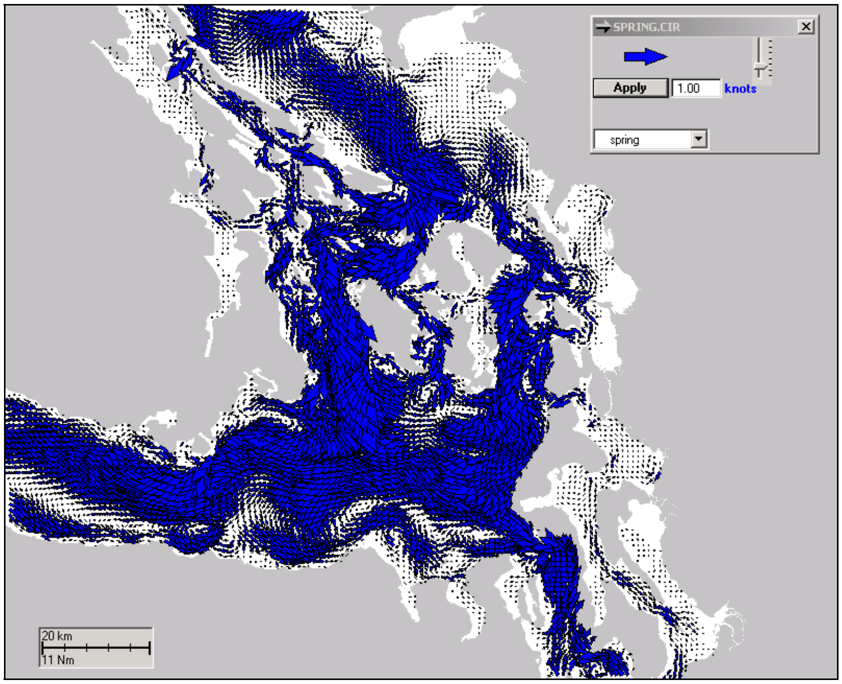


Figure XV.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction.

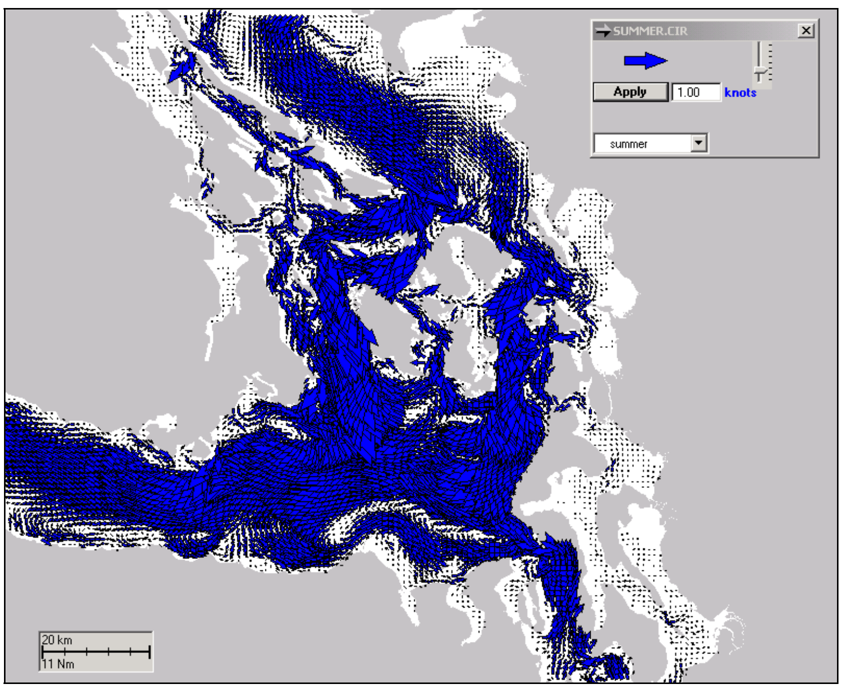


Figure XV.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.

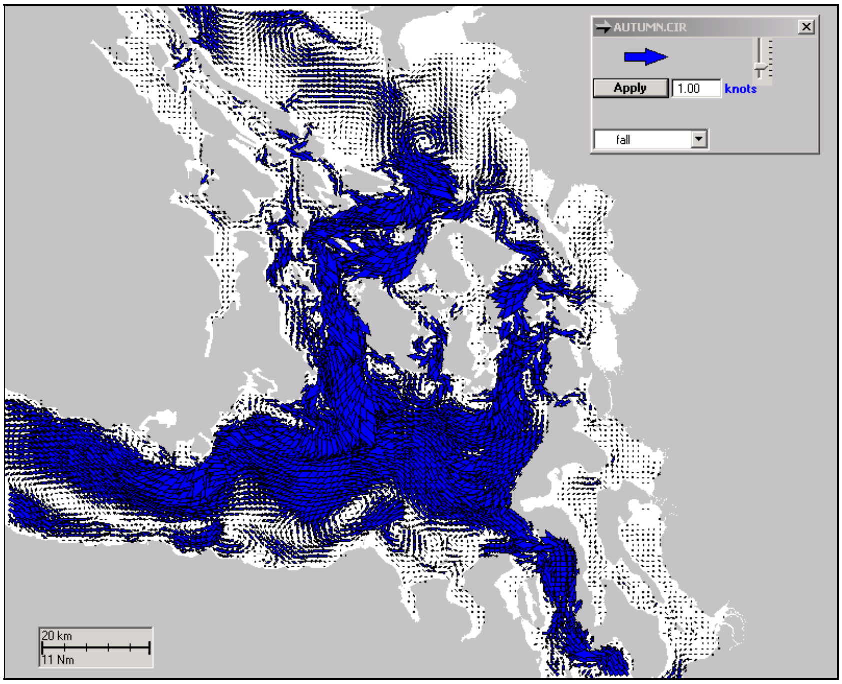


Figure XV.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction.

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 = $\mu g/L$ = 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 = $\mu g/L$ = 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

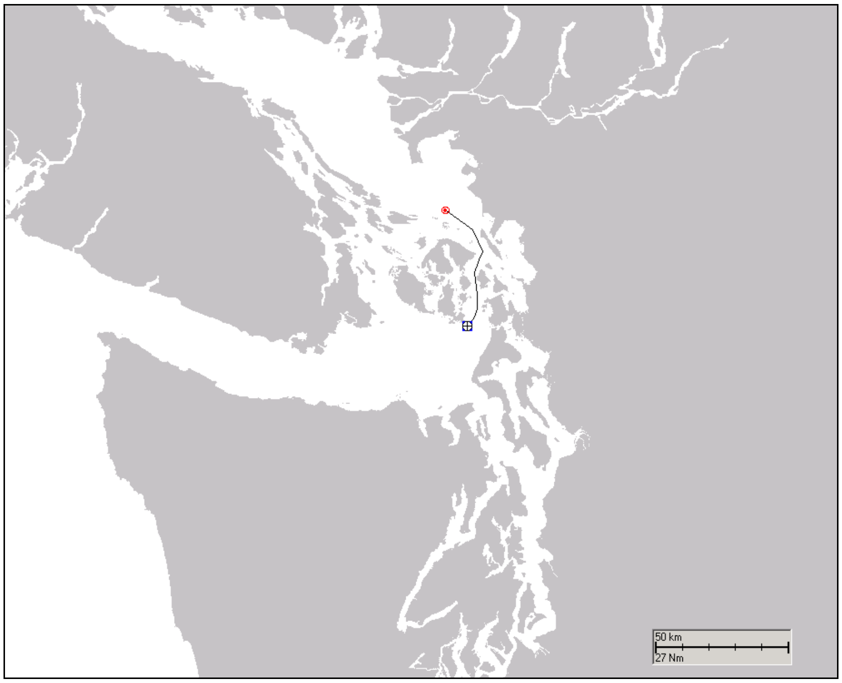


Figure XV.E-1 Varied range of spill site, Rosario Strait/Georgia Strait from the south end of Lopez Island to off Cherry Point.

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^{o} 57.76'W
Grid S edge	47^{o} 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.

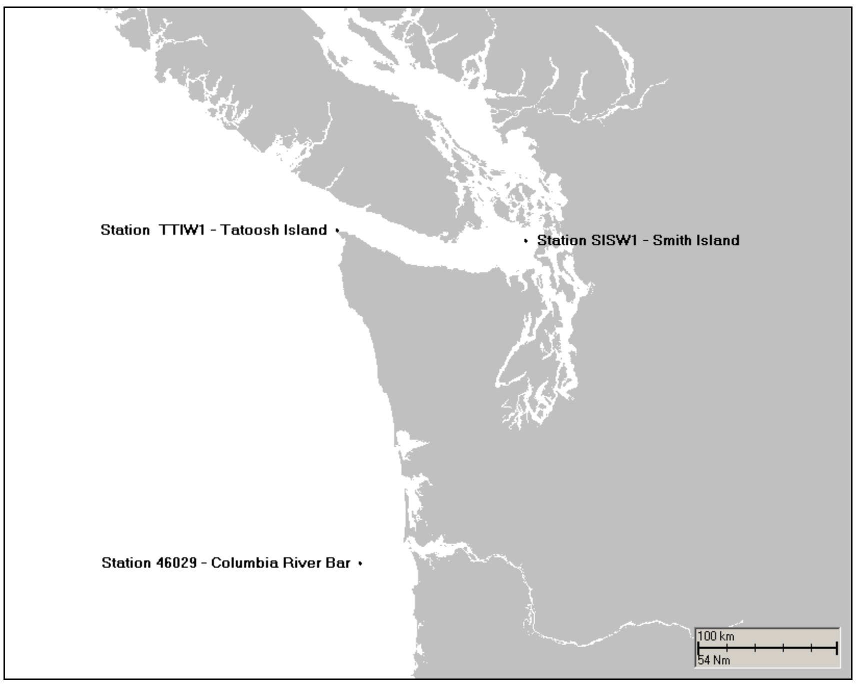


Figure XV.E-2 Wind Station Locations.

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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan, Ann Borowik, and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrenchmccay@asascience.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
May 2006

Table of Contents

XVI.A. Introduction 1
XVI.B. Maps of Exposure Probability and Time First Exposed 1
XVI.C. Statistics for All Model Runs 3
XVI.D. Shoreline Areas Exposed by Shore Type 6
XVI.E. Exposure for Representative Individual Model Runs. 8
XVI.F. Estimated Biological Impacts: Wildlife 12
XVI.G. Estimated Biological Impacts: Fish and Invertebrates... 15
XVI.H. Estimated NRDA Costs: Habitat Restoration Costs 17
XVI.I. Estimated NRDA Costs: Washington Compensation schedule 20

List of Figures

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). 2

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. 2

Figure XVI.C-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore. 5

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 (%). 5

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. 8

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. 9

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. 9

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. 10

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. 10

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. 11

List of Tables

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. 4
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). 6
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). 6
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). 7
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). 7
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. 13
Table XVI.F-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Wildlife injury (as numbers lost). 14
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. 16
Table XVI.G-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 16
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. 18
Table XVI.H-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration........................ 19
Table XVI.I-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.. 20

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)

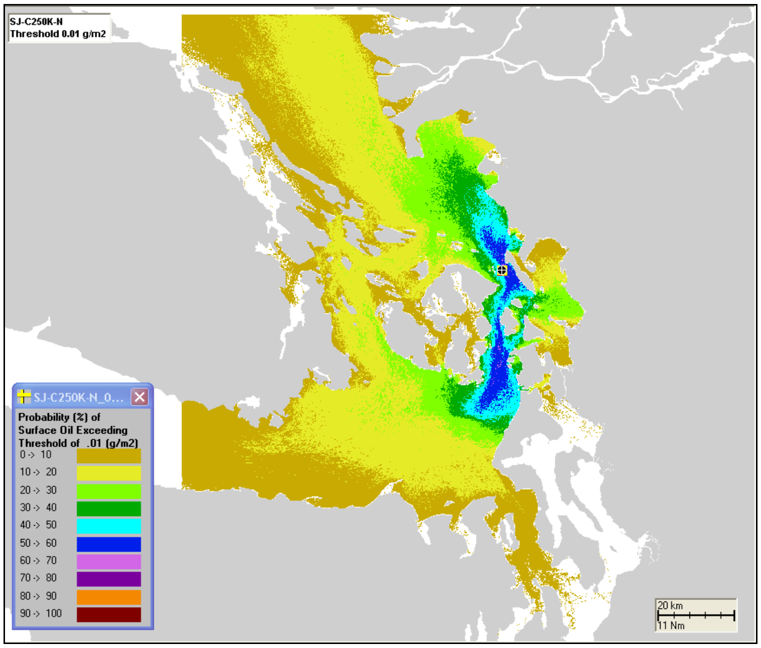


Figure XVI.B-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

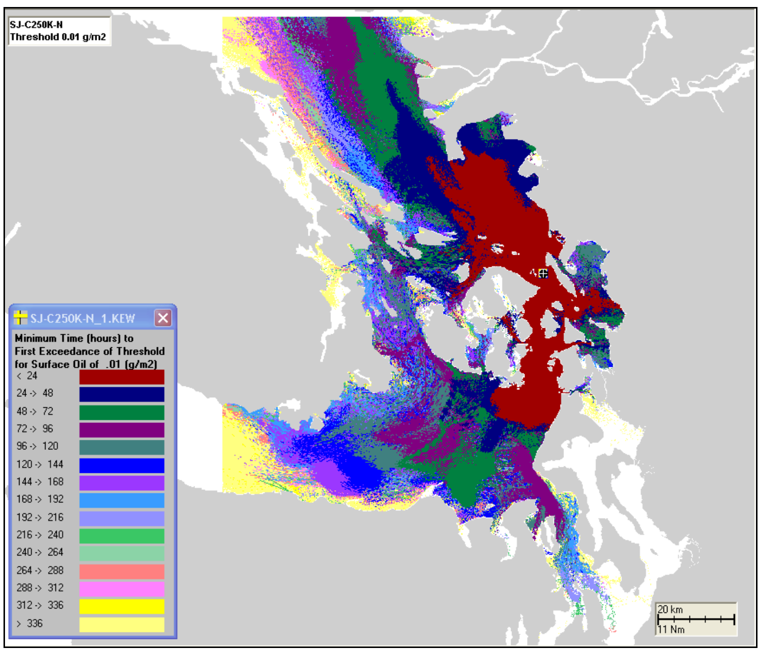


Figure XVI.B-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

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

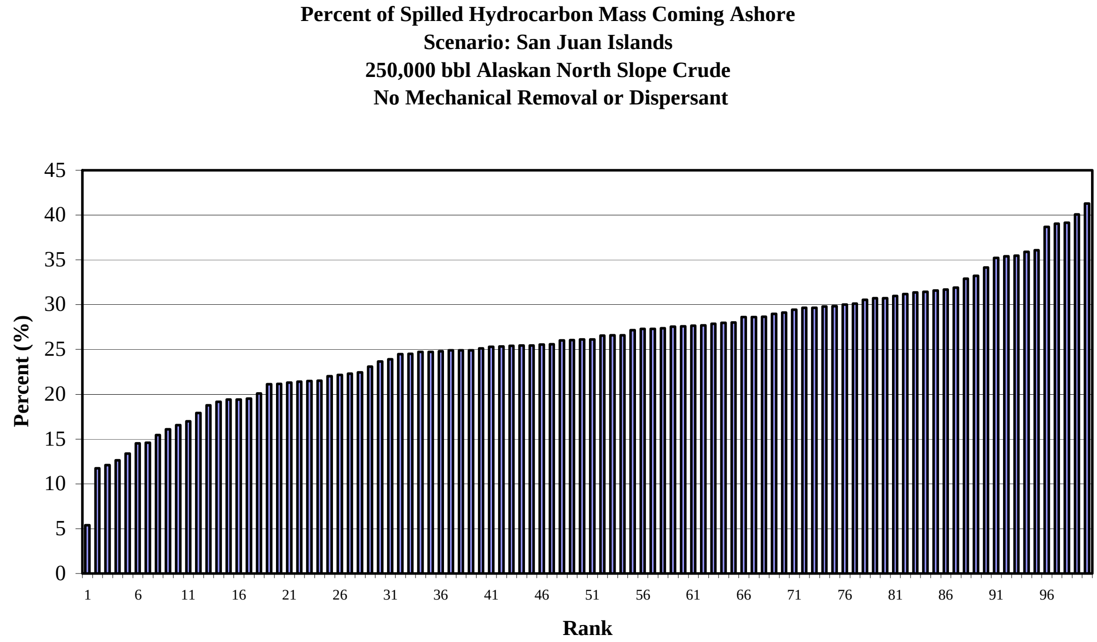


Figure XVI.C-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

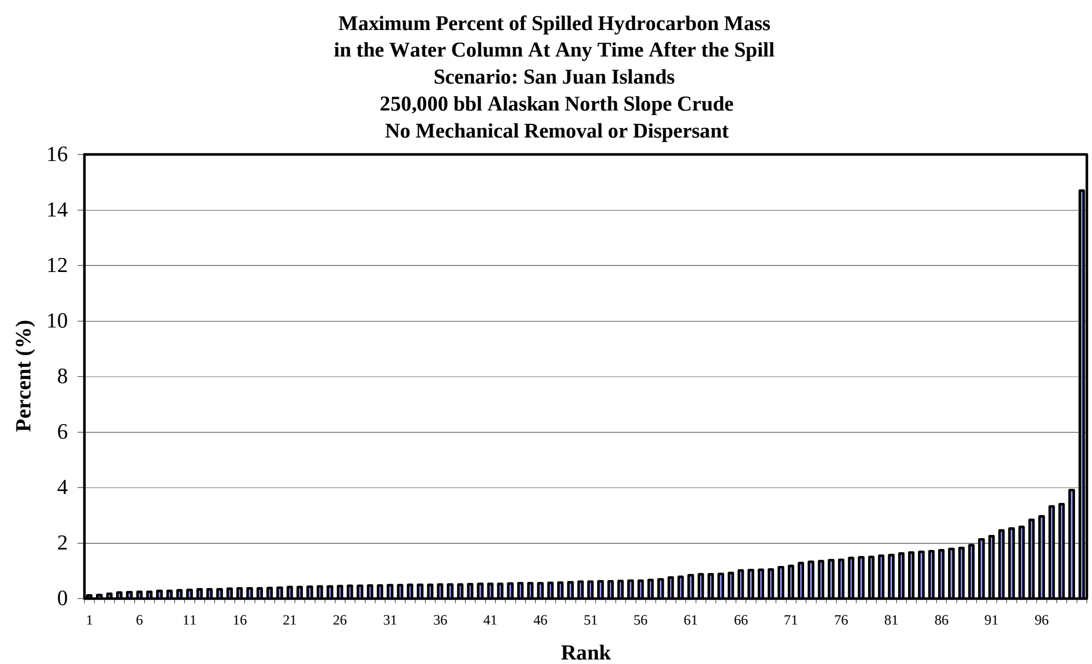


Figure XVI.C-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

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.

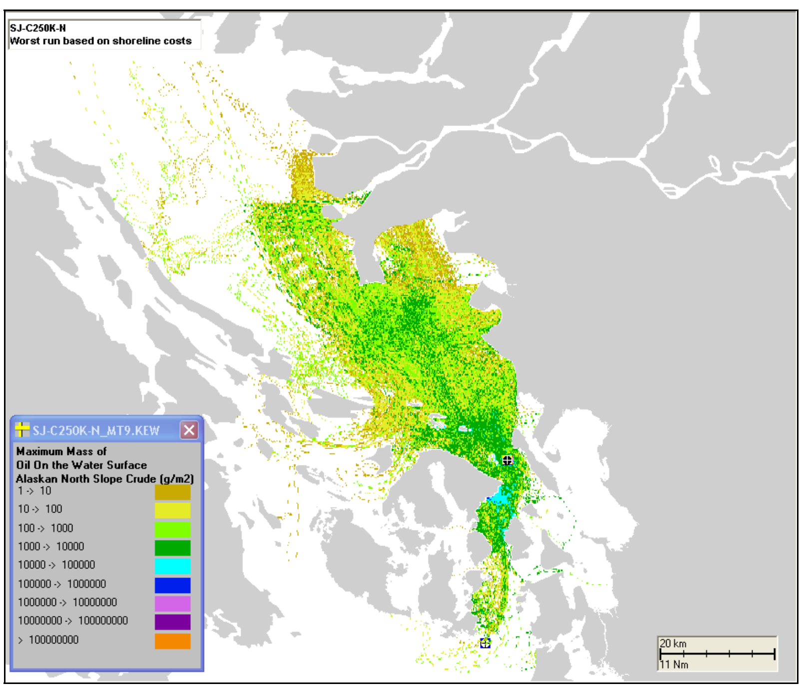


Figure XVI.E-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

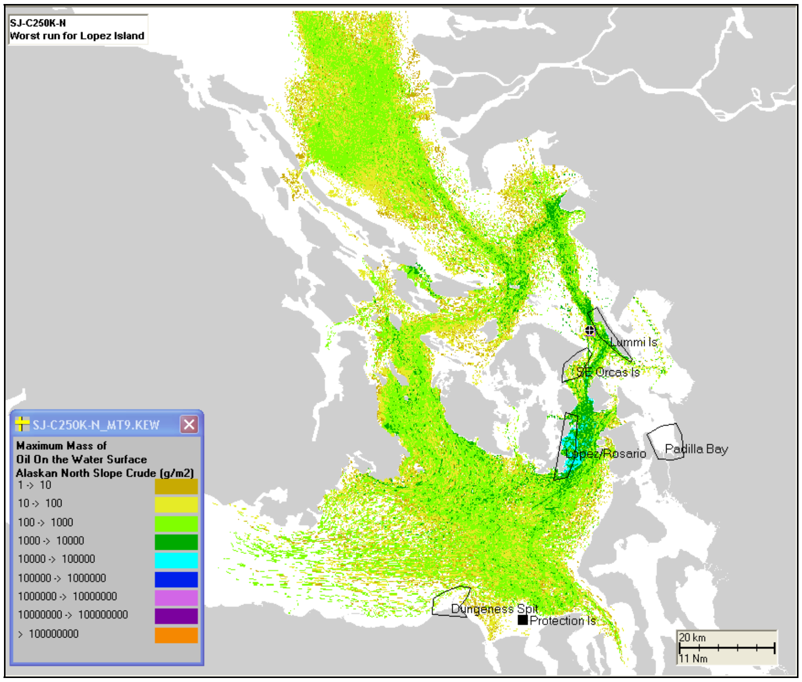


Figure XVI.E-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Lopez Island.

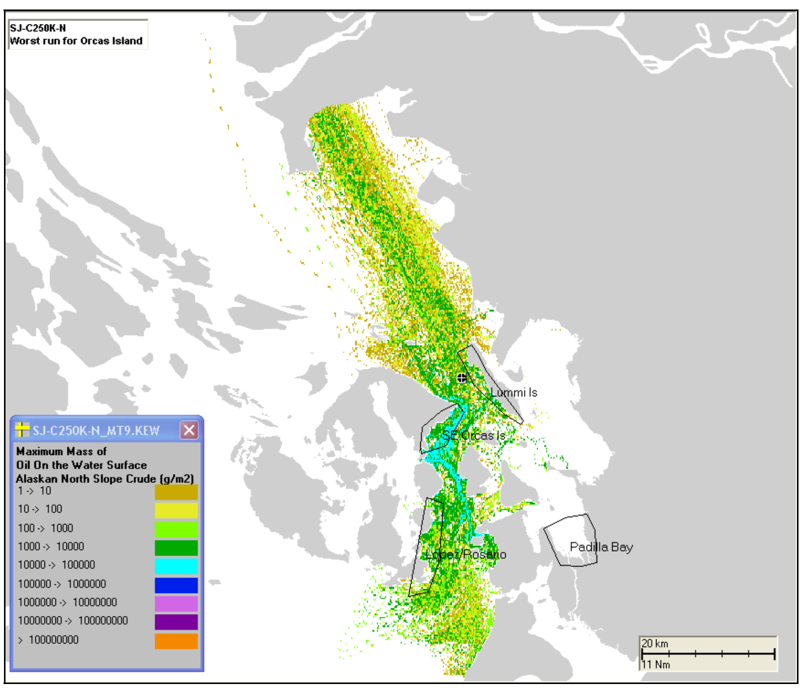


Figure XVI.E-3. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Orcas Island.

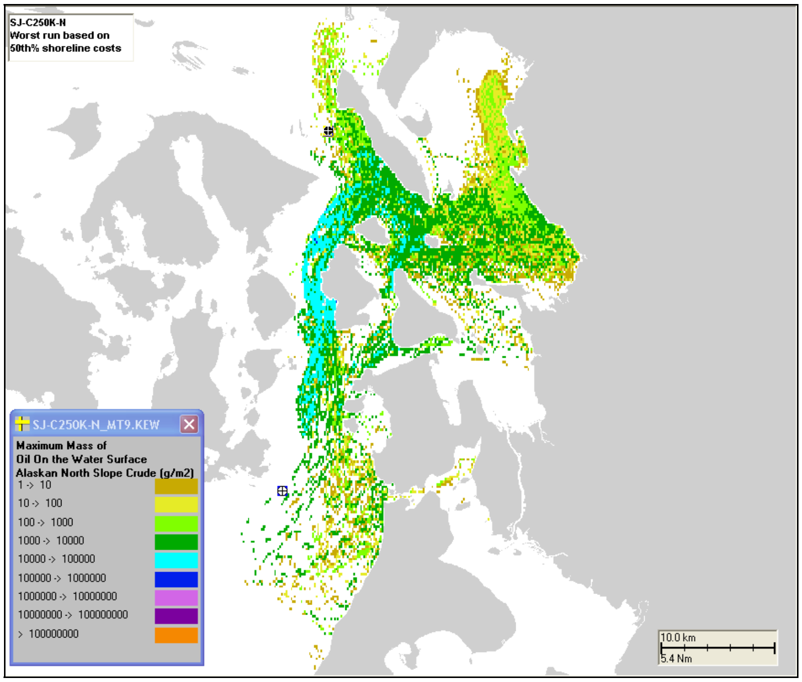


Figure XVI.E-4. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m²) for the 50th percentile run based on shoreline costs.

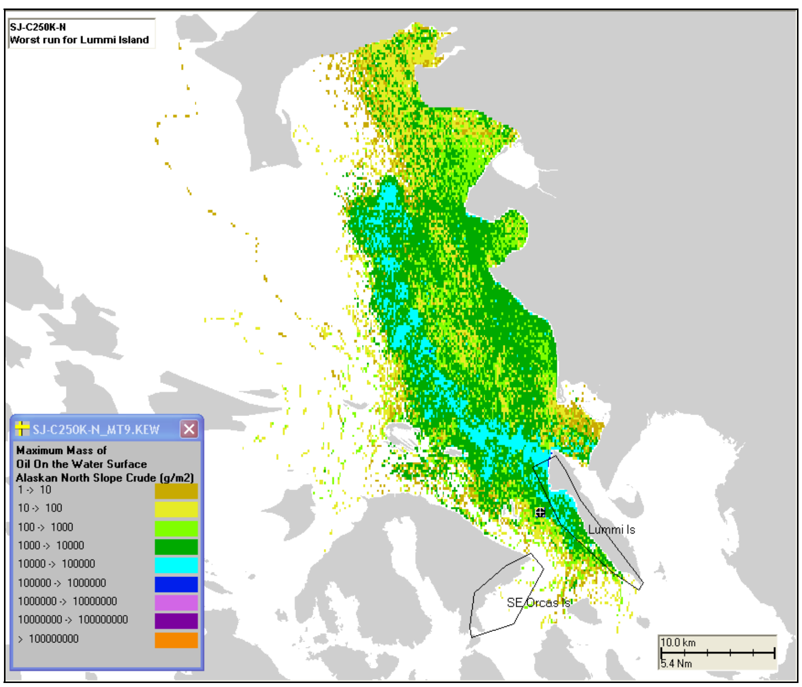


Figure XVI.E-5. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m²) for the worst run for Lummi Island.

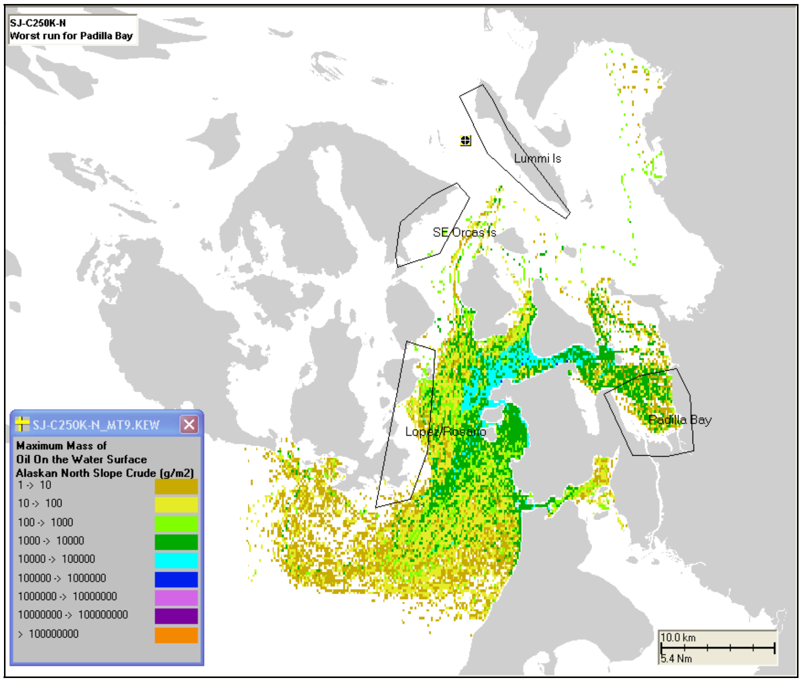


Figure XVI.E-6. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Padilla Bay.

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 >10g/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 >10g/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 5^{th} to 95^{th} 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 5^{th}, 50^{th} and 95^{th} 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

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan, Ann Borowik, and Claudia Suárez
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrenchmccay@asascience.com

and

Dagmar Schmidt Etkin
Environmental Research Consulting
41 Croft Lane
Cortlandt Manor, NY 10567-1160 USA
Tel: +1 914 734 7511
Fax: +1 914 734 2256
Email: etkin@environmental-research.com

Submitted to:
Linda Pilkey-Jarvis
Washington Department of Ecology
300 Desmond Drive
Lacey, WA 98503
Tel: 360-407-6000
Email: JPil461@ECY.WA.GOV

ASA 2003-111
May 2006

Table of Contents

XVII.A. Introduction 1
XVII.B. Oil Fate Over Time 3
XVII.C. Estimated Biological Impacts: Wildlife.. 78
XVII.D. Estimated Biological Impacts: Fish and Invertebrates 82
XVII.E. Estimated NRDA Costs: Habitat Restoration Costs 86
XVII.F. Estimated NRDA Costs: Washington Compensation schedule 95

List of Figures

Figure XVII.A-1 Sensitive sites for location: San Juan Islands. 2
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).. 4
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). 5
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).. 6
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.. 7
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........... 8
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.. 9
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... 10
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.. 11
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.... 12
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.. 13
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. 14
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).. 15
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). 16
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).. 17

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. 18
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. 19
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. 20
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. 21
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. 22
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. 23
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. 24
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. 25

List of Tables

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). 26
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). 28
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). 30
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). 32
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. 34
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. 36
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. 38
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. 40
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. 42
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. 44
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. 46
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. 48
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). 50
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). 52
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). 54

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). 56
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. 58
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. 60
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. 62
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. 64
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. .. 66
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. 68
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. 70
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. 72
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. 74
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. 75
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. 76
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. 77
Table XVII.C-1 San Juan Islands - Alaskan North Slope Crude, no removal: Wildlife injury (as numbers lost). 78
Table XVII.C-2 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Wildlife injury (as numbers lost). 79

Table XVII.C-3 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost). 80
Table XVII.C-4 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Wildlife injury (as numbers lost)... 81
Table XVII.D-1. San Juan Islands - Alaskan North Slope Crude, no removal: Fish and invertebrate injury (as biomass lost in kg). 82
Table XVII.D-2. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 83
Table XVII.D-3. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 84
Table XVII.D-4. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 85
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. 87
Table XVII.E-2. San Juan Islands - Alaskan North Slope Crude, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 88
Table XVII.E-3. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.. 89
Table XVII.E-4. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 90
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.. 91
Table XVII.E-6. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 92
Table XVII.E-7. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.. 93
Table XVII.E-8. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 94
Table XVII.F-1. San Juan Islands - Alaskan North Slope Crude, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 95
Table XVII.F-2. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 95
Table XVII.F-3. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 96
Table XVII.F-4. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 96

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 (99^{th} 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 50^{th} 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.

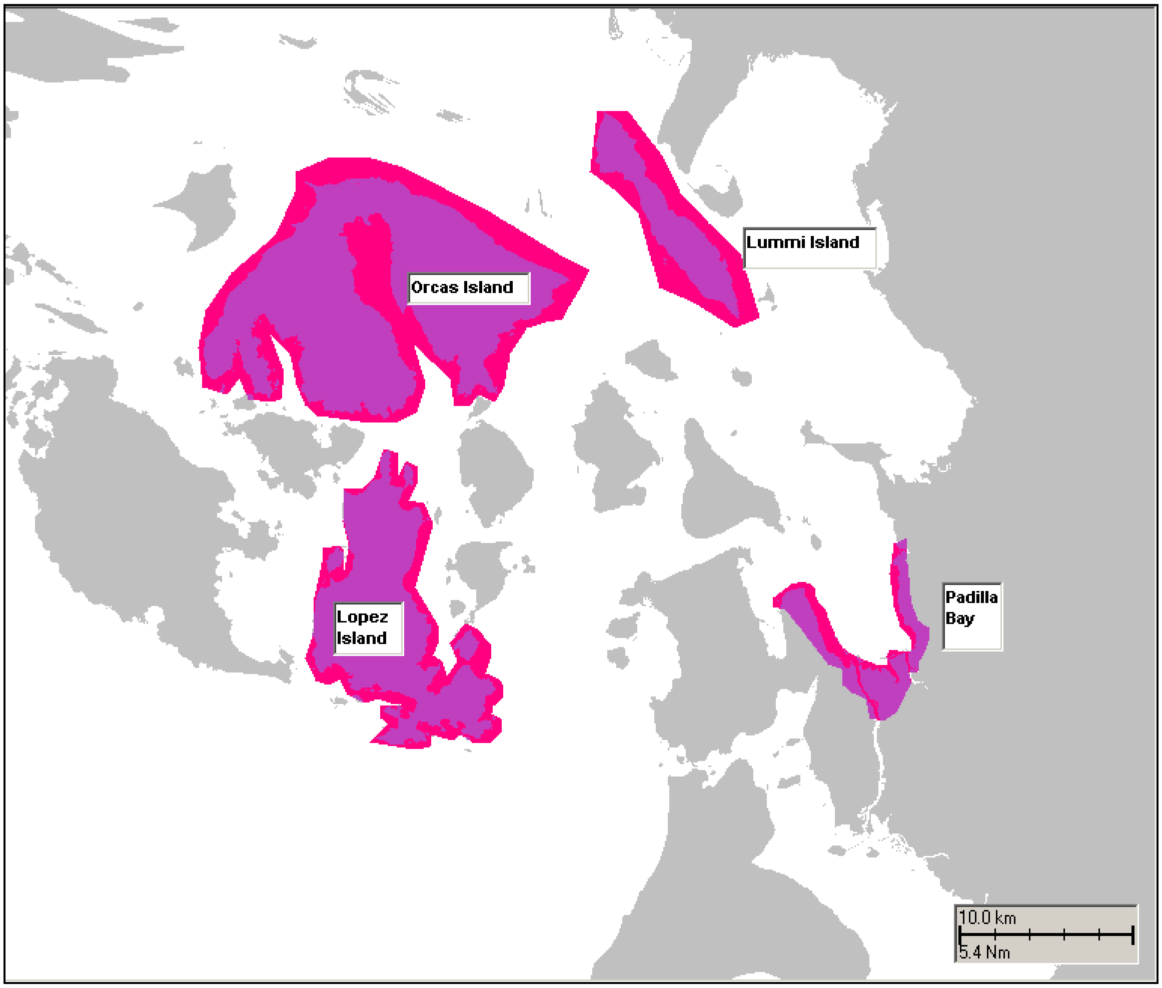
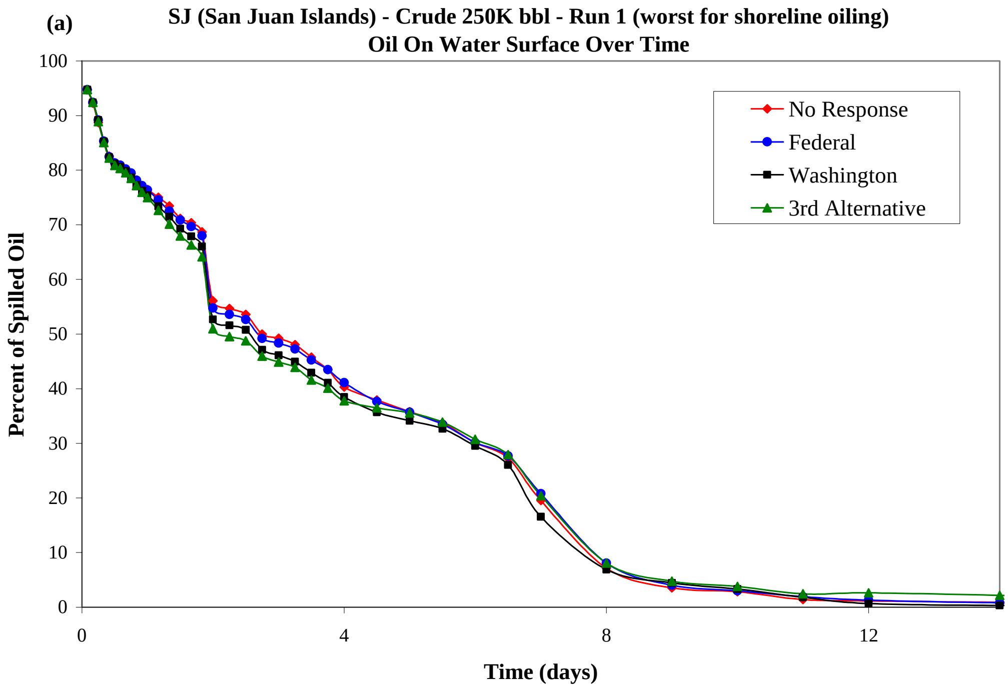


Figure XVII.A-1 Sensitive sites for location: San Juan Islands.

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.



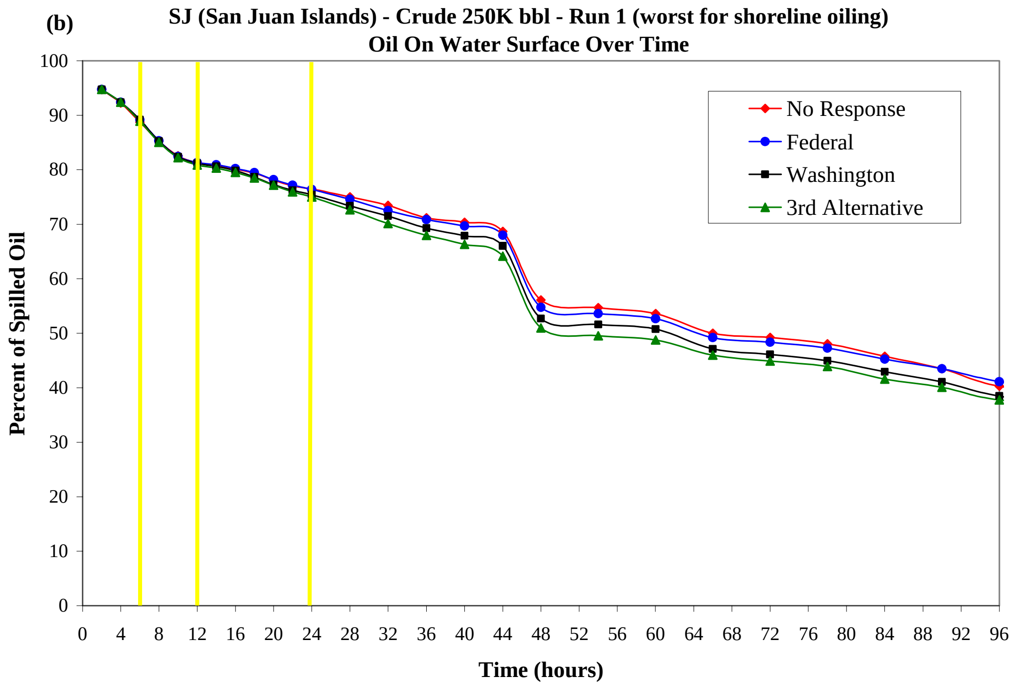
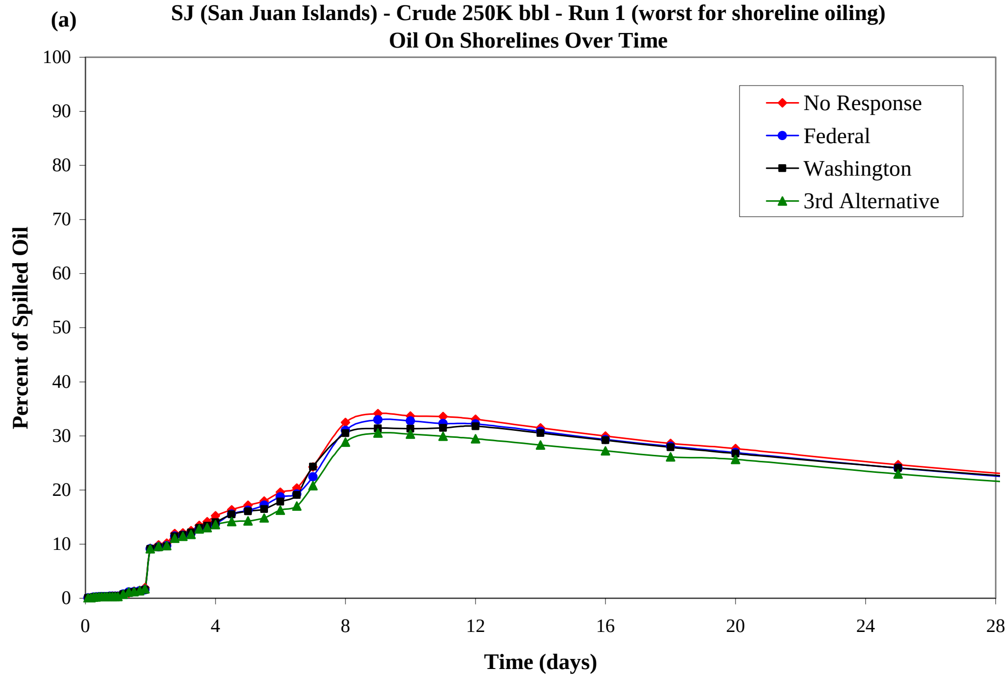


Figure XVII.B-1 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



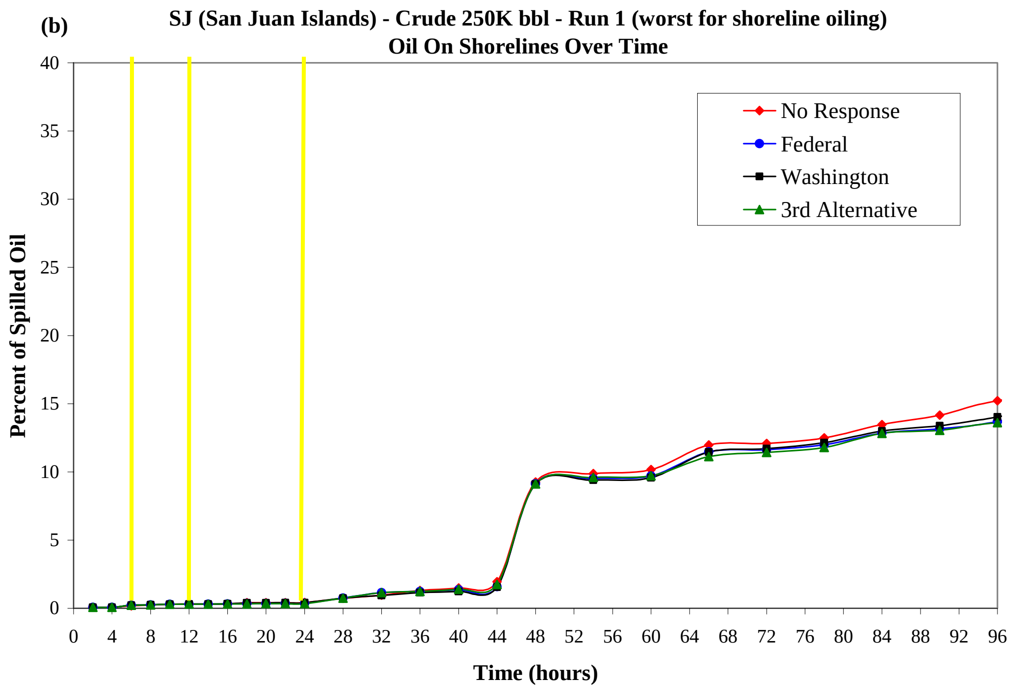
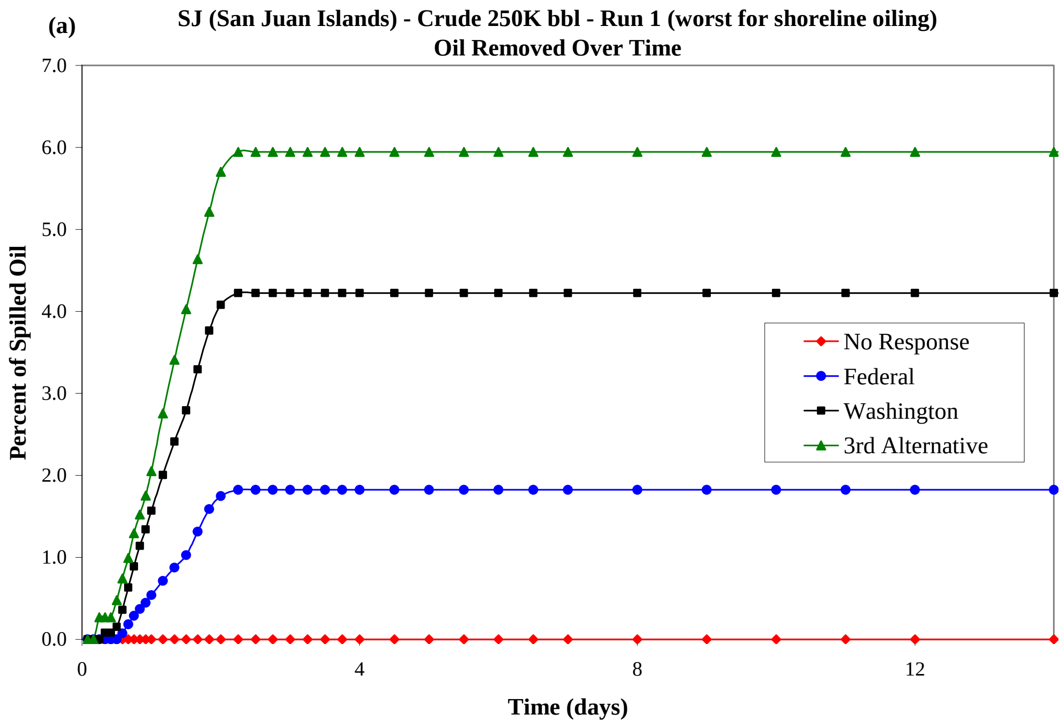


Figure XVII.B-2 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



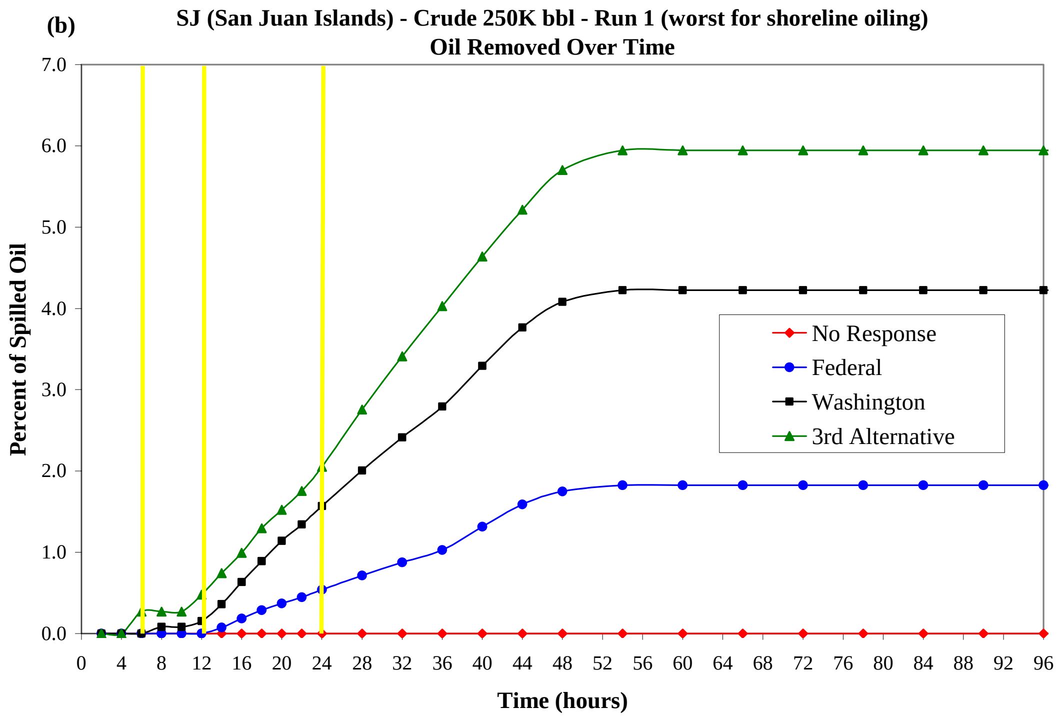
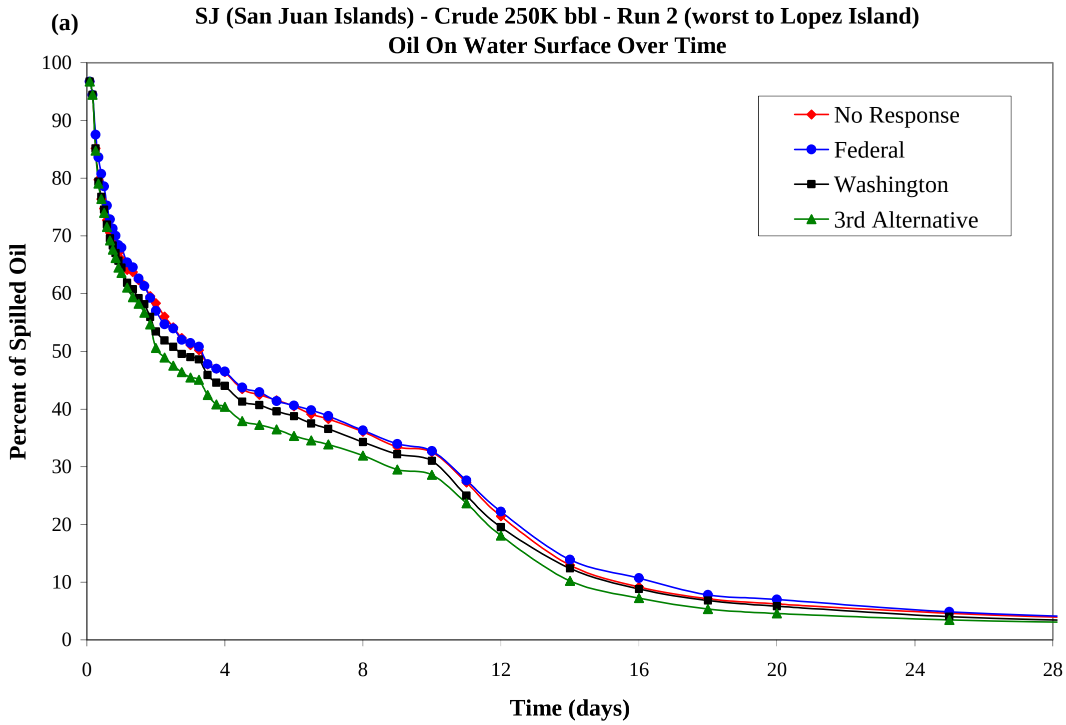


Figure XVII.B-3 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



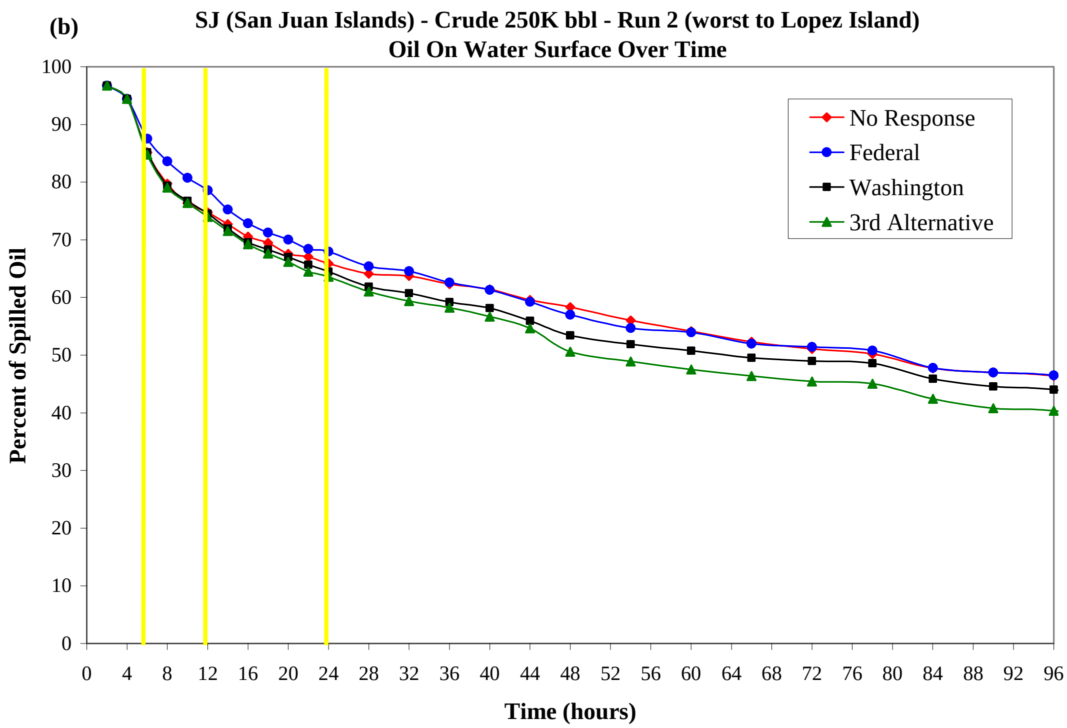


Figure XVII.B-4 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

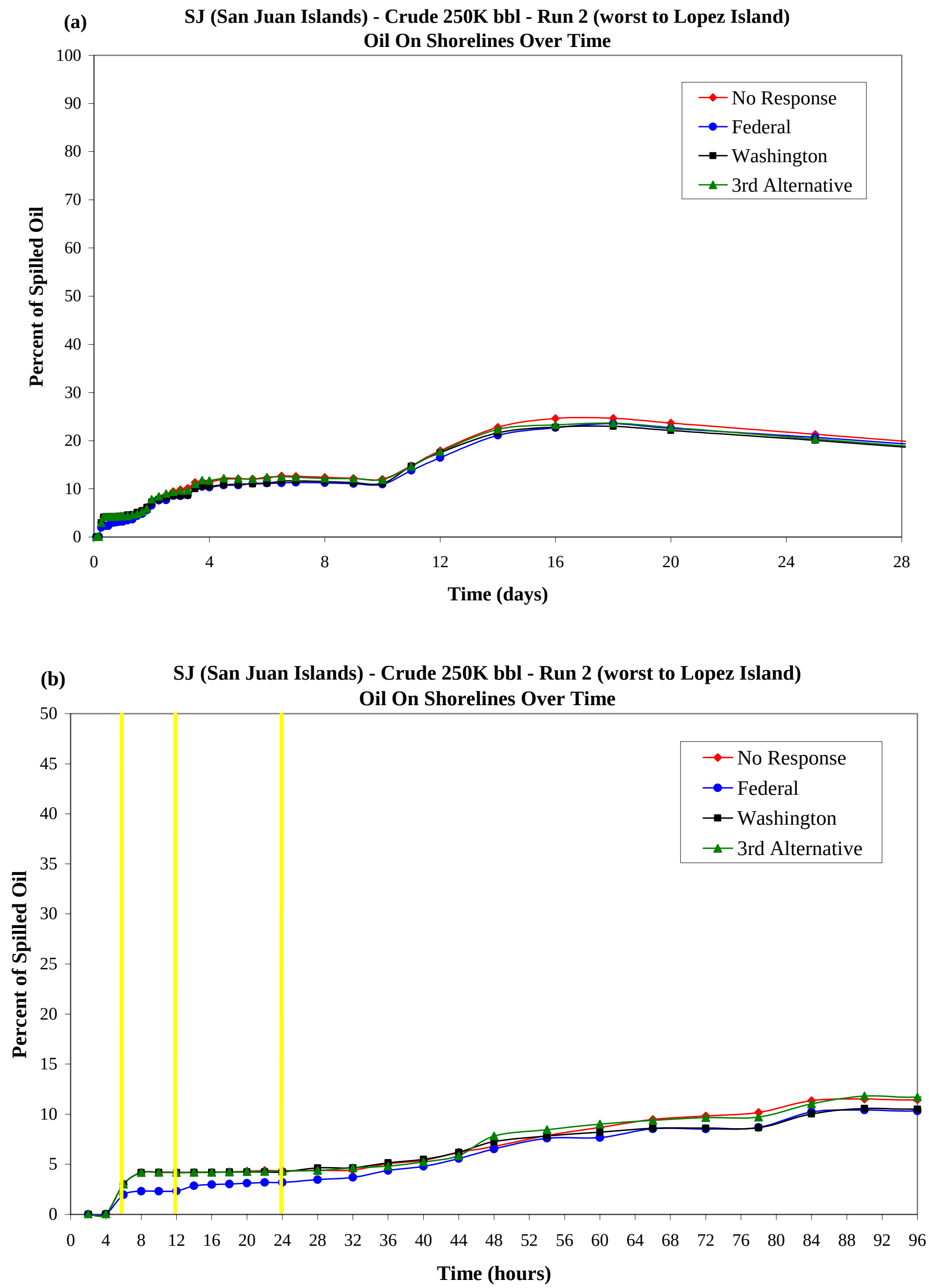
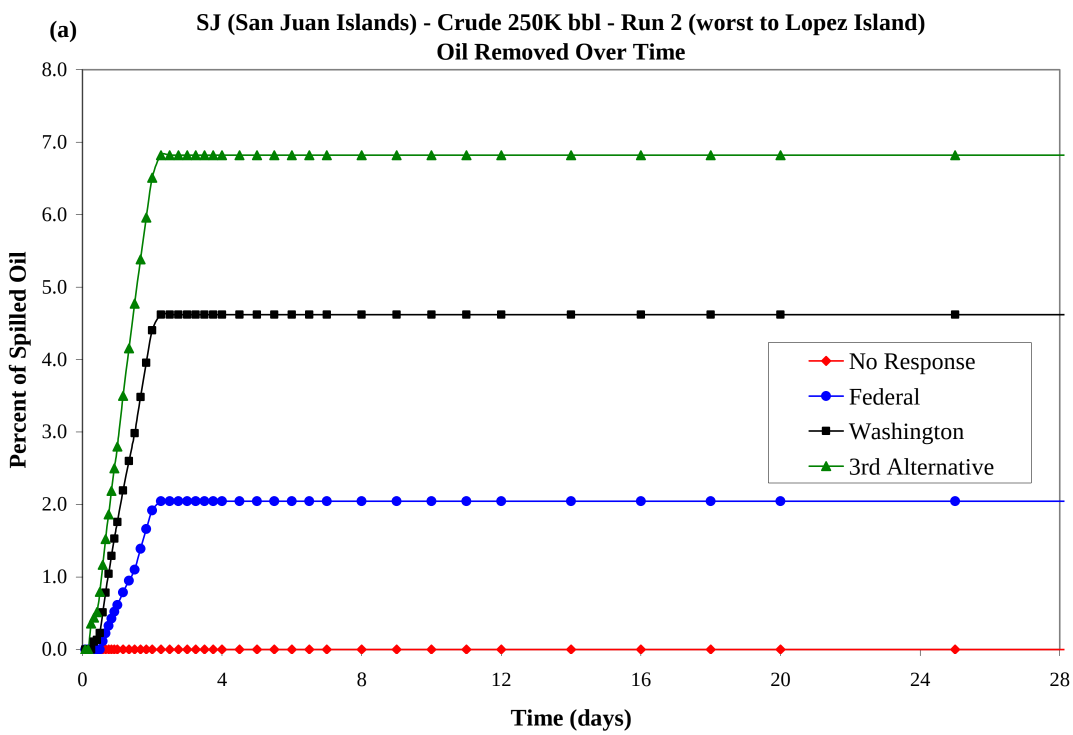


Figure XVII.B-5 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



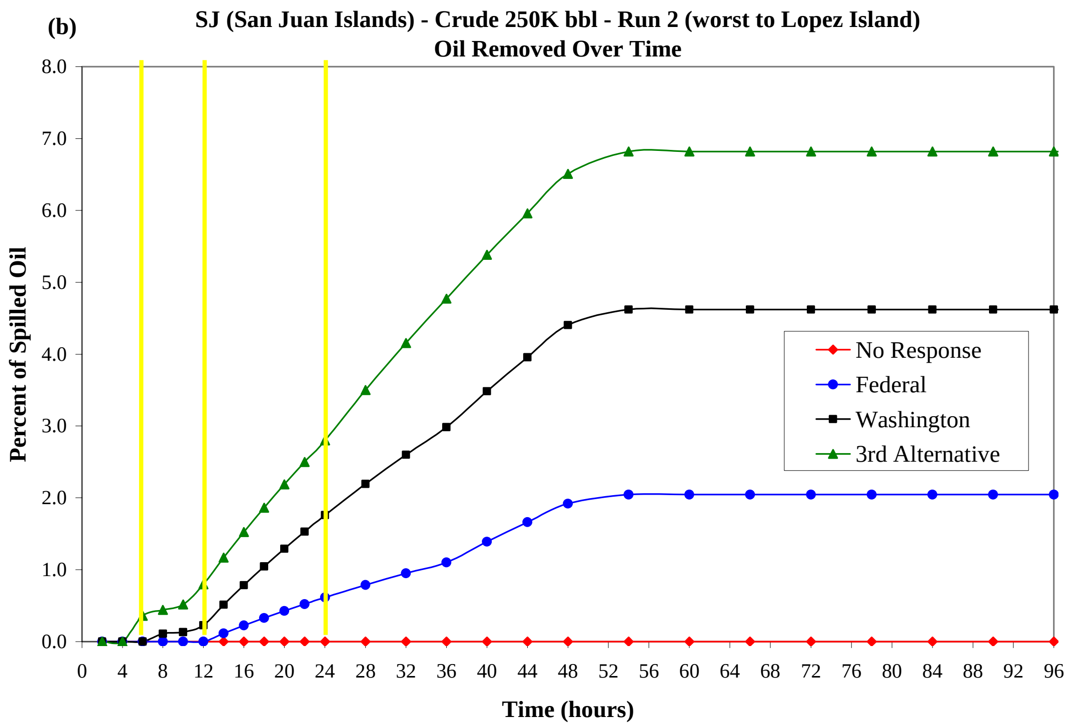
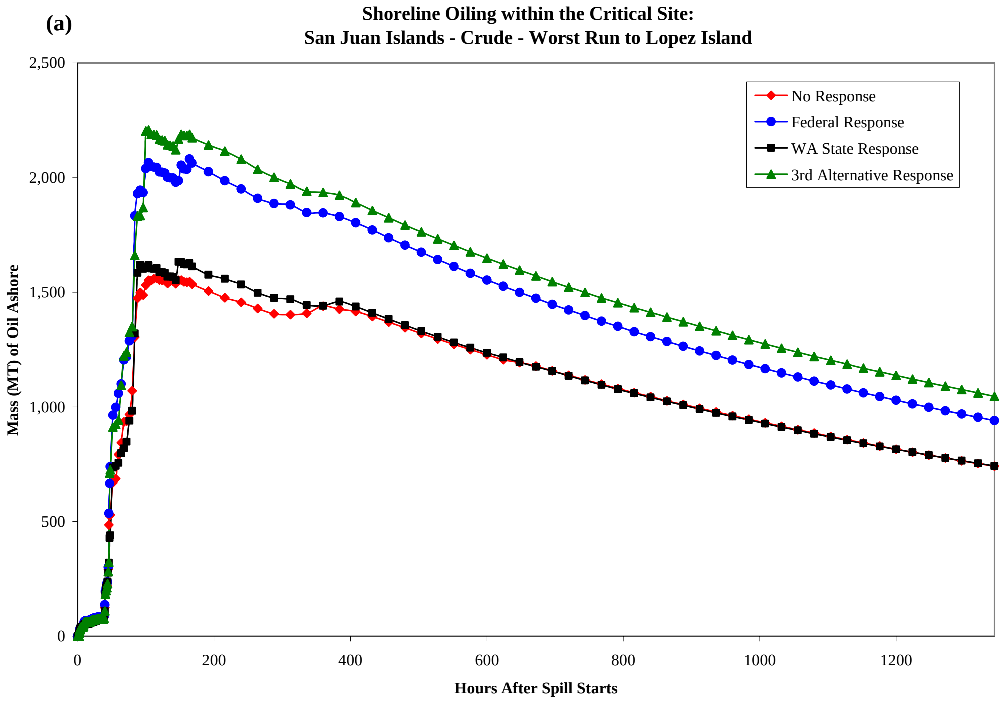


Figure XVII.B-6 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a.



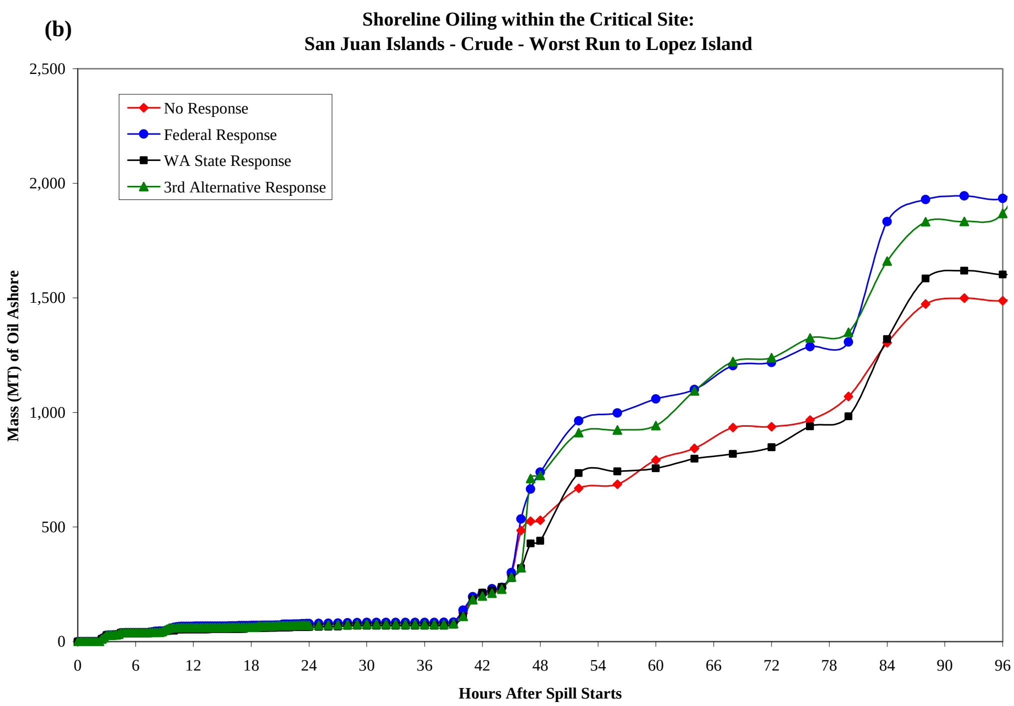
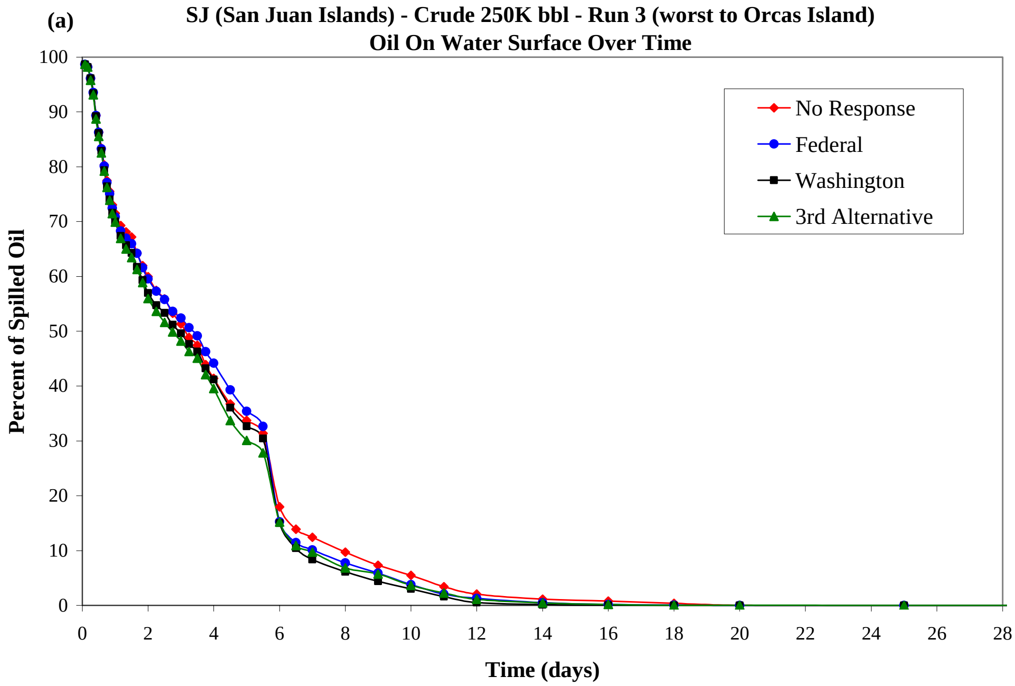


Figure XVII.B-7 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



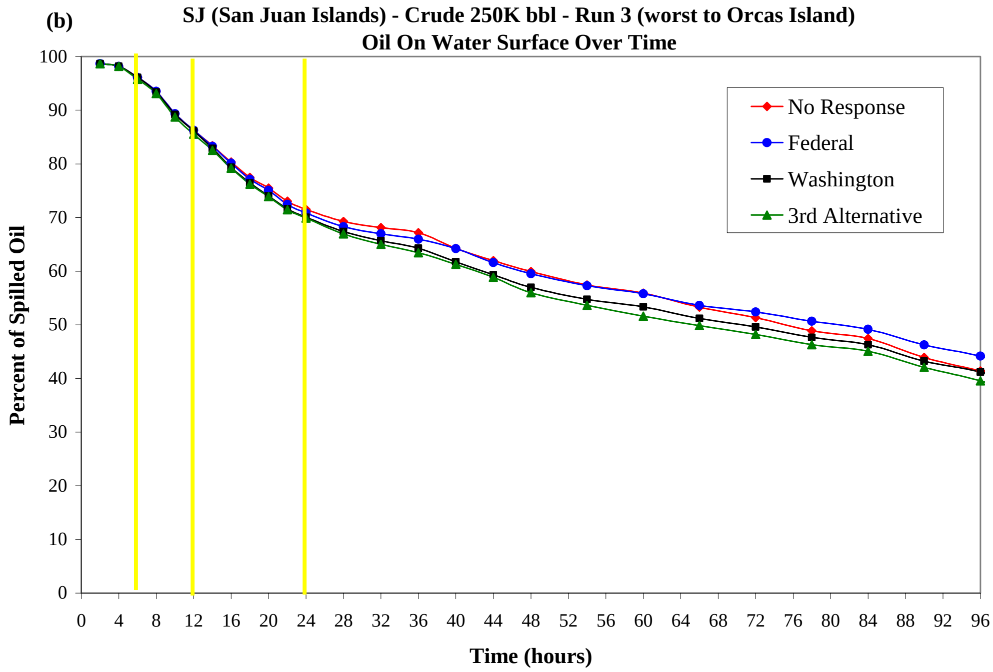
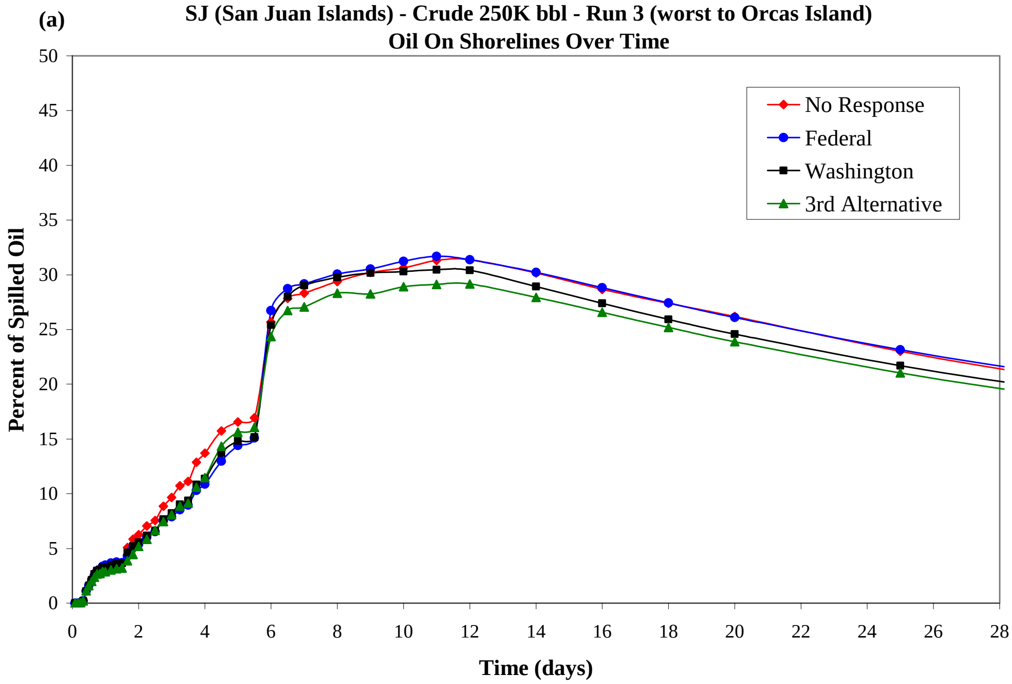


Figure XVII.B-8 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Orcas Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



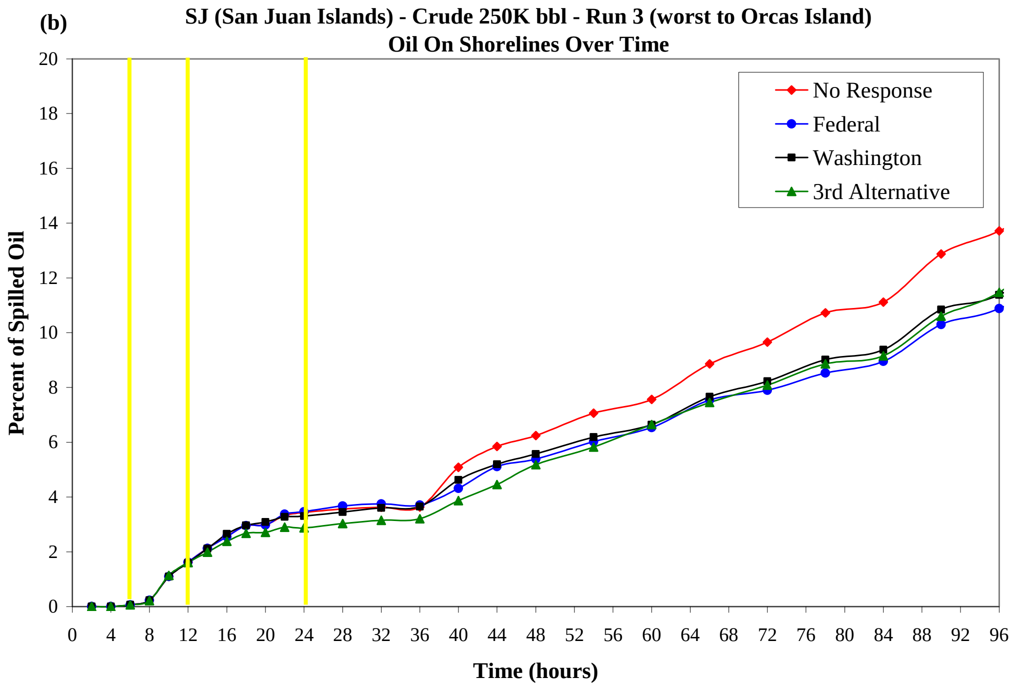
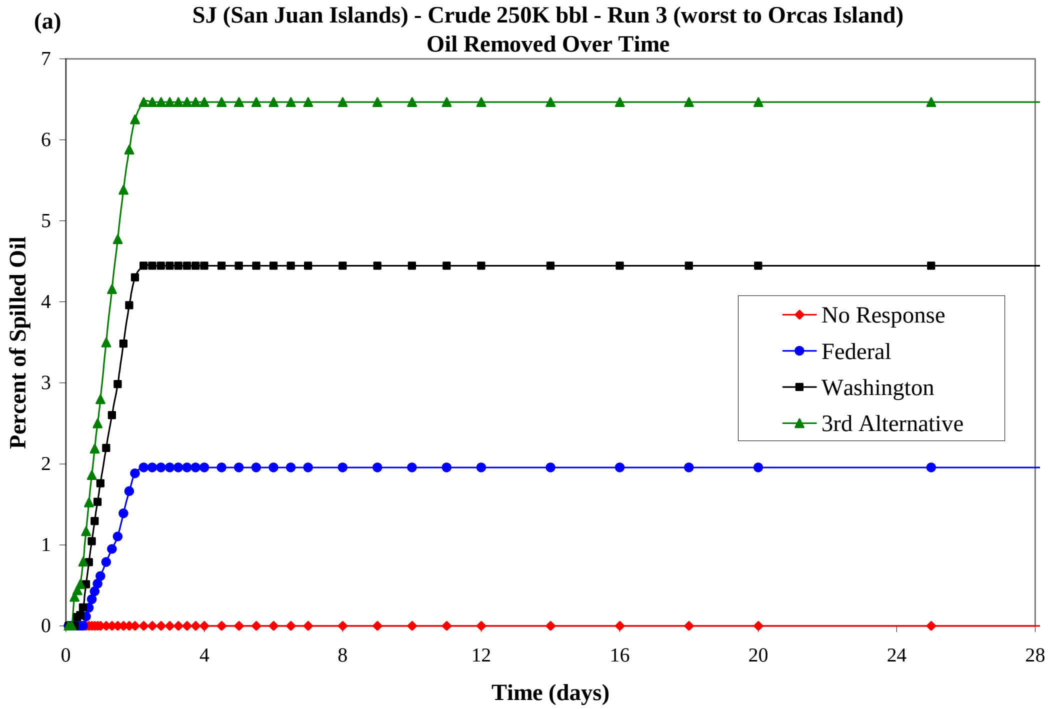


Figure XVII.B-9 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Orcas Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



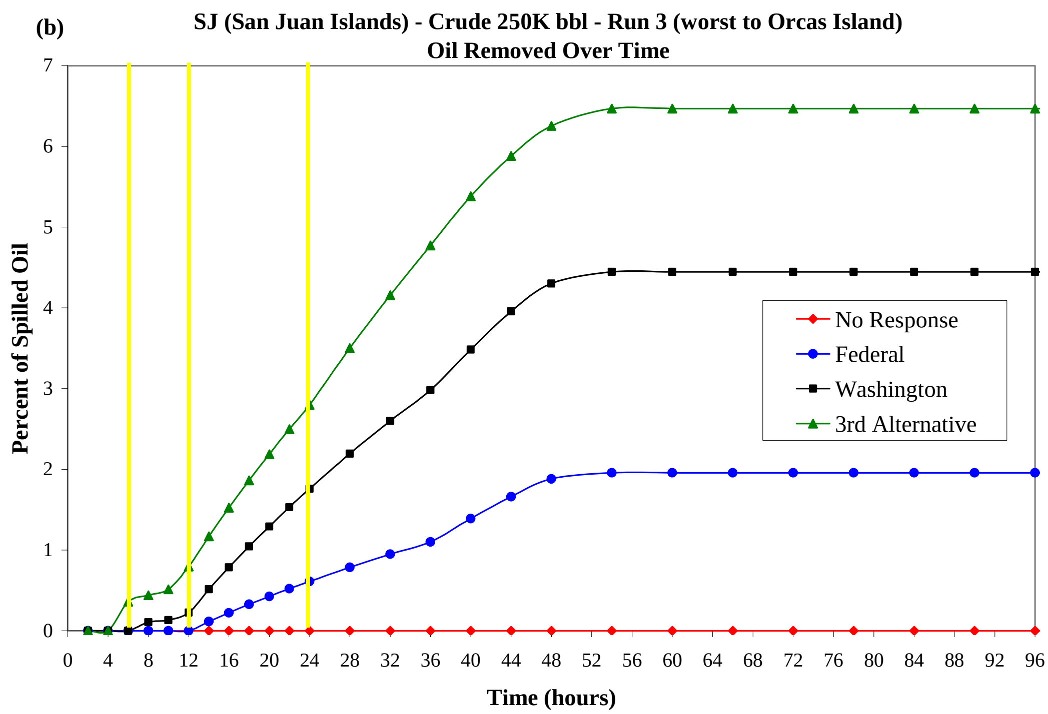


Figure XVII.B-10 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Orcas Island. Part b of this figure is a subset of Part a.

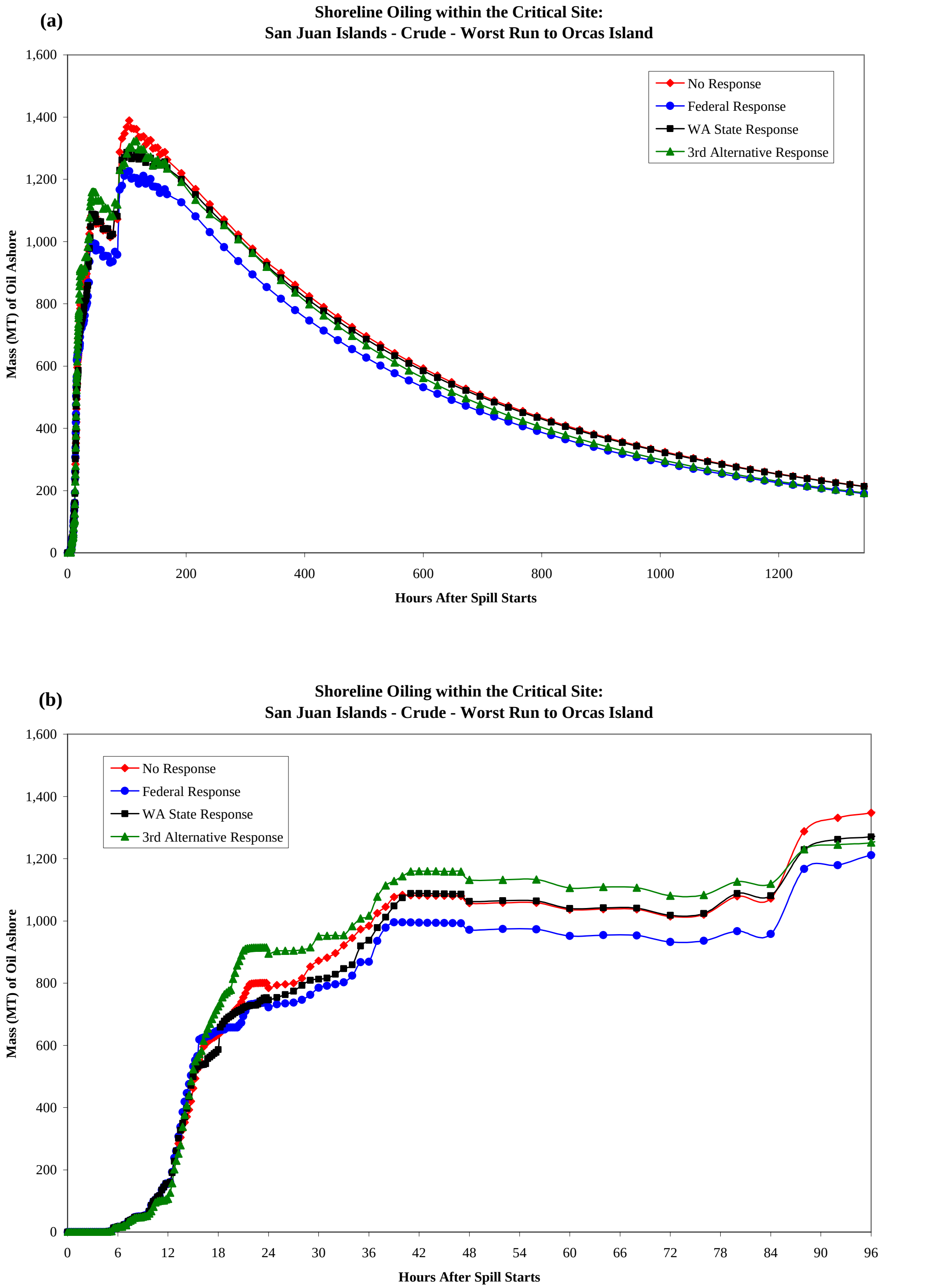
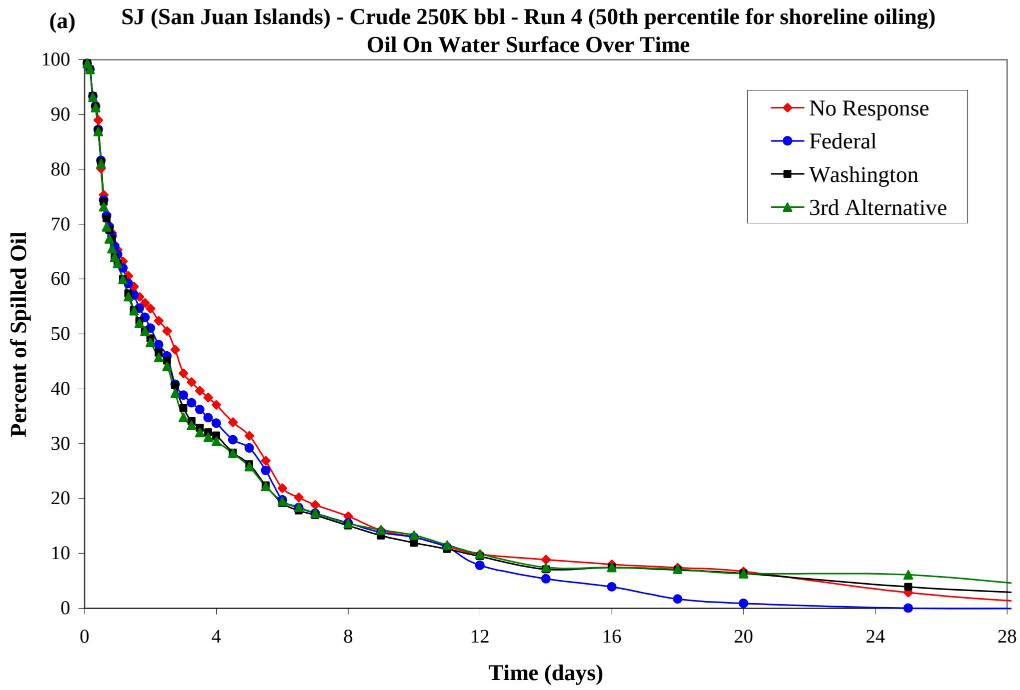


Figure XVII.B-11 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Orcas Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



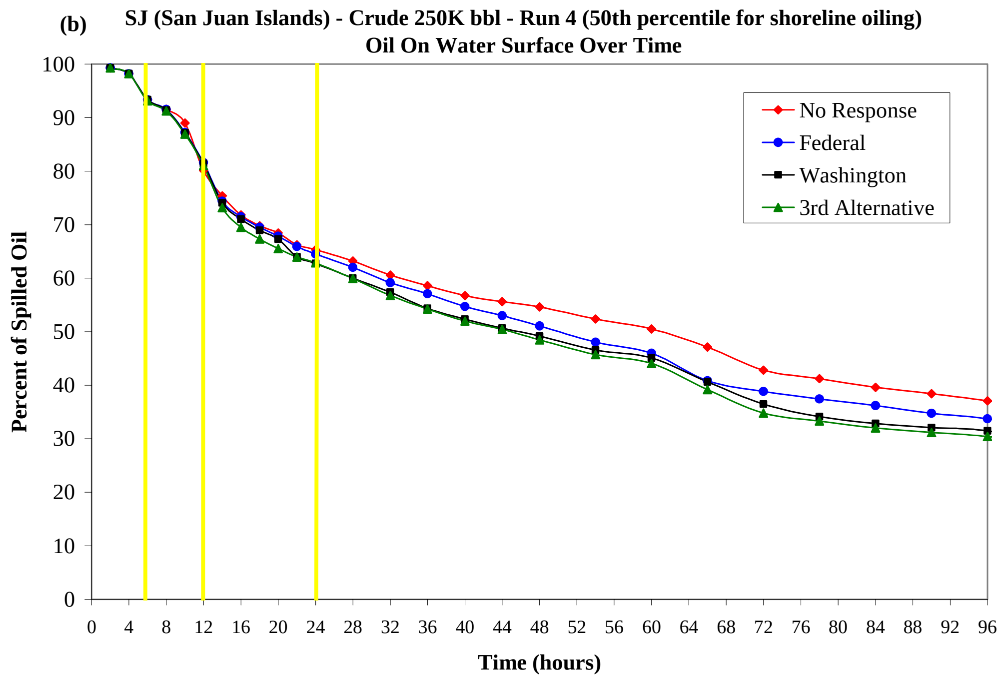
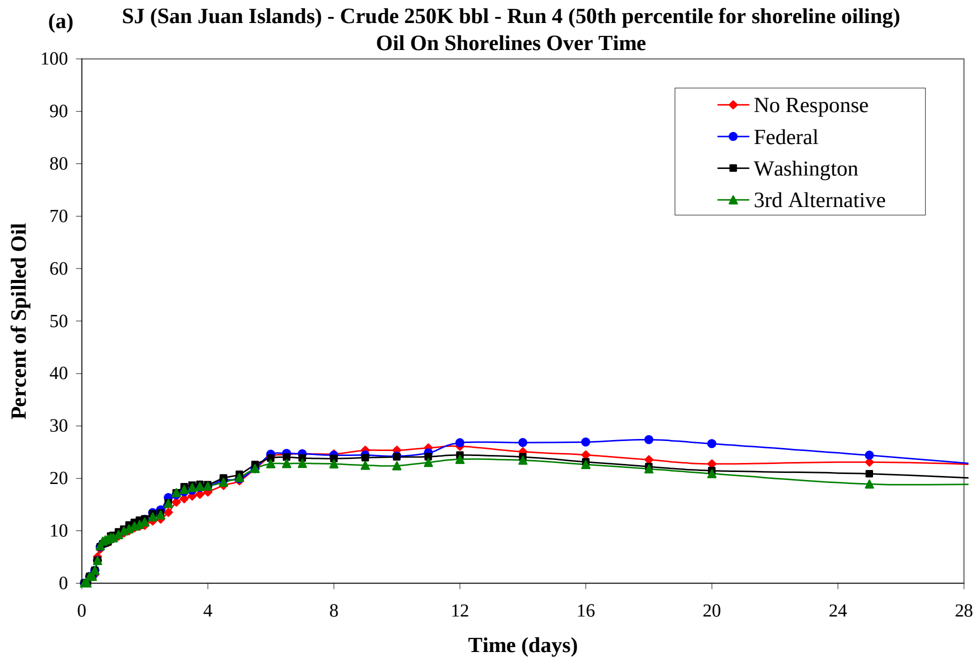


Figure XVII.B-12 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 50th percentile run (based on shore cost). Part b a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



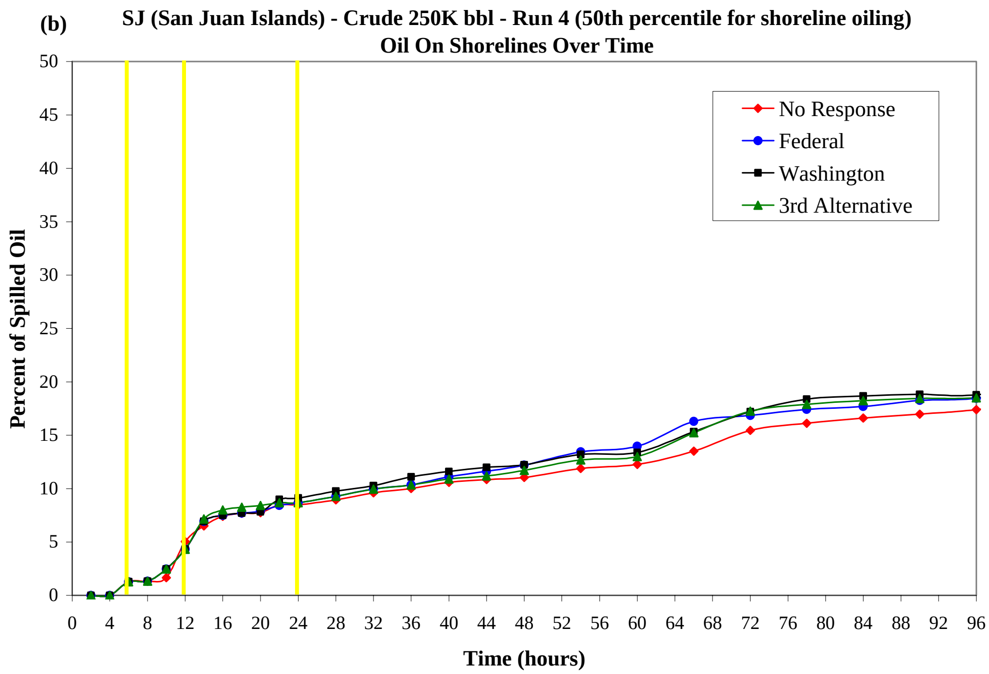


Figure XVII.B-13 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 50th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

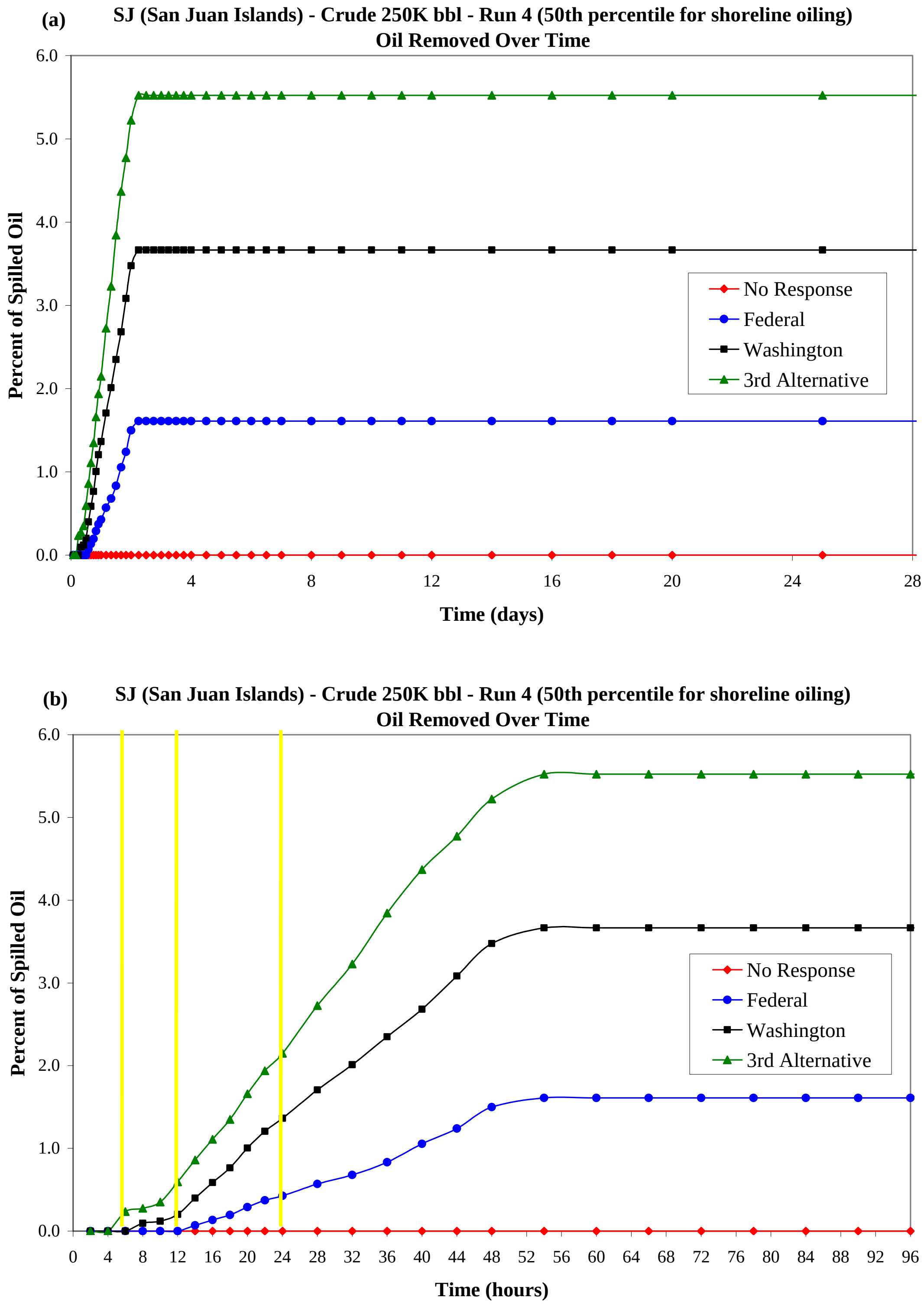
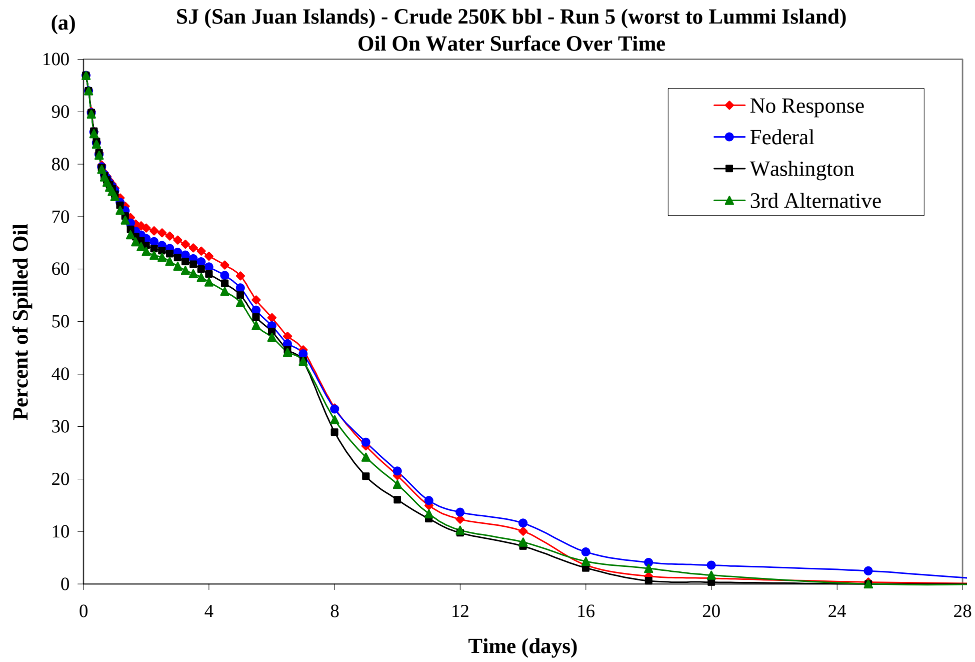


Figure XVII.B-14 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 50th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



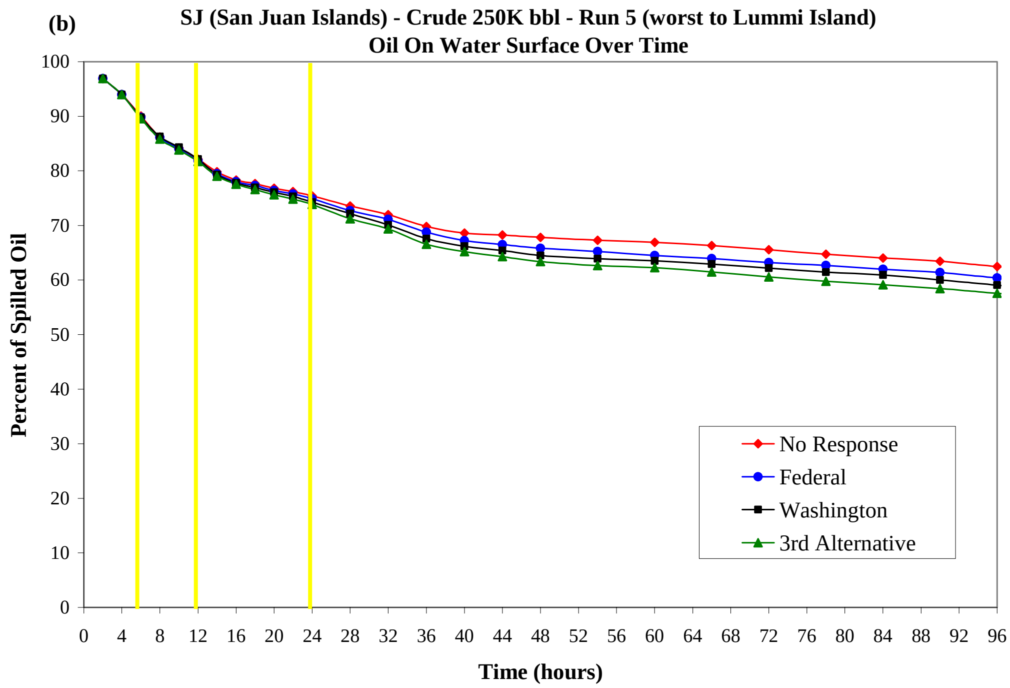


Figure XVII.B-15 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

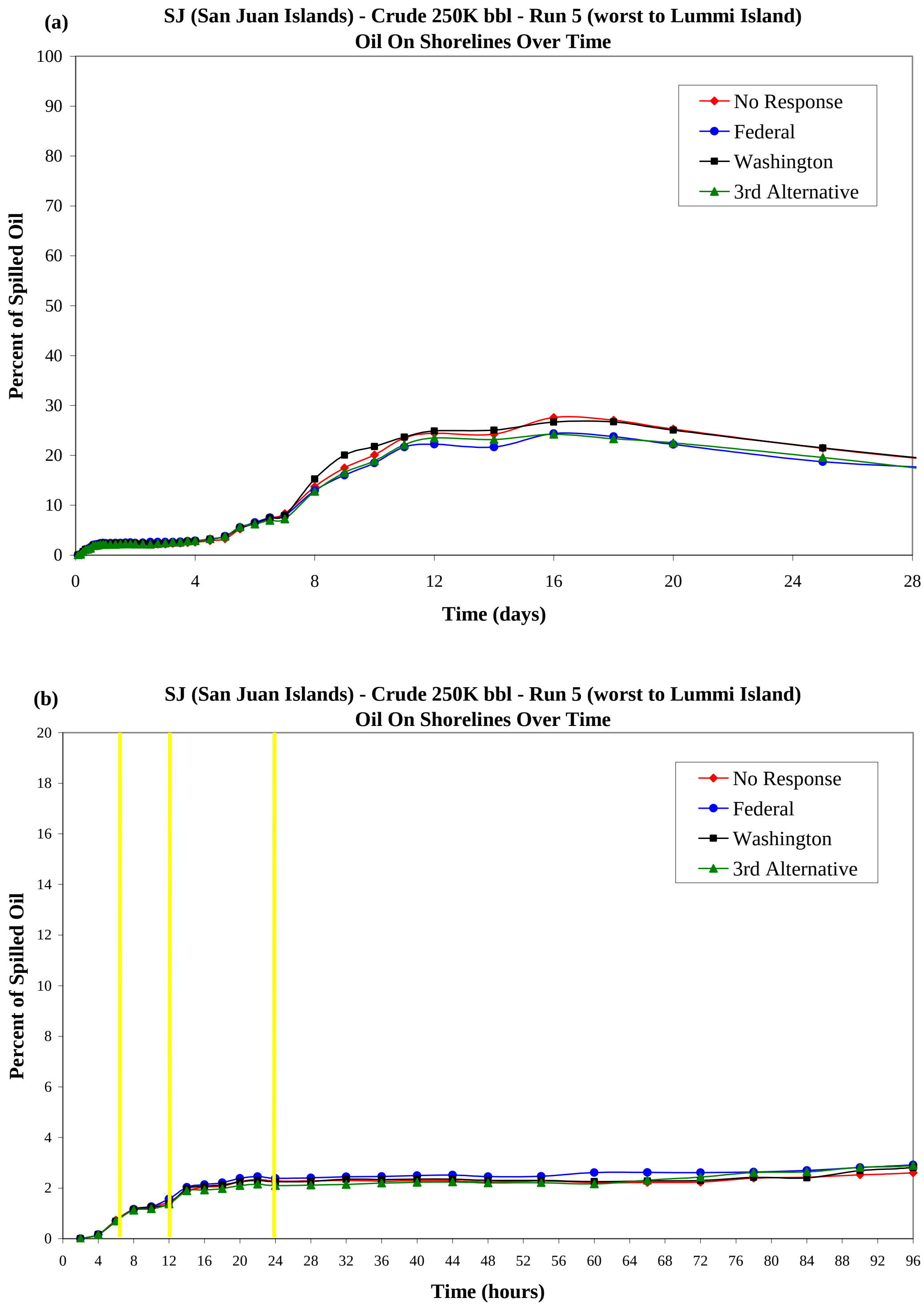
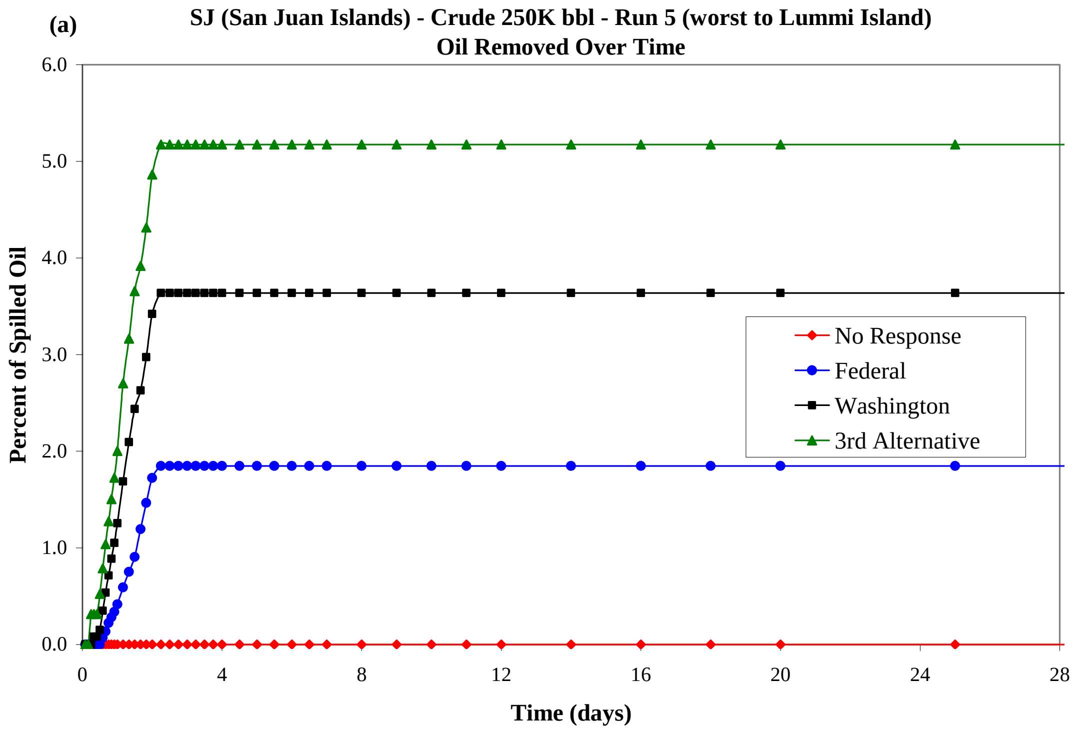


Figure XVII.B-16 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



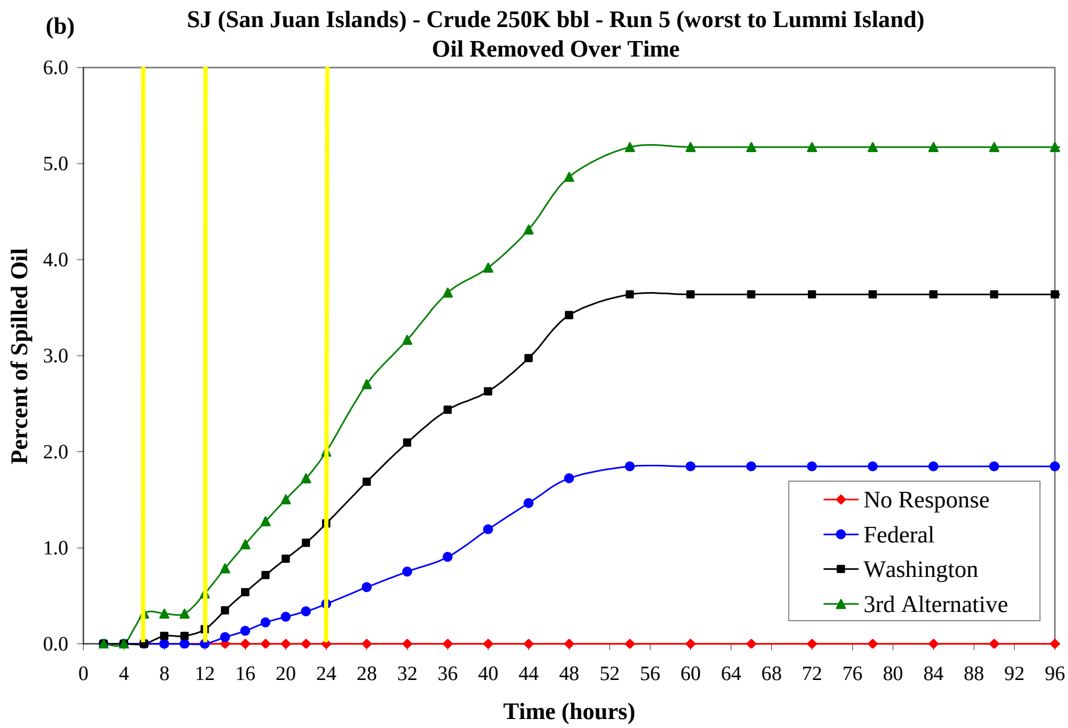
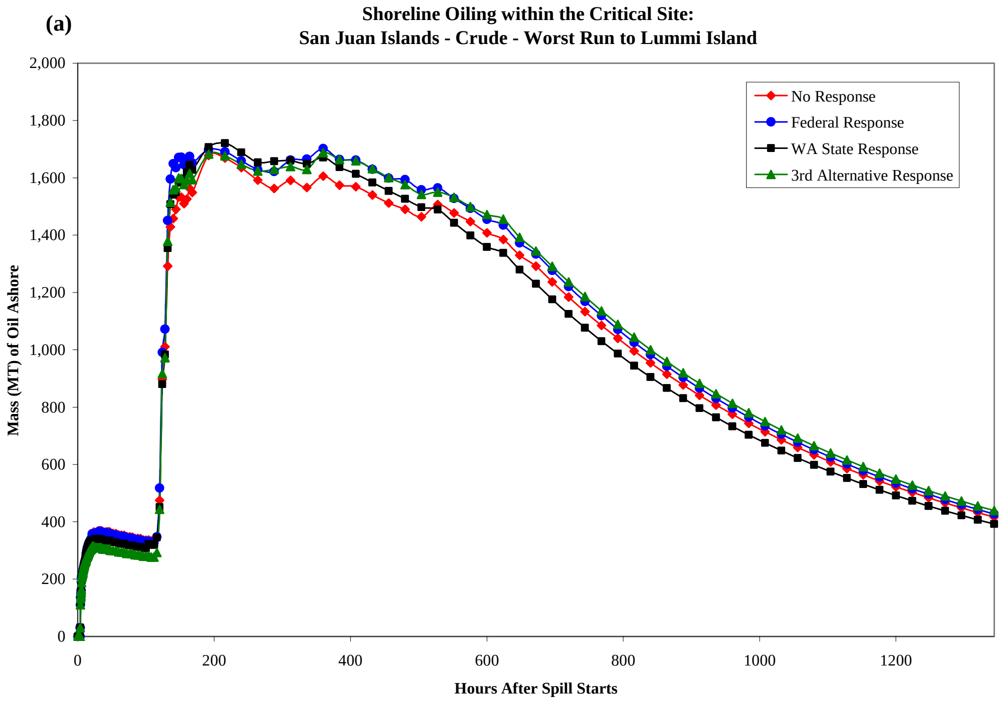


Figure XVII.B-17 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a.



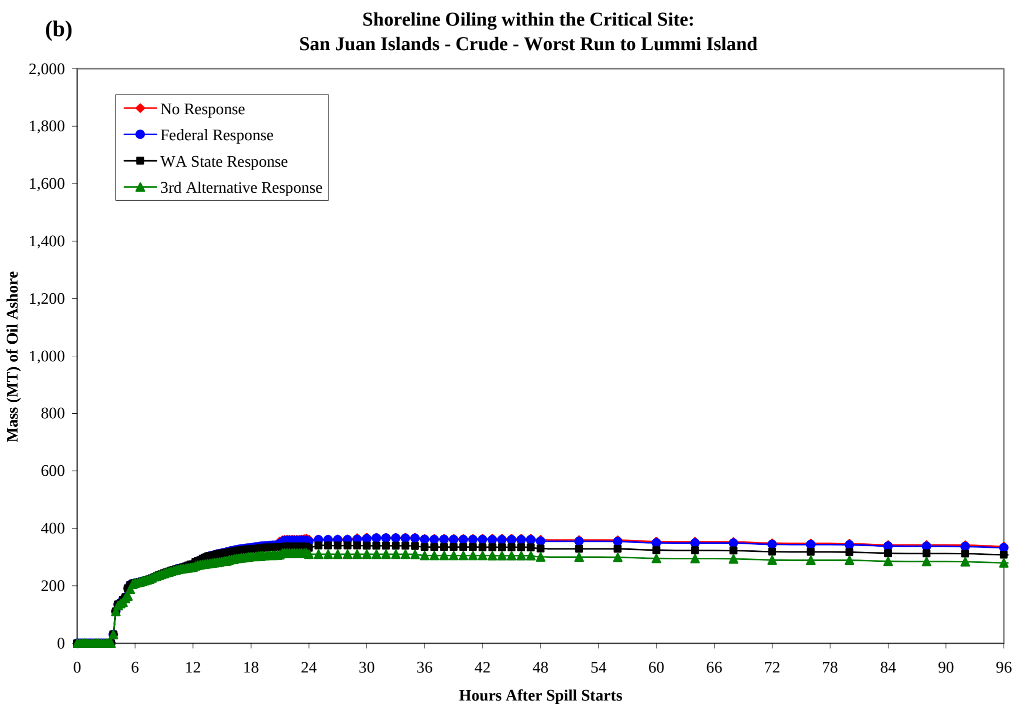
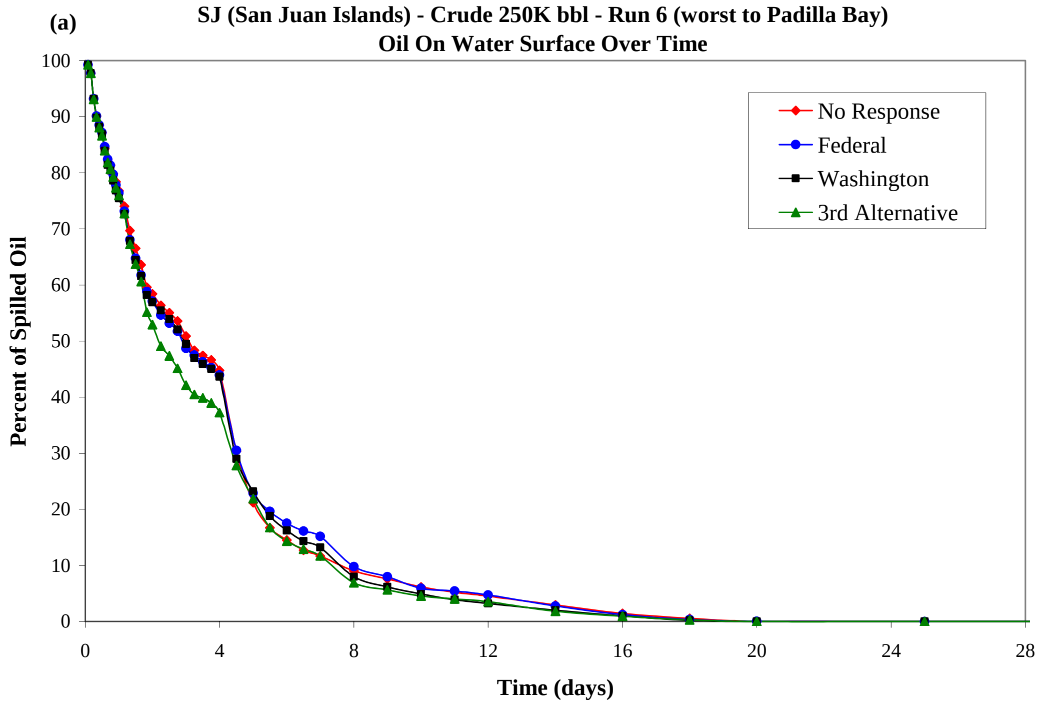


Figure XVII.B-18 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



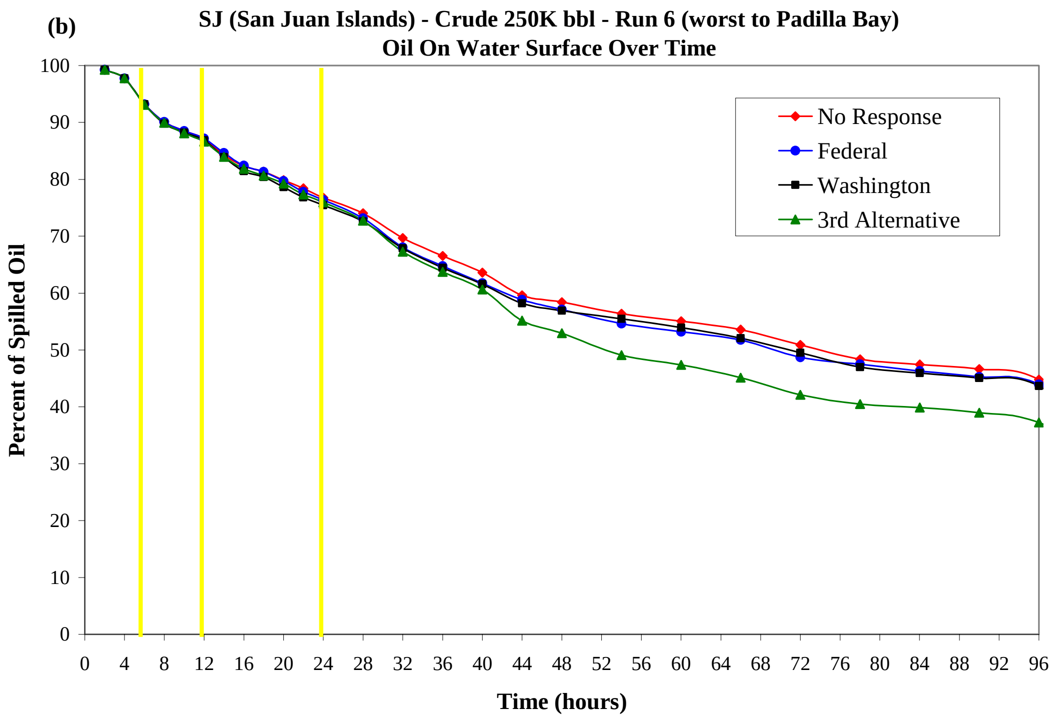
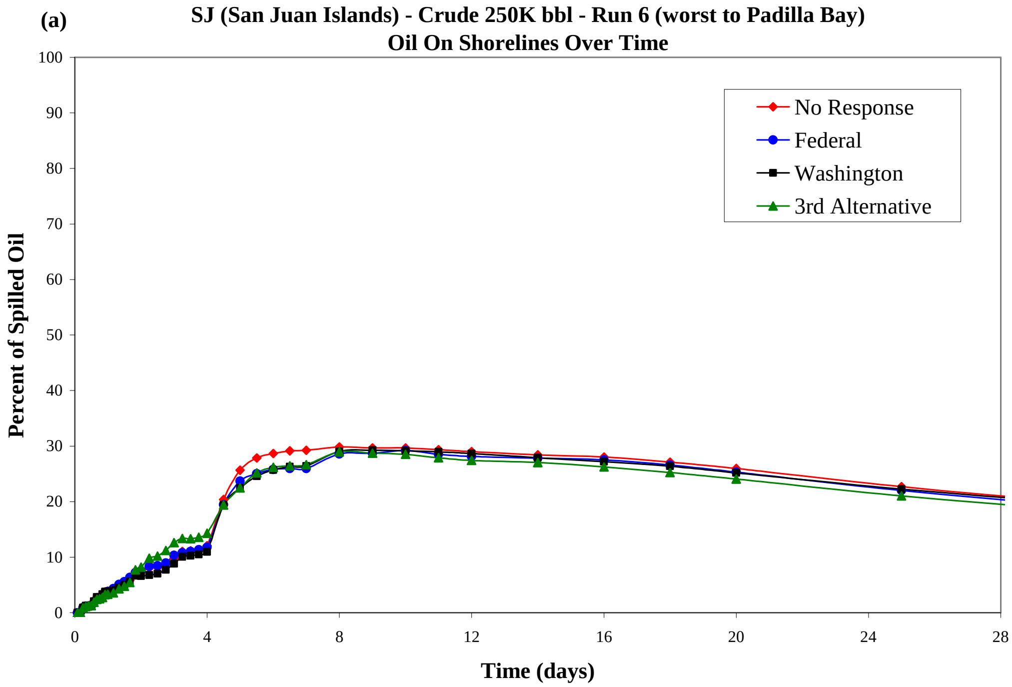


Figure XVII.B-19 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



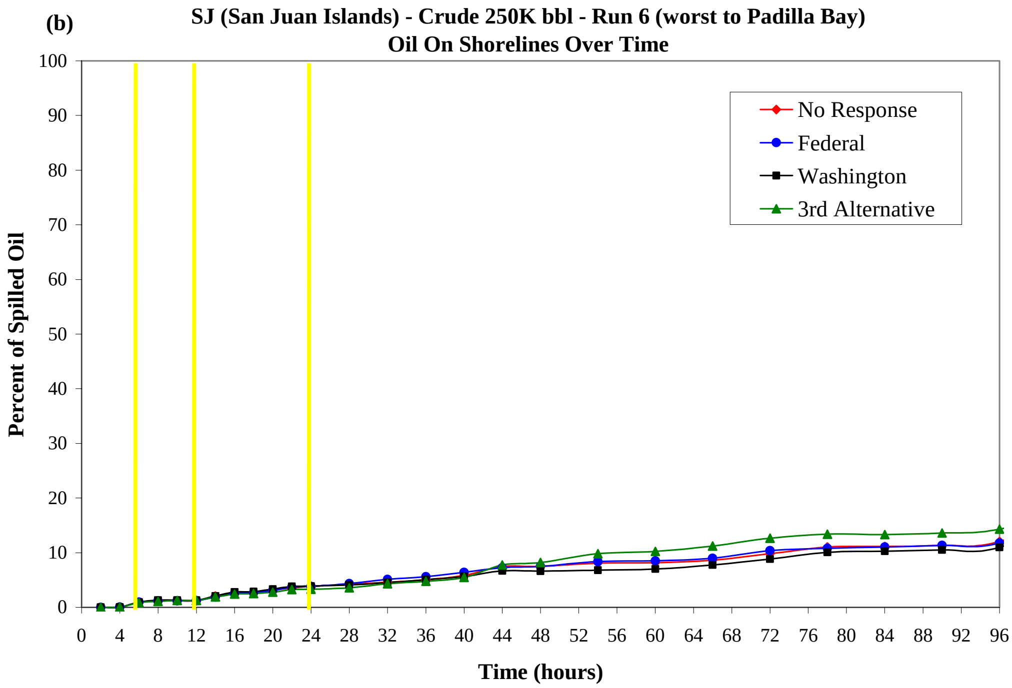
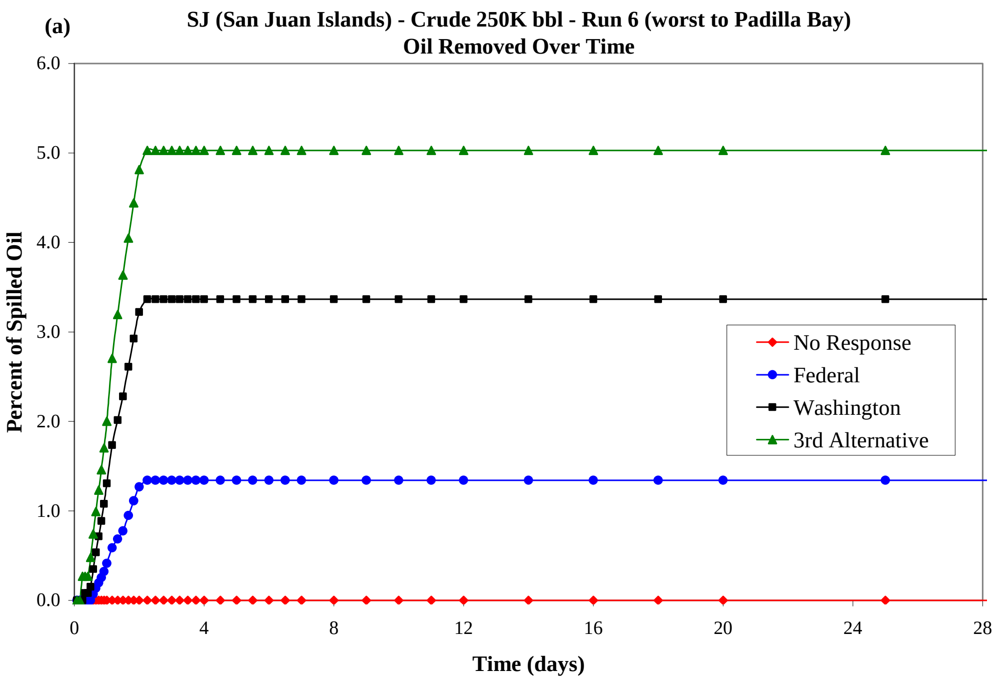


Figure XVII.B-20 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



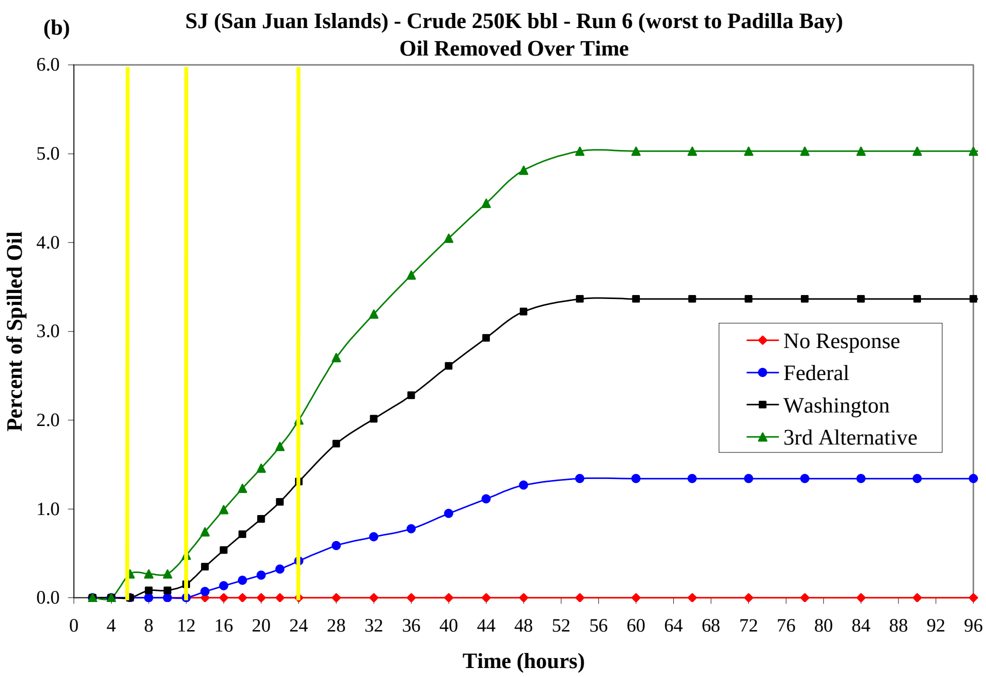
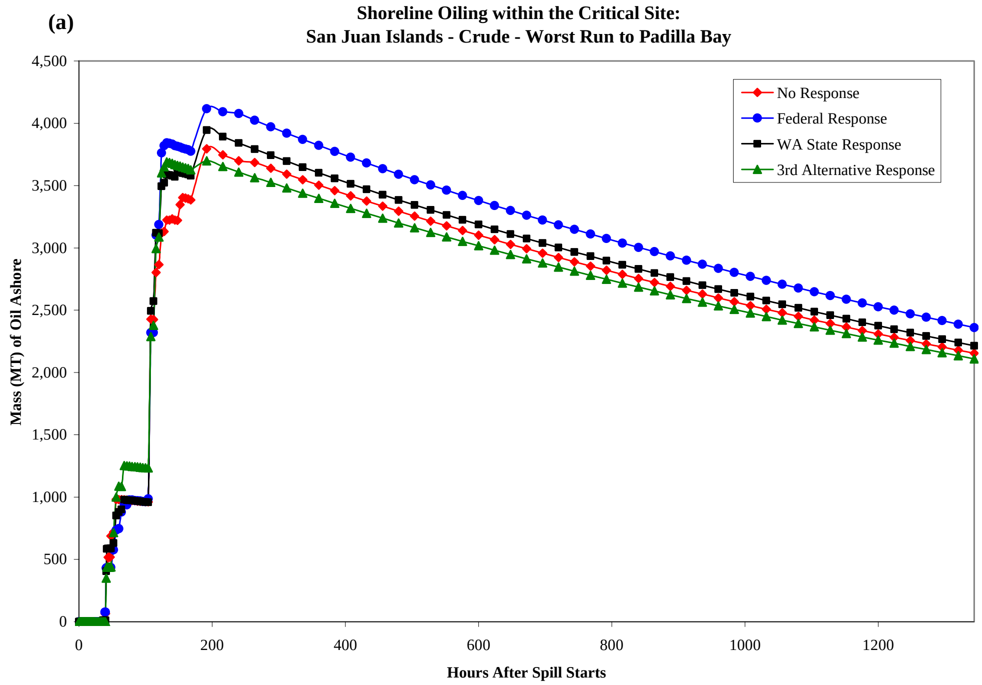


Figure XVII.B-21 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



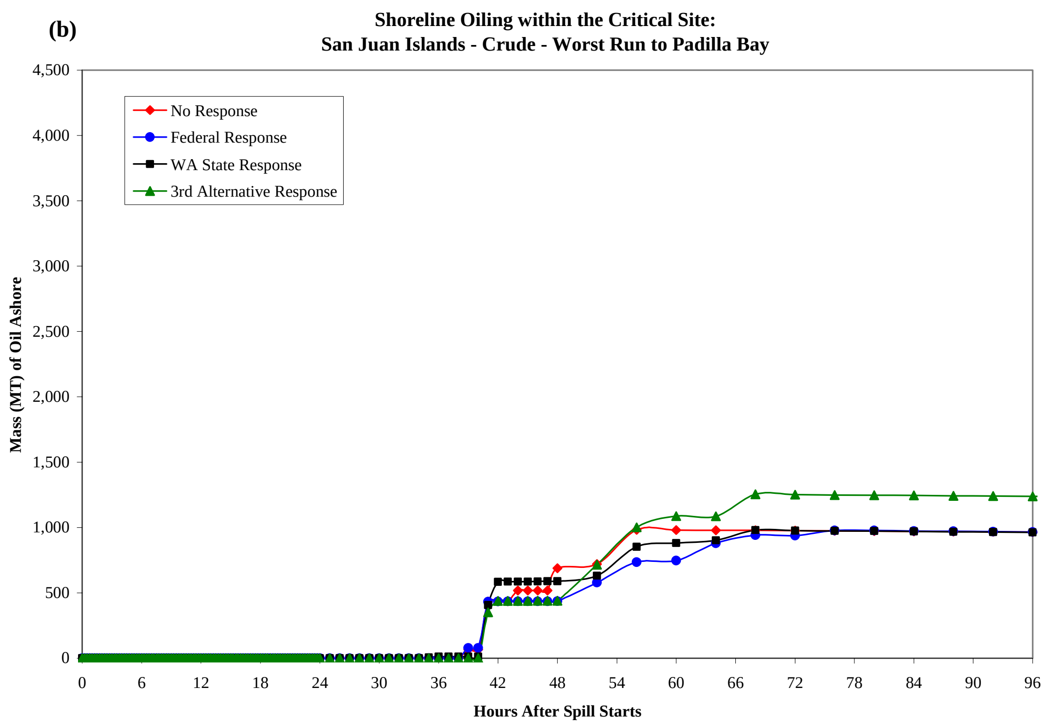


Figure XVII.B-22 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in 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	50^{th} 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